STATE OF CALIFORNIA

BEFORE THE AIR RESOURCES BOARD

Declaration of James M. Lyons

I, James Michael Lyons, declare as follows:

1. I make this Declaration based upon my own personal knowledge and my familiarity with the matters recited herein. It is based on my experience of nearly 22 years as a regulator, consultant, and professional in the field of emissions and air pollution control. A copy of my résumé is attached.

2. I am a Senior Partner of Sierra Research, Inc., an environmental consulting firm located at 1801 J Street, Sacramento, California. Sierra specializes in research and regulatory matters pertaining to air pollution control, and does work for both governmental and private industry clients. I have been employed at Sierra Research since 1991. I received a B.S. degree in Chemistry from the University of California, Irvine, and a M.S. Degree in Chemical Engineering from the University of California, Los Angeles. Before joining Sierra in 1991, I was employed by the State of California at the Mobile Source Division of the California Air Resources Board (CARB).

3. During my career, I have worked on many projects related to the following areas: 1) the assessment of emissions from on- and non-road mobile sources including ships and locomotives, 2) analyses of the unintended consequences of regulatory actions, and 3) the feasibility of compliance with air quality regulations.

4. I have testified as an expert under state and federal court rules in cases involving CARB regulations for gasoline, Stage II vapor recovery systems and their design, as well as combustion chamber system design. While at Sierra I have acted as a consultant on automobile air pollution control matters for CARB and for the United States Environmental Protection Agency. I am a member of the American Chemical Society and the Society of Automotive Engineers and have co-authored nine peer-reviewed monographs concerned with automotive emissions including greenhouse gases and their control. In addition, over the course of my career, I have conducted peer-reviews of numerous papers related to a wide variety of issues associated with pollutant emissions and air quality.

5. This Declaration summarizes the results of analyses I have performed regarding CARB staff's analysis of the criteria pollutant impacts of the Low Carbon Fuel Standard (LCFS) regulations, CARB's GREET Pathways for Brazilian Sugarcane Ethanol, and the feasibility of compliance with the LCFS, as an independent expert for Growth Energy. If called upon to do so, I would testify in accord with the facts and opinions presented here.

6. As part of the development of the LCFS regulations, CARB staff examined the impacts of the proposed regulations on emissions of the following criteria air pollutants: volatile organic compounds (VOC), carbon monoxide (CO), oxides of nitrogen (NOx), oxides of sulfur (SOx), and directly emitted particulate matter (PM) in two particle size ranges.

7. In the Initial Statement of Reasons (ISOR) for the regulation, CARB staff summarized its analysis of the impact of the LCFS on emissions of criteria air pollutants in the year 2020 in Table VII-13. This table showed that the overall impact of the LCFS would be a decrease in emissions of all six of the pollutants considered.

8. I have performed a review of the assessment presented in the Initial Statement of Reasons (ISOR) of the impact of the Low Carbon Fuel Standard (LCFS) regulations on emissions on criteria air pollutants in California and find it to be fundamentally flawed such that it is not reliable. First, the bases for this conclusion are that the source of much of the data presented in Table VII-13 of the ISOR is not described in the ISOR or in other documents in the record. Second, some data presented in Table VII-13 do not agree with data presented in Appendix F of the ISOR, which is purported to be the source of the data in Table VII-13. Finally, the analysis of the impact of zero-emission vehicles (ZEVs) on criteria air pollutants was performed incorrectly and does not account for the combined effects of the LCFS and CARB's Low Emission Vehicle (LEV) and ZEV regulations, which I estimate will lead to an increase rather than a decrease in emission of ozone precursors. A summary of my review of the ISOR criteria pollutant assessment is attached.

9. CARB has published three CA GREET pathways for ethanol derived from Brazilian sugarcane as well as proposed requirements for the establishment of new CA GREET pathways. I have reviewed these documents.

10. My review of CARB's CA GREET pathways for ethanol derived from Brazilian sugarcane indicates that they contain several errors, ignore important factors that have to be taken into account if they are to be considered accurate and have not been peer reviewed. As a result, they cannot be considered to conform to proposed CARB requirements that assessments of new pathways be scientifically defensible and it is not clear that if they were that they would satisfy CARB's proposed criterion for the substantiality of new pathways. A summary of my review of the CA GREET pathways is attached.

11. In order to demonstrate the feasibility of compliance with the LCFS, the CARB staff has assumed that large numbers of E85 capable flexible-fueled vehicles (FFVs) will be sold in California, that a refueling infrastructure will be developed to deliver E85 on a widespread basis and that owners of E85 FFVs will fill their vehicles predominantly if not exclusively with E85. However, even under the optimistic assumptions of the ISOR, the bulk of the vehicle fleet operating in California through 2020 will not be capable of operation on E85.

12. I have reviewed CARB's assumptions related to FFV sales and find them to be unreasonable as they do not comport with existing incentives (federal CAFE credits), currently leading vehicle manufacturers to produce FFVs that will be phased-out at the same time CARB assumes massive increases in FFV sales in California.

13. I have reviewed an analysis of the potential feasibility of compliance with the gasoline LCFS using ethanol from various sources prepared by Bill Hudson. My review indicates that the conclusion of that analysis, e.g. that there is little or no chance for compliance with the LCFS using ethanol is valid.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Executed this 19th day of August, 2009 at Sacramento, California.

JAMES M. LYONS

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Résumé

James Michael Lyons

Education

1985, M.S., Chemical Engineering, University of California, Los Angeles
1983, B.S., Cum Laude, Chemistry, University of California, Irvine

Professional Experience

4/91 to present — Senior Engineer/Partner/Senior Partner
Sierra Research

Primary responsibilities include oversight and execution of complex analyses of the emission benefits, costs, and cost-effectiveness of mobile source air pollution control measures. Mr. Lyons has developed particular expertise with respect to the assessment of control measures involving fuel reformulation, fuel additives, and alternative fuels, as well as accelerated vehicle/engine retirement programs, the deployment of advanced emission control systems for on- and non-road gasoline- and Diesel-powered engines, on-vehicle evaporative and refueling emission control systems, and Stage I and Stage II service station vapor recovery systems. Additional duties include assessments of the activities of federal, state, and local regulatory agencies with respect to motor vehicle emissions and reports to clients regarding those activities. Mr. Lyons has extensive litigation experience related to air quality regulations, product liability, and intellectual property issues.

7/89 to 4/91 — Senior Air Pollution Specialist
California Air Resources Board

Supervised a staff of four professionals responsible for identifying and controlling emissions of toxic air contaminants from mobile sources and determining the effects of compositional changes to gasoline and diesel fuel on emissions of regulated and unregulated pollutants. Other responsibilities included development of new test procedures and emission standards for evaporative and running loss emissions of hydrocarbons from vehicles; overseeing the development of the state plan to control toxic emissions from motor vehicles; and reducing emissions of CFCs from motor vehicles.

4/89 to 7/89 Air Pollution Research Specialist
California Air Resources Board

Responsibilities included identification of motor vehicle research needs; writing requests for proposals; preparation of technical papers and reports; as well as monitoring and overseeing research programs.

9/85 to 4/89 Associate Engineer/Engineer
California Air Resources Board

Duties included analysis of vehicle emissions data for trends and determining the effectiveness of various types of emissions control systems for both regulated and toxic emissions; determining the impact of gasoline and diesel powered vehicles on ambient levels of toxic air contaminants; participation in the development of regulations for "gray market" vehicles; and preparation of technical papers and reports.

Professional Affiliations

American Chemical Society
Society of Automotive Engineers

Selected Publications (Author or Co-Author)

"Effects of Vapor Pressure, Oxygen Content, and Temperature on CO Exhaust Emissions," Sierra Research Report No. 2009-05-03, prepared for the Coordinating Research Council, May 2009.

"Technical Review of 2007 EPA Regulatory Impact Analysis Methodology for the Renewable Fuels Standard," Sierra Research Report No. 2008-09-02, prepared for the American Petroleum Institute, September 2008.

"Impacts of MMT Use in Unleaded Gasoline on Engines, Emission Control Systems, and Emissions," Sierra Research Report No. 2008-08-01, prepared for McMillan Binch Mendelsohn LLP, Canadian Vehicle Manufacturers' Association, and Association of International Automobile Manufacturers of Canada, August 2008.

"Attachment to Comments Regarding the NHTSA Proposal for Average Fuel Economy Standards Passenger Cars and Light Trucks Model Years 2011-2015, Docket No. NHTSA-2008-0089," Sierra Research Report No. SR2008-06-01, prepared for the Alliance of Automobile Manufacturers, June 2008.

"Evaluation of California Greenhouse Gas Standards and Federal Energy Independence and Security Act – Part 1: Impacts on New Vehicle Fuel Economy," SAE Paper No. 2008-01-1852, Society of Automotive Engineers, 2008.

“Basic Analysis of the Cost and Long-Term Impact of the Energy Independence and Security Act Fuel Economy Standards,” Sierra Research Report No. SR 2008-04-01, April 2008.

“The Benefits of Reducing Fuel Consumption and Greenhouse Gas Emissions from Light-Duty Vehicles,” SAE Paper No. 2008-01-0684, Society of Automotive Engineers, 2008.

“Assessment of the Need for Long-Term Reduction in Consumer Product Emissions in South Coast Air Basin,” Sierra Research Report No. 2007-09-03, prepared for the Consumer Specialty Products Association, September 2007.

“Summary of Federal and California Subsidies for Alternative Fuels,” Sierra Research Report No. SR2007-04-02, prepared for the Western States Petroleum Association, April 2007.

“Analysis of IRTA Report on Water-Based Automotive Products,” Sierra Research Report No. SR2006-08-02, prepared for the Consumer Specialty Projects Association and Automotive Specialty Products Alliance, August 2006.

“Evaluation of Pennsylvania’s Implementation of California’s Greenhouse Gas Regulations on Criteria Pollutants and Precursor Emissions,” Sierra Research Report No. SR2006-04-01, prepared for Alliance of Automobile Manufacturers, April 12, 2006.

“Evaluation of New Jersey’s Adoption of California’s Greenhouse Gas Regulations on Criteria Pollutants and Precursor Emissions,” Sierra Research Report No. SR2005-09-03, prepared for the Alliance of Automobile Manufacturers, September 30, 2005.

“Evaluation of Vermont’s Adoption of California’s Greenhouse Gas Regulations on Criteria Pollutants and Precursor Emissions,” Sierra Research Report No. SR2005-09-02, prepared for the Alliance of Automobile Manufacturers, September 19, 2005.

“Assessment of the Cost-Effectiveness of Compliance Strategies for Selected Eight-Hour Ozone NAAQS Nonattainment Areas,” Sierra Research Report No. SR2005-08-04, prepared for the American Petroleum Institute, August 30, 2005.

“Evaluation of Connecticut’s Adoption of California’s Greenhouse Gas Regulations on Criteria Pollutants and Precursor Emissions,” Sierra Research Report No. SR2005-08-03, prepared for the Alliance of Automobile Manufacturers, August 26, 2005.

“Evaluation of New York’s Adoption of California’s Greenhouse Gas Regulations On Criteria Pollutants and Precursor Emissions,” Sierra Research Report No. SR2005-07-04, prepared for the Alliance of Automobile Manufacturers, July 14, 2005.

“Review of MOVES2004,” Sierra Research Report No. SR2005-07-01, prepared for the Alliance of Automobile Manufacturers, July 11, 2005.

“Review of Mobile Source Air Toxics (MSAT) Emissions from On-Highway Vehicles: Literature Review, Database, Development, and Recommendations for Future Studies,” Sierra Research Report No. SR2005-03-01, prepared for the American Petroleum Institute, March 4, 2005.

“The Contribution of Diesel Engines to Emissions of ROG, NOx, and PM2.5 in California: Past, Present, and Future,” Sierra Research Report No. SR2005-02-01, prepared for Diesel Technology Forum, February 2005.

“Fuel Effects on Highway Mobile Source Air Toxics (MSAT) Emissions,” Sierra Research Report No. SR2004-12-01, prepared for the American Petroleum Institute, December 23, 2004.

“Review of the August 2004 Proposed CARB Regulations to Control Greenhouse Gas Emissions from Motor Vehicles: Cost Effectiveness for the Vehicle Owner or Operator – Appendix C to the Comments of The Alliance of Automobile Manufacturers,” Sierra Research Report No. SR2004-09-04, prepared for the Alliance of Automobile Manufacturers, September 2004.

“Emission and Economic Impacts of an Electric Forklift Mandate,” Sierra Research Report No. SR2003-12-01, prepared for National Propane Gas Association, December 12, 2003.

“Reducing California’s Energy Dependence,” Sierra Research Report No. SR2003-11-03, prepared for Alliance of Automobile Manufacturers, November 25, 2003.

“Evaluation of Fuel Effects on Nonroad Mobile Source Air Toxics (MSAT) Emissions: Literature Review, Database Development, and Recommendations for Future Studies,” Sierra Research Report No. SR2003-10-01, prepared for American Petroleum Institute, October 3, 2003.

“Review of Current and Future CO Emissions from On-Road Vehicles in Selected Western Areas,” Sierra Research Report No. SR03-01-01, prepared for the Western States Petroleum Association, January 2003.

“Review of CO Compliance Status in Selected Western Areas,” Sierra Research Report No. SR02-09-04, prepared for the Western States Petroleum Association, September 2002.

“Impacts Associated With the Use of MMT as an Octane Enhancing Additive in Gasoline – A Critical Review”, Sierra Research Report No. SR02-07-01, prepared for Canadian Vehicle Manufacturers Association and Association of International Automobile Manufacturers of Canada, July 24, 2002.

“Critical Review of ‘Safety Oversight for Mexico-Domiciled Commercial Motor Carriers, Final Programmatic Environmental Assessment’, Prepared by John A Volpe

Transportation Systems Center, January 2002," Sierra Research Report No. SR02-04-01, April 16, 2002.

"Critical Review of the Method Used by the South Coast Air Quality Management District to Establish the Emissions Equivalency of Heavy-Duty Diesel- and Alternatively Fueled Engines", Sierra Research Report No. SR01-12-03, prepared for Western States Petroleum Association, December 21, 2001.

"Review of U.S. EPA's Diesel Fuel Impact Model", Sierra Research Report No. SR01-10-01, prepared for American Trucking Associations, Inc., October 25, 2001.

"Operation of a Pilot Program for Voluntary Accelerated Retirement of Light-Duty Vehicles in the South Coast Air Basin," Sierra Research Report No. SR01-05-02, prepared for California Air Resources Board, May 2001.

"Comparison of Emission Characteristics of Advanced Heavy-Duty Diesel and CNG Engines," Sierra Report No. SR01-05-01, prepared for Western States Petroleum Association, May 2001.

"Analysis of Southwest Research Institute Test Data on Inboard and Sterndrive Marine Engines," Sierra Report No. SR01-01-01, prepared for National Marine Manufacturers Association, January 2001.

"Institutional Support Programs for Alternative Fuels and Alternative Fuel Vehicles in Arizona: 2000 Update," Sierra Report No. SR00-12-04, prepared for Western States Petroleum Association, December 2000.

"Real-Time Evaporative Emissions Measurement: Mid-Morning Commute and Partial Diurnal Events," SAE Paper No. 2000-01-2959, October 2000.

"Evaporative Emissions from Late-Model In-Use Vehicles," SAE Paper No. 2000-01-2958, October 2000.

"A Comparative Analysis of the Feasibility and Cost of Compliance with Potential Future Emission Standards for Heavy-Duty Vehicles Using Diesel or Natural Gas," Sierra Research Report No. SR00-02-02, prepared for Californians For a Sound Fuel Strategy, February 2000.

"Critical Review of the Report Entitled 'Economic Impacts of On Board Diagnostic Regulations (OBD II)' Prepared by Spectrum Economics," Sierra Research Report No. SR00-01-02, prepared for the Alliance of Automobile Manufacturers, January 2000.

"Potential Evaporative Emission Impacts Associated with the Introduction of Ethanol-Gasoline Blends in California," Sierra Research Report No. SR00-01-01, prepared for the American Methanol Institute, January 2000.

"Evaporative Emissions from Late-Model In-Use Vehicles," Sierra Research Report No. SR99-10-03, prepared for the Coordinating Research Council, October 1999.

"Investigation of Sulfur Sensitivity and Reversibility in Late-Model Vehicles," SAE Paper No. 1999-01-3676, August 1999.

"Future Diesel-Fueled Engine Emission Control Technologies and Their Implications for Diesel Fuel Properties," Sierra Research Report No. SR99-08-01, prepared for the American Petroleum Institute, August 1999.

"Analysis of Compliance Feasibility under Proposed Tier 2 Emission Standards for Passenger Cars and Light Trucks," Sierra Research Report No. SR99-07-02, July 1999.

"Comparison of the Properties of Jet A and Diesel Fuel," Sierra Research Report No. SR99-02-01, prepared for Pillsbury Madison and Sutro, February 1999.

"Investigation of Sulfur Sensitivity and Reversibility in Late-Model Vehicles," Sierra Research Report No. SR98-12-02, prepared for the American Petroleum Institute, December 1998.

"Analysis of New Motor Vehicle Issues in the Canadian Government's Foundation Paper on Climate Change – Transportation Sector," Sierra Research Report No. SR98-12-01, prepared for the Canadian Vehicle Manufacturers Association, December 1998.

"Investigation of the Relative Emission Sensitivities of LEV Vehicles to Gasoline Sulfur Content - Emission Control System Design and Cost Differences," Sierra Research Report No. SR98-06-01, prepared for the American Petroleum Institute, June 1998.

"Costs, Benefits, and Cost-Effectiveness of CARB's Proposed Tier 2 Regulations for Handheld Equipment Engines and a PPEMA Alternative Regulatory Proposal," Sierra Research Report No. SR98-03-03, prepared for the Portable Power Equipment Manufacturers Association, March 1998.

"Analysis of Diesel Fuel Quality Issues in Maricopa County, Arizona," Sierra Research Report No. SR97-12-03, prepared for the Western States Petroleum Association, December 1997.

"Potential Impact of Sulfur in Gasoline on Motor Vehicle Pollution Control and Monitoring Technologies," prepared for Environment Canada, July 1997.

"Analysis of Mid- and Long-Term Ozone Control Measures for Maricopa County," Sierra Research Report No. SR96-09-02, prepared for the Western States Petroleum Association, September 9, 1996.

"Technical and Policy Issues Associated with the Evaluation of Selected Mobile Source Emission Control Measures in Nevada," Sierra Research Report No. SR96-03-01, prepared for the Western States Petroleum Association, March 1996.

“Cost-Effectiveness of Stage II Vapor Recovery Systems in the Lower Fraser Valley,” Sierra Research Report No. SR95-10-05, prepared for the Province of British Columbia Ministry of Environment Lands and Parks and the Greater Vancouver Regional District, October 1995.

“Cost of Stage II Vapor Recovery Systems in the Lower Fraser Valley,” Sierra Research Report No. SR95-10-04, prepared for the Province of British Columbia Ministry of Environment Lands and Parks and the Greater Vancouver Regional District, October 1995.

“A Comparative Characterization of Gasoline Dispensing Facilities With and Without Vapor Recovery Systems,” Sierra Research Report No. SR95-10-01, prepared for the Province of British Columbia Ministry of Environment Lands and Parks, October 1995.

“Potential Air Quality Impacts from Changes in Gasoline Composition in Arizona,” Sierra Research Report No. SR95-04-01, prepared for Mobil Corporation, April 1995.

“Vehicle Scrappage: An Alternative to More Stringent New Vehicle Standards in California,” Sierra Research Report No. SR95-03-02, prepared for Texaco, Inc., March 1995.

“Evaluation of CARB SIP Mobile Source Measures,” Sierra Research Report No. SR94-11-02, prepared for Western States Petroleum Association, November 1994.

“Reformulated Gasoline Study,” prepared by Turner, Mason & Company, DRI/McGraw-Hill, Inc., and Sierra Research, Inc., for the New York State Energy Research and Development Authority, Energy Authority Report No. 94-18, October 1994.

“Phase II Feasibility Study: Heavy-Duty Vehicle Emissions Inspection Program in the Lower Fraser Valley,” Sierra Research Report No. SR94-09-02, prepared for the Greater Vancouver Regional District, September 1994.

“Cost-Effectiveness of Mobile Source Emission Controls from Accelerated Scrappage to Zero Emission Vehicles,” Paper No. 94-TP53.05, presented at the 87th Annual Meeting of the Air and Waste Management Association, Cincinnati, OH, June 1994.

“Investigation of MOBILE5a Emission Factors, Assessment of I/M Program and LEV Program Emission Benefits,” Sierra Research Report No. SR94-06-05, prepared for American Petroleum Institute, June 1994.

“Cost-Effectiveness of the California Low Emission Vehicle Standards,” SAE Paper No. 940471, 1994.

“Meeting ZEV Emission Limits Without ZEVs,” Sierra Research Report No. SR94-05-06, prepared for Western States Petroleum Association, May 1994.

"Evaluating the Benefits of Air Pollution Control - Method Development and Application to Refueling and Evaporative Emissions Control," Sierra Research Report No. SR94-03-01, prepared for the American Automobile Manufacturers Association, March 1994.

"The Cost-Effectiveness of Further Regulating Mobile Source Emissions," Sierra Research Report No. SR94-02-04, prepared for the American Automobile Manufacturers Association, February 1994.

"Searles Valley Air Quality Study (SVAQS) Final Report," Sierra Research Report No. SR94-02-01, prepared for North American Chemical Company, February 1994.

"A Comparative Study of the Effectiveness of Stage II Refueling Controls and Onboard Refueling Vapor Recovery," Sierra Research Report No. SR93-10-01, prepared for the American Automobile Manufacturers Association, October 1993.

"Evaluation of the Impact of the Proposed Pole Line Road Overcrossing on Ambient Levels of Selected Pollutants at the Calgene Facilities," Sierra Research Report No. SR93-09-01, prepared for the City of Davis, September 1993.

"Leveling the Playing Field for Hybrid Electric Vehicles: Proposed Modifications to CARB's LEV Regulations," Sierra Research Report No. SR93-06-01, prepared for the Hybrid Vehicle Coalition, June 1993.

"Size Distributions of Trace Metals in the Los Angeles Atmosphere," *Atmospheric Environment*, Vol. 27B, No. 2, pp. 237-249, 1993.

"Preliminary Feasibility Study for a Heavy-Duty Vehicle Emissions Inspection Program in the Lower Fraser Valley Area," Sierra Research Report No. 92-10-01, prepared for the Greater Vancouver Regional District, October 1992.

"Development of Mechanic Qualification Requirements for a Centralized I/M Program," SAE Paper No. 911670, 1991.

"Cost-Effectiveness Analysis of CARB's Proposed Phase 2 Gasoline Regulations," Sierra Research Report No. SR91-11-01, prepared for the Western States Petroleum Association, November 1991.

"Origins and Control of Particulate Air Toxics: Beyond Gas Cleaning," in Proceedings of the Twelfth Conference on Cooperative Advances in Chemical Science and Technology, Washington, D.C., October 1990.

"The Effect of Gasoline Aromatics on Exhaust Emissions: A Cooperative Test Program," SAE Paper No. 902073, 1990.

“Estimation of the Impact of Motor Vehicles on Ambient Asbestos Levels in the South Coast Air Basin,” Paper No. 89-34B.7, presented at the 82nd Annual Meeting of the Air and Waste Management Association, Anaheim, CA, June 1989.

“Benzene/Aromatic Measurements and Exhaust Emissions from Gasoline Vehicles,” Paper No. 89-34B.4, presented at the 82nd Annual Meeting of the Air and Waste Management Association, Anaheim, CA, June 1989.

“The Impact of Diesel Vehicles on Air Pollution,” presented at the 12th North American Motor Vehicle Emissions Control Conference, Louisville, KY, April 1988.

“Exhaust Benzene Emissions from Three-Way Catalyst-Equipped Light-Duty Vehicles,” Paper No. 87-1.3, presented at the 80th Annual Meeting of the Air Pollution Control Association, New York, NY, June 1987.

“Trends in Emissions Control Technologies for 1983-1987 Model-Year California-Certified Light-Duty Vehicles,” SAE Paper No. 872164, 1987.

Review of CARB's Assessment of the Impact of the LCFS on Emissions of Criteria Air Pollutants in California

Summary

The assessment presented in the Initial Statement of Reasons (ISOR) of the impact of the Low Carbon Fuel Standard (LCFS) regulations on emissions of criteria air pollutants in California is fundamentally flawed and cannot be relied upon. The bases for this conclusion can be found in the following statements.

1. The source of much of the data presented in Table VII-13 of the ISOR is not described in the ISOR or in other documents in the record.

2. Some data presented in Table VII-13 do not agree with data presented in Appendix F of the ISOR, which is purported to be the source of the data in Table VII-13.

3. The analysis of the impact of zero-emission vehicles (ZEVs) on criteria air pollutants was performed incorrectly and does not account for the combined effects of the LCFS and CARB's Low Emission Vehicle (LEV) and ZEV regulations that will lead to increases, rather than decreases, in emissions.

Overall, a valid assessment of the impact of the LCFS on criteria air pollutants is expected to lead to a finding of increased emissions. This contradicts the finding upon which the Board relied in adopting the LCFS regulations, which was that the LCFS will result in no change or a decrease in emissions.

CARB Staff Analysis of the Air Quality Impacts of the LCFS

Page VII-1 of the ISOR states:

> *The proposed LCFS regulation is also expected to result in no additional adverse impacts to California's air quality due to emissions of criteria and toxic air pollutants. Based on the best available data, there may be a benefit in further reducing criteria air pollutants from the 2020 projected vehicle fleet.*

The basis for this statement can be found in Table VII-13 of the ISOR, which is reproduced below.

Table VII-13
Summary of 2020 Changes from the Production and Use of Low Carbon Fuels above the Baseline (tons/day)

Criteria Pollutants Emissions	VOC	CO	NOx	SOx	PM10	PM2.5
Petroleum Refining, Production, and Marketing	--	--	--	--	--	--
Electricity Production	--	--	--	--	--	--
Natural Gas Production	--	--	--	--	--	--
Cellulosic Ethanol Facilities	--	--	--	--	--	--
Biodiesel Facilities	--	--	--	--	--	--
Impact from ZEV	-4.11	-38.36	-6.03	-1.21	-0.71	-0.41
Impact from Bio/Renewable Diesel	--	--	-2.20	--	-0.75[a]	-0.71
Impact from CNG Vehicles	--	15.08	-1.64	--	-0.67	-0.63[a]
Impact from E85 Vehicles	0.23	--	--	--	--	--
Impact from In-State Bio-Refinery Truck and Rail Trips	--	0.52	5.19	0.03	0.11	0.10
Total Impact	**-3.88**	**-22.76**	**-4.67**	**-1.18**	**-2.02**	**-1.65**

[a] Number is obtained by assuming 94.7% of diesel PM is PM2.5

As shown, the ISOR indicates that the LCFS will cause increases in emissions of the six air pollutants considered by CARB staff because of truck and rail trips. Increases in VOC emissions are also indicated to occur due to the introduction of additional E85 vehicles, and increases in CO emissions are attributed to compressed natural gas (CNG) vehicles. However, the ISOR also indicates that there will be reductions in emissions of all six pollutants due to increases in the numbers of ZEVs and reductions in NOx and PM emissions from additional CNG vehicles and the use of bio/renewable Diesel fuels.

ZEVs – The staff analysis of ZEV impacts is discussed briefly on pages VII-17 and VII-20 of the ISOR, with the text on the latter page referring the reader to Appendix F8 for “detailed information.” It appears that the data presented in Table VII-13 were taken from Table F8-3 for the “Scenario 3&5” case and assume sales of an additional 130,000 battery electric vehicles (BEVs), 270,000 plug in-hybrid electric vehicles (PHEVs), and 40,000 fuel cell vehicles (FCVs) relative to the requirements of the current ZEV regulation. The only detail regarding how the estimates presented in Table F8-3 were computed is a statement on page F-52 that “All ZEV’s were assumed to replace vehicles meeting the ultra low emission vehicle (ULEV) standard…”

As noted in comments submitted to CARB regarding the impacts of the LCFS,[1] CARB’s assumption is simply incorrect and does not account for changes in the vehicle sales mix

[1] See *http://www.arb.ca.gov/lists/lcfs09/310-lcfs_letter.pdf* and page 16 of Appendix 2 of the Western States Petroleum Association’s comments at *http://www.arb.ca.gov/lists/lcfs09/277-wspacommentsonlcfsreg_409combined.pdf* .

that manufacturers would likely make in order to reduce their costs of compliance with the ZEV mandate and LEV regulations and that would lead to increased emissions of criteria pollutants. Although the actual impacts depend on both the characteristics of the ZEVs sold and the decisions made by vehicle manufacturers in response to the sale of greater than mandated levels of ZEVs, it is easy to estimate roughly the potential increase in emissions of criteria pollutants in order to illustrate that CARB's failure to even examine the issue fundamentally flaws its air quality analysis.

As noted in the comments referenced above that were submitted as part of the LCFS rulemaking, during 2015 to 2020 period where CARB assumes sales of ZEVs in excess of those required under ZEV mandate will occur most ZEVs (BEVs and FCVs) will receive 3 ZEV credits and that 15 (3/0.2) PZEVs could be downgraded to SULEVs, for each extra ZEV sold. Given the 170,000 extra ZEVs, assumed by CARB staff, this translates to a total of 2.55 million PZEVs that could be converted to SULEVs which is roughly equal to the 2.70 million PZEVs that would otherwise be expected from 2015 through 2020, given that they are expected to account for 30% and an assumed California sales volume of 1.5 million vehicles each year (1.5 million per year x 0.3 x 6 years).

As part of the 2000 biennial review of the ZEV mandate, CARB published the following table of emission factors, which includes battery electric, PZEV, and SULEV vehicles.[2] Note that there are two sets of CARB emission factors reported for SULEVs, one with and one without LEV II deterioration rates. Using those factors and assuming 12,000 miles per year of travel for each ZEV and PZEV/SULEV or 32.88 miles per day (12,000/365), one can easily estimate the potential magnitude of the emission increase associated with the increased sale of battery electric vehicles if manufacturers choose to sell SULEVs instead of PZEVs. For example, the reduction in NOx emissions associated with the sale of ZEVs instead of PZEVs is equal to the difference in NOx emissions (0.024 g/mi) times the number of vehicles (170,000) times the 32.88 miles per day equals 134,500 grams per day which in turn converts to 0.15 tons per day. The results of the similar calculations needed for the other pollutants and substitution of SULEVs for PZEVs are shown in Table A.

As shown in Table A, the potential emission increases of NMOG and toxics associated with downgrading of PZEVs to SULEVs are larger than the emission reductions due to ZEV replacement of PZEVs, which the NOx increases are larger under the with LEV II deterioration rates and the combination of NMOG+NOx is larger in both cases.

[2] See *http://www.arb.ca.gov/msprog/zevprog/2000review/staffreportfinal.pdf* .

Table 9-1
Estimated Direct Emissions Per Vehicle
(Tailpipe and Evaporative)

Vehicle Type	Tailpipe (g/mi)			Evaporative (g/mi)	
	NMOG	NOx	Toxics	NMOG	Toxics
BEV	0	0	0	0	0
PZEV SULEV	0.0067	0.024	0.0025	0.020	0.0007
PZEV HEV non-grid	0.0067	0.024	0.0025	0.020	0.0007
SULEV	0.0073	0.025	0.0027	0.032	0.0011
SULEV with LEV II DR	0.0150	0.030	0.0056	0.032	0.0011
MY 2002 vehicle	0.0620	0.173	0.0230	0.049	0.0016

It should also be noted that the small NMOG credit allowed for SULEVs certified to 150,000 mile standards is not likely to be sufficient to induce manufacturers to continue the certification of vehicles being downgraded from PZEV status to 150,000 miles. Further, even if manufacturers do continue this practice, there is no reason that they would continue to certify vehicles being downgraded from PZEV status to the optional zero evaporative emissions standards.

Table A
Potential Emission Impacts of ZEVs Accounting for the Impacts of the ZEV and LEV Regulations
(tons per day statewide in 2020)

Action	NMOG	NOx	Toxics
ZEV Replacing PZEV	-0.16	-0.15	-0.02
SULEVs Replacing PZEVs	+1.16	+0.09	+0.06
SULEVs with LEVII DR Replacing PZEVs	+1.87	+0.55	+0.32

<u>Bio/renewable Diesel</u> – The CARB analysis of biodiesel impacts on air pollutant emissions is detailed in Appendix F-7 of the ISOR and the results are summarized in Table F7-1, which is reproduced below. As shown, CARB staff evaluated three scenarios and came up with a range of NOx emission impacts that shows both the potential for emission increases as well as emission decreases from bio/renewable Diesel. There are also ranges shown for PM and reactive organic gas (ROG) emissions However, none of the values shown in Table F7-1 appear in the bio/renewable Diesel line of Table VII-13. Further, it is not known how CARB staff arrived at the values presented in Table VII-13

for bio/renewable Diesel fuels because there is no description of the methodology presented in the ISOR; there is only a reference on page VII-20 of the ISOR directing the reader to Appendix F7.

Table F7-1
Emissions Changes

Baseline	**ROG tons/day**	**NOX tons/day**	**PM2.5 tons/day**
on-road	32.6	435	14.2
off-road			
	Change in Emissions	Change in Emissions	Change in Emissions
Scenario one	BD/RD tons/day	BD/RD tons/day	BD/RD tons/day
on-road	0/0	0/0	0/0
off-road	0/0	0/0	0/0
Scenario two			
on-road	-.35/-.20	1.1/-2.3	-.22/-.12
off-road	-.70/-.41	1.0/-2.0	-.24/-.13
Scenario three			
on-road	-1.1/-.66	3.3/-6.6	-.68/-.36
off-road	-1.4/-.82	2.0/-4.1	-.49/.26

Scenario one: Assumes alternative diesel fuels have no net impact on emission rates for the entire 2020 fleet
Scenario two: Use pre-2007 emission factors only for retrofitted vehicles and no net impact on emission rates for 2010 vehicles. Use the pre-2007 emission factors for 50% of the 2020 off-road fleet
Scenario three: Apply pre-2007 emission factors to the entire 2020 fleet

<u>CNG Vehicles</u> – With respect to CNG vehicles, the ISOR states on page VII-20:

> *Staff analyzed the impacts of switching a number of diesel fueled HHDD trucks to CNG fuel to compare the change in PM and NOx emissions. This analysis was performed for 4,600 conversions by 2015 and 23,300 conversions by 2020. This analysis shows that switching from diesel fuel to CNG would result in a slight decrease in PM emissions, as well as a slight decrease in NOx emissions. Staff did not estimate any change in emissions of CO and NMHC. For more details, please see Appendix F9.*

As can be seen in Table VII-13, CARB staff reports an increase in CO emissions despite the statement above that there was no estimate made for CO. Further, as is the case with bio/renewable Diesel, none of the values shown in Table VII-13 can be found in

Appendix F9 and there is no discussion of where the values in Table VII-13 came from anywhere in the ISOR.

Review of CARB's CA GREET Pathways for Brazilian Sugarcane Ethanol

Summary

A review of CARB's CA GREET Pathways for Brazilian sugarcane indicates that they contain several errors, ignore important factors that have to be taken into account, and have not been peer reviewed. As a result, they cannot be considered to conform to proposed CARB requirements that assessments of new pathways be scientifically defensible; also, it is not clear that if even if they were defensible, they would satisfy CARB's proposed criterion for the "substantiality" of new pathways.

Overview

On July 20, 2009, CARB staff published the latest version[3] of its California-Modified GREET Pathways for ethanol derived from Brazilian sugarcane. The changes relative to the earlier version involve the establishment of two new fuel pathways for ethanol derived from Brazilian sugarcane:

1. Brazilian sugarcane with average production process, mechanized harvesting, and electricity co-product; and

2. Brazilian sugarcane with average production process and electricity co-product.

The carbon intensity (CI) value for the baseline pathway for ethanol Brazilian sugarcane is 27.40 grams of CO_2 equivalent emissions per MJ (gCO_2e/MJ) of energy contained in the ethanol. This value is the sum of the values shown in Table 1 after the addition of an additional 0.8 gCO_2e/MJ to account for emissions of methane and nitrous oxide during combustion. It should also be noted that CARB's value of 1.9 for ethanol production appears to reflect a mathematical error based on Table K of the CARB Pathway document, as the values presented there sum to 2.29. Correction of the error increases the baseline pathway value to 27.79 gCO_2e/MJ.

The CI value for the first new pathway listed above is 12.20 gCO_2e/MJ while that for the second new pathway is 20.40 gCO_2e/MJ. The latter value reflects a co-product credit of 7.0 gCO_2e/MJ resulting from electricity derived from fossil fuels being displaced by electricity generated from biomass burning during the production of ethanol from

[3] "Detailed California-Modified GREET Pathways for Brazilian Sugarcane Ethanol: Average Brazilian Ethanol, With Mechanized Harvesting and Electricity Co-product Credit, With Electricity Co-product Credit," Version 2.2, California Air Resources Board, Stationary Source Division, July 20, 2009, available at *http://www.arb.ca.gov/fuels/lcfs/lcfs.htm*.

sugarcane in Brazil. The former value includes that credit plus an additional co-product credit of 8.2 gCO_2e/MJ, which reflects an assumption by CARB staff that mechanized harvesting will completely eliminate the GHG emissions associated with cane straw burning. Correction of the apparent mathematical error of ethanol production would increase the CI values for new pathways to 12.59 and 20.79 gCO_2e/MJ, respectively.

Table 1
Carbon Intensity of Ethanol from Brazilian Sugarcane Using Average Production Processes

Primary Component	Sub-component	CI Value (gCO_2e/MJ)
Sugarcane Farming	**-**	**9.9**
	Farming	1.7
	Straw Burning	8.2
Agricultural Chemical Use	**-**	**8.7**
	Fertilizer	3.7
	Herbicide	0.3
	Pesticide	0.03
	Soil N_2O and NO	3.5
	Lime Application	1.2
Sugarcane Transport	**-**	**2.0**
	Trucking from Field to Ethanol Plant	2.0
Ethanol Production	**-**	**1.9**
	Residual Oil Burning	0.03
	Net Bagasse Burning	2.17
	Other sources	0.09
Ethanol Transport	-	**4.1**
	Rail in Brazil	0.72
	Pipeline in Brazil	0.45
	Tanker to U.S. Port	1.81
	Truck from Port	0.81
	Truck Distribution	0.32

In addition to publishing new pathways for ethanol derived from Brazilian sugarcane, CARB staff published a "Concept Paper" on August 4 regarding proposed procedures and guidelines for the establishment of CI values for new fuel pathways.[4] This document

[4] "Establishing New Fuel Pathways under the California Low Carbon Fuel Standard: Procedures and Guidelines," Preliminary Draft Concept Paper for Public Comment," August 4, 2009. Available at *http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.*

describes the documentation that must be submitted to CARB in order to establish a new fuel pathway as well as the criteria that CARB will use to evaluate the new pathway. The documentation and evaluation criteria for "Substantiality" and "Scientific Defensibility" set forth in the Concept Paper are reproduced below.

As can be seen, CARB is requesting large amounts of information, addressing a myriad of issues related to the CI of a given fuel. These include drawings, technical papers, and spreadsheets, which must be electronically submitted to CARB.

- Submit the necessary documentation in support of the establishment of the proposed new sub-pathway. The files submitted will be use to determine whether the proposed sub pathway meets ARB's minimum requirements for substantiality and scientific defensibility. Electronic files should be submitted using the secure LCFS file upload service available at the application web site (http://www.arb.ca.gov/fuels/lcfs/). ARB requests that as many files as possible be submitted in electronic form. Spreadsheets and similar files that contain calculated values must be submitted with all formulas intact and accessible to ARB evaluators. The files submitted will be preserved in their original forms for reference purposes. ARB evaluators will use copies of the original submissions in the evaluation process. Applicants are asked to submit the following documentation at a minimum. Additional documentation that directly supports the proposed new sub-pathway may also be submitted.
    - The official factory technical specifications of new equipment that contributes to the reported carbon intensity reductions.
    - Technical drawings, schematics, flow diagrams, maps, and other graphical representations describing the proposed process changes.
    - Technical papers reporting the results of pertinent greenhouse gas (GHG) emission studies. These could be articles from peer-reviewed journals, unpublished university or consulting reports, or studies that were prepared under contract to the applicant.
    - Emissions monitoring data not included in any of the studies submitted under item c, above. This could be data from governmental regulatory entities, or data collected by entities testing or using the proposed equipment and processes.
    - Spreadsheets, data files, and similar files documenting the quantitative lifecycle analysis behind the carbon intensity value for the proposed new pathway. Except where it is impossible to do so, the applicant must submit files of this type electronically, via the LCFS upload site. All such files must be submitted in a format that permits full and unimpeded access to all the data, formulas, and calculations they contain. In general, files of this type should be submitted in their native formats. CA-GREET files, in particular, must not be converted to any other format. If format conversions appear to be warranted in order to permit or improve access, the applicant must obtain ARB approval before proceeding with the proposed conversions.

- A preliminary determination concerning the likelihood that the proposed sub-pathway will create significant land use change impacts or other indirect impacts. See section III, below, for a discussion of how to reach a preliminary indirect effects determination, and of ARB's process for evaluating that determination.

The applicant's Method 2A submittal will be evaluated against the following criteria:

- *Substantiality*
  - The applicant must demonstrate his or her ability and willingness to produce more than ten million gasoline gallon equivalents per year (1,156 MJ) of the fuel covered by the new sub-pathway proposal. This requirement applies only when the total amount of the fuel sold in California by all providers of that fuel exceeds tem million gasoline gallon equivalents per year
  - The applicant must demonstrate that the proposed new sub-pathway will yield a carbon intensity improvement of at least five gCO_2e/MJ over the existing primary pathway. This carbon intensity improvement is calculated on a 'well-to-tank' (or 'source-to-tank') basis: all fuel lifecycle emissions except those resulting from the combustion of the fuel must be included.
- *Scientific Defensibility*
  - The minimum standard against which the Scientific Defensibility of a proposed new sub-pathway is measured is the robustness of the data and analysis on which the values existing lookup table are based. The LCFS regulation states, at §95486(e)(1)(A), that a new pathway is deemed to be scientifically defensible if the carbon intensity value it yields is at least as robust as the values currently in the lookup table. This robustness derives from the strength of the scientific and technical data behind the lookup table values.
  - The regulation provides an example of a method by which the scientific defensibility of a proposed new pathway can be demonstrated: publication of an article describing that pathway in a major, well-established and peer-reviewed scientific journal such as Science, Nature, Journal of the Air and Waste Management Association, or the Proceedings of the National Academies of Science (§95486(e)(1)(B)).
  - If the applicant does not publish a description of the proposed new sub-pathway, as described above, staff will evaluate the scientific defensibility of that pathway by, first, verifying all information submitted by the applicant for authenticity. This will consist of checking the information submitted against original sources wherever this is possible (e.g., confirming that

    submitted articles were actually published, and checking with the authors of unpublished reports). Once the authenticity of all submissions has been verified, those submissions will be evaluated to determine whether they adequately support the creation of the proposed new fuel sub-pathway. All calculations will be replicated and evaluated for appropriateness; selected results will be sent to expert third-parties for evaluation; equipment manufacturers will be asked to confirm that the technical specifications submitted are current and still considered to be valid, etc. Because the burden of demonstrating scientific defensibility is on the applicant, issues that arise during the evaluation process will be referred to the applicant for resolution.

With the respect to the evaluation criteria regarding substantiality, the CI value for the new pathway will be required to differ from that of the existing pathway by at least 5 gCO_2e/MJ and fuel produced using the new pathway will need to be in excess of 10,000,000 gasoline gallon equivalents per year—which is about 1.2 billion MJ, not 1,156 MJ as stated in the draft CARB document. Based on the energy content of anhydrous ethanol listed in the CARB sugarcane pathway document, the production volume required for a change in an ethanol pathway is about 14.6 million gallons per year. The scientific defensibility criteria include peer review of the methodology and data used in arriving at the CI value for the new pathway; and verification of the data, reports, and materials submitted to establish the CI value.

Review of CARB's GREET Pathways for Brazilian Sugarcane Ethanol

As documented above, the proposed CARB requirements for documenting CI values for new fuel pathways require that an applicant submit considerable data and information to substantiate CI values and that the data be capable of standing up to peer review. Notwithstanding these requirements, the CI value for the new pathway must also satisfy CARB requirements for "substantiality." This section discusses the results of a review examining how well the published CARB CI values for ethanol derived from Brazilian sugarcane satisfy CARB's own requirements.

Review of the Average Brazilian Ethanol Pathway – In terms of documentation, CARB has made available both the CA GREET model[5] and the pathway document referenced above. Although there was a "peer review" conducted regarding CARB's LCFS regulation, it does not appear that there has been a comprehensive peer review of the CA GREET spreadsheet model itself or any of the CARB Pathway documents. As evidence of this, the peer review of John Reily[6] indicates that he was provided with only the Initial Statement of Reasons for the regulation and its appendices, and none of the reviewers indicate that they actually reviewed either the CA GREET spreadsheet model or any of the pathway documents.

First, as noted above, even a cursory review of the CARB document regarding the average Brazilian pathway reveals a mathematical error associated with the contribution of GHG emissions during ethanol production to the CI value for the average pathway. Second, even a resource- and time-constrained review (as opposed to a comprehensive review) of the CA GREET model indicates that it contains an incorrect distance for the

[5] The February 2009 version of the model was reviewed and is available at *http://www.arb.ca.gov/fuels/lcfs/lcfs.htm*.

[6] See *http://www.arb.ca.gov/fuels/lcfs/peerreview/041409lcfs_reilly.pdf.*

transportation of Brazilian ethanol to California via tanker. As the comment in cell GU93 of T&D worksheet of the GREET spreadsheet model indicates, the 7,416-mile value presented in the Pathway document makes the following assumption.

> *EtOH produced in Brazil is assumed to transported from Santos in Brazil, to LA and NYC by a split of 50% and 50%. The distances from Santos to LA and NYC are 4930 and 7968 nautical miles, respectively. 1 nautical mile equals to 1.15 mile.*

Obviously, Brazilian ethanol shipped to New York City will play no role in the California LCFS program and the appropriate shipping distance is that to Los Angeles (LA) and, for some Brazilian ethanol, most likely the additional 400 miles required to reach the San Francisco (SF) area. Assuming a 50/50 split in Brazilian ethanol delivered to LA and SF, tanker emissions of GHG will increase by approximately 26% and the 1.81 gCO_2e/MJ value for tanker transport becomes 2.29 and the CI for the pathway increases to 28.27.

Another apparent error in CARB's analysis of the Brazilian sugarcane pathway is the 30-mile trip length reported in Table 5.03 of the Pathway document for GHG associated with ethanol distribution by truck in the U.S. As shown in cell GZ93, the correct distance is 50 miles. Use of this value increases GHG distribution emissions by 67% and the 0.32 gCO_2e/MJ value increases to 0.53, with the CI for the pathway increasing to 28.48.

These errors substantiate the evidence that neither the CA GREET model nor the Brazilian sugarcane pathway has been peer reviewed and that neither would meet the requirements for scientific defensibility proposed by CARB for establishing new pathways.

Another potential problem with the average Brazilian pathway raised by Wang, et al.,[7] is the discrepancy between the estimated N_2O emissions associated sugarcane farming incorporated in the CA GREET model and the much higher estimates recently published by Crutzen, et al. As stated by Wang, et al., with respect to this issue:

> *Nonetheless, N_2O conversion rates, which are subject to great uncertainties, need to be reconciled between the bottom-up and top-down approach.*

To highlight the potential impact of this issue on the Brazilian ethanol CI value, substitution of the upper range of the Crutzen et al. estimates (5%) for the value assumed in CA GREET (1.5%) would increase the "Soil N_2O and NO" from 3.5 gCO_2e/MJ to

[7] Wang, M., et al., "Life-cycle energy use and greenhouse gas emission implications of Brazilian sugarcane ethanol simulated with the GREET model", International Sugar Journal, Vol. 110, No. 1317, September, 2008.

about 11.5 gCO_2e/MJ with the net impact being an 8 gCO_2e/MJ increase in the CI value for Brazilian sugarcane ethanol.

<u>Review of the Electricity and Mechanized Harvesting Co-Product Credits</u> – As noted previously, the CARB Pathways that included electricity and mechanized harvesting co-products were published on July 20, 2009. There is no evidence that the revised Pathway document has been peer reviewed.

CARB calculates the electricity co-product credit using assumptions regarding the amount of thermal energy required to produce ethanol from a ton of sugarcane, the amount of ethanol that can be produced from a ton of sugarcane, and the efficiency of biomass boilers. CARB then subtracts that value from the energy associated with the amount of bagasse produced and adjusts the resulting value to account for the energy requirements of ethanol processing to arrive at an estimate of 0.96 kWh of excess electrical generation that can be exported per gallon of ethanol produced, which translates to the 7.0 gCO_2e/MJ co-product credit based on the assumption that the electricity generated from ethanol production displaces natural gas based electricity generation.

The source of the data used by the CA GREET model is reported in the Pathway document to be *"M. Wang, et al.: WTW Energy Used and GHG Emissions of Brazilian Sugarcane Ethanol – July 2007."* Although this incomplete reference precludes definitive identification of the source of the data used in the CA GREET model, it appears to be from a paper submitted for consideration by the International Journal of Life Cycle Assessment which is dated July 20, 2007 with a submission data to the journal of July 23, 2007. The following quote from this reference highlights the speculative nature of the value of electricity co-product credit: (it should be noted that this text is included verbatim in reference 7 – the 2008 Wang et al. publication)

> *We assumed in our analysis that the exported electricity from sugarcane ethanol plants will displace electricity generated in natural gas electric power plants, which are believed to be the marginal electric power plants in Brazil. On the other hand, if the exported electricity displaces the average electricity in Brazil (83% of which is from hydro-power), GHG emission benefits of sugarcane ethanol are reduced by up to 8 percentage points.*

Clearly, CARB needs to establish a much more robust basis for the value of the electricity co-product credit as even the authors who published it acknowledge its limitations and potential for it to be incorrect. It is premature for CARB to be considering the establishment of an electricity co-product credit for Brazilian sugarcane ethanol as much more research is required to accurately establish its value. Continuing, in arriving at the CI value for the combination of mechanized harvesting and electricity co-product credits, the electricity co-product credit discussed above is simply added to a GHG emissions credit value associated with not burning cane before harvesting.

The first problem with the combined co-product credit is that the CARB pathway with the electricity co-product credit does not account for is that the basic assumptions used in estimating the credit appear to be derived primarily from manual harvesting with trash burning, rather than mechanical harvesting of unburned cane. This can be seen in both the 2007 and 2008 Wang, et al., references as they cite data from 2005 and earlier during which time it is acknowledged that at least 65% of Brazilian cane harvesting was done manually with burning.

As evidenced from the proceedings[8] of a 2008 workshop conducted by the International Society of Sugar Cane Technologists (ISSCT), mechanically harvested unburned sugarcane clearly has different properties than burned manually harvested cane; and these differences have significant impacts on cane processing, ethanol production, and therefore the value of the electricity co-product credit. Clearly, in order to satisfy its own criteria for the establishment of a new CI value for this pathway, CARB would have to perform and make available for peer review a scientifically defensible analysis that considers these factors and accurately assesses the value of the electricity co-product credit.

Similarly, with respect to mechanized harvesting, CARB has ignored a number of factors affecting GHG emissions that affect the value of the co-product credit. For example, despite the fact that mechanized harvesting requires the use of additional Diesel fueled machinery, CARB has failed to consider those emissions in computing the co-product credit. Based on a Brazilian study,[9] the increase in Diesel fuel consumption associated with just the in-field equipment required during mechanized harvesting amounts to about 18.25 gallons per hectare. Given the GHG emission factor for Diesel tractors and assumed energy content of Diesel fuel used in the CA GREET model, this amounts to 181,280 gCO_2e per hectare. Given the 1,922 MJ of ethanol assumed to be produced per ton of sugarcane and the assumed average yield of 82.4 tons of cane per hectare, the fuel used just by the in-field harvesting equipment equals 1.15 gCO_2e/MJ, which alone reduces the harvesting co-product credit by 15%. A rigorous assessment would also have to account for additional factors such as loss of sugar via green cane deterioration, higher moisture content of bagasse, reduced yields due to soil compaction from operation of machines in the field, and changes in the use of agricultural chemicals depending on whether the material that would have been burned is left in the field or removed. As with the electricity co-product credit, in order to satisfy its own criteria for the establishment of a new CI value for this pathway CARB would have to perform and make available for peer review a scientifically defensible analysis that considers these factors and accurately assesses the value of the mechanized harvesting co-product credit.

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[8] "Green cane impact on sugar processing," ISSCT Process Workshop, Saint Denis, Reunion Island, October 2008 *http://issct.intnet.mu/processreport08.htm*.

[9] "Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil," Macedo, et al., March 2004.

In both cases, it is not clear that a scientifically defensible, peer-reviewed assessment of the GHG reductions that form the basis of the co-product credits would meet CARB's 5 gCO_2e/MJ criterion for substantiality.

Review of Assumptions Made Regarding E85 FFVs in the LCFS ISOR

Summary

In demonstrating the feasibility of compliance with the Low Carbon Fuel Standard (LCFS) regulations in the Initial Statement of Reasons (ISOR), CARB has assumed that there will be a large number of E85 FFVs sold in California during the period from 2015 through 2020. These assumed future E85 sales volumes are far larger than current FFV sales volumes. At present, FFV sales volumes are driven in large part by the availability of credits provided to FFVs under the federal Corporate Average Fuel Economy (CAFE) regulations that will first diminish and then be eliminated during the 2015 to 2020 period. Given that there is no existing state or federal regulation that would require vehicle manufacturers to build E85 FFVs in the volumes assumed in the ISOR and there will be no incentive to do so to earn CAFE credits, there is little support for the assumptions made by CARB regarding FFVs.

In addition to the availability of E85 FFVs, CARB has assumed that the number of E85 refueling facilities in California will grow from the approximately 40[10] in existence today to 4,000 to 5,000, and that vehicle owners will choose to fill their FFVs predominately with E85. At present, there is also little support for these assumptions.

Review of CARB Assumptions Regarding the Role of E85 FFVs in LCFS Compliance

In attempting to demonstrate the feasibility of compliance with the LCFS, CARB staff has, as indicated in the ISOR, assumed that there will be large increases in the number of flexible fueled vehicles (FFVs) sold in future model years and that those vehicles will operate exclusively on E85. In addition, should the assumption of exclusive operation on E85 not be correct, the ISOR states that the effect can easily be offset through the sale of even greater numbers of FFVs that effectively operate on gasoline-ethanol blends of somewhat less than 85% ethanol but far higher than E10. The volumes of E85 FFVs assumed in the ISOR to be sold in California during the years 2015 through 2020 are shown in Table 1. These numbers are also presented in terms of the percentage of total vehicle sales each year in California based on an assumption of annual light-duty vehicle sales of 1.5 million units per year.

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10 *http://www.afdc.energy.gov/afdc/ethanol/ethanol_locations.html.*

Table 1 **FFVs Sales Assumed In the LCFS ISOR**							
		Year					
	Scenario	2015	2016	2017	2018	2019	2020
Assumed Sales Volume	1	100,000	300,000	400,000	700,000	600,000	900,000
	2	100,000	300,000	400,000	800,000	800,000	1,000,000
	3	200,000	200,000	300,000	400,000	700,000	900,000
	4	0	0	100,000	500,000	500,000	700,000
	5	230,000	250,000	340,000	410,000	600,000	780,000
% of Total CA Sales[a]	1	6.7	20.0	26.7	46.7	40.0	60.0
	2	6.7	20.0	26.7	53.3	53.3	66.7
	3	13.3	13.3	20.0	26.7	46.7	60.0
	4	0	0	6.7	33.3	33.3	46.7
	5	15.3	16.7	22.7	27.3	40.0	52.0

[a] Percent of total California Sales based on an assumed annual California sales volume of 1.5 million vehicles.

There are a number of problems with the ISOR assumptions regarding FFVs. First, although FFVs are currently produced by a number of manufacturers, FFV production is not required under any current CARB regulation. The primary motivation for those manufacturers currently producing FFVs is that federal law provides limited credits that can be used towards compliance with Corporate Average Fuel Economy (CAFE) standards. Not all manufacturers have sought such credits, however, and those manufacturers that have done so have limited the number of FFV models they produce because of the limits on the available CAFE credits; in addition, with the enactment of the Energy Independence and Security Act of 2007, the credits that are available to FFVs will be phased out over the 2015 to 2020 model years, eliminating any incentive manufacturers would have to produce FFVs. Given the above, there is no reasonable basis upon which to conclude the large volumes of FFVs assumed by CARB staff will be produced.

Another issue associated with FFV certification in California during future model years is that CARB's Zero Emission Vehicle (ZEV) regulations require manufacturers to certify large volumes of new vehicles as "Partial Zero Emission Vehicles" (PZEVs), which means they must comply with Super-Ultra-Low Emission Vehicle (SULEV) exhaust emission standards, 150,000-mile emission warranty requirements, and Zero Evaporative Emissions standards. Such compliance is proving very difficult for vehicle manufacturers[11] and we are not aware of any FFV that has been certified as a PZEV to date.

As shown in Table 1, the ISOR assumes that by 2020 FFVs account for more than 50% of vehicles sold in California under four of the five scenarios, despite the fact that federal CAFE credits will have been eliminated by that time. In contrast to estimates of up to one million FFVs per year in the ISOR, estimated FFV sales for 2009 (when substantial CAFE credits are available) are less than 350,000[12] and previous CARB projections of E85 FFV penetration into the population through 2020 as shown in Table F6-1 of the ISOR reflect much lower annual sales volumes than 350,000.

In addition to the growth in E85 FFV sales volumes, the ISOR analysis rests on two other questionable assumptions. The first of these is that the number of refueling facilities offering E85 in gasoline will grow from the current number of about 40[13] to 4,000 to 5,000 stations as indicated in Section VIII of the ISOR. The second questionable assumption is that the low carbon intensity ethanol required under the LCFS for use in E85 will be available at a price that will allow the E85 to cost considerably less than gasoline and cause owners of FFVs to use it, rather than gasoline, in their vehicles.

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[11] See, for example, "Fuel Economy & Emissions: Ethanol Blends vs Gasoline," presented by Kevin Cullen of General Motors, September 10, 2007.

[12] Herwick, G., "Opportunities for E85 in California," presented to California Air Resources Board Meeting on Vapor Recovery for E85 Facilities, February 2, 2006.

[13] *http://www.afdc.energy.gov/afdc/ethanol/ethanol_locations.html.*

REFERENCES

State of California
California Environmental Protection Agency

AIR RESOURCES BOARD

STAFF REPORT

2000 ZERO EMISSION VEHICLE PROGRAM BIENNIAL REVIEW

August 7, 2000

EXECUTIVE SUMMARY

In 1990, California embarked on an ambitious strategy to reduce vehicle emissions to zero. This objective was to be achieved through the gradual introduction of electric vehicles into the California fleet. Specifically, the Air Resources Board mandated that at least 2 percent, 5 percent and 10 percent of new car sales be zero-emitting by 1998, 2001 and 2003, respectively.

The Zero Emission Vehicle (ZEV) mandate for passenger cars has been adjusted twice since then, in 1996 and 1998. The underlying goal, however, has not changed. California remains committed to achieving zero emissions performance wherever feasible in the vehicle fleet. The challenge is determining ***how*** to achieve sustainable success in the field.

As evidence of the State's commitment, California has partially subsidized the introduction of battery electric vehicles through grants and fleet purchases. That support is expected to continue.

The rationale for California's commitment is simple. Zero-emission technology is necessary to achieve the State's public health protection goals. Health-based state and federal air quality standards continue to be exceeded in regions throughout California, and more areas of the State are likely to be designated as nonattainment with promulgation of the new federal eight-hour ozone standard. California's burgeoning population and robust economy mean continued upward pressure on statewide emissions. Manufacturing, power generation, petroleum refining, goods transport, home heating and cooling, personal mobility and a wide range of human activities all have direct air pollution consequences. Accomplishing zero emissions in any of these source categories (or portion thereof) mitigates their adverse impacts and protects human health.

Zero-emission technologies also transcend some of the persistent problems with conventional air pollution sources. Combustion-based engines are inherently higher emitting and prone to deterioration over time. Catastrophic failures are also a concern. Older gasoline-powered vehicles, for example, become gross emitters if their emission control systems fail. Combustible fuels also have significant "upstream" impacts. Refining, fuel storage and delivery all have associated emissions from both routine operations, accidents (breakdowns, fuel spills), and ongoing compliance problems (e.g., leaking underground tanks). Apart from upset conditions that may occur during electric power generation, zero emission vehicles have none of these vulnerabilities. A battery powered electric car will remain emission-free throughout its useful life.

Current ZEV Mandate

ARB regulations require that 10 percent of the new light-duty vehicles offered for sale in California for model year 2003 be zero emitting. This requirement applies to intermediate and large volume vehicle manufacturers only.

Manufacturers have significant flexibility in meeting the ZEV requirements. Auto companies can earn extra ZEV credits by introducing vehicles before 2003, thereby reducing their total obligation. Extra credit is also available for battery electric vehicles with more than a 100 mile range per charge. Manufacturers may also delay compliance by one year provided they produce two years' worth of ZEVs by the end of 2004. Finally, large manufacturers can satisfy up to 6 percent of the 10 percent ZEV requirement with near-zero emitting technologies, and intermediate manufacturers may meet the entire 10 percent obligation via that route (producing no electric vehicles at all).

Eleven auto manufacturers are expected to qualify as ***"intermediate"*** in 2003: BMW, Hyundai, Isuzu, Jaguar, Kia, Mazda, Mitsubishi, Rover, Subaru (Fuji), Volkswagen and Volvo. Six auto companies are expected to qualify as ***"large"*** in 2003: DaimlerChrysler, Ford, GM, Honda, Nissan and Toyota.

If no change is made to today's ZEV regulation, staff estimates that approximately 22,000 electric vehicles would need to be offered for sale in 2003 to meet a four percent ZEV requirement. However, this total could change significantly, up or down, based on each manufacturer's actual production decisions and their chosen compliance path. As noted above, early ZEV introduction or the use of additional vehicles with extended range would decrease the 2003 obligation. Reduced reliance on PZEVs, on the other hand, would increase the number of ZEVs needed.

The ZEV mandate continues in 2004 and each year thereafter. Again, if the rule is unchanged, staff estimates ZEV availability will grow gradually over time, reaching 31,000 to 78,000 units (4 percent to 10 percent) by 2006.

The September 2000 Biennial Review

When the ZEV mandate was adopted in 1990, electric vehicles were in a very early stage of development. To ensure successful implementation, the Board directed staff to report biennially on the status of technological progress. The September 2000 biennial review is the fifth in-depth examination of the technical and economic issues related to ZEVs. Since auto makers generally need three years' lead time for production, this biennial review is also the last significant opportunity to assess their readiness for meeting the 2003 requirements.

This report describes the current status of ZEV technology and the prospects for near- and long-term improvement. The analysis is based upon experience gained through the 1996 Memorandum of Agreement (see below), staff meetings with each of the affected manufacturers, contract work performed by outside experts, and extensive comments received at two public workshops conducted earlier this year.

1996 Memorandum of Agreement

The original ZEV mandate called for 2 percent penetration in 1998 (approximately 20,000 vehicles). However, in 1996, the ARB determined that a smaller introduction was warranted given the status of electric vehicle technology at the time. Accordingly, the ARB's Executive Officer entered into Memoranda of Agreement (MOAs) with large volume manufacturers to produce a limited number of ZEVs, specifically 3,750 vehicles between calendar years 1998, 1999 and 2000. Multiple credits for advanced batteries reduced the total legal commitment to just over 1,800 electric vehicles.

Today there are approximately 2,300 electric vehicles on the road in California. The products are highly attractive, high performing and range in style from vans, pick-up trucks, sport utility vehicles and station wagons to two-seater sports cars. All of these electric vehicles were introduced within the last four years. The only significant gap is the absence of a 4-door, 5-passenger ZEV sedan, which no manufacturer is currently producing.

Although the market is just forming, customer interest is encouraging and suggests that additional demand exists for ZEV products. Unfortunately, the full extent of this demand cannot be quantified because very few electric vehicles are available. Those manufacturers who have met their quotas have largely ceased production. Companies still making ZEVs have encountered production delays and are mostly marketing to fleets. This virtual "black out" condition was not anticipated when the MOAs were signed in 1996. It also complicates staff's analysis of market readiness for 22,000 ZEVs in 2003. When even the most motivated customers cannot obtain electric vehicles, the ability to gauge broader consumer interest and acceptance are severely diminished.

The primary reason for the "black out" is cost. Manufacturers are not yet able to produce a competitively priced electric vehicle without incurring significant losses on each unit leased or sold. The secondary reason is uncertainty. Car companies are unwilling to invest in volume production until they see the business case for each ZEV model, a certain market, and a definitive regulatory signal from the State.

Implementation of Year 2003 Requirements

1. Vehicle Technology Assessment

There is no technological barrier to building battery powered ZEVs; the issue is cost and consumer acceptance. With regard to near-zero emission vehicles, technology exists which allows vehicles to achieve the required level of performance. Several manufacturers have stated, however, that due to lead time considerations they will not be able to build enough PZEVs to take full advantage of the partial ZEV option in 2003. If they cannot overcome those challenges, more battery electric vehicles will be needed to meet the 10 percent ZEV mandate. Hybrid vehicles are an environmentally attractive product and could achieve near-zero (PZEV) emissions performance in the near future. Finally, hydrogen powered fuel cell vehicles have potential to become an additional pure ZEV technology, but will not be commercially available by 2003. These conclusions are explained in more detail below.

Battery electric vehicles are clearly technologically feasible. Seven models are on the road including GM's EV1 2-seat sports car; the Chevrolet S-10 and Ford Ranger pick-up trucks; Honda's EV PLUS (a 4-seat, 2-door platform comparable to Honda's CRV), the Toyota RAV4 sport utility vehicle; Nissan's Altra EV station wagon; and the DaimlerChrysler EPIC minivan. In addition, several classes of smaller battery electric vehicles are emerging. These include low-speed vehicles (LSVs, also referred to as "neighborhood electric vehicles" or NEVs) and low-range vehicles designed for in-city driving (City EVs). Examples of the latter include the Ford TH!NK, the Toyota E-COM, and Nissan's Hyper-Mini. All of these vehicles qualify as ZEVs under the current ARB regulation.

Regarding PZEVs, the leading candidates are extremely clean gasoline-powered cars, with or without hybrid electric drive-train technology. To qualify for PZEV credit, a vehicle must be certified to the super ultra low emission level (SULEV) exhaust standards, have zero evaporative emissions, and come with a 150,000 mile warranty. To date, only the Nissan Sentra has achieved PZEV status. Three other vehicles (Honda Accord, Honda Civic GX, and Toyota Prius) have attained the SULEV criteria, but have not met the remaining requirements. Both large and intermediate volume manufacturers are concerned about their ability to overcome all the engineering challenges implicit in the PZEV criteria by 2003. If they cannot reach that objective, up to the full 10 percent of battery electric cars may be required. Staff concurs that the PZEV criteria are extremely challenging and that some manufacturers will be unable to take full advantage of the PZEV option in 2003.

Hybrid electric vehicles are the newest entrants to the advanced vehicle field. These vehicles combine batteries, a supplemental electric drive train, and a downsized conventional fuel tank to increase overall efficiency. Hybrid vehicles consume less fuel per mile of operation, thereby reducing upstream environmental impacts and releases of climate changing gases. Hybrid vehicles may also be low, ultra low or super ultra low emitting if they are designed to meet those respective exhaust standards. Two hybrid vehicles are currently available: the Honda Insight and the Toyota Prius. Although neither qualifies for PZEV credit at this time, there is no inherent technological reason why hybrids cannot achieve PZEV performance. The main obstacle is the time needed to design, test and perfect the necessary emission controls.

Fuel cell vehicle (FCV) technology has the potential to be zero emitting when powered by pure hydrogen from a relatively clean source. The California Fuel Cell Partnership is examining the potential for commercializing such technology, along with other FCV fuel types. A few prototype vehicles are available for testing and demonstration.

2. Battery Technology Assessment

Batteries are the single most expensive component of electric vehicles. For that reason, affordable battery packs--both today and when produced in volume--are crucial to achieving a sustainable electric vehicle market. ARB's existing regulations also place a premium on advanced (long-range) battery technology. This preference was based on early survey results and upon staff's judgment that electric vehicles with greater than 100 mile range will sell better, to more people and for more uses, than shorter range vehicles.

ARB contracted with a team of outside experts to obtain the best available information on battery advances, costs and future trends. The Battery Panel concluded that nickel metal hydride (NiMH) batteries were the most promising advanced technology, having both high performance and the longest useful life. Unfortunately, the Panel also concluded that battery costs are high and will not meet cost-competitive targets for some time. Although volume production will help, a breakthrough is needed to achieve truly affordable NiMH packs.

Several commenters have suggested that ARB revisit its preference for advanced battery technology. Lead acid (PbA) batteries, they suggest, could meet market needs at a far lower cost. Their justification is two-fold. First, several EV drivers testified at staff workshops that that their actual driving needs were lower than they anticipated before they leased a ZEV and that they would not pay a premium for greater range. In addition, some auto manufacturers are closely examining the business case for lead-acid based City Cars that would be overtly marketed as limited range, niche vehicles. The opposing view is that advanced batteries meet a broader range of driving needs, produce less waste (since they last longer), and may ultimately serve a larger consumer market.

3. Infrastructure Assessment

Unlike conventional vehicles, battery powered ZEVs do not require an extensive "fueling" infrastructure since most customers will recharge at work or at home. The availability of public charging stations is nonetheless extremely important because of its influence on consumer confidence and acceptance. Public chargers also enable ZEV owners to drive longer distances, and to reach more destinations than they otherwise might.

The public infrastructure for electric vehicles continues to expand in California. Currently, there are about 400 public charging stations statewide with approximately 700 separate chargers. Most of these were constructed with a combination of government and electric utility funds. Recently, a few private companies have begun to offer electric charging services to their customers. The most notable example is Costco, which has a corporate-wide "all electric" philosophy. Staff expects these services to expand as additional local governments and private companies embrace electric vehicle technologies.

The most difficult issue affecting public charging infrastructure is the absence of uniform charging standards or equipment. A little more than half of the chargers are inductive; the rest are conductive. Current vehicles use a 220 volt system. When City Cars come to market, they will introduce the need for a new minimum voltage of 110. There is no easy way around this dilemma. Because the chargers are integrally linked to vehicle design and have competitive characteristics, manufacturers are unwilling and may actually be unable to move toward full standardization.

Fast charging has been successfully demonstrated in the DaimlerChrysler EPIC minivan and holds great promise for the future. However, there is a significant economic barrier: fast charging is more expensive per station and would require extensive financial support to implement. Fast chargers also require special battery packs that can receive rapid charging without producing excessive heat.

4. Market Assessment

There is significant disagreement over the extent of market demand for electric vehicles. Manufacturers assert that the lack of leases during the first years when vehicles were available means that the market can only absorb a few hundred ZEVs per year. Electric vehicle advocates and fleet operators point to current waiting lists as evidence of strong customer interest and pent-up demand. Staff views this as the most difficult area in which to develop reliable estimates. The entire market is new and product availability has been constrained such that true consumer interest is exceedingly difficult to gauge.

The recent emergence of fundamentally new ZEVs–namely city cars and neighborhood EVs–further complicates staff's assessment. Although the business case for inexpensive, in-town EVs appears to be promising, there is as yet no market experience for selling these products in the U.S. Manufacturers will have to start from scratch in building consumer awareness and interest.

Left unchanged, the current ZEV requirement will result in approximately 22,000 electric vehicles by 2003. That represents almost a ten-fold increase over the number of ZEVs on the road in California today. The quantity of ZEVs will grow in 2004, 2005 and 2006 as ZEV production ramps up per the current ARB regulation. Whether all of these vehicles can be successfully marketed and placed is a key issue facing the Board.

Studies and surveys indicate that the primary factors affecting EV market demand are range, recharge time and competitive pricing. Based on experience to date and public testimony, staff has identified several other factors that are critical to ongoing success. The single greatest need is for near term ZEV availability, followed by a smooth, orderly buildup from the current base. Other important factors include public infrastructure, additional vehicle platforms, public education (including real time information on available products, subsidies, station locations, and how to go about obtaining a ZEV), and making all ZEV products available to retail customers.

Cost Estimates

Today's ZEVs are more costly for manufacturers to make than any other vehicle technology being produced for sale between now and 2003. As noted above, most of that cost differential stems from the battery pack. The cost gap will narrow as technology improves and manufacturers move to volume production. However, there is no getting around the fact that near-term ZEVs will be relatively more expensive to produce. Staff estimates that the incremental costs for ZEVs in 2003 will range from $7,500 for City EVs, up to more than $20,000 for freeway capable ZEVs with advanced NiMH batteries. These calculations exclude the costs incurred for research and development of each ZEV model.

Under an optimistic but nonetheless plausible scenario, battery EVs could become cost-competitive with conventional vehicles on a lifecycle cost basis. This scenario assumes volume production of more than 100,000 ZEVs.

It is important to distinguish cost from price. Staff has estimated the cost of ZEV production to manufacturers, and the cost of operating ZEVs over their useful life. That is not the same as estimating the price at which various electric vehicles would be offered for sale. Price is set in a competitive environment and can differ from cost for several reasons. In initial years, manufacturers will not be able to recover the full cost of ZEV production through prices alone. This shortfall will be wholly borne by the automakers unless California offers full or partial subsidies to mitigate the revenue gap.

During the MOA period, California provided $5,000 per vehicle "buy down" grants to offset the higher incremental cost of producing ZEVs. These grants were given to the auto manufacturers, who applied them as a discount to their ZEV lease or purchase prices. With some exceptions, the $5,000 grants were funded fifty/fifty by the California Energy Commission and local air pollution control districts. CEC's funding for this program came from the State's Petroleum Violation Escrow Account (PVEA), while districts have relied upon their motor vehicle registration fee surcharge revenues. Subsidies of up to $500 were also available for the installation of individual, at-home charging stations. Both of these financial incentive programs are funded only through FY 2000-2001.

To support a significantly higher penetration of ZEV vehicles, California will need to continue its subsidy programs–at least through the initial years. It will also be necessary to identify an alternate fund source. The State's entire PVEA account will be exhausted by the end of next year. Moreover, local air districts have multiple, competing claims on their vehicle registration fee revenue (including heavy-duty diesel clean-up programs) and are unlikely to be able to continue to allocate large amounts to ZEV subsidies.

Environmental, Energy and Economic Benefits

ZEVs provide comprehensive environmental, energy and societal benefits.

With respect to the environment, ZEVs are the "gold standard" for vehicular air pollution control. They reduce both criteria and toxic pollutant emissions to the maximum feasible levels. High-efficiency ZEVs and hybrid electric near-ZEVs also cut emissions of carbon dioxide and other greenhouse gases. Finally, ZEVs minimize the multi-media impacts of vehicle operation, eliminating the need for a whole host of upstream petroleum refinery, storage and delivery activities. Admittedly, ZEVs have their own upstream impacts related to power generation and create new waste disposal issues. However, on an overall lifecycle basis, they are environmentally superior to conventional automobiles. As California's power generation system becomes increasingly cleaner, so too will the upstream emissions associated with ZEVs.

Regarding energy use, vehicles powered by grid electricity increase the diversity of California's transportation energy system. This reduces the State's dependence on foreign oil and contributes to greater stability in the overall transportation fuels market. Advanced battery ZEVs and hybrid electric near-ZEV technologies are also highly efficient; reducing absolute energy demand per mile of vehicle operation. Finally, ZEVs have the potential to be powered by renewable sources of energy such as wind, hydropower or solar energy.

The societal benefits of ZEVs include their clean, quiet operation in neighborhoods and on city streets. ZEVs can also benefit the State's economy. Because of their high technology leadership, California companies have the technical and scientific capability to play significant roles in the design, development and production of advanced technology zero emission components and vehicles.

In public comments, automakers stated that the direct air quality benefits of the ZEV program are minor and, therefore, not worth the investment in electric cars. Staff recognizes that in the near-term, due to the small penetration of ZEVs and corresponding improvements in conventional cars, fleet-wide benefits will be modest. However, this is a long-term strategy. On a per vehicle basis, ZEVs are significantly cleaner than even the cleanest gasoline-powered alternative. They will steadily reduce emissions as their fleet penetration grows. Even more importantly, ZEVs have no risk of in-use emission control system failures. They are the only technology that is guaranteed to *permanently* reduce emissions over time.

Conclusion

California has made significant technological progress toward its zero emission objectives. More than two thousand battery EVs are on the road, illustrating that ZEVs can be built and deployed. There are a variety of attractive ZEV platforms. Also, their respective characteristics meet a wide range of market applications including fleets, small businesses and private commuting. While electric vehicle range is limited and recharging times are long, ZEVS are in everyday use in many different circumstances across the state. All evidence and testimony points to the fact that those who are using today's EVs are very pleased with their performance.

Progress has been less pronounced on the economic side. Staff's cost analysis concludes that both the initial and lifecycle costs of battery EVs will significantly exceed those of comparable conventional vehicles in the 2003 timeframe. However, in volume production and with improved technology, battery EVs could become competitive on a lifecycle cost basis.

The near term cost premium for ZEVs is not surprising since every incremental step in pollution control provides benefits at a higher marginal cost. The ZEV program, moreover, is not a typical step-wise adjustment but a transformative leap forward. Given the sweeping nature of ZEVs' environmental, energy and societal effects, it is reasonable to expect that the program will be more expensive in its early years than more limited measures. At the same time, the fact that costs impose burdens must also be acknowledged. While higher costs persist, state subsidies could be very important to mitigate impacts on auto manufacturers and to nurture a growing ZEV market.

The market for battery EVs is just starting to be understood and is very difficult to quantify. As noted above, the 2003 ZEV mandate represents a ten-fold increase in the number of actual battery EVs on the road. Placing all of those vehicles within a year or two and sustaining those sales in 2004, 2005 and beyond is a significant marketing challenge by anyone's measure.

Staff has identified a number of applications that are well suited to using ZEVs and which could absorb several thousand units. Actual vehicle sales/leases will depend on consumer awareness and interest, available products and their net market price (minus any subsidies or tax incentives that may be provided). These factors suggest that much more extensive public education is needed. In addition, continuity of ZEV production is critical. Market acceptance cannot build, and volume production cannot be achieved, if ZEVs continue to be available only in boom and bust cycles.

The 1996 MOA was a highly collaborative effort between the State of California, automakers, public utilities, local governments, fleet operators and many private ZEV enthusiasts who put their own dollars on the line. As ZEV penetration grows, this partnership needs to continue and expand. Teamwork among all the interested parties will increase the probability of success and hasten the advent of a truly self-sustaining ZEV market.

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1. INTRODUCTION

1.1 Background

Air quality in California has improved dramatically over the past 25 years, largely due to continued progress in controlling pollution from motor vehicles. Faced with ever more stringent regulations, vehicle manufacturers have made remarkable advances in vehicle technology. Several thousand zero-emission vehicles are now in everyday service on California roads, and the latest conventional internal combustion engine vehicles achieve emission levels that seemed impossible just a few short years ago.

Despite this progress, however, air quality in many areas of the state still does not meet federal or state health-based ambient air quality standards. Mobile sources still are responsible for well over half the ozone-forming emissions in California. The relative contribution of passenger cars and small trucks is expected to decline over time as new standards phase in , but in 2020 such vehicles will still be responsible for about 10 percent of total emissions. State and federal law requires the implementation of control strategies to attain ambient air quality standards as quickly as practicable.

Mobile sources are also the primary source of emissions of toxic air contaminants in California, and a major contributor to greenhouse gas emissions. The facilities needed to refuel the current vehicle fleet (service stations, bulk terminals, refineries) are significant sources of smog precursors, air toxics, water pollution, and hazardous waste.

1.2 The Zero Emission Vehicle Program

The Zero Emission Vehicle (ZEV) program was originally adopted in 1990, as part of the first ARB Low-Emission Vehicle regulations. The ZEV program is an integral part of California's mobile source control efforts, and is intended to encourage the development of advanced technologies that will secure increasing air quality benefits for California now and into the future. ZEVs have significant long-term benefits because they have no emission control equipment that can deteriorate or fail, and generate only minimal "upstream" refueling and fuel cycle emissions.

Under the 1990 regulations, the seven largest auto manufacturers were required to produce ZEVs beginning with model year 1998. In model years 1998 through 2000, two percent of the vehicles offered for sale in California by large volume manufacturers were to be ZEVs, and this percentage was to increase to five percent in model years 2001 and 2002, and ten percent in model years 2003 and beyond.

In 1996 the ARB modified the regulations to allow additional time for the technology to develop. The requirement for ten percent ZEVs in model years 2003 and beyond was maintained, but the sales requirement for model years 1998 through 2002 was eliminated. At that same time, the ARB entered into Memoranda of Agreement (MOAs) with the seven largest vehicle manufacturers. Under the MOAs the manufacturers must place more than 1,800 advanced-battery EVs in California in the years 1998 through 2000, and the ARB must work with state and local governments to help develop ZEV infrastructure and remove barriers to ZEV introduction.

In 1998 the ARB provided additional flexibility in the ZEV program by allowing additional types of vehicles to be used to meet program requirements. Under the 1998 amendments, manufacturers can use extremely clean advanced-technology vehicles (referred to as “partial” ZEVs) to meet the 10 percent ZEV requirement, except that large-volume manufacturers must, at a minimum, have 4 percent of their sales be vehicles classified as “full” ZEVs.

1.3 ARB Long-Term Vision

Simply put, continued reliance on today’s technology will not allow California to reach its health-based air quality goals. In ARB’s vision of the future, therefore, the entire vehicle fleet will produce zero tailpipe emissions, and will use fuels with minimal “fuel cycle” emissions (emissions that occur due to vehicle refueling and the related production or transportation of fuel). As an ancillary benefit to the advanced technologies employed, the future vehicle fleet also will be highly energy efficient, use diverse energy sources, and will result in reduced emissions of greenhouse gases. In considering the ZEV program, it is essential to keep this long-term perspective firmly in mind

In public comments, manufacturers have stated that they do not expect to see a zero emission fleet in any reasonable planning timeframe. Manufacturers do expect that in the future, global customer demands will reward companies that can meet society’s transportation needs while eliminating harmful environmental impacts.

1.3.1 Continued Emphasis on Zero Emissions

Battery-powered electric vehicles and other ZEVs such as hydrogen fuel cell vehicles hold distinct air quality advantages over technologies that use a conventional fuel such as gasoline in a combustion engine. High volatility liquid fuels such as gasoline are responsible for significant fuel cycle emissions. Vehicles with combustion engines inevitably exhibit deterioration that results in increased emission levels as the vehicle ages. They are also subject to becoming gross polluters if critical emission control systems fail. Although new vehicles have more durable emission control systems and on-board diagnostic systems that are effective in alerting owners to emission related problems, owners may not respond to failure signals promptly. The inspection and maintenance program will not capture vehicles that are operated without being registered, and repair cost limits may permit continued operation of some high emitting vehicles.

For all of these reasons, vehicles with no potential to produce emissions are the “gold standard” of even the cleanest, most advanced new technologies. The commercialization of ZEVs is critical to the long-term success of California’s clean air program. Even with the full implementation of the LEV II program, emissions from light duty vehicles will still represent some 10 percent of total emissions in the South Coast Air Basin. Achieving the new air quality standards for particulate matter, not to mention the state ozone standard, will require further reductions. Taking into account the anticipated growth in the number of light-duty vehicles and the number of miles they travel each day, it is clear that we need to eliminate emissions related to vehicle deterioration and fuel use from a significant portion of the light-duty vehicle fleet. ZEVs can accomplish this goal.

1.3.2 Near-Zero Technologies Also Play a Major Role

The ZEV requirements have been instrumental in promoting battery, fuel cell, component and vehicle research and development. These requirements have also been successful in spawning a large variety of extremely low-emission vehicle technologies. Many of these technologies have at least some of the desirable qualities inherent to ZEVs, such as extremely low emissions of smog precursors and toxic air contaminants, reduced emissions of greenhouse gases, extended durability, or high efficiency.

Such vehicles will play a major role in achieving further air quality improvement. First of all, many of the technologies can be adopted at relatively low cost. For example, staff estimates the incremental cost of going from a SULEV to a PZEV to be about $500. Vehicles using these technologies thus have the potential for widespread early market penetration. Although the near-ZEV vehicles are not as clean as ZEVs, if produced in large numbers they provide a significant air quality benefit relative to the conventional vehicles that they replace.

Second, because many of these vehicles use components also found on zero emission vehicles (e.g. battery packs, controllers, and electric drive), volume production of near-zero vehicles will help reduce the cost of components used on zero emission vehicles and hasten their commercialization.

1.3.3 Linkage to Broader Issues

The mission of the Air Resources Board is to protect public health through the reduction of air pollution. The Board’s primary focus is on the reduction of smog-forming pollutants and toxic air contaminants. To date, most discussion of ZEV air quality impacts has focused on their smog benefits.

In addition to their dramatic reduction in smog-forming pollutants, ZEVs also provide reductions in the emissions of toxic air contaminants. The benefits of reductions in toxic air contaminants are felt statewide. Recognizing that mobile source pollution from highway traffic may disproportionately affect nearby inner city and low-income neighborhoods, reductions in toxic emissions from motor vehicles can also help address community level public health concerns.

Above and beyond these traditional air pollution benefits, ZEVs can also make significant positive contributions in other environmental areas. For example, the use of alternative fuels can reduce the multimedia impact of fuel spillage on water quality, and can increase the diversity of California's energy supply. The smooth, quiet operation of electric drive vehicles can improve the quality of life in crowded urban areas. Electricity and hydrogen, which can be used to power ZEVs, can be produced from renewable resources such as solar, wind or hydropower, or biomass feedstocks. Thus these technologies can help pave the way towards a sustainable energy future.

Perhaps the most important ancillary benefit, though, is that high-efficiency ZEVs and hybrid electric near-ZEVs can lead to significant reductions in emissions of CO_2 and other greenhouse gases. The Air Resources Board does not currently regulate emissions of greenhouse gases. The Board is, however, working with the California Energy Commission to better understand the contribution of mobile sources to total greenhouse gas emissions, and quantify the climate change impact of various fuels and vehicle technologies. Even in the absence of specific regulatory requirements it is clear that, other things being equal, technologies that achieve lower greenhouse gas emissions are the preferred alternative. Meanwhile, auto manufacturers worldwide are working to reduce greenhouse gas emissions from their vehicles in keeping with the Kyoto Protocol and other requirements in place or pending in other markets.

ZEVs can benefit California's economy as well as our public health. Because of their high-technology leadership, California companies have the technical and scientific capability to play a significant role in the design, development and production of advanced technology zero emission components and vehicles. ARB is currently developing estimates of some of the economic benefits of the ZEV program.

ZEVs thus have the capability to provide comprehensive environmental, energy and societal benefits. While the Board's consideration of the ZEV regulation is firmly rooted in its air quality mandate and authority, the Board is aware of the multi-faceted effects of its policy choices. Over the long term the Board, in cooperation with its sister agencies, will devote increasing attention to an integrated consideration of such broader issues.

1.4 Progress Since the 1998 Biennial Review

Perhaps the best way to characterize progress over the two years since the last Biennial Review is to say that EVs have rapidly moved into widespread real world applications.

In July of 1998, when the last Biennial Review staff report was released, manufacturers had just introduced their vehicles. On March 29, 2000, numerous enthusiastic EV drivers arrived en masse in their leased vehicles to testify at the ZEV Review workshop in Sacramento. Others arrived in rental electric vehicles they had picked up at the Sacramento airport. On that same day, dozens of EVs were at work elsewhere in the Sacramento area for a variety of state and local agencies. Down Interstate 80 in West Sacramento, plans were underway for a groundbreaking ceremony for the headquarters of the California Fuel Cell Partnership. In Los Angeles, electric minivans were in use shuttling passengers to and from Los Angeles International Airport. In Yosemite Valley, two electric vehicles provided zero emission mobility for park staff and visitors. In the Bay Area, San Diego, Ventura, the Gold Country, the San Joaquin Valley, Los Angeles, and elsewhere around the state, electric vehicles were in daily use. Some specific highlights of recent progress include:

- More than 2,300 electric vehicles in a variety of configurations have been delivered for lease or sale in California.
- All of the required MOA vehicles produced to date have been successfully leased. At present there are more interested customers than there are vehicles available.
- General Motors has released the “Generation II” NiMH version of the EV1, featuring a range of 142 miles, and a NiMH version of the S-10 pickup.
- DaimlerChrysler released a NiMH version of the EPIC minivan. EPIC minivans using fast charge are in daily use by Xpress Shuttle serving passengers at Los Angeles International Airport.
- Ford has released a NiMH version of the Ranger pickup.
- Ford has created a Th!nk subsidiary to market advanced technology vehicles, and has announced plans to market City and neighborhood sized EVs.
- Ford introduced an innovative and successful program to market the EV Ranger to schools and parks at a reduced rate of $199 per month.
- The United States Postal Service has ordered 500 electric vehicles, based on the Ford Ranger platform, for mail delivery in California.
- Honda has begun to re-market vehicles after the expiration of the original three year lease, resulting in additional zero emission miles of service. Most of these vehicles are being re-leased by the original drivers, giving evidence of high customer satisfaction.
- Toyota has introduced vehicles with a second generation, smaller, inductive charging paddle.
- Nissan has introduced the first electric vehicle powered by lithium-ion batteries.

- Nissan has introduced a Sentra vehicle that meets partial ZEV credit requirements.
- Manufacturers have continued to refine and improve power control electronics, electric drivetrains, and other components. For example, General Motors is developing a Generation III electric drivetrain.
- Southern California Edison operates a fleet of 320 EVs, which has logged more than 3.5 million miles of service.
- As of July 1, 2000, electric vehicles that have secured the appropriate permit sticker from the California Department of Motor Vehicles are authorized to travel in High Occupancy Vehicle lanes regardless of the number of occupants.
- Under recent legislation, the registration fee paid by electric vehicles is now no greater than that of a comparable conventional vehicle.
- More than 120 public fleets around the state have used EVs under the ARB's Electric Vehicle Loan Program, and several California utility companies have conducted highly successful loan programs within their jurisdictions.
- State and local government fleets have made major purchase commitments.
- EVs are available for rent at the Los Angeles, Ontario and Sacramento airports and in Beverly Hills, and will soon be available at the Burbank and Orange County airports as well as downtown Sacramento.
- Significant public infrastructure continues to be installed around the state.
- The California Fuel Cell Partnership has been formed, with the goal of demonstrating fuel cell vehicle technology and alternative fuel infrastructure over the next four years.
- Automakers and the public sector have supported the ZEV program with significant incentives for vehicles and for infrastructure.

1.5 The 2000 Biennial Review Process

When the ZEV requirement was adopted in 1990, low- and zero-emission vehicle technology was in a very early stage of development. The Board acknowledged that many issues would need to be addressed prior to the implementation date. Thus the Board directed staff to provide an update on the ZEV program on a biennial basis, in order to provide a context for the necessary policy discussion and deliberation. The next biennial review of the ZEV program is scheduled for September 2000.

The ARB is committed to working closely with all interested parties to ensure that they have an opportunity to provide comments and suggestions throughout the review process. The key milestones of the review process have been as follows:

March 29, 2000	Public Workshop Background Information for the September Review Sacramento
March 30, 2000	Public Workshop Multi-Manufacturer Ownership Arrangements

	Sacramento
May 31-June 1, 2000	Public Workshop Background Information for the September Review Diamond Bar
August 7, 2000	Staff Report released to the public
September 7, 2000	Board Meeting

1.6 The Purpose of This Document

In preparing for the Board's upcoming Biennial Review, the goal of the staff is to provide a thorough, accurate portrayal of the current status of ZEV technology and the prospects for improvement in the near- and long-term. Staff efforts have included meetings with vehicle manufacturers, environmental groups, and other interested parties, on-site visits to the large vehicle manufacturers in Japan and in Michigan, discussions with EV drivers, and research on current and pending technologies and their environmental impacts. ARB also has contracted with outside technical experts to review the state of battery technology and production costs, and assess the full fuel cycle emissions and energy efficiency of various vehicle types and fuel sources.

This document is descriptive rather than proscriptive—it does not draw conclusions or make recommendations. Rather, the purpose of this Staff Report is to put forth technical information, and provide a framework and context for the Board's consideration of the relevant issues.

1.7 Public Comments

At the March 2000 public workshop, three public comment sessions were conducted. These sessions addressed the preliminary staff assessment, the EV driver experience, and advances in ZEV technology. Seventy-three individuals testified at the workshop, and staff received nearly forty additional written submittals. At the May 2000 workshop, sessions addressed the EV market, the report of the Battery Technology Advisory Panel, environmental benefits, and cost. More than 100 individuals testified, and numerous separate written submittals have been provided.

In seeking public comment, staff hoped to identify areas where the staff report could be strengthened or improved, and bring to light issues that the public believes should be highlighted for the Board's consideration. The extensive public comment provided has been valuable during preparation of this Staff Report. Information provided as part of public comment is incorporated or noted as appropriate throughout the body of the Staff Report.

2 MANUFACTURER STATUS

2.1 Introduction

The ZEV requirement applies to large and intermediate volume manufacturers (defined below). Beginning in model year (MY) 2003, at least 10 percent of the passenger cars and light duty trucks below 3,750 pounds gross vehicle weight produced and delivered for sale in California by large and intermediate volume manufacturers must be ZEVs. An intermediate volume manufacturer may meet this ZEV requirement entirely with partial ZEV allowance vehicles (defined in Section 4.3.1) or credits generated by such vehicles. A large volume manufacturer must meet at least 40 percent of its ZEV requirement with pure ZEVs, full ZEV allowance vehicles, or credits generated by such vehicles. Large volume manufacturers may, at their option, meet the remaining 60 percent of their ZEV requirement with partial allowance vehicles or credits generated by such vehicles. A small volume manufacturer is not required to meet the percentage ZEV requirements, but may earn and market credits for the ZEVs or ZEV allowance vehicles it produces and delivers for sale in California.

2.2 Manufacturer Volume Classifications

Because MY 2003 is quickly approaching and production planning is well underway, ARB staff has attempted to establish each manufacturer's volume classification and, thus, each manufacturer's ZEV requirement.

For purposes of classification for 2003, small volume manufacturers are defined as those with California sales below 4,500 per year, using the average number of vehicles sold over the preceding three years. Small volume manufacturers are not subject to the ZEV requirement. Based on current production and sales data, ARB staff expects the small volume manufacturers in MY 2003 to be the following:

- Dae Woo
- Ferrari
- GFI
- Lamborghini
- Lotus
- Porsche
- Rolls Royce
- Saab
- Suzuki

Intermediate volume manufacturers are defined for 2003 as those with California sales between 4,501 and 35,000 light and medium duty vehicles per year, again averaged over the preceding three years. Based on the same data, ARB staff expects the intermediate volume manufacturers in MY 2003 to be the following:

- BMW
- Subaru (Fuji)
- Hyundai
- Isuzu
- Jaguar
- Kia
- Mazda
- Mitsubishi
- Rover
- Volkswagen
- Volvo

Large volume manufacturers are defined as those that are not small volume manufacturers or intermediate volume manufacturers. Based on the same data, ARB staff expects the large manufacturers in MY 2003 to be the following:

- DaimlerChrysler
- Ford
- GM
- Honda
- Nissan
- Toyota

During public comment at the March workshop, one manufacturer recommended that the minimum annual sales threshold for a large manufacturer be increased above the current level of 35,000. This manufacturer noted that automakers just above this cutoff are far more limited in resources than the existing large manufacturers, who typically have annual California sales of at least 100,000 and often substantially more. Another manufacturer made a similar recommendation, with similar reasoning, regarding the minimum annual sales threshold for an intermediate volume manufacturer, currently set at 4,500. Representatives of several intermediate volume manufacturers testified that due to constraints imposed by the planned dates for introduction of new engines and vehicle platforms, they would not be able to produce the required number of PZEVs as early as 2003.

2.3 Potential Classification Changes

Although previously categorized as a large-volume manufacturer, Mazda has consistently been selling fewer than 35,000 vehicles in California in recent years. Mazda will be considered an intermediate volume manufacturer beginning in MY 2003 if its production volume remains at the current level.

BMW and Volkswagen have each been selling approximately 35,000 vehicles per year in California in recent years. If their 2000 through 2002 MY average sales exceed 35,000, they will need to meet ZEV requirements as large volume manufacturers beginning in MY 2006.

Subaru, which is currently considered an intermediate volume manufacturer, has been selling near the lower limit of the intermediate volume manufacturer classification in California in recent years. Therefore, depending on its actual sales in model years 2000 through 2002, Subaru may be classified as either an intermediate or a small volume manufacturer in MY 2003.

In 1998 Isuzu produced only light duty trucks between 3,751 and 5,750 pounds gross vehicle weight (LDT2s), which are not subject to the ZEV requirement. Rover produced only medium duty vehicles, also not subject to the ZEV requirement. Therefore, although Isuzu and Rover are intermediate volume manufacturers, they will not need to produce any ZEVs in MY 2003 if they continue to produce only LDT2 and medium duty vehicles.

2.4 Multi-Manufacturer Ownership Arrangements

In recent years there have been many new multi-manufacturer arrangements, which have made it difficult to delineate individual companies. For example:

- Ford fully owns Volvo and Jaguar, and partially owns Mazda
- General Motors fully owns Saab, and partially owns Suzuki and Subaru
- DaimlerChrysler partially owns Mitsubishi and Hyundai
- Nissan is fully owned by Renault
- Volkswagen fully owns Rolls Royce
- Kia is partially owned by Hyundai, Ford, and Mazda

Thus the question arises—against what base should the “10 percent of sales” ZEV obligation be assessed? Currently, manufacturer sales numbers are not aggregated if the manufacturers are “operationally independent”. Because the meaning of this term is not always readily apparent given the variety of ownership situations, ARB staff held a workshop on March 30, 2000 to clarify the ZEV-related emission compliance liabilities of companies in multi-manufacturer arrangements. Manufacturers have reviewed the implications of using the CAP2000 aggregation provisions for this purpose. (The CAP2000 regulations govern how sales from small manufacturers partially owned by other firms are aggregated for purposes of regulatory compliance).

In general, the CAP2000 provisions are believed by manufacturers to be too restrictive. Manufacturers have recommended alternative procedures, but no consensus exists. Staff will work to finalize a proposal such that majority interest in a company triggers liability for ZEV obligations. The resulting policy will be implemented either by regulatory amendments or through issuance of a

Manufacturer's Advisory Correspondence. Appropriate lead time will be provided before any changes become effective.

2.5 ZEV Production to Date by Large Manufacturers

The ZEVs that have been placed in California by large manufacturers as of March 31, 2000 are described in the following table.

Manufacturer	Model	Battery Type	Lease Cost ($)[a]	City Range[b]	Highway Range[b]	Number Placed
Daimler Chrysler	EPIC	PbA	NA	70	65	17
	EPIC	NiMH	450	92	97	185
Ford	Ranger	PbA	varied	84	69	52
	Ranger	NiMH	varied	94	86	356
GM	EV1	PbA (Delco)	349	75	78	400
	EV1	PbA (Panasonic)	424	111	113	0
	EV1	NiMH	499	143	152	162
	S-10	PbA	439	46	43	110
	S-10	NiMH	440	92	99	117
Honda	EV Plus	NiMH	455	125	105	276
Nissan	Altra	LiIon	599	120	107	81
Toyota	RAV4	NiMH	457	142	116	486

a. Lease prices shown include governmental incentives.

b. Unless otherwise noted, all range figures used in this document are based on the urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) test cycles. Real world driving range will be less.

Overall, manufacturers have adopted similar strategies to make these vehicles attractive to customers. The vehicles typically are available via a three-year lease without a down payment. This reduces the risk to the customer that their vehicle will be obsolete in a few years due to technical advances. Similarly, the warranty provided on the vehicles is comprehensive, and covers all components. This eliminates any durability issues or concerns on the part of the customer. Several manufacturers also include a charger in the lease. Finally, the lease typically includes roadside assistance services.

Because production levels for these vehicles are not yet sufficient to justify assembly line tooling and manufacturing techniques, in many (but not all) cases the vehicles have been produced in a "batch" process. Under this method, a small quantity of vehicles is built at one time. A new batch is produced when necessary.

Some details regarding the specific activities of each manufacturer are provided in the EV Market section below.

2.6 ZEV Volume Estimates for 2003

California sales of passenger cars plus light duty trucks by the large automobile manufacturers total approximately one million vehicles per year. As a rule of thumb, therefore, each one percent of vehicle sales equals about ten thousand vehicles per year.

The calculation of the actual number of vehicles needed to meet the ZEV requirement in any given year is considerably more complex, however, due to several factors:

- Manufacturers can earn “multipliers” for vehicles with extended range, with additional allowances for vehicles delivered prior to 2003. Taken together these two factors can result in up to 10 allowances per vehicle for vehicles delivered in MY 1999 and 2000. Specifically, each ZEV and full ZEV allowance vehicle that is produced and delivered for sale in California in the 1999 to 2007 model years, and that has an extended electric range, qualifies for a ZEV multiplier as shown below. These multipliers are based on range alone and are not dependent on the type of battery or the battery specific energy.

All-electric range	MY 1999-2000	MY 2001 -2002	MY 2003-2005	MY 2006-2007
100-175 miles	6-10	4-6	2-4	1-2

- In addition to the multipliers discussed above, ZEV credits “banked” in a prior year have greater value when “cashed” in a subsequent year, based on the relative values for the NMOG fleet average for the years in question. Under this provision, for example, ZEV credits earned in 1999 are multiplied by 1.82 if used in 2003, and credits earned in 2000, 2001 and 2002 are multiplied by 1.18, 1.13, and 1.1 respectively. Taking into account all available multipliers, a single 175 mile range vehicle placed in 1999 would earn 18.2 allowances.
- Manufacturers are given one additional model year to make up any shortfall in ZEV production. Thus, a manufacturer could choose to satisfy both its 2003 and 2004 obligation with vehicles delivered in 2004.
- In order to meet their obligation, large manufacturers must offer for sale a minimum of 4 percent pure ZEVs. They may, however, choose to meet the entire 10 percent requirement using pure ZEVs.

To provide a context for the Board’s evaluation of the ZEV program, staff have developed a "base case” estimate of the number of ZEVs that the large manufacturers must produce in 2003 in order to satisfy the 4 percent ZEV requirement. Due to trade secret considerations this estimate does not rely on any confidential information provided in the manufacturer product plans. Instead, it is calculated using publicly available information, with the following assumptions:

- The vehicles offered for sale in 2003 are identical in performance to the vehicles currently or most recently offered by the manufacturers. (The specific vehicles, their test cycle range, and the resulting number of allowances earned per vehicle are shown below.)
- Manufacturers do not take advantage of the multipliers available for early introduction; the entire 2003 obligation is met with vehicles produced in 2003.
- Each manufacturer's production volume in 2003 is equal to its production volume in 1998.
- Manufacturers meet 60 percent of their ZEV obligation using partial ZEV allowances, and 40 percent of their obligation (4 percent of sales) using pure ZEVs. (An estimate assuming that manufacturers meet their entire 10 percent obligation with pure ZEVs, using no partial ZEV allowances, is shown for comparison purposes.)

With these assumptions, 2003 pure ZEV production would be as follows:

Manufacturer	1998 Production	ZEV model	Urban Range[a]	Multiplier per vehicle	2003 ZEV Obligation	
	(PC+LDT1)		(miles)		4%	10%
GM[b]	84,106	1999 NiMH EV1	143	3.144	1,070	2,675
	84,106	1999 PbA EV1	111	2.293	1,467	3,667
	42,053	1999 NiMH S10	92	1.000	1,682	4,205
TOYOTA	201,473	1998 RAV4 EV	143	3.141	2,565	6,414
FORD	186,977	1999 NiMH Ranger	71	1.000	7,479	18,698
HONDA	172,768	EV Plus	125	2.672	2,586	6,466
NISSAN	88,455	2000 Altra	129	2.773	1,276	3,189
DAIMLER CHRYSLER	105,691	1999 NiMH EPIC	92	1.000	4,228	10,569
TOTAL	965,630				22,353	55,884

a. Test cycle range. Real world driving range will be less.

b. This estimate assumes that GM sales are 40 percent NiMH EV1, 40 percent Panasonic PbA EV1, and 20 percent NiMH S10.

This estimate, at roughly 22,000 vehicles, corresponds to about 2.3 percent of the passenger car and light duty truck production of the affected manufacturers. It must be noted, however, that actual 2003 ZEV production may vary significantly from this number due to the various factors discussed above. For example, several manufacturers have testified that due to lead time considerations they will not be able to take full advantage of the PZEV option in 2003. Thus they will need to place more than 4 percent ZEVs in the early years. On the other hand, the manufacturers' obligations for 2003 can be significantly reduced if they take advantage of the multiple credits available for early introduction. For example, the table below shows the number of vehicles needed by Honda and Toyota to meet the 4 percent requirement in 2003, with and without early introduction of vehicles. Additional credits will be needed to meet the obligation for 2004 and later years.

Scenario	2001	2002	2003	Total (3 years)
Honda, without early introduction	0	0	2586	2586
Honda, with early introduction	500	500	641	1641
Difference	500	500	-1945	-945
Toyota, without early introduction	0	0	2565	2565
Toyota, with early introduction	500	500	742	1742
Difference	500	500	-1823	-823

Looking at the cumulative effect of the program over time, the regulation requires placements in 2004 and 2005 equivalent to those in 2003, and a greater number in 2006 and beyond as multiple credits begin to be phased out. Again using our base case assumptions, the required number of vehicles in 2006 is about 31,000 for a 4 percent requirement, and about 78,000 to meet 10 percent. Thus over the 4 year period from 2003 through 2006, the base case estimate of the total number of vehicles ranges between about 100,000 (4 percent) and 250,000 (10 percent).

Manufacturers are required, under the Memoranda of Agreement with the ARB, to submit confidential product plans outlining the product mix that they will use to meet the 2003 requirement (see Section 3.2.3 below). All manufacturers submitted these plans on a timely basis. All manufacturers demonstrated that they have the technical capability to produce the quantity of vehicles needed to meet their 2003 obligation. The manufacturers uniformly argue, however, that the cost of these vehicles remains high, and foreseeable battery technology will result in limitations on vehicle range. Thus in their view it will be very difficult to develop a self-sustaining mass market for battery electric vehicles at this time.

Staff notes that technical advances are steadily reducing the cost premium associated with ZEVs and that increased production volume will bring about further reductions. Battery cost will, however, remain high for the foreseeable future.

3 COMPLIANCE WITH THE MEMORANDA OF AGREEMENT

3.1 Introduction

In 1996, the Executive Officer of the Air Resources Board and all seven large auto manufacturers signed Memoranda of Agreement (MOAs). The large auto manufacturers who signed the MOAs are General Motors, Ford, Chrysler (now DaimlerChrysler), Honda, Nissan, Toyota, and Mazda. The MOAs are intended to help ensure progress towards a successful launch of a sustainable market for zero emission vehicles in California, by using market based strategies for introduction of zero emission vehicles. They include binding commitments from each of the seven auto manufacturers as well as from ARB.

Under the MOAs, the auto manufacturers committed to:

- Offset the emission benefits lost due to the elimination of the ZEV requirement for 1998 through 2002;
- Establish and maintain the capacity to produce a specific number of ZEVs based on manufacturer estimates of customer demand. Each manufacturer confidentially submitted this information to ARB. Several manufacturers judged the market to be zero, based on available product, planned battery use and anticipated costs.
- Submit annual progress reports, and biennial product plans outlining how they will comply with the 2003 requirement;
- Participate in a technology development partnership, including continued investment in ZEV and battery research and development, and placement of advanced battery-powered ZEVs in marketplace demonstration programs;
- Collaborate with the ARB and the State Fire Marshal on ZEV safety training; and
- Provide the ARB with an on-site review of manufacturer activities and hardware related to the ZEV program.

The ARB, meanwhile, committed in the MOAs to working with state and local governments and others to help develop ZEV infrastructure and remove barriers to ZEV introduction. Specifically, the ARB must:

- Facilitate the purchase of ZEVs in state fleets;
- Address insurance and financing issues;
- Work with other state agencies to ensure the availability of battery recycling;
- Work with local governments on planning and permitting of charging stations;
- Work with utilities and electrical contractor trade groups to ensure adequate training for installation and maintenance of EV charging systems;
- Support the efforts of the National Electric Vehicle Infrastructure Working Council;
- Work with the State Fire Marshal and other emergency response officials to create a comprehensive ZEV emergency response training program;
- Observe the activities of the U.S. Advanced Battery Consortium; and

- Support the development and implementation of reasonable incentive programs that enhance the near-term marketability of ZEVs.

3.2 Manufacturer Commitments

All of the large auto manufacturers submitted the annual reports and the product plans as required. These reports outline the progress made towards meeting the requirements of the MOAs. The following information is based on the manufacturers' submittals as well as private meetings and phone conversations with manufacturers.

Staff concludes that the manufacturers and the ARB have met the commitments made in the MOAs. The remainder of this chapter provides detail on the individual tasks.

3.2.1 Cleaner Cars Nationwide (National Low-Emission Vehicle Program)

The MOAs require the auto manufacturers to introduce low-emission vehicles nationwide in 2001, three years earlier than could be required under federal law. The National Low Emission Vehicle (NLEV) program was included in the MOAs to offset the emission increases associated with the 1996 revisions to the ZEV program, and thereby maintain the integrity of ARB’s State Implementation Plan. Because non-California vehicles frequently travel through California or relocate to California from other states, cleaning up non-California vehicles results in emission reductions within California’s borders. A 1996 ARB staff analysis indicates that the NLEV program will full meet the 2010 emission goals of the MOA.

In March 1998, the U.S. Environmental Protection Agency (EPA) announced that 23 automobile manufacturers--including the seven manufacturers that signed the MOA--and nine northeastern states have agreed to the new voluntary NLEV program. Starting in 1999, light-duty vehicles and light-duty trucks sold in the northeast are meeting more stringent emission requirements. The program will be expanded nationally in 2001. This agreement between the EPA and the auto manufacturers will fulfill the MOA obligation.

3.2.2 Market-Based ZEV Launch

The MOAs express the auto manufacturers’ commitment to have the capacity to produce a certain number of ZEVs “that could be sold in California if warranted by customer demand” (Section I.B.). These vehicles are in addition to the demonstration vehicles discussed under Section 3.2.4.2 below. The specific number was separately and confidentially determined by each manufacturer. The purpose of this element of the MOA was to ensure that manufacturers have the production capacity to meet their estimate of market demand for ZEVs during the ramp-up period prior to 2003. Attached to each MOA as Exhibit A was the manufacturer’s confidential November 1995 submittal identifying the manufacturer’s annual capacity to produce ZEVs for the 1996 through 2002 model years, in accordance with their estimate of market readiness. Several manufacturers judged the market to be zero, based on available product, planned battery use and anticipated costs.

The timing of vehicle introduction by the various manufacturers has varied, based upon the type of vehicle, the battery employed, specific technical challenges that needed to be overcome, and near-term targeted markets. As of January 2000, Ford, General Motors, Honda and Toyota have placed a total of 738 vehicles above and beyond those required under the MOA demonstration program.

The RAV 4, Altra and EPIC vehicles are currently only marketed to fleets, and production quantities are limited. Honda has announced that it will not produce additional vehicles, and will focus its efforts on evaluating customer satisfaction and providing customer support for vehicles currently in service. The net result of these manufacturer actions is that fleet customers face limited product availability, and the only vehicle marketed to retail customers, the EV1, is sold out. There is no four passenger, family vehicle currently available to the public.

Some parties have argued that the limited availability of vehicles constitutes evidence that manufacturers are not complying with their MOA commitment. As defined in the MOA, *"Capacity to produce" means that the manufacturer has available adequate vehicle production facilities either in-house or contractually with others, including the in-house ability or outside contracts sufficient to supply major vehicle parts and component needs. "Capacity to produce" does not obligate the manufacturer to produce, deliver or sell a specified number of ZEVs.* (Definitions, Section X.D.). A lack of available product therefore does not in and of itself signify noncompliance with the MOA.

An evaluation of compliance with the market-based ZEV launch requirement of the MOAs also requires an interpretation of the phrase "if warranted by customer demand". In the view of staff, a reasonable interpretation of customer demand implies demand that exists when the vehicle is priced at or near the manufacturer's cost. The current lease rates for the vehicles do not recover the relatively high cost of producing an EV today. Although it is common for manufacturers to sell some vehicles at a loss for larger corporate strategy purposes, the current differential between the lease prices for battery electric vehicles and the manufacturers' cost is substantial. Manufacturers have used various methods to determine the lease prices used for today's vehicles, but in no case have the vehicles been priced at a level that is close to the manufacturers' cost. Although we do not know what demand would exist if the vehicles were priced to recover at least the majority of their cost, presumably it would be less than that seen over the past several years.

In sum, staff concludes that manufacturers are in compliance with their commitment to have the capacity to produce vehicles that could be sold in California if warranted by customer demand. As is discussed in the EV Market chapter below, however, the production gap between now and 2003 is interfering with the necessary continuity in ZEV market penetration.

3.2.3 Zero Emission Vehicle Product Plans

Under the MOAs, the manufacturers are required to submit ZEV product plans prior to November 1 of the year preceding the scheduled review (in this instance, prior to November 1, 1999). Each manufacturer must submit corporate product plans that demonstrate compliance with the ZEV requirement for 2003. All of the manufacturers submitted the required plans on a timely basis. The product plans identify the manufacturers' strategies for 2003, including key decision points and other milestones.

ARB staff have carefully reviewed the product plan submittals. Staff also made site visits to Japan and Michigan to tour the manufacturers' research and development facilities, and receive briefings on their research efforts. Based upon the review and site visits, staff is confident that the product plans accurately represent the status of work at the manufacturers.

The information in these confidential product plans provides part of the basis for the staff assessment of the current status of ZEV technology, discussed elsewhere in this document.

3.2.4 Technology Development Partnership

Under the Technology Development Partnership component of the MOA, the auto manufacturers agreed to make good faith efforts to promote and develop a market for ZEVs and to ensure ongoing ZEV-related research and development. To accomplish this effort, each manufacturer committed to continue battery research and development throughout the term of the MOA, and to place new ZEVs with advanced technology batteries into service in California through the advanced technology battery demonstration project.

3.2.4.1 Research and Development

All of the large manufacturers have extensive internal research and development efforts underway. The briefings and staff site visits in Michigan and Japan conclusively demonstrated that all manufacturers are actively pursuing a full range of zero and near-zero emission vehicle technologies. The extensive staffing levels and other resource commitments dedicated to advanced technology give evidence of the manufacturers' conviction that in the future, customers will be favorable towards products that offer ongoing environmental improvement. Staff was impressed with the intense work underway in a variety of program areas, and the commitment by all manufacturers to play a leadership role in the commercialization of zero and near-zero emission vehicles.

In addition to in-house efforts, under the terms of the MOA General Motors committed to contribute $8.9 million during Phase II of the United States Advanced Battery Consortium (USABC), while DaimlerChrysler and Ford have committed $3.34 and $6.67 million respectively. All three manufacturers are on target with their contributions and will completely contribute the full amounts by 2002.

3.2.4.2 Advanced Technology Battery Demonstration Project

The auto manufacturers each also agreed to produce their pro-rata share of up to 3,750 advanced battery vehicles between 1998 and 2000, and place them in demonstration programs designed to validate the new technology. Table 3-1 below shows each manufacturer's share of the total ZEVs to be placed in demonstration programs.

To receive MOA ZEV credit towards the commitments enumerated in Table 3-1, a ZEV must use advanced batteries. For the purposes of the MOAs, "advanced battery" means a battery with a specific energy of at least 40 watt-hours per kilogram (Wh/kg) for the 1998 calendar year and at least 50 Wh/kg for 1999 and subsequent calendar years. (Specific energy is the amount of energy per unit of weight and is related directly to range).

Table 3-1
Auto Manufacturer MOA Advanced Battery Demonstration Commitments

Calendar Year	Number of Vehicles (Based on Average Market Share)							Total by Year
	Chrysler	Ford	General Motors	Honda	Mazda[a]	Nissan	Toyota	
1998	51	181	182	101	28	70	135	748
1999	103	363	365	202	55	141	271	1,500
2000	103	363	366	203	55	141	271	1,502
Total								3,750

a. Mazda's MOA obligation has been met by Ford.

The amount of credit given in the MOA for an advanced battery-powered ZEV is based on the specific energy of the batteries. Manufacturers may reduce the total number of ZEVs required if the batteries used in the vehicles have a specific energy greater than 50 Wh/kg. Table 3-2 on the next page indicates the number of credits that are granted for ZEVs that use advanced batteries.

Table 3-2 MOA ZEV Credits Allowed for an Advanced Battery-Powered ZEV	
Specific Energy	Number of ZEV credits allowed
40 Wh/kg (1998 only) 50 Wh/kg (1999 and 2000)	One
60 Wh/kg	Two
90 Wh/kg	Three

The advanced battery-powered vehicles that are being produced today have specific energy ratings of between 55 and 85 Wh/kg depending on the battery technology used. It is expected that advanced battery-powered EVs to be marketed in 2003 will fall approximately within this range as well.

Linear interpolation is used to determine the number of MOA credits earned by ZEVs with specific energy over 50 Wh/kg. Therefore, ZEVs placed as part of the Technology Development Partnership are generating from 1.5 to 2.8 MOA ZEV credits per vehicle. As a result, the actual number of vehicles to be produced to meet the auto manufacturers' advanced battery vehicle MOA commitments will be approximately 1,800 rather than 3,750.

In early 1999, both Honda and Toyota completed placement of advanced battery-powered electric vehicles for the Technology Development Partnership. General Motors, Ford, DaimlerChrysler and Mazda are on track to complete their commitments by the end of 2000. Nissan requested and received approval to delay placement of a small portion of their vehicles for one year (until 2001) due to a battery supplier issue.

As of January 2000 there were already more than 1,300 advanced battery electric vehicles placed in California as a result of this project. At the conclusion of the project, there will be more than 1,800 electric vehicles operating on advanced technology batteries on the roads of California.

3.2.5 Annual Reports

The MOAs require manufacturers to file an annual report within 90 days after the close of each calendar year. The annual reports must provide information regarding ZEVs placed in California and elsewhere in the United States during the previous calendar year. The annual report must also contain information regarding the placement of ZEVs under the Technology Development Partnership. All manufacturers have submitted their annual reports as required.

3.2.6 Collaboration with ARB and State Fire Marshal

The MOAs require manufacturers to collaborate with the ARB and the State Fire Marshal to develop the curriculum and materials necessary for a comprehensive ZEV safety-training program. This training program, which was completed in 1998, is described in more detail under the description of ARB's related commitment in Section 3.3.8 below.

3.2.7 On-Site Review

The MOAs require the manufacturer to provide ARB staff with an on-site review of activities and hardware related to the manufacturer's ZEV program. ARB staff visited Honda, Nissan and Toyota facilities in Japan in December 1999, and visited General Motors, Ford and DaimlerChrysler facilities in Michigan in February 2000. During these visits ARB staff received extensive briefings on the manufacturers' activities, and had the opportunity to view and/or test-drive a variety of vehicles. As a result of these visits and the information that has been provided, ARB staff have a thorough understanding of the status of work at each manufacturer.

3.3 Air Resources Board Commitments

As its part of the MOA, ARB committed to a number of tasks aimed at making California ready for the ZEV market. The following sections summarize the activities that the ARB has undertaken or supported to meet the commitments made in the MOA.

3.3.1 Purchase/Lease of EVs by State and Local Governments

The MOAs specify that ARB must facilitate the purchase of ZEVs for appropriate applications in state fleets. ARB must work with the California Department of General Services and the California Energy Commission to establish vehicle specifications for the State Bid List, and work with the Department of General Services Office of Fleet Administration to ensure the sale or lease of ZEVs to selected state agencies.

The Department of General Services has executed Master Service Agreements with the General Motors Acceptance Corporation (for the EV1 and the Chevrolet S-10), American Honda Motor Co., Inc. (for the EV PLUS), Toyota Motor Company (for the RAV4), and Ford Motor Credit (for the Ford Ranger). These Master Service Agreements allow all state agencies, as well as the University of California, California State University, the Community Colleges, and local governments, to lease ZEVs according to pre-defined and pre-approved terms, conditions and lease rates. This greatly simplifies the leasing process and allows for more rapid acquisition of vehicles. Additional Master Service Agreement with DaimlerChrysler Corporation (for the EPIC) and Nissan (for the Altra EV) are currently being developed.

As of May 2000, 28 different state and local agencies have leased or committed to lease more than 100 vehicles under these Master Service Agreements and prior agreements. These numbers are expanding rapidly due to the ***ev Sacramento*** program, discussed in Section 3.3.1.2 below. Leases or commitments have been made by the following:

- Department of General Services
- Department of Water Resources
- Department of Forestry and Fire Protection
- Department of Justice
- Department of Parks and Recreation
- Department of Food and Agriculture
- Department of Toxic Substances Control
- Department of Social Services
- Cal/EPA
- Air Resources Board
- Integrated Waste Management Board
- California Energy Commission
- California Highway Patrol
- CalTrans
- Bureau of Automotive Repair
- Office of State Printing
- Franchise Tax Board
- California Exposition and State Fair
- University of California, Davis
- University of California, Los Angeles
- California State University, Chico
- Sacramento County
- City of Sacramento
- City of Citrus Heights
- Sacramento Metropolitan Air Quality Management District
- Sacramento Metropolitan Airport
- Sacramento Public Library

These totals do not include a large number of local agencies that have leased ZEVs using mechanisms other than the state Master Service Agreement.

The ARB and other state and local agencies have undertaken other activities to further encourage ZEV leasing, such as the following:

3.3.1.1 The EV Loan Program

To encourage the use of EVs in public fleets and address its obligation under the MOAs, the ARB designed a three-year program to loan EVs at no cost to federal, state and local government agencies. The South Coast Air Quality Management

District provides financial support for the operation of the program within its jurisdiction. The Department of General Services (DGS) assists with housing, maintaining and dispatching the loan program EV fleet.

The goals of the EV Loan Program are to encourage EV leasing by providing public agencies with a no-risk opportunity to see if electric vehicles meet agency needs, familiarize senior officials with vehicle capabilities, and publicize the availability of electric vehicles to governmental agencies and to the public at large.

The loan fleet includes fifteen vehicles--four GM EV1 vehicles with lead acid batteries (currently returned to GM due to the recall), six Honda EV Plus vehicles with nickel metal hydride batteries, and five Ford Ranger pickups with nickel metal hydride batteries. Six additional vehicles (two Chevrolet S10 pickups and four Toyota RAV4 vehicles, all with nickel metal hydride batteries) have been ordered to expand the program.

The EV Loan Program began operation on a pilot basis in Sacramento in March 1998, using one Honda EV Plus that was provided by the DGS. The loan program's own vehicles were delivered in June 1998 (EV Plus), August 1998 (EV1), and January 1999 (Ford Ranger). The program expanded to Los Angeles in September 1998, the Bay Area in October 1998, and San Diego in April 1999.

As of June 2000 , there have been more than 131 loans completed. Loan durations ranged from several days to three months, but the majority were one month. Fifteen loans are in progress, and thirteen additional agencies are waiting to participate. Although forty-three vehicles have been leased as a result of the program, this number would be higher if additional vehicles were available.

The EV Loan Program is a large-scale effort to provide public agencies with the opportunity to drive EVs. The program has demonstrated that public agencies, when given real-world experience with EVs, often find that the vehicles provide an environmentally sound way to meet many of their fleet needs. The agencies have been able to develop a good understanding of EV range, reliability, operating and maintenance costs, infrastructure requirements, and other data needed to make informed leasing decisions, both now and in the future.

In response to this program and to show support for EVs, many government agencies and utilities have adopted resolutions that require that EVs be purchased or leased for their fleet. These agencies have the necessary funding available but cannot get the vehicles. Thus the goal of this program--to encourage EV leases--is frustrated when there are no vehicles available.

This program has also provided ARB staff with extensive experience with EVs on longer trips in real world conditions. In order to supply EVs to as many agencies as possible, ARB staff have delivered these vehicles to agencies in areas such

Santa Cruz, Bodega Bay, Sonoma County, Channel Islands National Park, Ventura County, San Jacinto, Lake Perris and Palm Springs. Although additional planning and time is needed to deliver the vehicles to these areas, staff have always been successful and have learned a lot about the functionality of EVs in real world conditions.

3.3.1.2 Department of General Services Outreach

The Department of General Services, Office of Fleet Administration, has an aggressive program in place to encourage state agencies to lease electric vehicles. In addition to its support for the EV loan program described above, the Department:

- Provides free daily use of EVs through the state vehicle pool fleet
- Provides ride and drive opportunities to state executives
- Provides flexible lease terms with no-penalty cancellation provisions
- Sends letters to state fleet managers and Business Services Officers outlining EV availability
- Showcases EVs at numerous conferences and other events
- Participates in the national Clean Cities program
- Maintains a web site providing information on EV options

3.3.1.3 ev Sacramento

Many California public agencies are already using electric vehicles. EVs are being driven by agency administrators, field and technical staff, and have been incorporated into a variety of public programs. One barrier that has hindered public agencies in acquiring electric vehicles, however, has been their higher initial cost when compared to their conventionally fueled counterparts.

ARB is committed to increasing the use of EVs by State agencies, and initiated ***ev Sacramento*** to assist with this commitment. The goal of ***ev Sacramento*** is to assist State and local public agencies in the Sacramento region to lease EVs at competitive prices. By offsetting the initial higher costs of these vehicles, this program will significantly expand the use of EVs in the Sacramento area.

The program is jointly administered by the ARB and the Department of General Services Office of Fleet Administration. ***ev Sacramento*** is a three-year program, and includes most of the EVs that are now commercially available. The vehicles that are available through the program include the GM EV1, Toyota RAV4 EV, Ford Ranger, , and the Honda EV Plus. Program staff is also working with Nissan to include the Altra in the program. Vehicle rollout began in May 2000. State and local agencies in the Sacramento area are eligible to participate. Participants pay reduced lease payments that are comparable to lease rates for conventional vehicles. In addition, ***ev Sacramento*** staff coordinate the delivery of the vehicles and the installation of charging infrastructure, and provide all training and user support.

As of June 2000, 21 state and local agencies have committed to lease 76 vehicles. ***evSacramento*** is currently fully subscribed, and there is a waiting list of public agencies that would like to lease vehicles if they become available. Originally 120 vehicles were to be included in the program; however due to limited vehicle availability staff has only been able to lease 76 vehicles to date. Although placements to date are less than the target of 120 vehicles, this is solely due to the lack of vehicle availability. The current mix of vehicles in the program is 34 RAV4 EVs, 30 Ford Rangers, 2 EV1s, and 10 Honda EV Pluses. Staff is currently working with Nissan to include ten Altras into the program.

3.3.1.4 State Budget

Each year, the state Budget Act appropriates funds from the Petroleum Violation Escrow Account (PVEA) to support a variety of energy and transportation projects. Portions of this funding have been used to subsidize the purchase of electric vehicles and infrastructure by local agencies.

The 2000-2001 Governor's Budget includes significant funding from the Petroleum Violation Escrow Account and the General Fund for electric and alternative fuel vehicles, incentives and infrastructure. Highlights include:

- $5 million for the Air Resources Board to participate in the Fuel Cell Partnership
- $6 million for the California Energy Commission to establish a clean fuels infrastructure for public agencies
- $5 million for the California Energy Commission to establish the Vehicle Efficiency Incentive program to provide incentives for the lease or purchase of electric, hybrid electric, and fuel cell vehicles
- $1 million for the California Energy Commission to develop a hydrogen fuel infrastructure as part of the Fuel Cell Partnership
- $0.5 million for the California Energy Commission to study issues affecting hydrogen fueling infrastructure
- $4 million for the Department of General Services to purchase alternative fuel vehicles for the state vehicle fleet

3.3.2 Insurance

The ARB is required to work with the California Department of Insurance to establish reasonable rates for insuring new ZEVs, to promote insurance industry awareness of ZEVs, and to resolve other issues related to insuring ZEVs.

ARB staff and Department of Insurance staff are not aware of any insurance issues that have arisen with the market-based launch of EVs over three years ago. The EV user has had little difficulty obtaining necessary insurance. At least one manufacturer, Honda, includes comprehensive and collision insurance in the lease package. For drivers of other EV models, the insurance experience appears to have been smooth, with comparable coverage and rates available including second car discounts. On occasion, the EV user may need to spend additional time in the process if the insurer has not had experience writing a policy for an EV.

Based on an informal ARB staff survey of retail EV users in California, it appears that insurance for EVs is available from virtually every insurance company licensed to do business in California. Staff also met with a local insurance broker, who represents a larger company, to discuss the process for establishing the insurance rate for an EV. The broker indicated that the process is identical to that used for any vehicle on the market. With the make and model in hand, the broker looks up a vehicle's "insurance rating group" (IRG). Vehicles with similar characteristics, (e.g., replacement and repair costs, typical damage, and model year) may be placed in the same IRG. If a vehicle has not been assigned to an IRG, or is a new model or model year not covered by an IRG, the industry standard practice is to calculate a rate based on the manufacturer's suggested retail price (MSRP). The broker visited by staff had an IRG manual that contained specific instructions for EV rates to be calculated using the MSRP.

As no significant insurance issues have arisen with the market-based launch, ARB staff concludes that insurance issues will not present obstacles to further expansion of the EV market. Staff will, however, continue to monitor insurance availability for EVs as the market grows.

3.3.3 Financing

The ARB is required to work with the California Department of State Banking to develop risk assessment data to assist in securing financing for the purchase or lease of ZEVs.

To date, financing issues have not presented obstacles to further expansion of the EV market. Financing has not presented a problem for retail consumers because to date the vehicles are primarily leased rather than purchased. The decision to lease EVs to consumers rather than sell the vehicles has not been based on concerns about financing availability. Rather, the auto manufacturers have indicated that offering lease programs to consumers protects customers from risks associated with investing in new, quickly changing technology. ARB staff will continue to monitor these areas to ensure that any future issues that arise are dealt with in a timely manner.

3.3.4 Battery Recycling

The MOA directed the ARB to work with the Department of Toxic Substances Control, the Integrated Waste Management Board, and the Office of Environmental Health Hazard Assessment to ensure the availability of sufficient battery recycling capacity.

To address issues related to EV battery disposal and recycling, the ARB contracted with ARCADIS Geraghty & Miller in 1994. This contract work was broken into two main tasks. First, the contractor evaluated battery technologies based on their performance and recyclability. This work was completed in March of 1995. In addition to determining where efforts should be focused in establishing new recycling facilities and developing cleaner technologies, task one recommended that a deposit of between $100 to $150 be levied on light-duty vehicle batteries to ensure they are returned for recycling.

Task two compared the relative health and hazard impacts from EV battery recycling technology, and was completed in April of 1999. The main focus of task two was to compare the relative impact of recycling EV batteries in terms of cancer, toxicity, and ecotoxicological potential, as well as leachability, flammability, and corrosivity hazards. These impacts were evaluated for recycling methods, including smelting, electrowinnowing, and other appropriate techniques that apply to different battery technologies. A multi-attribute impact analysis was performed on the health and hazard effects resulting from the recycling and disposal of each battery type. The methodology used a semi-qualitative ranking to weight the relative impact and establish a health and environmental impact score for each battery type.

Due to the substantial uncertainties surrounding the analyses, the methodology is designed for comparison purposes only. While current battery constituents are fairly well known, they do vary with manufacturer and are likely to change in the future. In addition, there are substantial uncertainties surrounding the health impact values and future recycling technologies. With this said, a broad conclusion of the analysis is that the more advanced batteries represent a great improvement over conventional lead-acid batteries, both in terms of battery performance and impacts from recycling spent batteries.

In addition to this contract work, ARB staff has also followed battery recycling issues at the national level by participating on the Department of Energy's Advanced Battery Readiness Working Committee. One of the Committee's main activities is to address issues related to EV battery disposal and to review progress made in developing new recycling methods for advanced batteries.

At this time, there do not appear to be any overwhelming obstacles to recycling the battery technologies expected in the 2003 timeframe. Currently, there is one facility in the United States capable of recycling nickel-based batteries. Another plant in Canada is now successfully recycling large military lithium-based batteries. While recycling technologies are being developed and are expected to be in place, it will be necessary to build new recycling plants for certain battery types, such as lithium-ion, to accommodate their use in large quantities. Any new recycling facilities would be required to meet stringent air quality and environmental regulations that would minimize any adverse effects of the recycling processes.

3.3.5 Assist Local Governments with Public Infrastructure

The MOA requires the ARB to work with automakers, the California Energy Commission, and local governments to provide assistance in planning and permitting quick charge and public charging stations. ARB has worked with utilities and electric vehicle infrastructure providers to assess charging station implementation issues and ensure that public charging facilities are developed as needed. This group instigated and coordinated the development of training for building officials involved with permitting and inspection of infrastructure installations. Specifically, following adoption of the California code revisions described under Section 3.3.6 below, a training program was developed for building officials that covered the following:

- The new Building Code and Electric Code provisions governing EVs;
- Plan check and inspection techniques for the new regulation;
- An overview of current and emerging EV technologies including automotive, batteries and charging equipment;
- An opportunity to see and drive current production vehicles; and
- Hands-on experience with charging system equipment.

The current status of public infrastructure is discussed in more detail in Section 6.2 below.

3.3.6 Training for Installation and Maintenance of EV Charging Stations

The MOAs directed ARB to work with utilities and trade groups representing electrical contractors to provide training for installation and maintenance of electric vehicle charging systems.

To address issues associated with installation of EV chargers, especially related to building codes, electrical codes and training of permitting and inspection personnel, the California Energy Commission formed the Building Codes Working Group. The Building Codes Working Group included the Energy Commission, the ARB, the California Building Officials, the California Electric Transportation Coalition, California utilities, General Motors, and Hughes Power Systems. The Building Codes Working Group developed revisions to the California Building Standards to allow for safe installation of electric vehicle charging systems. The Building Code changes, effective in 1996, defined EV charging equipment, added safety requirements, clarified the definition of refueling, and added ventilation requirements. The Building Codes Working Group also modified the California Electric Code to include a requirement to use approved or UL listed EV charging equipment.

In an effort to provide a national standard for building code requirements related to EV charging systems, the Building Code Working Group focused much of its efforts through 1997 on preparing modifications to the National Electric Code. Changes suggested by the Building Code Working Group were forwarded to the

National Infrastructure Working Council for approval and submittal to the National Electric Code governing organization.

Additional activities of the Building Code Working Group included development of Interim Disabled Access Guidelines for Electric Vehicle Charging Stations in cooperation with the State Architect. Since EV charging stations are offered as a service to the general public, they are required to be accessible to those with disabilities. The guidelines give potential public infrastructure providers guidance on making installations accessible to those with disabilities.

The final project undertaken by the Building Code Working Group was the development of an informational brochure for building officials, contractors and consumers. The brochure provides information about permitting and inspection requirements, cites appropriate building and electric codes and gives phone numbers for agencies that can provide further information.

Between 1996 and 1997, California electric utilities and infrastructure providers met monthly to establish and coordinate the multiple steps of the charger installation process. Southern California Edison has written and distributed installation guidelines for private electrical contractors and utility personnel. electric utilities have trained their own customer service and operations personnel on EV installations, established 800 numbers for EV-related inquiries, and created special EV rates. Utilities and infrastructure providers continue to provide training for individual jurisdictions on an as-needed basis.

Extensive training for EV charger installations is also conducted by equipment manufacturers and installation service providers. There are now at least two dozen licensed electrical contractors who are certified to do installations. When larger numbers of vehicles become available there will be a need to expand the network of trained installers, but the procedures for ensuring safe code-compliant installations are already in place and residential installations have generally been proceeding smoothly.

3.3.7 Support Efforts of National Infrastructure Working Council

The National Infrastructure Working Council was initiated by EPRI, at the request of its member utilities, to work on a variety of infrastructure issues including standardization of power supply, emergency disconnect, and standard conductive and inductive charging systems. California's electric utilities have played an active role in the Council. Under the MOAs, ARB is required to support the Infrastructure Working Council's efforts.

ARB staff has attended the Infrastructure Working Council's meetings, observing and participating in the Health and Safety Committee, the Connector and Connecting Stations Committee and the Connector Standardization Subcommittee of the Bus and Non-Road Committee. ARB's participation in the Health and Safety Committee has been focused on assistance with the proposed modification of the National Electric Code. ARB and California Energy

Commission staff have observed and provided comments to the Connector and Connecting Stations Committee. This Committee, in turn, provided input to the Society of Automotive Engineers, which adopted a single standard for the butt-type conductive connector used by Honda and Ford. ARB staff has also observed the early work of the Bus and Non-Road Committee and has been asked to participate in the Connector Standardization Subcommittee as it works to determine the need for connector standardization for buses and non-road vehicles.

3.3.8 Training Programs for Emergency Response

ARB is required to work with the State Fire Marshal and other state and local emergency response officials and towing companies to create a comprehensive training program to ensure preparedness for incidents involving EVs.

Similar to the Building Code Working Group, the California Energy Commission formed the Emergency Response Working Group with ARB, the California Office of the State Fire Marshal, the California Highway Patrol, utilities, auto manufacturers and industry organizations such as the California Electric Transportation Coalition. The purpose of the working group was to develop training designed to inform emergency response personnel about EVs and the differences in response procedures for incidents involving EVs.

In 1998, the Emergency Response Working Group completed the development of a training program consisting of material to train instructors, an instructor's manual and compact disc, and slide teaching materials and student manuals. Train-the-trainer courses have been held throughout the state. Through the Infrastructure Working Council, the complete package of training materials has been distributed to every state Fire Marshal Office in the United States.

Some local Councils of Government have taken the initiative to train their member jurisdictions. To staff's knowledge, no public safety issues have arisen regarding the safety of EVs or the actions of emergency response personnel in responding to an EV accident.

3.3.9 Observe Activities of the U.S. Advanced Battery Consortium (USABC)

The MOAs require ARB to maintain its commitment to observe the activities of the United States Advanced Battery Consortium (USABC) regarding the development of advanced technology batteries. The mission of the USABC is to pursue research and development of advanced energy systems capable of providing future generations of electric vehicles with significantly increased range and performance. The USABC has defined Mid-Term, Intermediate-Term ("Commercialization") and Long-Term criteria that set forth increasingly stringent goals for acceptable electric vehicle performance and economics. Now widely accepted as goals for ongoing development, these criteria are viewed by the

USABC as the minimum standards that must be met if EVs are to be acceptable to a significant percentage of vehicle users.

Through the USABC, the three large U.S. vehicle manufacturers are committed to development of advanced batteries in keeping with their MOA obligation. ARB staff continues to attend the USABC Technical Advisory Committee (TAC) meetings on a quarterly basis. By attending these meetings, ARB staff is able to monitor the progress of USABC contracts with various developers and gain insight as to the contractors' progress. While much of the information obtained is confidential, the following provides a general overview of current USABC activities and developments.

The USABC completed its developmental efforts for Mid-Term battery technologies in 1999. The SAFT nickel-metal hydride (NiMH) and Ovonic Battery Company (OBC) NiMH technologies successfully demonstrated improvements in battery performance, cycle life, and cost reduction. For example, compared to the USABC Mid-Term goals of 80 Whr/kg, 150 W/kg, and 1,000 cycle life, both developers have achieved at least 70 Whr/kg, 150 W/kg, and 800 cycles. In fact, the SAFT technology has realized a cycle life well in excess of 1,000 cycles. For hybrid applications, where power is of greater importance than energy, OBC has achieved specific power levels surpassing 750 W/kg. While the cost of each NiMH technology is currently more than twice the USABC Mid-Term goal of $150/Kwhr, both manufacturers have successfully reduced production cost by over 25 percent during the last two years.

Current USABC programs are focused on long-term battery technologies and meeting the USABC Commercialization and Long-Term and goals. Two major contracts are currently in place investigating lithium-based battery technologies. The SAFT Lithium-Ion contract is currently in Phase I of the development process and is primarily focused on cell and module optimization. The Lithium-Polymer contract is also at the development phase with promise to offer a safe and cost effective battery technology within the next five years. These lithium-based technologies are expected to achieve specific energies well in excess of 100 Whr/kg. Improved specific power of greater than 200 W/kg and a cycle life of more than 600 are also expected. The key characteristic of battery cost should also benefit from these two technologies.

The USABC is expected to initiate a Phase III program this year. Phase III funding will be approximately $62 million and span a total of four years. USABC has indicated that those technologies capable of realizing the long-term goals will be considered.

3.3.10 Reasonable Incentives

Under the MOAs, ARB must support the development and implementation of reasonable incentive programs that enhance the near-term marketability of

ZEVs. Because ZEVs are a relatively new technology and are currently produced in limited quantities, they are more expensive than conventional vehicles. To enhance vehicle marketability in the near term and to assist in the transition to large volume production, it is vital to provide support, both monetary and non-monetary, in the form of vehicle and infrastructure incentives.

Where possible, the ARB and other state agencies have supported the development and implementation of various incentive programs. The California Energy Commission has continued to support vehicle buy-down programs at the district level and has recently provided matching funds for the development of EV infrastructure. Recent legislation authored by Assembly Member Cuneen and signed by Governor Davis allows single occupant vehicles with “inherently low emissions” (ZEVs, as well as vehicles using alternative fuels, with extremely low tailpipe emissions and zero evaporative emissions) to use high occupancy vehicle lanes.

The following list provides an example of the federal, state, local and private incentive programs currently available.

3.3.10.1 Federal Incentives

- Tax credit for 10 percent of the cost of an EV, up to $4,000, through 2004.
- Business tax deduction of $100,000 for electric recharging sites.
- The Energy Policy Act of 1992 authorized a ten year $50 million EV demonstration program and a fifteen year $40 million cooperative program between government and industry to research, develop and demonstrate EV infrastructure. (To date no funds have been appropriated for this purpose.)
- Elimination of the luxury tax for alternative-fueled vehicles.

3.3.10.2 State of California Incentives

- Incentives are available to reduce the lease cost of EVs. In general half of the funding is provided by the California Energy Commission, with matching funds from local air quality management districts. The air district programs are described below.
- CEC funds support the installation of EV charging infrastructure by new purchaser or lessee.
- PVEA funds are made available to local governments to support the lease of alternative fuel vehicles.
- Senate Bill 1782 (Thompson, 1997) reduced the vehicle registration fee for EVs by charging EVs an amount corresponding to the fee that would be due for a comparable conventional vehicle.
- As of July 1, 2000, EVs with the appropriate permit sticker are allowed access to HOV lanes regardless of the number of occupants.

3.3.10.3 Local Incentives

- The Mobile Source Reduction Committee (MSRC) of the South Coast Air Quality Management District was the first to offer public and private customers an EV buydown. A $5,000 rebate per EV purchased or leased is available through their Quick Charge EV buy-down program.
- The MSRC, through its ZEV Purpose Built Buy-Down Program, has provided incentives to fleets in the South Coast Air Basin that have purchased or leased a minimum of ten ZEVs. This program has provided incentives for 400 EVs at $5,000 each for the United States Postal Service.
- The MSRC in conjunction with the CEC and auto manufacturers provides incentives for consumers or fleets using the Quick Charge and/or Purpose Built Fleet Buy Down incentives to defray the cost of installing a charger at one's home or worksite.
- The Bay Area Air Quality Management District (BAAQMD) “Charge!” program offers grants to subsidize installation of public EV charging stations. To date $150,000 has been awarded for 26 sites, and additional funds are available.
- The BAAQMD's Vehicle Incentive Program (VIP) provides public agencies with $6,000 per highway ZEV, $3,000 per city ZEV and $1,500 per neighborhood and three-wheeled ZEV.
- In conjunction with the CEC, several Air Pollution Control Districts offer $5,000 for the purchase or lease of EVs for public and private customers.
- The Los Angeles Airport offers free parking and charging for EVs in its Central Terminal Area. Charging stations were installed at the Los Angeles Airports as part of the Quick Charge Los Angeles EV program.
- The City of Sacramento offers free EV parking and charging at city garages.
- The City of San Francisco is installing EV charging at city garages.
- The City of Vacaville provides $6,000 per EV purchased or leased as well as incentives to city fleets and for charging infrastructure.

3.3.10.4 Utility Activities

- The Los Angeles Department of Water and Power, Sacramento Municipal Utility District, Pacific Gas and Electric Company, Southern California Edison, and the San Diego Gas and Electric Company all provide “time of use” rates to retail EV customers. Time of use rates are very low during hours in which demand is low, such as off-peak and overnight when most EVs are being charged. Additional electricity use during these hours can benefit utilities by using existing capacity built to meet peak demand but otherwise lying idle, and by allowing more efficient generation by online power plants. These time of use rates typically result in at least a fifty percent reduction in the cost of charging, with rates around 5 cents per kilowatt-hour.
- The shareholders of San Diego Gas and Electric have provided $50,000 in seed money to help local businesses and governments install charging stations in the utility’s service area.
- To encourage market development, California’s electric utilities have been loaning electric vehicles to their public and private customers since the early

1990's. While this activity is not part of the MOAs, it indicates active support for the ZEV program.

In addition to the incentives and other activities described above, the ARB has been working cooperatively with government agencies, auto manufacturers and other stakeholders to determine the most effective way to support the introduction of ZEVs into the marketplace.

On problem in the development of the EV market has been the timing of incentive availability versus vehicle availability. The first incentive program, adopted by the MSRC, was in place more than a year before any vehicles were offered for lease. Now, many incentive programs are in operation but there are few vehicles available.

New monetary as well as non-monetary incentives need to be investigated in addition to possible extensions of the incentives that currently exist. Many of these existing incentives were put into place prior to the 1996 amendments to the ZEV program and end prior to 2003. It would be appropriate to extend them through 2003 to foster the commercialization of ZEVs during the market-based introductory period as well as provide incentives for the vehicles at a time when they will be required in larger quantities.

3.4 Additional ARB Activities

ARB has instigated or been involved in a number of outreach programs, events and research contracts in addition to those addressed in the MOAs. Board members and staff have participated in local outreach as well as attended conferences and exhibitions promoting the use of zero-emission vehicles.

3.4.1 ARB Test Fleet

The ARB has acquired a test fleet of EVs, with three GM S-10s, three GM EV1s, and two Honda EV PLUS vehicles. In an effort to gather information about the vehicles, their usage patterns, and issues associated with everyday EV use, ARB has set up a system to allow ARB employees to use the vehicles for between two days and a week. Employees are encouraged to do outreach to schools and other local groups. Participating employees are given a specific vehicle to drive for a week or a weekend and are encouraged to use the vehicle for as much of their normal driving as possible. Employees are then required to fill out a log that indicates usage pattern and any suggestions regarding vehicle usability and accessibility. This system has been very successful and gives ARB and users the opportunity to gain valuable experience with EVs and infrastructure. Based on discussions with employees and entries in the EV logbooks, these experiences are typically very positive and users find that the vehicle meets practically all their driving needs.

ARB staff have also driven a wide range of other vehicles to learn first hand about their operating characteristics.

3.4.2 EV Rental Demonstration Program

The ARB and the South Coast Air Quality Management District (SCAQMD) are working together to support an electric vehicle rental demonstration program. This program will provide high visibility and convenient availability of EVs. The EV Rental Demonstration has the following objectives:

- Establish a successful EV rental program that will give a large number of the general public and government employees the opportunity to experience the benefits and attributes of EVs.
- Provide positive image of EVs for public and policy makers.
- Gain valuable information regarding the use of EVs in rental car fleets.
- Provide clean air benefits in those areas renting the EVs.

EV Rental Cars L.L.C. was chosen through a competitive bidding process to conduct the EV Rental Demonstration program. EV Rental Cars is working jointly with Budget Rent-a-Car to rent EVs. EVs are currently available for rent at the Los Angeles International Airport, the Sacramento International Airport, Ontario International Airport, and Beverly Hills. The program is slated to expand to additional Budget Rent-a-Car locations at Burbank Airport, John Wayne Airport in Orange County, and downtown Sacramento.

The ARB is providing $100,000 to co-fund this program and 5 Honda EV Plus vehicles. The SCAQMD is providing $200,000. In addition, EV Rental Cars and the other subcontractors involved in the program will cost-share by contributing $252,000 in cash and $523,755 in-kind to this project. These subcontractors include SMUD, the City of Burbank, the City of Anaheim, the Los Angeles Department of Water and Power, and Southern California Edison.

3.4.3 EV Long-Term Placement Program

The Honda Motor Company provided funding for Supplemental Emission Projects, as part of a Settlement Decree with ARB. The Supplemental Emission Projects include the Electric Vehicle Long Term Placement Program, under which 25 Honda EV Plus electric vehicles have been made available to public agencies for long-term loans (6 months to one year). The goals of the Electric Vehicle Long Term Placement Program are to promote greater awareness of electric vehicles among the public, familiarize senior public and private officials with electric vehicles and their capabilities, and encourage the leasing of electric vehicles by public agencies.

The Electric Vehicle Long Term Placement Program is a three-year program, now in its first year of operation. Vehicles have been placed with a variety of public agencies:

- Yosemite National Park (2 vehicles)
- State Parks in Sacramento and San Diego (1 vehicle each)
- Griffith Park, Los Angeles
- San Joaquin Valley Air Quality Management District
- Sacramento Metropolitan Air Quality Management District
- Ventura County Air Pollution Control District
- Yolo-Solano Air Pollution Control District
- Resources Agency Secretary
- Trade and Commerce Agency Secretary
- EV Loan Program, Bay Area (2 vehicles) and San Diego (1 vehicle)
- DGS State Garage Daily Rental
- ARB vehicle fleet (4 vehicles)
- EV Rental Fleet (5 vehicles)

Agencies that have received vehicles will provide a brief report at the end of the placement. The report will summarize the accomplishments of the program, identify activities in which the vehicle was used, and note any problems that occurred. This data will provide on-going information by which to evaluate the effectiveness of the program, as well as track any vehicle or charging problems that may have occurred. After agencies have concluded their loans, ARB staff will solicit new participants for the program.

3.4.4 Participation in Conferences and Exhibitions

ARB has participated in a number of conferences and exhibitions including the North American Electric Vehicle Infrastructure Conference, several international Electric Vehicle Symposia, the World Electric Vehicle Expo, the Los Angeles International Auto Show, and various Clean Cities Conferences. ARB has attended, contributed papers and/or purchased booth space at these and other gatherings. In addition, Board members and staff have participated in ride and drive programs, public relations events and technical advisory groups.

3.4.5 Outreach Events

Board members and staff have been very proactive in conducting public outreach to schools, community events, and community groups. These outreach events have been very successful at a "grass-roots" level. Often, a Board or staff member is accompanied by a member of the Zero-Emission Vehicle Implementation Section who may give a presentation or participate in a demonstration of the vehicle.

Over the past twelve months, ARB staff using vehicles from the ARB test fleet have participated in thirty-four outreach events at schools and more than twenty other events at youth groups, fairs, Earth Day celebrations, and other similar locations. Over the same time period staff from the ZEV implementation Section participated in an additional sixteen events including Science Day at the State

Capitol, Clean Air Day, and the Los Angeles International Auto Show. These events provide participants with an opportunity to gain experience with new vehicle technology and have questions answered about EV capabilities.

4 VEHICLE TECHNOLOGY ASSESSMENT

4.1 Introduction

In June 1999, ARB began meeting with auto manufacturers to discuss their obligations and plans for meeting the ZEV requirement in MY 2003. In December 1999 and February 2000, ARB staff visited all the large volume manufacturers in Japan and in the US to examine, first hand, the progress each manufacturer is making in preparing to meet the ZEV requirement as detailed in their product plans. Prior to the site visits, each manufacturer had provided ARB staff with product plans describing in detail how they intend to meet the MY 2003 ZEV requirement. The product plans included information regarding key development stages, decision points, and other milestones. In addition, the site visits provided ARB staff with a chance to examine prototypes of various types of advanced vehicle technologies.

This chapter discusses the development status of “pure” zero emission vehicles, and “full” and “partial” ZEV allowance vehicles. It concludes with a discussion of new categories of vehicles such as city and neighborhood electric vehicles. These latter vehicles are discussed separately because they have different operating characteristics than full range vehicles and are intended to fill different market segments.

4.2 Pure ZEV Vehicles

This section evaluates the progress made to date in developing “pure” zero-emission vehicles--vehicles having no direct emissions. Vehicles can be certified as ZEVs if they produce zero exhaust emissions of any criteria pollutant (or precursor pollutant) under any and all possible operational modes and conditions. These vehicles do, of course, result in a small amount of indirect emissions at stationary sources such as power plants or hydrogen production facilities due to the generation of electricity or hydrogen for use on board the vehicle. In the discussion of vehicle emissions (Section 9) the indirect emissions and environmental impacts from these stationary sources will be quantified in order to allow a meaningful comparison to other vehicle technologies.

Pure zero-emission vehicles hold distinct air quality advantages over technologies that use a conventional fuel such as gasoline in a combustion engine. Vehicles with combustion engines inevitably exhibit deterioration that results in increased emission levels as the vehicle ages. They are also subject to becoming gross polluters if critical emission control systems fail. High volatility liquid fuels such as gasoline are responsible for significant fuel cycle emissions. For all of these reasons, vehicles with no potential to produce emissions are the “gold standard” of even the cleanest, most advanced new technologies.

From the inception of the ZEV program, the battery electric vehicle has been the leading candidate for meeting the ZEV percentage requirements due to its stage of commercial development. Since 1990, worldwide effort in the research and development of vehicle and battery technology has advanced the prospects for the successful commercialization of electric vehicles. More recently, fuel cell technology has gained worldwide attention as a technology capable of supplanting current internal combustion engine vehicles in the market while providing zero direct emissions (when using stored hydrogen). The following sections provide a summary of the developmental status and infrastructure needs for these two technologies.

4.2.1 Battery Electric Vehicles

Battery electric vehicles were first commercialized more than one hundred years ago. After giving way to gasoline vehicles in the first part of this century, several efforts were made in the 1960's and 1970's to reintroduce and commercialize the technology. While the basic concept of today's electric vehicle remains the same, significant advances in components and vehicle technology have provided new opportunities for the use of electric drive in passenger vehicles.

4.2.1.1 Description of Technology

Battery electric vehicles use an electrochemical battery to store energy. In addition to this energy source, an electric vehicle employs an electric powertrain that includes a motor and controller. Electric vehicles use one of three different types of electric motors: DC (both series and shunt), AC-induction, and permanent magnet DC-brushless. Controllers used with these motors are usually either solid-state electronic, pulsed-width modulation with power transistors, or insulated gate bipolar transistors. Other components include the battery management system, battery charger, state-of-charge meter, charging connector, and electronic protection devices.

4.2.1.2 Development Status

Historically, the inability of batteries to store sufficient energy at a reasonable cost has limited the market for battery electric vehicles. However, considerable advances in the last ten years in component technology have greatly improved overall vehicle efficiency and thus range. By improving the efficiency of drivetrain components and optimizing the combined operation of the battery and drive train under normal operating conditions, EVs currently available can deliver nearly three times the range of EVs from the 1970's having the same amount of stored energy. Just as important, these advances have also included new designs that are projected to be cost comparable to the internal combustion engine vehicle in large volume production (not including the battery). At mandate volumes, however, cost studies conclude that electric vehicle drivetrains, not including the battery, will be more expensive than ICE vehicle drivetrains.

The improved efficiency has been achieved in large part due to the improvements in efficiency of each component mentioned above and through the integrated operation of battery and drivetrain under normal vehicle operating conditions.

California's electric utilities have been involved in the technology assessment of EVs for the past 10 years. Utility fleet data provides an excellent means of observing how EVs operate in daily use. Staff has received comments from the California Electric Transportation Coalition as well as workshop presentation from the fleet manager for Southern California Edison. This information indicates that today's EVs have proven reliable. The Southern California Edison EV fleet employs over 8,000 kWh of NiMH batteries that have traveled over 3 million EV miles. Some vehicles are approaching 40,000 miles with no repairs required. The battery module failure rate for the fleet has been less than 0.07 percent.

4.2.2 Fuel Cell Vehicles

Fuel cells are electrochemical devices that allow for the conversion of chemical energy of fuels directly into electricity. By doing so, the technology avoids the loss of efficiency and emissions of air pollutants that occur with the use of combustion-based engines. While originally discovered in 1839, the first practical use of the technology occurred during the early years of the manned space program in the 1960's. Subsequent manned space efforts, up to and including the Space Shuttle program, have continued to rely upon fuel cells for electric power. This success, in turn, has resulted in large efforts and investments in the technology to develop fuel cell technology for both stationary and mobile applications.

More focused efforts to develop the technology for transportation have resulted in significant improvements in the core technology. The key motivations for this recent interest include concern over urban pollution, a need for alternatives to a diminishing oil supply, and growing concern over global climate change due to carbon dioxide emissions from mobile sources. Because fuel cells are powered by alternative fuels, and operate at high efficiency, fuel cell vehicles can help achieve both energy efficiency and energy diversity goals. A fuel cell vehicle can either store hydrogen or obtain hydrogen through the reformation of an alternative fuel.

4.2.2.1 Description of Technology

While there are several different fuel cell technologies available for use in vehicles, the leading candidate for automotive application is the proton exchange membrane (PEM). Simply described, a fuel cell consists of a membrane, two electrodes, and gas chambers. In acid electrolyte, hydrogen reacts at the electrode, giving up electrons while hydrogen ions are passed through the electrolyte. The electrons are used to operate an electric motor that can then propel the vehicle. After transferring to the cathode side, the hydrogen ions combine with oxygen (typically from the air) and the electrons that have produced work, to form water. Since no combustion is involved, water is the only byproduct from the process. Many of the same components needed by a battery electric vehicle (e.g. the electric power train) are also necessary in a fuel cell electric vehicle.

4.2.2.2 Development Status

In 1998, the ARB contracted with a Panel of experts in fuel cell technology to assess the current status of fuel cells for transportation applications. According to the Panel's review of the technology, significant advances in fuel cell stack technology in recent years have overcome the technical barriers to attaining the performance needed for fuel cell electric vehicle engines.

Efforts are now ongoing worldwide to integrate the latest fuel cell designs into fuel cell engines, and ultimately fuel cell electric vehicles. The biggest challenge now facing automakers is to package the necessary hardware and reduce the cost of the technology to a level comparable to the internal combustion engine. Based on recent visits to manufacturer research and development facilities, however, staff concludes that mass production fuel cell vehicles will not be available until beyond 2003.

Manufacturers continue to advance the state of fuel cell technology. For example, recent news reports have described:

- Significant improvement in fuel cell stack performance under freezing conditions
- Development of next generation stacks that provide higher power while reducing system size and weight
- Introduction of new prototype vehicles by DaimlerChrysler, Ford (Th!nk) and General Motors
- Development of advanced fuel system technologies
- Groundbreaking for the headquarters and associated support facilities for the California Fuel Cell Partnership

The availability projection noted above applies to for fuel cell vehicles that reform (or extract hydrogen from) a fuel such as methanol or fuel cell compatible gasoline on board the vehicle. The operation of a reformer, however, results in ozone precursor emissions. Thus, to achieve zero direct emissions the vehicle has to store hydrogen on board the vehicle. While this greatly simplifies the vehicle's design (e.g. no reformer), it raises new issues regarding the storage of sufficient quantities of hydrogen on the vehicle. The storage of hydrogen, even at fairly high compression (e.g. 5,000 psi), requires roughly 10 times the volume that is needed for the storage of an equivalent amount of energy in gasoline form. Because the fuel efficiency of a fuel cell is significantly higher than that of an internal combustion engine, less fuel is needed to go a given distance. Nevertheless, passenger cars are not currently able to accommodate enough hydrogen for adequate range without seriously compromising the passenger and cargo space.

Manufacturers have explored options that include storing the hydrogen in low-temperature liquid form, or bound chemically to a metal alloy. Efforts continue, but the potential for breakthroughs in hydrogen storage remains uncertain. While a hydrogen fuel cell vehicle is believed to be the best long-term approach, its commercial introduction is not expected until beyond 2003. As part of research and development of fuel cell vehicles, automakers will demonstrate passenger cars using stored hydrogen in liquid form. The goal is not to demonstrate the commercial feasibility of this design, but rather to test, evaluate and refine all aspects of the fuel cell stack and engine.

To address fuel cell vehicle and infrastructure issues, in April 1999 California Governor Gray Davis and industry leaders announced a fuel cell vehicle Partnership that will demonstrate clean transportation technology on California's roadways in the future. The "California Fuel Cell Partnership - Driving the Future" makes the state home to a unique collaboration of auto manufacturers (DaimlerChrysler, Ford, Honda, Hyundai, Nissan, Volkswagen), energy providers (BP Amoco [formerly ARCO], Shell, Texaco), fuel cell companies (Ballard Power Systems, International Fuel Cells), and government agencies (California Air Resources Board, California Energy Commission, South Coast Air Quality Management District, United States Department of Energy, United States Department of Transportation). Associate members, who bring specific expertise to aid in fuel, vehicle and bus demonstration activities, include Air Products and Chemicals, Inc., Linde AG, Praxair, Methanex, the Alameda-Contra Costa Transit District, and the SunLine Transit Agency.

The Partnership will demonstrate fuel cell powered electric vehicles under real day-to-day driving conditions. The Partnership will place about 50 fuel cell passenger cars and fuel cell buses on the road between 2000 and 2003.
In April 2000 the Partnership formally signaled the start of construction for a fuel cell vehicle headquarters facility in West Sacramento with a groundbreaking ceremony. The facility, which will house fuel cell electric vehicles and a hydrogen refueling station, will serve as an operations base for executing the Partnership's goals of demonstrating fuel cell vehicle technology and an alternative fuel infrastructure over the next four years. The 55,000 square-foot, state-of-the-art facility is expected to open in autumn 2000.

4.3 Full and Partial ZEV Allowance Vehicles

In 1998 the ARB modified the ZEV requirement to allow ZEV credit to be earned by vehicles with near-zero emissions. This section discusses the development status of such vehicles.

4.3.1 Definitions and Requirements

Under LEV II, ZEV-like vehicles may qualify to earn a ZEV allowance of between 0.2 and 1.0 per vehicle. Vehicles that qualify for a ZEV allowance of 1.0 are known as full ZEV allowance vehicles. Vehicles that qualify for a ZEV allowance of between 0.2 and 1.0 are known as partial ZEV allowance vehicles (PZEVs). Staff believes that this ZEV allowance approach towards satisfying the ZEV requirement will promote the continued development of battery-powered electric and zero-emitting fuel cell vehicles, while encouraging the development of other advanced technology vehicles that have the potential for producing extremely low emissions and some ZEV-like characteristics. Manufacturers will be able to decide which mix of vehicles makes the most technological and economic sense based on their own strengths in each area.

Large automakers must meet at least 40 percent of their ZEV requirement with pure ZEVs, full ZEV allowance vehicles, or credits generated by either of these vehicle types. They may meet the remaining 60 percent of their overall ZEV requirement with PZEVs earning ZEV allowances of less than one.

To earn a ZEV allowance for a vehicle, the manufacturer must, at a minimum, meet the following baseline PZEV requirements:

- Certify vehicle to 150,000 mile SULEV emission standards
- Certify vehicle to zero evaporative emission standards
- Certify vehicle to meet OBD II requirements for SULEVs, and
- Extend performance and defects warranty to 15 years/ 150,000 miles

One important advantage of battery and hydrogen fuel cell electric vehicles is that their “tailpipe” emissions do not increase when their components fail and are in need of repair. The extended warranty requirement for PZEVs is a very important element of LEV II and is intended to address this issue. It requires manufacturers to provide a 150,000 mile emission warranty under which all malfunctions identified by the vehicle’s OBD II system will be repaired under warranty for a period of 15 years or 150,000 miles (whichever occurs first). This warranty is necessary to ensure that vehicles receiving credit for near zero emissions are able to maintain this performance throughout the useful life of the vehicle, as is the case with pure ZEVs.

Vehicles that meet all of these minimum or “baseline” requirements earn a 0.2 PZEV allowance. Since ARB regulations do not specify particular fuel or propulsion technologies, there is a wide variety of potential vehicle fuel and drive system combinations that may qualify for PZEV allowance in the coming years. The overall ZEV allowance assigned to a vehicle is the sum of 3 individual assessments:

- Baseline (minimum) PZEV allowance 0.2
- Zero emission vehicle miles traveled (VMT) allowance or Advanced Componentry 0.0 to 0.6
- Low fuel cycle emissions allowance 0.0 to 0.2

Table 4-1 on the next page lists a number of existing and hypothetical vehicle types, along with estimates of the maximum potential ZEV allowance they might be eligible to earn:

Table 4-1
Examples of Partial ZEV Allowance Vehicles, Full ZEV Allowance Vehicles, and ZEVs

Vehicle Type (Must meet all PZEV requirements)	Primary Energy Source	Secondary Energy Source	Zero Emission Range (miles)	PZEV Baseline Allowance	Zero-Emission VMT Allowance	Low Fuel Cycle Emissions Allowance	Total ZEV Allowance
Gasoline ICE	Gasoline	N/A	0	.2	0	0	.2
Gasoline ICE / HEV	Gasoline	Electricity	0	.2	.1 (components)	0	.3
CNG ICE	CNG	N/A	0	.2	0	.2	.4
LFCE ICE HEV, 0 mile ZE range	CNG, hydrogen	Electricity	0	.2	.1 (components)	.2	.5
Gasoline ICE HEV, 20 mile ZE range	Grid Electricity	Gasoline	20	.2	.3 +.1 (max off-vehicle charging)	.1	.7
Hydrogen ICE	Hydrogen	N/A	0	.2	.3 (0 NMOG)	.2	.7
Methanol Reformer FCV	FC Methanol	Electricity	0	.2	.3 (0 NOx)	.2	.7
Gasoline ICE HEV, 40 mile ZE range	Grid Electricity	Gasoline	40	.2	.4 + .1 (max off-vehicle charging)	.16	.8
LFCE ICE HEV, 20 mile ZE range	Grid Electricity	CNG, etc.	20	.2	.3+.1 (max off-vehicle charging)	.2	.8
LFCE ICE HEV, 40 mile ZE range	Grid Electricity	CNG, etc.	40	.2	.4 + .1 (max off-vehicle charging)	.2	.9
Direct Methanol FCV	FC Methanol	Electricity	Any				ZEV
Battery EV	Grid Electricity		Any				ZEV
Stored Hydrogen FCV	Hydrogen		Any				ZEV

Abbreviations used in the table are:

CNG:	Compressed natural gas
FCV :	Fuel cell vehicle
HEV:	Hybrid electric vehicle
ICE:	Internal combustion engine
LFCE:	Low fuel cycle emissions
FC Methanol	Methanol that is compatible for use in fuel cells
PZEV	Partial Zero Emission Vehicle
SULEV	Super Ultra Low Emission Vehicle
VMT:	Vehicle miles traveled
ZE Range:	Zero-emission range

It should be emphasized that the LEV II regulations do not establish specific ZEV allowances to be earned with particular fuel or propulsion technology choices. Rather, allowances are earned according to the three factors noted above, and depend on the actual performance achieved by a vehicle with a particular fuel and propulsion technology. The examples in the table below indicate staff's current assessment of the maximum achievable allowances possible for the vehicle types shown.

4.3.2 PZEV Availability

The following section outlines current information regarding the availability of production PZEVs, today and in the future (2003 and beyond).

4.3.2.1 MY 2000 PZEVs Presently Available

At the present time, only the Nissan Sentra 'CA' ("Clean Air") has achieved California certification for PZEV credit. Staff does not anticipate any further applications for PZEV certification for MY 2000 vehicles.

Nissan Sentra CA (Gasoline SULEV, PZEV Credit =.2)

Make	Model	Emissions Class	City/ Hwy EPA MPG	Primary Energy	Secondary Energy	Primary Propulsion	Secondary Propulsion
Nissan	CA	PZEV-.2 (SULEV)	26/ 33	Gasoline	N/A	Gasoline ICE	N/A

The 2000 model year Nissan Sentra CA is the first vehicle to be ARB-certified to meet SULEV requirements as well as the additional warranty and evaporative emissions controls necessary to achieve a baseline PZEV rating. Several key technologies allow the Sentra CA to achieve PZEV performance levels. These include:

- Double-wall exhaust manifolds,
- Quicker warm-up catalyst

- A new combustion control sensor, and
- An electronically controlled swirl control valve that reduces hydrocarbon emissions in both cold and warm start situations.

In addition, the radiators of all Sentra CAs are coated with Engelhard Corp.'s PremAir® coating, which converts ozone passing the radiator into oxygen.

The Sentra CA will be a limited production vehicle. Sales of the Sentra CA began in April 2000 in California.

4.3.2.2 MY 2000 SULEVs Not Qualifying For PZEV Credit

In addition to the Nissan Sentra CA, three other MY 2000 vehicles have met certification requirements for the SULEV standard. These vehicles will not earn PZEV allowances, however, because they do not yet meet all of the minimum baseline requirements necessary for PZEV status.

The MY 2000 Honda Accord SE has been certified to SULEV emissions standards, but has not been certified to attain PZEV allowance requirements for durability, warranty, or zero evaporative emissions at this time. The Accord SE would be eligible for a 0.2 ZEV allowance if the additional PZEV requirements were to be met.

The MY 2000 Honda Civic GX is a CNG fueled ICE vehicle that is ARB certified as a SULEV and already meets zero evaporation requirements. It does not yet offer the enhanced 150,000-mile emissions warranty required for PZEV baseline certification. Honda states that they do not yet have sufficient durability data on this vehicle to justify the warranty extension necessary for PZEV certification. Since CNG fueled SULEVs that qualify for a PZEV baseline allowance of 0.2 would also be eligible to receive 0.2 allowance for low fuel cycle emissions, the Civic GX could someday qualify for a 0.4 PZEV allowance.

The Toyota Prius, the Japanese version of which was the first modern-day HEV to be offered for sale, has been certified as a MY 2001 SULEV. Toyota is not expected to apply for certification to PZEV levels. As of January 2000, Toyota had delivered more than 30,000 units to customers in Japan, and US deliveries are expected to commence shortly.

Although the current Prius HEV is capable of traveling very short distances in ZEV mode, it cannot attain the minimum 20-mile all electric range necessary to earn a zero-emission range allowance. (Note that all energy in the Prius battery is provided by the on-board auxiliary power unit or by regeneration--it does not use any grid electricity). If future versions of the Prius or similar gasoline HEVs with negligible zero emissions range met PZEV requirements, they would attain an overall PZEV allowance of 0.2 baseline plus 0.1 for advanced electric drivetrain componentry, for a total PZEV allowance of 0.3.

Make	Model	Emissions Class	City/ Hwy EPA MPG	Primary Energy	Secondary Energy	Primary Propulsion	Secondary Propulsion
Honda	Accord SE	SULEV	23/30	Gasoline	N/A	Gasoline ICE	N/A
Honda	Civic GX	SULEV	28/34 (equivalent)	CNG	N/A	CNG ICE	N/A
Toyota	Prius	SULEV	52/45	Gasoline	Electricity: 1.8 kWh total energy, ~.18 kWh useful energy[a]	Gasoline ICE, (52 kW)	Electric Motor, (33 kW)

a. In operation the vehicle management system limits battery output to only a portion of its rated capacity.

4.3.2.3 Other Production Vehicles With Some PZEV Characteristics

The Honda Insight is the first modern-day HEV to be offered to customers in California. It is currently certified at ULEV emissions level, so it cannot yet qualify for a PZEV baseline allowance. The Insight HEV design emphasis is on high efficiency, and hybridization enables it to achieve the highest mileage and consequently the lowest CO_2 emissions of any gasoline-powered passenger car available in the United States.

The Toyota Prius platform, if modified to have a larger battery, a larger electric motor, and a charging port, could serve as the basis for a vehicle with significant zero-emissions range. Because the present design of the Honda Insight powerplant links the electric motor directly to the engine, it is not capable of any motor-only, zero-emission operation.

Ford has recently announced that it will be offering a 2003 MY hybrid version of its new sport utility vehicle (SUV), the Escape. This hybrid SUV is expected to achieve nearly 40 mpg (city) and will also be certified to the SULEV emission standard. The hybrid Escape is expected to provide acceleration similar to the V6 Escape, while achieving better fuel economy than the 2 liter 4 cylinder Escape (23/28 mpg city/hwy). Ford is also pursuing the development of a zero evaporative emissions system for the Escape. An Escape that met PZEV requirements would qualify for a 0.3 PZEV allowance.

Make	Model	Emissions Class	City/ Hwy EPA MPG	Primary Energy	Secondary Energy	Primary Propulsion	Secondary Propulsion
Honda	Insight	ULEV	61/70	Gasoline	Electricity ~.9 kWh total, ~.09 kWh useful energy[a]	Gasoline ICE (54 kW)	Electric (10 kW)
Ford	Escape	SULEV (Target)	TBD	Gasoline	Electricity TBD	Gasoline ICE (TBD)	Electric (TBD)

a. In operation the vehicle management system limits battery output to only a portion of its rated capacity.

4.3.2.4 Other Power-Assist HEVs

Staff expects several additional "power-assist" parallel HEVs to become available before 2004. These HEVs are also expected to be equipped with relatively small motors with less than 25 percent of engine power capability, and small battery packs (less than 2 kWh). Although these power-assist HEVs are designed primarily to improve fuel economy and do not necessarily reduce criteria emissions, they can significantly reduce CO_2 emissions. Sales of "power assist" HEVs would also require manufacturers to increase their design and production capability for electric motors, inverters, and battery packs, which may be used in other types of electric-propulsion vehicles.

4.3.2.5 PZEV Availability in MY 2003 and Beyond

Under the ZEV regulation, intermediate manufacturers may meet their entire ZEV obligation using PZEVs, and large manufacturers may meet 60 percent of their ZEV obligation with PZEVs. In order to take full advantage of this flexibility using 0.2 credit PZEVs, intermediate manufacturers would need to certify 50 percent of their fleet as PZEVs (50 percent of the fleet at 0.2 credits per vehicle equals 10 percent) and large manufacturers would need to certify 30 percent of their fleet (30 percent of the fleet at .2 credits per vehicle equals 6 percent). Other than the Nissan Sentra CA, discussed above, no manufacturer has announced definitive plans to market PZEVs in MY 2003. The timing of PZEV introduction likely will be affected by manufacturer-specific external cycles such as the planned retirement date for engine families and their replacement by new engines. Staff anticipates, however, that additional PZEV models will be announced prior to 2003.

Manufacturers have indicated that the most difficult challenges to be met for PZEV certification are the zero evaporative emission level and the 150,000-mile emissions warranty. In public comments, Honda pointed out that it has requested information from ARB regarding specific test procedures to be used to demonstrate compliance with the zero evaporative emission requirement. Staff notes that due to the many variables involved, ARB seeks to provide maximum flexibility and has encouraged manufacturers to develop and propose test procedures appropriate to their individual systems. To date one manufacturer has successfully done so, and it is staff's understanding that other proposals are planned. GM stated in workshop testimony that due to the technical challenges, and the high volume of PZEVs it would need to produce to meet 60 percent of its ZEV requirement (roughly 65,000 vehicles at 0.2 credits per vehicle), GM will be unable to use PZEVs to meet any significant portion of its ZEV requirement in 2003. Another concern stated by GM is the potential impact on the palladium (Pd) market when introducing significant numbers of PZEVs. PZEVs would likely require very high Pd loading on catalytic converters, and with large-scale introduction of PZEVs, GM is concerned that Pd demand will exceed supply, thereby significantly increasing the price of Pd. Staff is unable to verify the likelihood of this scenario.

Other large manufacturers (including Ford, DaimlerChrysler, and Toyota) have indicated that PZEVs will not be available in sufficient quantity to take full advantage of the 60 percent level allowed under the regulation for 2003.

Some intermediate volume manufacturers have also noted specific concerns in meeting the ZEV requirement in the early years (i.e. before 2006). Instead of making limited lines of specialty high ZEV allowance vehicles, as may be an option for a larger manufacturer, an intermediate volume manufacturer will need to incorporate significant numbers of PZEVs into its major product lines in order to meet its ZEV requirement. Such a large-scale introduction will require a longer phase-in period. Therefore, although intermediate volume manufacturers may begin introducing PZEVs in 2003, they have stated that the volume of PZEVs that they are able to produce would not be sufficient to meet the ZEV requirement in the first year of the program. They anticipate reaching compliance within 2 to 3 years. One manufacturer has suggested that manufacturers in such situation may require an extension in meeting the ZEV requirement.

4.3.3 All Electric Range and Efficiency Improvement

Both battery EVs and hybrid electric vehicles with zero-emission range that are able to charge from the electric grid can achieve high efficiency along with extremely low emissions. Today’s typical battery EVs achieve efficiencies of 400-500 Whr per mile (AC) and the EV1 efficiency has been tested at 250 Whr per mile. These vehicles thus are demonstrating a plug to wheels efficiency equivalency of 77-154 MPG (assuming energy content of gasoline is 38.6 kWh/gal). This high energy efficiency results in correspondingly low CO_2 emissions. Vehicle CO_2 emissions are discussed more completely in Section 9 below. Although vehicle operating efficiency and CO_2 emissions are not regulated by the ARB, staff recognizes that inefficient vehicles require more costly and complex systems to control criteria emissions. In addition, a malfunctioning low-efficiency gasoline vehicle operating up to 2 years between smog inspections has the potential to emit many times more emissions than a faulty high-efficiency vehicle.

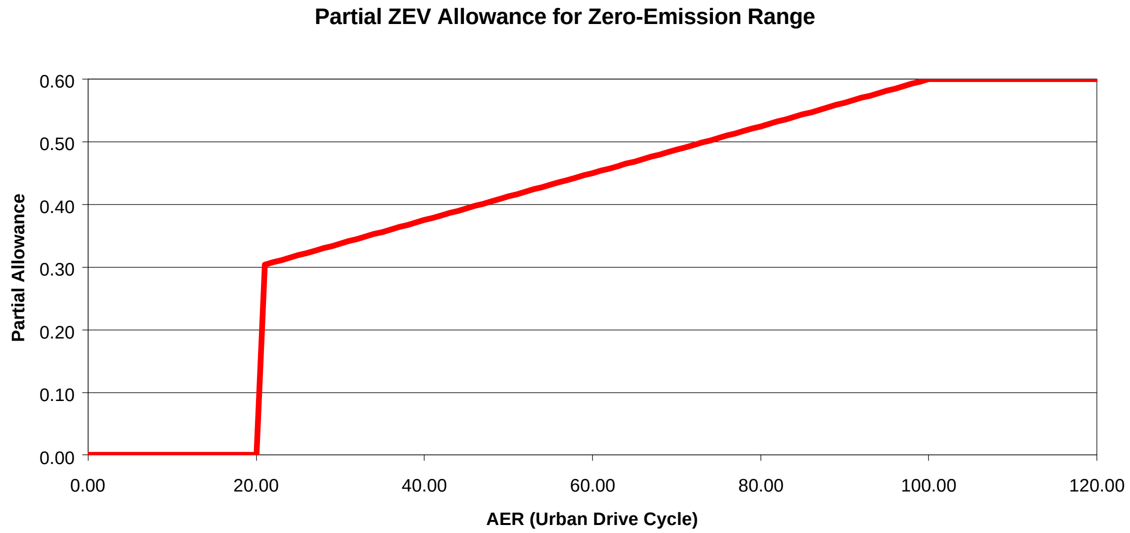
4.3.4 Partnership for a New Generation of Vehicles

The Partnership for a New Generation of Vehicles (PNGV) is a collaboration between the United States Government and the large domestic automakers. The long–term goal of the PNGV is to develop vehicles that will deliver up to three times today's fuel efficiency (80 miles per gallon) and cost no more to own and operate than today's comparable vehicles. At the same time, this new generation of vehicles should maintain the size, utility and performance standards of today's vehicles.

The PNGV program near-term development emphasis has been on diesel-powered vehicles, because its goals are narrowly focused on fuel efficiency. The Partnership has, however, also funded developments that may have significant impact on future emissions reductions. Program contractors have developed improvements in lightweight materials, high-power batteries, fuel cell components, and reductions in vehicle road-load. For example, a recent PNGV-funded prototype announcement for the GM Precept discloses an extremely low aerodynamic drag coefficient of .163, which is less than one-half of the drag exhibited by a typical modern car. The ability of auto manufacturers to reduce aerodynamic drag to these extraordinarily low values will substantially reduce the power and energy storage requirements of future ZEVs and PZEVs, and may accelerate the introduction of cost-effective near-zero or zero emission vehicles.

4.3.4 HEVs With Significant Zero Emission Range

Three PZEV allowances are added together to determine a vehicle's overall allowance. One of these three, the zero-emission VMT allowance, is based on the potential for realizing zero-emission vehicle miles traveled, and is determined as shown in the graph below.



During the development of LEV II, ARB staff believed that manufacturers would develop HEVs with battery packs that were smaller and less expensive than those needed for battery EVs, but still big enough to provide significant ZEV range and to justify recharging from the electric grid. These smaller packs for HEVs might have an energy storage capacity as low as 10-15 kWh instead of 30+ kWh in battery EVs, but would be sufficient to enable vehicles to attain a relatively large zero emission VMT allowance. Based on public announcements to date, however, staff does not believe that grid-charged hybrid electric capability will be made available on any MY 2000-2003 vehicles. The only hybrid electric vehicles expected during this time will probably be equipped with very small battery packs of less than 2 kWh capacity that are charged from gasoline-derived energy only. While LEV II was written to encourage vehicles with zero-emissions range like grid-connected HEVs because of their low emissions, high efficiency, and other ZEV-like attributes, it is unlikely that manufacturers will make use of this option to achieve higher PZEV allowances for zero-emission range before 2004.

Automotive manufacturers and researchers have, however, developed and demonstrated several prototype HEVs that demonstrate significant zero-emission range and are able to charge their battery packs with grid-supplied electricity. No manufacturer has announced when these types of HEVs will become available, and most cite the same primary obstacle that has resulted in the slow introduction of battery EVs--high battery cost. Although many of these advanced prototypes would not yet meet ARB's SULEV requirements, with further engine refinement to SULEV standards they would achieve very high PZEV credits because of their ZEV range capability.

Examples of functional concept "grid connected" hybrid vehicles include:

- Several GM EV-1 based show cars,
- GM Triax,

- DOE/ SAE Futurecar and Futuretruck Student-competition HEVs,
- Suzuki EV Sport,
- Volvo HEV,
- Ovonic-Modified (grid connected) Toyota Prius,
- Audi Duo.

Studies of the feasibility of such vehicles are underway, including work at U.C. Davis and EPRI. Staff believes that such vehicles offer many potential advantages, which justify their favorable treatment under the ZEV credit mechanism. Cost remains an obstacle due to the larger battery packs required for significant all-electric range.

4.4 On-Road Low Speed and City Electric Vehicles

Several classes of small on-road electric vehicles have begun to emerge in the last few years that will displace gasoline vehicle usage and increase overall zero-emission miles traveled within California. These vehicle types include low speed vehicles (LSVs).and city electric vehicles (CEVs). LSVs are not necessarily electric; LSVs that use electric drive are also referred to as neighborhood electric vehicles (NEVs). In this staff report we use “LSV”--the legal classification adopted by the National Highway Traffic Safety Administration—to refer only to electric drive vehicles. The specific characteristics of these vehicle types are discussed in more detail below.

LSVs and CEVs are under consideration because they offer a number of desirable characteristics:

- Very high efficiency
- Affordable to build, and affordable to purchase
- LSV performance is adequate with existing, affordable, lead acid batteries
- CEV battery pack energy storage requirements are only about 1/3 that of a full sized EV, so the latest battery technology can be more affordable.
- Reduced congestion (possible to park two LSVs in a single parking space)
- Many potential niche market applications (station cars, resorts, theme parks, national parks, campuses, planned communities).

4.4.1 Background--Emerging Small EV Classes

Small EVs exhibit a wide range of capabilities and performance levels. They may be broadly classified as shown on the next page. Similar characteristics for full-range EVs are shown for comparison purposes.

Under current state law and ARB regulation, LSVs and City EVs all qualify as “passenger cars” and therefore are eligible to earn full ZEV allowances. In terms of trip replacement and the resulting air quality impact, however, it is clear that a LSV, City EV, and a full-range EV differ significantly. ARB staff plan to better quantify the relative air quality benefits of the various new categories of vehicles.

Vehicle Type	DOT Class	Curb Weight	Energy Storage Capacity	Drive System Peak Power	Maximum Speed	Typical Range[a]	Examples
e-bikes, scooters, motorcycles, etc. [b]	N/A	Varies	0.3- 2.8 kWh	~1kW- ~10 kW	Varies	less than 20 miles	ZAP, ebike, etc.
LSV	LSV (Low Speed Vehicle)	950-1400 lbs.	4-9 kWh	~5-15 kW	Less than 25 mph (limited by LSV rqmnts.)	20-30 miles	GEM, Th!nk Neighbor, Bombardier NV, etc.
City EV (CEV)	PC	1800-2500 lbs. typ.	10-15 kWh	~20-30 kW	Typ. less than 62 mph	Typ. 40-80 miles	Toyota e-Com, Nissan HyperMini, Th!nk City, etc
3-Wheeled Enclosed Motorcycle[b]		Varies	3-10 kWh	Varies	28-60 mph	20+ miles	Sparrow
Full-range EV	PC	3200+ lbs.	15-35+ kWh	50-150 kW	70-80 mph	40-140 miles	EV1, EV-Plus, RAV4 EV, Altra, etc.

a. Test cycle range. Real world driving range will be less.
b. Not eligible for ZEV credit.

4.4.2 City EVs (CEVs)

This emerging class of vehicles is much smaller than most American vehicles and exhibits lower performance than the ICE vehicles currently available on the American market, but they are much more car-like than LSVs. Although the current prototypes listed below are not yet safety certified, production City EVs sold in the United States in quantities greater than 2,000 will be required to meet all existing federal DOT/Federal Motor Vehicle Safety Standards (FMVSS) requirements for equipment and crash protection. All are equipped with dual air bags, and many offer anti-lock braking systems.

Examples of near-term CEVs include:

Make	Model	Passengers	Curb Weight	Maximum Speed	Range[a]/ Power	Battery Type
Toyota	e-Com	2	1742 lbs.	62 mph	60 miles 19 kW	Panasonic NiMH 288 volts x 28 ahr
Th!nk	City (MY 00)	2	2046 lbs.	54 mph	50 mi 27 kW	Saft NiCad 114 X volts 100 ahr
Th!nk	City (MY 01+)	2	TBD	TBD	TBD	TBD
Nissan	Hyper-mini	2	1852 lbs.	62 mph	60 miles 24 kW	Shin Kobe LiIon
Honda	City-Pal	2	2310 lbs.	68 mph	80 miles	NiMH 288 volts 28 ahr

a. Test cycle range. Real world driving range will be less.

Auto manufacturers are planning to sell large quantities of CEVs elsewhere in the world, especially in countries where fuel prices are relatively high or gasoline infrastructure is scarce. Most City EVs fit within the Japanese “microcar” classification limits, which restrict vehicle size to a length of less than 3400 mm (11 feet 2 inches) and a width of less than 1480 mm (4 feet 10 inches). In Japan, there is growing interest in this “microcar” class of for use as second vehicles. Some City EVs whose lengths are less than 2500 mm (8 feet 2 inches) are capable of parking 2-to-a-parking space to help avoid urban congestion. In countries where fuel costs are high, CEVs will be able to provide lower cost of ownership even in the relatively low build quantities expected in the early years of production. They are equipped with battery packs that are approximately one third the capacity (and cost) of those found in full-size, full-performance EVs. City EVs are also expected to demonstrate better operating efficiency than larger EVs and LSVs. All CEVs currently proposed are planning to make use of advanced battery technology (NiMH or LiIon).

Toyota is providing a fleet of 13 left-hand drive eComs for a demonstration program in Irvine, California. This program will be run by UC Irvine’s National Fuel Cell Research Center in cooperation with Toyota. The e-Com can charge at either 120 VAC Level I or Level II Inductive charging stations.

The Th!nk City is currently available for lease in Scandinavia. Plans are for 700 units to be imported into the US in 2000, with more than 300 of them coming to California for demonstration programs. Safety features include a driver-side airbag and seat belts with pre-tensioners.

Nissan’s Hypermini is the only City EV that is presently equipped with Lithium Ion batteries. Safety features include both dual airbags and anti-lock brakes. A Nissan Hypermini station car demo program in Yokohama began in January 2000, with others to follow. Thirty vehicles are allocated for demonstration in California beginning this year.

4.4.3 Low Speed Vehicles (LSVs)

Low speed vehicles have a curb weight of under 1800 lbs., are equipped with speed limiting devices that limit maximum speed to 25 mph, and are restricted to use on roads with posted speed limits of under 35 mph. This vehicle class was legalized on a community basis in California with the passage of Assembly Bill 110 in 1999. Arizona was the first state to legalize LSVs on a statewide basis. LSVs are not necessarily electric drive. In practice we expect that the vast majority of LSVs in California will be electric drive, and in this document we use the term LSV to refer to electric drive vehicles. An LSV with electric drive is also referred to as a Neighborhood Electric Vehicle.

The National Highway Traffic Safety Administration (NHTSA) has excluded LSVs from the category of “passenger car” and defined a new Federal Low-Speed Vehicle class to establish minimum safety and equipment standards for these vehicles (49 CFR Parts 531.3 and 571.500). These regulations define a LSV as “a 4-wheeled vehicle, other than a truck, whose speed attainable in 1.6 km (1 mile) is more than 32 kph (20 mph) and not more than 40 kph (25 mph) on a paved level surface”. Federal requirements do not require LSVs to make use of electric propulsion. The California vehicle code was modified under Senate Bill 186 to accommodate this new federal classification, and these vehicles have been legal for use on public roads statewide since January 2000. Under California law and ARB regulation, however, LSVs qualify as “passenger cars”, even though they are subject to different crash test requirements. Thus federal and state law differ on this point. Because they qualify as passenger cars under state law, LSVs are eligible to earn full ZEV allowances. Another important distinction between Federal and California law is California’s additional restriction of unladen weight to 1,800 lbs. or less.

Although these vehicles appear to be similar to golf carts, they offer substantially more performance, better safety features, and are much more road worthy. LSVs are generally capable of much better acceleration than golf carts and can achieve 25 mph quite rapidly. Golf cart performance is restricted in accordance to cooperative industry standards to 13-15 mph, due to safety and turf maintenance concerns on golf courses. LSVs are usually equipped with higher-pressure road tires that might damage turf if used on a golf course, and LSVs must also be equipped with much better brakes than would be needed on a golf course. At the present time, all LSVs on the market are purpose-built designs intended for use as LSVs and are not derivatives of existing golf-cart designs. These improvements also increase the price of a LSV to more than $3,000, which is more than a typical electric golf cart.

At the present time, LSVs do not display efficiency labeling, as is required of all other road vehicles. Present EPA test procedures specify that the test vehicles must operate at speeds that are above the capability of LSVs, so the existing test procedure cannot be used to measure the fuel economy or range of these vehicles. Although test information is not yet available for these vehicles, it is believed that their operating efficiency may not be nearly as high as that of City EVs, which are equipped with much more technologically sophisticated componentry. In many cases, it is possible that LSV operating efficiency may even be poorer than that of full-size and full-range battery EVs. These vehicles generally have battery pack capacities of about 8 kWh, but the pack cost is quite low due to the low cost of the batteries used.

Examples of near-term LSVs are as follows:

Make	Model	Passengers	Curb Weight	Range[a]/ Power	Battery Type
Th!nk	Neighbor	2	950 lbs.	25 mile/ 5 kW	TBD
Th!nk	Neighbor	4	1200 lbs.	25 mile/ 5 kW	TBD
Bombardier	NV	2		30 mile/ 3.7 kW	Sealed lead-acid 72 volt system
GEM	E 825	2+ short bed pickup	980	25-30 miles/ 2.6 kW	Flooded Lead-Acid 72 volt system
GEM	E 825	2+ long bed pickup	1200	25-30 miles/ 2.6 kW	Flooded Lead-Acid 72 volt system
GEM	E 825-2	2	980	25-30 miles/ 2.6 kW	Flooded Lead-Acid 72 volt system
GEM	E 825-4	4	1280	25-30 miles/ 2.6 kW	Flooded Lead-Acid 72 volt system

a. Test cycle range. Real world driving range will be less.

Deliveries of the Th!nk Neighbor are scheduled to commence in November, 2000. It will be available for sale at selected Ford dealers, via the internet, and at other unspecified outlets, and base price is expected to be approximately $6,000.

Bombardier was the first LSV to apply for ARB certification. The Bombardier vehicles make use of sealed, maintenance-free lead acid batteries, and are available at a base price of $6,199.

GEM has received certification for its MY 1999 vehicles. Prices vary with model, and range from $7,000 to $10,000. Unlike some other LSV models, the GEM charging circuitry is designed to be compatible with existing, 120 VAC commercial GFCI-equipped outlets.

GEM LSVs are the only ones equipped with flooded lead-acid batteries (all others are sealed designs), and will therefore require battery maintenance. GEM recommends checking/ adding battery water to each cell at least once a month.

As noted above, although LSVs are not “passenger cars” under federal law, under current state law and ARB regulation LSVs qualify as “passenger cars” and therefore are eligible to earn full ZEV allowances. Due to their limited range and functionality, it is apparent that such vehicles will replace far fewer vehicle miles traveled, or trips, than City EVs or full range EVs. Staff thus has significant concerns regarding how such vehicles should be treated for ZEV credit purposes. ARB staff plan to evaluate the use and resulting emission benefits of such vehicles as information becomes available.

5 BATTERY TECHNOLOGY ASSESSMENT

5.1 The Battery Panel

The cost of batteries, both today and when produced in volume, is one of the most critical parameters of this review. To obtain the best available assessment, the ARB has contracted with a team of outside experts. The Year 2000 Battery Technology Advisory Panel has met with leading battery suppliers and auto manufacturers. Their task was to review the state of the art regarding advanced battery design and manufacturing techniques, and report back to staff regarding likely cost trends for 2003 and beyond. The Executive Summary of the Panel's draft final report is attached to this Staff Report as Appendix A. The full text of the Panel's report is available on the ARB Biennial Review website at http://www.arb.ca.gov/msprog/zevprog/2000review/2000review.htm.

Interested parties have been given the opportunity to comment on the draft final report. Comments received to date have been conveyed to the Panel for their consideration. The final report will be available to the public at the September 7, 2000 Board hearing and will reflect the comments and feedback received as appropriate.

5.2 Range vs. Cost

The current structure of the ARB regulatory and incentive scheme for ZEVs and partial ZEVs is intended to encourage the development of advanced batteries that will allow battery EVs to achieve extended range, long battery life, and lower lifecycle cost. For example, additional credit is given in the near term for ZEVs with a range of greater than 100 miles.

This approach has been taken in order to encourage the development of vehicles with sufficient range to cover the majority of trips taken by typical drivers. Such range has been thought to be necessary to achieve mass-market penetration. In addition, the use of advanced batteries has the potential to extend the life of the battery pack compared to conventional lead acid batteries, and thereby reduce the need to replace battery packs during the vehicle life. It has long been assumed that technical advances will reduce the cost of advanced batteries such that in addition to providing extended range, they will be more cost effective than conventional batteries on a lifecycle cost basis.

Some parties have argued that the ARB preference for advanced batteries should be revisited. Proponents of this view make the case that lead acid batteries may be cost-effective in several EV and HEV configurations, and they question whether the increased range afforded by advanced batteries justifies the extra cost. They also note that lead acid batteries are well suited for fast charging. Others have argued that one appropriate niche for battery EVs could be smaller, shorter-range vehicles for urban and commuter use, and that the ARB incentive structure should not discourage such applications.

Two threads of public comment that relate to this issue were presented at the March workshop. First, many EV drivers of lead acid vehicles testified that their existing vehicles provide more than adequate range for their daily driving needs. (This point is discussed in more detail in Section 7, of this report, EV Market.) They see no advantage to batteries that provide additional range at an increased cost, and would not take advantage of such an opportunity.

Second, one speaker presented an analysis of the “cost of increased range”. In this analysis, the cost of an advanced lead acid vehicle was compared to that of a nickel metal hydride vehicle with greater range. This speaker concluded by recommending that the ARB eliminate the 100-mile minimum electric range threshold for granting multiple ZEV credits. This would allow shorter-range vehicles to qualify for multiple credits, and in the view of the speaker would increase the options available to ZEV manufacturers and purchasers. One possible outcome of this scenario would be a shift towards shorter-range, less expensive lead acid vehicles.

One other effect of such a change would be that larger NiMH vehicles (GM S-10, Ford Ranger, and DaimlerChrysler EPIC), which under the current regulation only get a 1.0 credit because their electric range is less than 100 miles, would get multiple credits. Specifically, if the ZEV multiple credit line were to be linearly extended below 100 miles, in 2003 the S-10 and the EPIC would get about 1.8 credits, while the Ranger would get about 1.2 credits. Thus, without a shift to lower-range lead acid vehicles, fewer vehicles would be necessary to comply with the 2003 requirement.

The staff cost analysis, presented in Section 8, contains a detailed comparison of lifecycle costs for lead acid and NiMH batteries in a variety of vehicle configurations.

5.3 Possible Actions to Reduce Battery Cost

In public comment, several parties suggested that battery cost could be reduced if there were greater standardization in several key areas, including:

- The size and shape of different types of battery packs (NiMH, LiIon, PbA) so that battery packs could be readily switched out without changes to the vehicle.
- Voltage levels among the various manufacturers of NiMH and among the three battery chemistries.
- Battery management systems, both thermal and electrical management.

It also was suggested that guaranteeing a high volume of battery orders to one or more manufacturers could decrease battery cost. Battery manufacturers have indicated that a volume of approximately 20,000 batteries is necessary to realize economies of scale in battery production. Several utilities have proposed a competition among battery manufacturers that would reward the winning company or companies with a large order in return for passing on the cost saving from higher volume production.

6 INFRASTRUCTURE ASSESSMENT

6.1 Introduction

To achieve zero and near-zero (SULEV) emission levels, together with minimal upstream refueling emissions, the advanced technology vehicles being developed by manufacturers often require the use of fuels other than conventional gasoline. Therefore it will be critical to ensure that the necessary refueling infrastructure is in place to support their widespread introduction.

Recently, the South Coast Air Quality Management District and CALSTART announced an Internet web sit that allows drivers of alternative fuel vehicles to locate refueling stations quickly and easily throughout California. The site covers electric, compressed and liquefied natural gas, propane and methanol fueling facilities. The site will also list ethanol and hydrogen fueling facilities when they become publicly available in California. Clean Car Maps is located at http://www.cleancarmaps.com. Users pick an alternative fuel and enter an address and they will receive a map with icons designating the locations of refueling sites in the area. Users can then click on the site name to get comprehensive refueling information from a web database.

6.2 Battery EVs

Public infrastructure enhances the utility of battery electric vehicles. Drivers can extend the length of their trips if they know that convenient recharging facilities will be available at their destination.

The charging facilities at individual locations vary. A grocery location may be equipped with a single electric charging station. A public parking garage is more likely to provide both inductive and conductive charging stations. Major destinations will have a larger number of charging stations. For example, parking Lot 1 at Los Angles International Airport is equipped with ten inductive electric chargers and 6 conductive chargers, and Lot 6 is equipped with additional inductive and conductive electric charging stations.

The public infrastructure for electric vehicle charging continues to expand in California. Currently, there are about 400 public charging stations statewide, which offer about 700 chargers--about 400 inductive and about 300 conductive. The bulk of the locations are in the greater Los Angeles/South Coast area, the San Francisco Bay area, the Sacramento Metropolitan area, and San Diego. In recent years, public infrastructure has expanded to locations in the North Coast, Central Coast, Sacramento Valley and San Joaquin Valley.

Public comments from the California Electric Transportation Coalition provide useful background on EV infrastructure. Points made in the Coalition comments include the following:

- Charging has been successfully deployed for large, centrally fueled fleets. Southern California Edison, for example, has 400 installed chargers with an additional 200 circuits already in place.
- Workplace charging requires more attention. While some employers have been slow to embrace employee charging, others have taken laudable initiatives. Apple Computers in Cupertino will offer their employees free EV charging and parking until 25 percent of the vehicles that employees drive to the Apple site are electric.
- There are still two competing charging technologies, with a single charging standard no closer. Both charger types have proven convenient to use and reliable. Because of the vehicles available, conductive chargers dominate fleet applications, while inductive chargers are more evenly divided between fleet and consumer applications,.
- Prices have come down for both inductive and conductive charging equipment over the past two years, although some chargers are still subsidized by their manufacturers and automakers. Innovations currently being implemented may help reduce equipment and installation costs further. For example, the United State Postal service \fleet will test a conductive dual-head conductive charger that requires no manual intervention to switch from charging one vehicle to another. Use of this type of charger allows for a lower installation cost. Other innovations such as multiple chargers on a single pedestal, or load management systems, will reduce the cost of infrastructure installation per vehicle even further. In addition, one manufacturer has developed a Level 2+ conductive charger that could provide faster charging at a minimal incremental cost.
- Failure rates for chargers have been lower than expected, averaging less than 2 percent where data are available. To date most repairs have been covered under warranty, although with some chargers now coming out of their 3-year warranty period that will change.
- Fast charging has been successfully demonstrated. Chrysler's EPIC minivan is successfully using fast charging for airport shuttle vehicles, demonstrating economic feasibility in a centrally fueled fleet. Fast charging will become more economic as the number of EVs on the road increases.

In public comments, manufacturers noted the extensive efforts by some automakers to develop EV infrastructure. Many of these efforts in the areas of building code revisions, inspector training, and similar preparatory work are discussed in more detail in Section 3 above. Manufacturers also noted that the installed base of public electric vehicle chargers is sparse relative to the installed base of gasoline pumps, especially when the long recharge time needed for electric vehicles is taken into account.

ARB staff will continue participating in efforts to expand public infrastructure for electric vehicles. There do not appear to be any barriers that would prevent the expansion of public charging as needed to accommodate increasing numbers of

EVs on the road. ARB staff has, however, identified several areas that warrant review in the near term:

- Centralization and maintenance of up-to-date information on public charging station locations and operational status, with dissemination of the information via Internet and annual publication (currently being provided by CalStart and Clean Car Maps).
- Review and revision, if appropriate, of the criteria for selecting public charging locations to take into account recent increases in electric vehicle range.
- Modification of the public infrastructure to accommodate upgrades to chargers and connectors, and additional electric charging technologies.
- Development of state regulations and local ordinances to discourage parking of internal combustion engine vehicles ("ICEing") at electric vehicle charging stations.
- Promotion of a courtesy charging protocol to allow more than one user access to a single electric charging station.

One issue of concern that can affect both the cost and utility of public charging is the lack of progress towards a single electric vehicle charging standard. This could increase the cost for installing or retrofitting existing public charging stations if a decision for a uniform standard is not made well before the public charging system is expanded to accommodate increasing numbers of vehicles on the road.

ARB has previously considered the possibility of establishing standards that would govern the type of charger to be installed when public agencies provide incentives or funding for public infrastructure. Staff believes that ARB has the regulatory authority to establish standards for electric vehicle charging systems. It was suggested at the workshop that ARB consider the establishment of a Technical Advisory Panel to make recommendations to ARB on this issue.

6.3 Grid-Connected Hybrid Vehicles

Grid-connected HEVs are generally expected to make use of the same public and private electric charging infrastructure that is currently being installed for battery EVs. One possible difference between battery EVs and PZEV HEVs would be a potential reduction in the demand for higher-power (Level II) charging stations, due to the fact that such HEVs can run on APU power when their battery packs are depleted. It may even be possible for 20 to 40 mile zero-emission range HEVs to make significant use of Level 1 charging (standard 120 VAC), because the smaller battery packs in these HEVs will be able to accumulate useful charge in reasonable time periods with more commonly available Level 1 outlets.

6.4 Fuel Cell Vehicles

In addition to testing vehicles, the California Fuel Cell Partnership (discussed in section 4.2.2.2 above) will also identify fuel infrastructure issues and prepare the California market for this new technology. Initial demonstration vehicles will run on hydrogen, directly from tanks on board the vehicles. Subsequent demonstration vehicles are likely to run on methanol fuel. Technology for other liquid fuels such as a cleaner form of gasoline will be evaluated. A key goal of the Partnership is to determine the best fuel infrastructure for the market entry of fuel cell vehicles.

The Partnership will be devoting considerable attention to fuel cell fuel infrastructure issues. Staff will monitor the Partnership's efforts in this regard and report on status as appropriate.

6.5 Compressed Natural Gas (CNG) Vehicles

There are currently about 230 CNG vehicle refilling stations in California, of which 104 are available to the public. Most of these are "fast fill" type stations that are capable of refilling CNG vehicles in as little as 2 to 4 minutes.

Although the "fast fill" fuel dispensing infrastructure is relatively sparse, low pressure natural gas is already delivered to most residences in California. Thus manufacturers are working to develop "time fill" devices that would be suitable for home refueling use. These "time fill" devices may take 6-8 hours (overnight) to fill a vehicle, but their availability could make dedicated CNG vehicles a much more viable option for non-fleet users.

7 THE EV MARKET

7.1 Introduction

One key issue, as we look to 2003, is the nature and extent of expected market demand for electric vehicles. Does a market exist for a large number of electric vehicles? Of all the issues associated with the zero emission vehicle regulation, this one appears to generate the greatest divergence of opinion and the most strongly held beliefs. It is also the question for which the least amount of hard data is available.

Several basic points have emerged in the course of staff's investigation, workshop testimony, and subsequent public comment:

- Those companies that actively marketed EVs to retail customers (GM and Honda) made broad-based promotional efforts that attempted to assess the potential retail market for EVs. Other manufacturers used marketing efforts appropriate for the fleet market.
- Customer demand for the vehicles, as evidenced by actual leases, was limited under the circumstances and conditions that prevailed in the initial marketing period, and fell short of manufacturer expectations. For many months the available inventory of vehicles was in excess of customer demand.
- At present, due to the halt in EV production by most manufacturers, the demand for vehicles exceeds the available supply, both for retail customers and for fleets. It is unclear if demand exceeds the level that prevailed during the time that vehicles were available.
- The performance characteristics of today's EVs meet a wide variety of potential applications. Drivers of EVs report using the vehicle more than they expected to, and the EV is nearly always the vehicle of choice for trips within its range.
- The process of leasing an EV, as reported by EV drivers and those who attempted to lease vehicles, has been described as far more difficult than the process of acquiring a conventional vehicle. Although the evidence presented is anecdotal, rather than survey-based, staff believes that taken as a whole this testimony provides persuasive evidence that such difficulties indeed have occurred in real world EV leasing.
- Different parties have come to markedly different conclusions regarding the EV market for 2003.

To further address market related issues, this chapter first discusses EV market demand as evidenced to date. It then discusses the potential market in 2003. Finally, it outlines key elements needed to mount a successful EV marketing effort consistent with the 2003 regulation.

We recognize that considerable time and effort could be spent debating the strengths and weaknesses of the manufacturers' past efforts. The central issue before the Board, however, is what is likely to occur under the very different circumstances of 2003. Thus our focus throughout the Biennial Review process is on looking forward rather than backward.

7.2 EV Market Experience to Date

This section summarizes available information regarding EV marketing experience, drawing upon staff's review of marketing strategies and efforts undertaken to date by manufacturers, the results reported during the MOA placement programs, testimony at the March 2000 and May 2000 workshops, and public comment.

7.2.1 Manufacturer Marketing Strategies and Efforts

In letters dated September 28, 1999, and November 2, 1999, ARB staff requested information on auto manufacturers' marketing activities since the initial ZEV launch. All auto manufacturers responded to the request in a timely manner.

The manufacturers offered a variety of EV platforms to the marketplace. Only General Motors offered more than one platform. The majority of the manufacturers targeted fleet commercial customers to meet their MOA obligations. Two manufacturers, GM and Honda, had retail customers as their primary market targets. Table 7-1 below describes each manufacturer's market target groups and its EV platform. The majority offered their EVs through three-year leases. The leases typically covered batteries, maintenance and road service; some leases included insurance or chargers. The lead acid battery version of the Chevrolet S10 Electric truck and the Ford Ranger were offered for purchase.

Table 7-1
Manufacturers' Market Targets and Vehicle Models

Manufacturer	Primary Market Target and Vehicle Model	
	Retail Customer	Fleet/Commercial Customer
Daimler-Chrysler		EPIC (5 passenger minivan)
Ford		Ranger EV (2 passenger truck)
General Motors	GM EV1 (2 passenger car)	Chevrolet S10 Electric (2 passenger truck)
Honda	EV Plus (4 passenger car)	EV Plus (4 passenger car)
Nissan		Altra (4 passenger minivan)
Toyota		RAV4 (5 passenger sport utility)

The majority of the manufacturers describe the introduction of their production EV models as demonstration programs, with goals that focus on advanced battery evaluation and on market and infrastructure issues important for future growth in the EV market. To retain control over the vehicles for evaluation purposes and to protect the customer from "demonstration" EV technology, manufacturers offered the EVs for lease only in most cases. Several manufacturers mentioned that support of charging infrastructure was a component of their marketing of the EVs. The majority identified the fleet market approach as the most reliable and effective means to assess the operational and durability aspects of EVs. Prime fleet customers were identified as those required to purchase alternative fuel vehicles under the Energy Policy Act (EPACT), including government agencies and electric utilities, and companies wanting to promote an environmentally conscious image. Some manufacturers mentioned that they wanted to avoid "higher risk" factors associated with retail marketing. According to information available to ARB staff, about two thirds of the EVs in California have been placed in fleets and about one third have been placed with retail customers.

Several manufacturers reported EV marketing expenditures, on a per vehicle basis, of up to several orders of magnitude higher than expenditures for similar conventional (non-electric) vehicles. ARB staff and some manufacturers attribute the higher expenditures per vehicle to the limited number of EVs being produced and the cost of the additional educational aspects of marketing to promote a new technology. However, ARB staff also received information that indicates that marketing expenditures for a newly introduced conventional car model can be similar in magnitude in the first or second year of introduction.

In the Preliminary Draft Staff Report, staff stated that manufacturers focused their marketing efforts on small, narrow target audiences. In public comments, Honda has presented information indicating that its promotions and marketing efforts were broad-based, and used many of the same techniques that are used for conventional vehicle promotion and marketing. Similar comments were made with respect to GM's marketing for the EV1. Staff agrees that these promotional efforts were directed at broad market segments, and has revised this section accordingly.

The next sections provide more detail regarding the activities of individual manufacturers.

DaimlerChrysler. DaimlerChrysler's demonstration program has used a single EV model, the five passenger EPIC minivan. EPIC is an acronym for Electric Power Interurban Commuter. The EPIC combines the Dodge Caravan/Plymouth Voyager minivan platform with advanced electric vehicle technology and off-board chargers that provide fast recharging capability. Using the fast charge, the EPIC is capable of more than 300 miles service in a single day.

Staff notes that the EPIC's charging system differs from the standard inductive and conductive systems used by all other vehicles. For a captive fleet with central recharging this is not a problem, and the fast charge capability provides significant benefits. For other applications that need to make use of public charging infrastructure, including retail public customers, the lack of a standard charging interface presents an impediment to more widespread use.

DaimlerChrysler chose the minivan platform for the EPIC because of the popularity of its minivans and because of the minivan's versatility to either carry passengers or to be used as a utility vehicle. The EPIC, with a combination passenger and cargo payload of 925 pounds, has initially been marketed for lease to fleet customers. DaimlerChrysler identified governmental entities, electric utilities and commercial fleets with short-range delivery requirements as primary targets with a particular interest in the U.S. Postal Service.

To meet its MOA commitment, DaimlerChrysler began to place MY 1999 NiMH battery-powered EPICs in the 1998 calendar year. To date, 185 EPICs have been placed in California. Major customers include the Xpress airport shuttle service at Los Angeles International Airport, US Postal Service offices in Harbor City and Huntington Beach, UCLA, military bases, municipalities, and business fleets. EPICs are also placed at dealers where they are used for demonstrations.

DaimlerChrysler has used a target-direct-mail campaign with small incentives (including radios and flashlights), advertisements in regional business journals, literature and the normal government and utility fleet bid process to market the EPIC. Fleet managers have been invited to selected dealers for a test ride and may have been visited by DaimlerChrysler's Alternative Fuel Vehicle Sales and

Marketing representatives. The primary marketing theme has been "Meet the EPIC Electric Minivan - Batteries Included" with emphasis on the EPIC's practicality and zero emissions.

<u>Ford</u>. The Ranger EV truck is the single model used in the Ford demonstration program to date. Based on Ford's best-selling compact truck platform, the Ranger EV has a regular cab and payload capacity of 700 pounds if equipped with lead-acid batteries, or 1,250 pounds with NiMH batteries. Ford first introduced its lead-acid battery-powered version of the Ranger EV pickup truck in 1998. The NiMH version was made available in 1999.

Prior to introducing the Ranger EV, Ford conducted focus groups, marketing clinics and dealer meetings. Ford has targeted fleets for these vehicles because it perceives fleet customers as generally having shorter, more predictable driving patterns than retail customers. However, Ford has marketed the Ranger EV to both fleet and retail customers. Sales and service are through Ford dealers to provide customers with a "mainstream" or "conventional car" experience. To date, 356 Ranger EVs have been placed in California (of a total of 915 nationwide). The California customers are predominately government with some utility, private fleet, and retail customers. Ford appears to have retained about ten percent of these California Ranger EVs for demonstration purposes.

Ford reports that it has 15-20 Ranger EVs scheduled continuously at various events including government fleet events, dealer events, media events and auto shows. Other Ford marketing efforts include joint marketing with utilities, telemarketing, direct mailings, Ford websites, and on-going print ads. Ford's marketing message appears to focus on the Ranger EV having the "Best in Class" design features of a gasoline Ranger and proven advanced EV technology to guarantee it is "Built Ford Tough". According to Ford, its California marketing expenditures per Ranger EV in 1999 were 6.5 times that of a comparable gasoline Ranger.

In August 1999 Ford introduced additional incentives to encourage Ranger EV leasing. A reduced lease rate of $199 per month was put into effect for a Youth Awareness Program, and $7000 vouchers were made available to reduce the lease cost to public and private schools, parks, and zoos. These incentives resulted in an increase in lease rates, up to an annual rate of about 1200 vehicles per year.

Ford has entered into an agreement with the United States Postal Service to provide 500 electric vehicle platforms, based on the Ford Ranger, for use as Postal Service vehicles. Most recently, Ford has announced plans to market the two passenger Th!nk City and Th!nk Neighbor vehicles in the United States—the first vehicles of that type to be offered by a major automobile manufacturer in this country. The Th!nk vehicles will be marketed to the general public. Ford has indicated that it believes a market exists in the United States for these urban commuter cars, and has recently undertaken a television advertising effort featuring the Th!nk City. Various demonstration programs featuring the Th!nk and other similar vehicles are being planned.

General Motors. General Motors offered two EV models in its demonstration program, the 2-passenger GM EV1 with a payload of 440 pounds and the Chevrolet S-10 Electric compact truck with a payload of 950 pounds. General Motors has marketed three versions of the EV1--the 1997 Generation I with lead acid batteries, and the 1999 Generation II with advanced lead acid or with NiMH batteries. The EV1 has been marketed for retail applications, with 768 placed in California. The Chevrolet S-10 Electric, offered with lead-acid or nickel-metal hydride batteries, has been marketed for commercial applications with 227 placed in California, out of more than 450 placed nationwide by the end of 1999. The target customers for the Chevrolet S-10 Electric include electric utilities, government agencies, colleges and universities, theme parks, zoos and airports.

In support of EV technology development and marketing, General Motors began consumer research in 1989. Their market research efforts have included a two and one-half year consumer test fleet drive program beginning in 1994 (the PrEView Drive), an early adopter marketing focus group, an EV1 owner survey, and recent market positioning research. Through customer input from the PrEView Drive, General Motors modified its EV product and determined the attributes of the early adopter target market.

General Motors gave the EV1 a unique General Motors (GM) badge and served retail customers through selected Saturn dealers and an EV specialist team. Currently, 33 Saturn retailers in Los Angeles, Orange County, San Diego, the San Francisco Bay area, Sacramento, Phoenix and Tucson lease and service the EV1.

Due to the recent recall, the MY 1997 Gen I EV1 vehicles are being stored by General Motors until the engineering and validation of a new replacement charge port is completed. Drivers who lost the use of Gen I vehicles are being given the option to transition to a Gen II EV1, or wait until rebuilt Gen I EV1s are available. Staff's understanding is that demand for Gen II EV1 vehicles exceeds the available supply. General Motors has not committed to additional production at this point.

General Motors marketing efforts have targeted regional market locales and used various media including television, radio, outdoor, newspaper, magazines, Internet site, direct mail, and brochures. The marketing efforts include promotional activity at schools and events, an EV1 test drive road show, and owner club support. Marketing themes have included "Upgrade your drive. The electric car is here.", "You can't hear it coming. But it is.", and "Clean air goes in here. Clean air comes out here."

Honda. Honda originally intended to place roughly 75 percent of its 2-door, 4-passenger EV Plus vehicles with retail consumers through selected dealers. Honda started with four dealers and market areas and expanded later to four additional dealers and market areas. To date, about one-half of the 276 vehicles placed in California have gone to retail consumers. While Honda made a deliberate decision to market the EV Plus to a broad market, the EV Plus retail customer profile was typically that of an "Enviro Leader" or a " Techno Champ." The "Enviro Leader' was described as having a concern for society and ecology, at the vanguard of environmentalism, politically active, and pragmatic, seeking a "mainstream EV." The “Techno Champ” was described as the affluent innovator, with a technology focus, driven to make an "EV statement", believing the EV PLUS is the "best EV made”, and dedicated to the EV.

According to Honda, its MOA demonstration program was intended to introduce the product to the retail market, create public awareness and interest in the EV Plus, and get potential customers into the dealerships and encourage them to experience the EV Plus. Honda indicated that it made an extensive effort to market the EV Plus, and provided dealer support beyond that which is customary for Honda or the industry. To that end, Honda reported that it provided free support and training to the dealers, broadly marketed the EV Plus, encouraged and received extensive media evaluation of the product, supported numerous private and public events, placed prominent ads on a regular basis in many magazines and newspapers, and made direct mail solicitations. Marketing themes included "A car with a cord. Sounds like Honda" and "Zero gallons to the mile."

Honda reported that it helped each potential customer assess the possible utility of the EV Plus by considering is operating characteristic, including its "real world" range of 60 to 80 miles per charge. Honda has an ongoing study of EV customers for customer satisfaction. Additionally, Honda has conducted a study of EV "Intenders" (those who expressed interest but did not lease the vehicle). These studies are described below.

In 1999, Honda completed its MOA commitment and finished placing the last of its Honda EV Plus vehicles. Although Honda does not plan to continue production of the EV Plus at this time, it maintains the capability to resume production. Honda currently is focusing its efforts on EV Plus customer satisfaction issues, which will continue at least until the end of the vehicle leases. In addition, at the conclusion of their initial three-year leases the Honda vehicles are being re-leased, with the original customers being offered the opportunity to re-lease the vehicles at a reduced monthly rate of $299.

Nissan. Nissan's demonstration program is using an all-new Altra EV 4-passenger 4-door minivan with a payload of 820 pounds. The Nissan Altra EV is the first production electric vehicle that is equipped with lithium-ion batteries. Nissan outfitted the first 30 demonstration Altra EVs with data loggers that record

31 different types of information on vehicle performance. Nissan also conducted various customer surveys and interviews to provide basic data for evaluation of vehicle performance, and user perception and experience.

Anticipated individual buyers were identified as wealthy homeowners with a fleet of two or more vehicles. The distance between home, work and the nearest Nissan retailer would be typically 30 miles or less. These customers were also expected to be highly educated couples living in suburbs or fringe towns of major metropolitan centers. Technically savvy early adopters, and those committed to environmentally friendly products were also expected to be early Altra EV buyers. Target fleet customers were expected to be both those required to purchase alternative fuel vehicles under the Energy Policy Act (EPACT) and also those companies wanting to promote an environmentally conscious image.

Initially, 30 demonstration vehicles were split evenly between the retail and fleet markets by the Los Angeles office of Nissan's American research subsidiary, Nissan Research & Development. The individual drivers are Nissan employees using the company vehicle lease program; other Altra EVs have been placed with utilities located in Northern and Southern California. A market-oriented program to place 98 demonstration Altra EVs is to be conducted by Nissan's American sales and marketing headquarters, Nissan North America. To date, 81 vehicles have been placed statewide.

The Altra EV vehicles were made available to demonstration customers directly from Nissan through a comprehensive lease program. A direct lease approach was selected for this program rather than a typical dealership distribution so information would flow directly between customers and the test engineers. To date, the majority of Nissan's marketing activities focus on fleet managers, through participation in key conferences and EV events. Nissan has additionally supported various public awareness/educational events. The marketing theme was "a friendly, high-tech electric vehicle for every day life."

After the initial California placement in 1998, Nissan decided to change to a different lithium-ion battery supplier. Due to efforts in making this change, Nissan did not produce any MY 1999 Altras. The new battery pack was incorporated in MY 2000 and was introduced in California in December 1999. Nissan plans to fulfill its MOA commitment by the end of calendar year 2001.

Mazda. To date, Mazda has purchased credits to meet its MOA obligations and therefore has not offered any ZEVs under the Mazda nameplate.

Toyota. The Toyota demonstration program uses a single EV model, the RAV4 EV. This EV is based on an existing platform, Toyota's 4-door, 5-passenger RAV4 sport utility vehicle. The RAV4 EV has a payload capacity of 827 pounds. Toyota considered several surveys of retail customers and placed prototypes with electric utilities before deciding to focus initial marketing efforts on major electric power utilities and fleet customers. Toyota has placed 486 RAV4 EVs in California to date (of 683 placed nationwide), primarily in electric utilities and government fleets. Toyota initially provided RAV4 EV servicing through contracted utilities and a municipality, and later expanded to offer service at a few select dealers.

To reach the fleet market, Toyota has concentrated RAV4 EV advertising efforts on print ads in various fleet publications, supporting product brochures, Internet website marketing ads, and direct active participation in alternative fuel vehicle promotional events such as EV expositions, auto shows, and "ride and drives". Some marketing themes that Toyota has used include "all the comforts of a RAV4 but none of the gas, oil, exhaust…", "the technology may be new, but the reliability is Toyota through and through" and " you may not be able to tell you're driving an electric vehicle. But the environment can."

In April 1999, Toyota announced that it had placed enough vehicles to satisfy its MOA commitment. Toyota continues to produce a limited number of additional vehicles beyond the required MOA level, and will continue product development and the collection of in-use information about range, performance and market acceptability of the RAV4 EV.

7.2.2 Early Market Placement Results

This section describes the results of the initial EV marketing efforts by the major manufacturers.

In public comments, manufacturers pointed out that for many months, when all manufacturers had products available, vehicle inventory greatly exceeded the demand for vehicles. For example, when GM first introduced the EV1, “the majority of 1997 was characterized by steadily increasing inventory, throughout the first three-quarters of the year. There was a backlog of over a year’s supply on hand that needed to be marketed and sold. The following year, sales remained at a steady but low level. All told, the number of days' supply of EV1s averaged over 200 days 80 percent of the time during the first two years of EV1 production. This level exceeds the norm of 60 days supply by over three times. There were excessive levels of inventory available for over 2 years.”

Honda, the other manufacturer that offered vehicles to the general public, noted that both GM and Honda had experience of 2 years or more of retail EV promotion and availability with very little response from the general public despite significant marketing campaigns.

Several manufacturers observed that from their standpoint the sale of EVs has been very labor intensive and expensive relative to conventional vehicles. For example, sales staff need extensive training, additional time and effort is needed to educate customers regarding new technology, the ratio of sales to initial inquiries is low, and much time and effort are needed to deal with infrastructure installation issues. These manufacturers indicated that the time it took to place the MOA vehicles, the lease rate adjustments made for marketing purposes, and the incentive programs offered reflect a limited fleet niche EV market. They conclude that a general EV market does not exist that would be profitable for EV dealers even with considerable support from the manufacturers for marketing, promotional materials, and sales staff and automotive technician training. In general, manufacturers argued that there are fundamental challenges to placing EVs at the required levels, due to high cost, limited range, long recharge times, value/cost perceptions and the difficulties inherent in achieving widespread market penetration with a new technology.

Meanwhile, some parties have argued that the manufacturer marketing and sales efforts were intentionally half-hearted and ineffective. Staff does not subscribe to this viewpoint. Rather, staff concludes that the manufacturers made good-faith efforts to meet their MOA demonstration vehicle placement obligations. The manufacturer strategies and efforts have, after all, been successful in accomplishing their intended purpose. All MOA vehicles produced to date have been placed, and at present the number of interested customers exceeds the number of vehicles available. Through the MOA program manufacturers gathered valuable information regarding EV customer preferences and needs.

7.2.3 Measures of Customer Satisfaction

In assessing the results of EV marketing to date, it is important to review the experience of those drivers using the vehicles that have been placed. One clear message provided at both workshops is that those who drive electric vehicles are extremely happy with them. Numerous drivers took personal time off from work and journeyed to Sacramento and Diamond Bar just to emphasize their satisfaction with their vehicles and their desire that the availability of ZEVs be expanded. Drivers appreciate being able to drive without directly contributing to smog, fuel spillage, climate change, or other pollution problems. In addition to such societal benefits, drivers also mentioned many desirable attributes of the vehicles that are enjoyed in everyday commuting. Drivers spoke of the convenience of home charging, the smooth, quite acceleration, the low operating cost, and vehicle reliability.

In public comments, manufacturers noted that the EV drivers who testified at the workshop do not represent the population of California vehicle purchasers. This group has already self-selected to be EV owners with lifestyle and driving conditions that are acceptable to the category, and are willing to be the first to invest in new innovations. Staff agrees surveys of EV owners and drivers do not allow conclusions to be reached on market penetration of EVs, because the surveys do not include non-owners. That is, the sample is not representative of the vehicle purchasing population in California. Nevertheless such information provides important insights to manufacturers, regulators and future customers on the utility and viability of EVs in the "real world". Lessons learned with the EVs placed to satisfy MOA obligations can be used to better define the future EV marketplace by educating potential customers, identifying necessary technology improvements, and identifying desirable EV platforms.

Various organizations, including the manufacturers, have surveyed the selected individuals or agencies that have received MOA EVs. ARB staff received testimony at the May 2000 workshop regarding a recent major statewide survey of EV drivers. Staff also received testimony at the March 2000 workshop regarding several Internet-based surveys of EV drivers. The results of these past surveys and surveys planned in the near term are briefly described here.

<u>March 2000 EV Owners Survey By the Mobile Source Air Pollution Reduction Review Committee (MSRC) and Air Districts</u>

The Mobile Source Air Pollution Reduction Review Committee (MSRC) was created by the California Legislature in 1990 to oversee programs, funded by a $4 motor vehicle registration fee, to reduce air pollution from mobile sources pursuant to the California Clean Air Act and the local Air Quality Management Plan. In March/April 2000, the MSRC and five air districts conducted a survey of electric vehicle owners. The focus of this comprehensive survey effort was to understand how EVs are being used in both retail and fleet applications. Results of the survey will lay the foundation for a statewide EV Education Program, funded by the Department of Energy (DOE) through the California Energy Commission (CEC) and administered by the Clean Car Education Program (CCEP).

For the past several years, five air districts partially funded by the CEC to provide EV incentives have been required to survey incentive recipients and report the results to the CEC on a biannual basis. The recent survey project took that activity one step further by looking at the results statewide, rather than district by district, and by evaluating the results along with those of other past surveys conducted on this subject. As the CCEP gets off the ground, it will be important to have a clear idea of who the first EV drivers are and the vehicle attributes that they most appreciate. This information will assist the CCEP in developing messages for the public concerning electric transportation.

- A total of 294 surveys were received, which reported on 311 electric vehicles (an overall survey response rate of 49.5 percent, as compared to the response rate of 35 percent for a 1998 MSRC survey).
- Fifty-two percent of the vehicles were from the South Coast Air Basin (Orange County and non-desert portions of Los Angeles, Riverside, and San Bernardino counties); 31 percent were from the Bay Area, while the remaining vehicles were from Sacramento, San Diego, Santa Barbara, Ventura, and San Luis Obispo counties.
- Fifty-eight percent of vehicles reported were EV1s.

Surveys were distributed to fleet operators and retail consumers. Owners were requested to complete the survey on existing and previously owned electric vehicles. Therefore, owners whose vehicles have been recalled, or owners whose leases have expired, are also included in the responses. Sixty eight percent of the vehicles were 1998 or 1999 model year, twenty-two percent were 1996 or 1997 model year, and ten percent were 2000 model year or not specified. The annual average miles driven was 7,700.

Specific findings reported by the MSRC include the following:

Vehicle Usage.

- Fourteen percent of respondents reported they drove their EV over 50 miles per day.
- Ninety-one percent state that they use a freeway weekly if not daily; of the total, forty-two percent reported driving on the freeway on a daily basis. Only eight percent indicated that they never access freeways while driving their electric vehicle.
- Seventy percent indicated that they use their EV as their primary vehicle, and of those, ninety-three percent have another vehicle available to them, but they prefer to drive the EV as their primary vehicle.
- Owners use their electric vehicles in variety of ways:
  68 percent for work or school commuting purposes,
  64 percent for shopping and/or errands during the week,
  55 percent for work-related purposes during the week, and
  41 percent for weekend or recreational purposes.
- Fifty-one percent of respondents (56 percent in the SCAB) indicated that they use public charging stations at least once a week. Forty-nine percent (67 percent in the SCAB) reported they drive their EV much more or somewhat more because public charging is available. Sixty-four percent (69 percent in the SCAB) reported that they did not have workplace charging but would use it if they did.
- Table 7-3 shows that a large percentage of drivers use their EVs more than they thought they would prior to acquisition. Currently, seventy-four percent indicated that they drive their EV more than 75 percent of the time.

Table 7- 3: Percentage of Driving in EV		
Proportion of Driving	Expected, Prior to Ownership	Actual, After Ownership
Less than 25%	10%	7%
26% to 50%	20%	6%
51% to 75%	15%	7%
76% to 100%	46%	74%
No Response	9%	6%

Owners' EV Experience.

- Eighty-percent of those surveyed were more satisfied with their EV than with their current gasoline car.
- Drivers indicated that overall they were extremely satisfied with their electric vehicles.
- Features contributing to drivers' satisfaction include appearance and acceleration.
- Drivers are only partially satisfied with vehicle driving range and heating system. (The MSRC survey description combines both range and heating system. Looking at the survey results for driving range, staff found that 74 percent of the drivers indicated that they were satisfied, very satisfied, or extremely satisfied with the range of the vehicle.)
- Limited vehicle range, lack of public awareness and marketing are considered to be the most important reasons why the number of EV leases have not been greater.
- Forty percent (55 percent in the SCAB) indicated that one time in four, drivers find a gasoline-powered vehicle parked in a public charging stall.
- Sixty-three percent of respondents reported that incentives were a very important or somewhat important factor in influencing their decision to lease an EV.
- Seventy-seven percent would lease another EV***.***

EV Owner Demographics. EV owner demographics are very similar to those indicated in the 1998 MSRC survey, as well as other surveys conducted to monitor the use of electric vehicles throughout the state.

- 72 percent of the primary drivers were male and 18 percent were female. Nine percent of the respondents reported that both male and female members of their household were the primary driver, and one percent did not respond. The percentage of women drivers has increased since previous surveys.
- Forty-seven percent of EV drivers are 35-50 years old.
- The majority of respondents indicated they were employed as business (31 percent) or technical (23 percent) professionals. Ten percent were retired.
- Fifty-eight percent of respondents reported an annual income of less than $150,000.

August 1998 Electric Vehicle Owner Survey by the MSRC

In mid-1998, the MSRC distributed a survey to 284 EV Owners/Lessors who took advantage of the MSRC's buy-down incentive. 106 surveys were returned (36 percent response rate). The majority of the respondents were most likely retail customers, given that 77 percent of the surveys received were from drivers of the EV1. The average length of ownership was slightly more than 13 months, and the average annual mileage was about 8,100.

The survey focused on characterizing the EV driver and EV use. 82 percent of the EV drivers were male. The EV was typically the primary car in a household with more than one vehicle. When asked why they leased their EV, the top three responses were (1) concern for the environment or a desire to do their part to help clean the air, (2) a desire to be one of the first to adopt an up and coming technology, and (3) a good fit between the EV's range and their commute patterns and habits. Based on the survey, the EVs appeared to meet a wide variety of transportation needs:

- Commute to and from work or school (71 percent)
- Work/business purpose during the work day (63 percent)
- Shopping, errands during the week (88 percent)
- Family trips/outings, errands on the weekend (75 percent)

EV1 Drivers Club Survey

Testimony was received at the March 2000 workshop regarding an online survey conducted via the EV1 Club Internet list. It was reported that about 130 persons took the survey with over 80 percent driving EV1s and the remainder driving the Honda EV Plus and Ford Rangers. Vehicle usage and owner experience were similar to that described above for the MSRC surveys. This survey additionally queried the drivers for their opinion on the importance of various factors affecting public acceptance of EVs. The majority of drivers reported that:

- Public awareness, the cost of the EVs, range, and availability of EVs are extremely important or most important factors.
- The variety of EVs and lease-only placements were not important or somewhat important.
- The minimum guaranteed daily range to make an EV practical would be between 60 and 100 miles.
- Advertising and marketing of EVs by automakers has not been effective.
- The public has not been effectively educated regarding EVs.
- EVs have not been effectively made available to the public.

EV Driver Testimonies on the Internet

At the March 2000 workshop, staff received a package of more than 80 EV driver testimonials that had been collected from several Internet sites. These were primarily testimonials on the driver experience with leased or rented EV1s and the EV Pluses, but did include some for the Ford Ranger, conversions and even the Toyota Prius hybrid electric vehicle. The drivers were consistently pleased with vehicle performance, ease of driving and recharging, lower fuel and maintenance costs, and the minimal maintenance requirements. The drivers found vehicle range more than adequate for their typical daily needs, Many drivers hoped to retain the EVs after the current leases expire and expressed strong support for the ARB's ZEV requirements.

Air Resources Board Internal User Survey

The ARB Test Fleet, described further in Chapter 6.4.1, makes vehicles available to ARB employees for a period of two days up to a week. From July 1997 to August 1999, 245 employees made more than 2,800 trips with the test fleet. Two popular test fleet vehicles, a Honda EV Plus and a GM EV1, have been driven more than 25,000 miles and 20,000 miles, respectively. The employees were asked to complete a survey regarding their experience with each EV model. Analysis of 141 surveys returned by 99 employees indicates that the respondents typically had a positive to most positive overall experience driving the EVs. About 60 percent of the respondents indicated that they would consider leasing an EV for personal use. Some respondents identified several factors that they considered as impediments to leasing, including limited range, cost, and the inconvenience of charging. However, it should be noted that the test fleet user does not typically have access to a charger at home and must share access to chargers at work.

To date, one staff person at ARB has successfully leased an OEM EV, a Ford Ranger; several staff own electric conversions. In recent months, the ZEV Implementation Section at ARB has had a noticeable increase in the number of inquires from ARB and other governmental agency staff regarding the availability of EVs to retail customers. This increased level of interest seems to coincide with publicity regarding new HOV access for EVs beginning July 1, 2000, and increased awareness of free EV parking at many public garages serving business and governmental centers. Awareness and interest in leasing EVs continue to build within the ARB and other state agencies.

Office of Fleet Administration Daily Rental Electric Vehicle Survey

The Department of General Services, Office of Fleet Administration operates several State garages that provide daily and long-term vehicle rentals to state agencies. Since July 1997, the State garage in Sacramento has offered free daily rental of the Honda EV Plus and the GM EV1. As of October 1999, more than 525 round trips, averaging 20 miles, have been made with a fleet of five EVs. The EV users were given the opportunity to complete a short survey on their EV driving experience. ARB staff analyzed 70 surveys turned in over a several month period in mid-1999. All of the respondents indicated that they were satisfied with the overall performance of the EV and that the driving range of the EV met their needs (for the rental). Almost 70 percent indicated that they would consider leasing or buying an EV. The most frequent comment received was that the EV was easy to drive and performed well. 10 of the 84 respondents also mentioned that the range was too limited for full-time use.

Southern California Edison Fleet Experience and Municipal Fleet Survey

SCE Fleet Experience. SCE staff testified at both workshops regarding the SCE's successful 12-year demonstration of a wide variety of EV models and prototypes. Overall EV penetration of the SCE's entire light duty fleet is more than 11 percent with some business units over 60 percent. By early 2000, more than 4.5 million miles had been placed on more than 420 EVs. SEC took a "mission match" approach to marketing and placing the EVs within their fleet. In a SCE questionnaire, 50 percent to 100 percent of the drivers responded that their EV was suited for their application and reliable, available 97 percent of the time. According to maintenance records, the highest incident repairs are related to tire replacements (49 percent), auxiliary systems (11 percent), batteries (10 percent), and charger (9 percent). SCE also found that operating an EV is less costly than operating a gasoline vehicle due to lower fueling costs and maintenance requirements.

According to SCE staff, the process of expanding its EV fleet has had its challenges. SCE staff identify several areas of improvement necessary to allow EVs to reach their full potential, including the need for efficient and reliable EV ordering and delivery, standardized EV charging equipment, and availability of vehicle parts. Having found that EVs work successfully in their fleet applications, SCE staff plans to place an additional 200 EVs each year in the fleet, but are concerned with declining product availability.

SCE Municipal Fleet Survey. In 1999, Southern California Edison surveyed a total of 63 municipal agencies, colleges and transit agencies regarding their experience with their EV fleets. These fleets had a total of 178 EVs including the Chevrolet S10, Ford Ranger, GM EV1, Honda EV Plus, and Toyota RAV4. These agencies also had 67 vehicles in the acquisition process. These vehicles are typically used for administrative, enforcement and inspection purposes or as pool/loaner vehicles. On a per vehicle basis, 84 percent of those surveyed were satisfied with the operation of the EV. Areas of dissatisfaction included reliability, range and seat/payload capacity. While 96 percent of the agencies were interested in expanding their EV fleets, the respondents cited cost (33 percent) and performance/range (53 percent) as barriers to greater EV use.

<u>EV Rental Cars Electric Vehicle Customer Satisfaction Survey</u>

EV Rental Cars, in conjunction with Budget Rent-a-Car, provides rentals of electric and alternative fuel vehicles at several locations in California including the Los Angeles, Sacramento, and Ontario airports. EV Rental conducted phase one of an Electric Vehicle Customer Satisfaction Survey in May 2000. The sample in phase one consisted of 29 electric vehicle renters. The number of males surveyed outnumbered the women surveyed by 6 to 1, and most of the rentals were for business purposes.

The overall experience of the electric vehicle renters was very positive. Of those surveyed, 93 percent were satisfied with the overall performance of the electric vehicle. Almost 80 percent said the vehicle's driving range met their needs and 76 percent said they would consider leasing or buying an electric vehicle. The customers indicated that they chose to rent the EV because driving it is better for the environment (41 percent), they were interested in the new technology of the EV, and the cost of the rental was less than expected (12 percent). EV Rental indicated that phase two of the survey will be available in mid-August 2000.

<u>May 2000 Electric Vehicle Fleet Managers Workshop Survey</u>

On May 23, 2000, Southern California Edison conducted an EV Fleet Managers Workshop, inviting more than one hundred representatives of municipal fleets, transit agencies, universities, and private businesses in the South Coast Air Basin. In response to an initial survey attached to registration materials, the fleet managers identified nine issue areas for discussion at the workshop including vehicle reliability, maintenance support, manufacturer support, operator and maintenance training, delivery delays, vehicle range, infrastructure, costs, and vehicle appropriateness. An expanded survey and evaluation form was developed and used at the workshop for roundtable discussions, moderator-led discussion, and written responses. The response rate was about 50 percent including follow-up telephone communications. Tabulated results and a summary of remarks are described in a report prepared by The Planning Center, "<u>EV Fleet Issues: Perspectives of Fleet Managers</u>". The report concludes that non-availability is the largest concern of EV fleet managers, and that this issue is critical to continuing EV market growth and overshadows the other concerns of reliability, maintenance support and limited range. The report further concludes that the future of the EV market is still very dependent upon government mandates and incentive programs, and that continued financial support for the incremental cost of vehicles and expansion of the EV infrastructure is needed.

7.2.4 Marketing Issues

This section touches on various issues that have arisen in the course of the initial EV market demonstration programs.

Vehicle Availability. Many speakers at the workshops testified that although they are interested in leasing an EV, they have been unable to do so because vehicles are not currently available. For example, drivers who lost the use of an EV1 due to the General Motors recall, and who wish to replace the EV1 with another electric vehicle, have in most cases been unable to do so. A fleet manager for a major utility testified that he anticipated having difficulty meeting his desired lease level of about 200 EVs annually, and another fleet manager reported similar problems. Staff has received public comment documenting that fleet managers for at least 14 other private and public fleets would like to lease a total of more than 40 vehicles, but cannot due to lack of availability. The affected fleets include at a minimum the following:

- City of West Covina
- City of Burbank
- City of San Francisco
- City of Santa Rosa
- City of Newport Beach
- City of Huntington Beach
- City of Pasadena
- Xpress Shuttle
- VTA
- Novell
- Anaheim
- Anaheim Transportation Network
- Los Angeles Department of Water and Power
- City of West Hollywood

ARB staff has experienced this problem first-hand, in that ARB has been unable to obtain the desired number of vehicles for the EV Sacramento and EV Loan programs, which place EVs with government agencies. This lack of availability of electric vehicles is due to the decision by most manufacturers to curtail production after placing the vehicles required for their MOA demonstration programs. Toyota and Ford are still taking orders to be filled next year, with one experiencing production delay because of a component supply problem.

The MOAs were originally intended to provide a ramp-up to 2003. In retrospect, it appears that the combination of the MOAs and the existing level of multiple credits offered for early introduction have not been sufficient to encourage significant vehicle production in 2000 though 2003.

Lease Process Difficulties. Staff has received testimony and written submittals from individuals indicating that in their view they had to overcome unusual barriers in order to lease an EV. Examples included sales staff who are unfamiliar with the vehicles, long delays in getting information, ambiguous or contradictory information regarding “waiting lists” to obtain vehicles, and long delays in getting vehicles once orders had been placed. Some EV drivers also stated they have more recently stopped encouraging potential customers to visit EV dealers, because test drive opportunities are difficult to arrange and the dealers are uncertain regarding when EVs would be available.

Regarding delays, Ford testified that some of its delays in vehicle availability were due to quality control issues and supplier problems, which occur on conventional vehicles as well. Manufacturers also stated that the only additional barriers or delays specific to acquiring an EV are attributable to issues regarding the proper installation of home recharging sites. Charger installation involves an initial inspection of the site, contractor installation, and local agency inspection to ensure all aspects are safe and meet local code requirements.

7.2.5 Applicability to 2003

All major manufacturers have placed vehicles in response to the MOAs between the automakers and the ARB. Under the MOAs, the automakers committed to participate in an advanced technology battery demonstration project. Each automaker agreed to produce their pro-rata share of approximately 1,800 advanced battery vehicles between 1998 and 2000. In addition to the MOA vehicles, several manufacturers have also offered vehicles on a voluntary basis, separate from the MOA requirement. Such vehicles include the lead acid versions of the Chevrolet S-10, Gm EV1, Ford Ranger, and Chrysler EPIC, as well as the NiMH Toyota RAV4 EV.

Although manufacturers have devoted great effort to these placements, as described elsewhere in this section, ARB staff believes that the marketing of electric vehicles to date has differed from a normal market in several significant respects:

- Only two manufacturers, GM and Honda, offered their vehicles to retail customers with broad-based marketing efforts. The remaining manufacturers marketed only to fleets, using a marketing approach appropriate for fleet sales.
- Although a variety of vehicle platforms was produced, none of the manufacturers chose to develop a five passenger four door sedan.
- Manufacturers used a variety of approaches to sell, distribute and service the vehicles, but no manufacturer marketed its vehicles at all dealerships.
- Due to the new technology employed, EVs imposed unusual information and training demands on all involved parties--customers, dealership staff, infrastructure providers, and marketing staff.
- Manufacturer pricing strategies were intended to gather information about customer demand, but were not set in a competitive fashion based on prices of otherwise equivalent conventional vehicles.
- Most vehicles were available for lease only rather than for purchase, and some leases included low mileage caps of 10,000 miles per year..

Staff recognizes that there were valid reasons for all of these choices. For example, range, cost and packaging trade-offs entered into the choice of vehicle platforms, and low volume vehicles are often made available through only a limited number of dealerships in recognition of the training and expertise necessary to support unique vehicles. Staff is not criticizing the approaches that were taken, but rather pointing out that in some respects they were not typical of mainstream vehicle marketing.

Manufacturers have stated that it was difficult to place the relatively small number of MOA vehicles. The manufacturers then go on to conclude that based on their MOA experience it will be almost impossible to meet the 2003 requirement. They argue that fundamental EV marketing difficulties associated with battery technology, cost, vehicle range and customer preferences will not change in any significant respect between now and 2003.

Staff believes, however, that the results of the MOA marketing efforts, with vehicles priced well above similar conventional vehicles, do not necessarily indicate that a broad based approach from all manufacturers, with competitive pricing, could not succeed. When Ford reduced its price on the EV Ranger, for example, the available vehicles were quickly placed.

In summary, the MOA marketing efforts provide an opportunity to begin to understand the factors involved in advertising, selling and supporting electric vehicles. Lessons have been learned which will be of value in future efforts. The MOA experience does not, however, lead to definitive conclusions about the prospects for 2003.

7.3 The 2003 Market

This section reviews available information that will assist in assessing the potential market for EVs in 2003 and beyond. It addresses customer awareness, studies of market demand, and possible applications well suited to the use of EVs.

7.3.1 Customer Awareness

Testimony at the March and May workshops addressed the general point that it has been difficult for the public to get information regarding available electric vehicles and their characteristics. Drivers testified that their neighbors, friends and interested persons on the street do not know that production EVs are available to "regular people." These EV drivers expressed concern with the adequacy of manufacturer marketing efforts and government agency educational programs. In their public comments, automakers pointed out the aggressive measures that they have taken to provide information regarding their electric vehicles, including websites, television and newspaper advertisements, and toll-free telephone lines.

The level of public awareness was addressed in a more systematic way in recent research on EV Market awareness conducted by the Pacific Gas and Electric Company (PG&E). To determine the extent of target-market awareness of available light-duty, highway-legal EV products, PG&E surveyed a random sample of its residential customers. For seven consecutive weeks beginning on March 28, 2000, surveys were mailed each week to 450 residential customers. Of the 3,150 surveys mailed, 737 were completed by June 9, 2000 (23 percent response rate). PG&E assumed that the EV manufacturers are targeting California residents who are 25–54 years old with at least some college education. EV marketing effectiveness was evaluated for this subset of respondents. Data on income were not collected.

The survey consisted primarily of questions about customer satisfaction with Pacific Gas and Electric Company's service, but included two EV and three demographic questions. Introductory text immediately prior to the EV questions provided background. Awareness of available EV products was measured with multiple-choice questions: "Which, if any, companies do you think are selling or leasing EVs today in California? (Please check all that apply)" and "Which, if any, types of electric vehicles do you think are being sold or leased today in California? (Please check all that apply)." Survey respondents were deemed to be aware of EV products if they checked a correct combination of EV company and type.

EVs have primarily been promoted in marketing campaigns by EV manufacturers. Incentive programs by government agencies and education efforts by EV industry organizations, environmental advocacy groups, and electric utilities complement the automaker marketing campaigns. Despite these EV marketing activities, in Northern and Central California awareness of available light-duty, highway-legal EVs is low. Only 7 percent of the target group (25–54 year old, college-educated) in Northern and Central California are aware of at least one of several EV products. In the San Francisco Bay Area only 9 percent of this group in are aware of at least one EV product.

The researchers concluded that before EV range, operation and maintenance, and user satisfaction become important considerations to the consumer, the market must become aware of the product's existence. With so few people aware of available products, it is premature to make conclusions about the sufficiency of EV market demand.

7.3.2 EV Market Studies

Testimony was received at the May 2000 workshop regarding several market studies that have been sponsored by automakers or other interested parties.

Brief descriptions of the market studies are provided below. It should be noted that the studies are in progress or preliminary and have not been reviewed by ARB staff.

National Economic Research Associates

Toyota and General Motors recently sponsored a study of customer choices among internal combustion engine vehicles (ICEVs) and electric vehicles. The study was conducted by a researcher at the University of California, Berkeley and National Economic Research Associates, Inc. (NERA). The study's objectives were to determine how customers value electric vehicles relative to internal combustion engine vehicles and the impact of additional information on customers' valuations. According to workshop testimony, this study was conducted over the telephone with materials mailed in advance; respondents were not given the opportunity to test drive an EV. A sample of over a thousand recent new car buyers (cars purchased within the last three years) were given choice situations that varied vehicle attributes including vehicle type, engine type, purchase price, operating cost, performance and range. The respondents were split into basic and enhanced information level groups; the enhanced group was provided an air quality write-up and an article on EVs and ICEVs. The researcher used a mixed logit method to evaluate the response as varying vehicle attributes.

The study found a low demand for EVs because customers place a large negative valuation on EVs for reasons other than their price, performance, and operating costs. The study estimated that customers would require a $28,000 price differential in order for 50 percent of customers to choose the electric RAV4. Describing the impact of the negative valuation, the researcher indicated that since the average retail transaction price of an internal combustion engine Toyota RAV4 is about $21,000, this would mean that the average consumer would not accept a RAV4 EV if it were offered for free. According to the study, this is due to shortcomings that are characteristic of EVs, such as limited range. The researcher also indicated the negative valuation is still significantly strong even when consumers are informed about the potential positive effect of EVs on California air quality.

In staff's view, the reported finding that a typical customer would not accept a free RAV4 EV is counterintuitive to say the least. With a waiting list for ZEVs at lease rates of $450 per month or more, clearly many customers would be happy to get a free RAV4 EV. We also have numerous questions regarding the study methodology. Toyota and GM plan to provide staff with a copy of the report and a briefing by the researchers but this information has not been received in time to be included in this Staff Report.

Green Car Institute Market Research

The Green Car Institute is an independent, nonprofit agency created to further the acceptance and adoption of low emission and clean fuel vehicles by American motorists. Green Car Institute is engaging in a study to investigate the current and future market for electric vehicles, taking into account the state's experience up to now and likely experience in light of the mandate for 2003. In preliminary market research, Green Car Institute found that a variety of barriers have combined with the nature of the MOA demonstration projects to limit penetration of electric vehicles during the past several years:

- Fleet buyers are confronted with a different purchase process for EVs.
- Fleet availability and suitability of EVs is not marketed consistently.
- Private buyers are also confused and misled by EV marketing.
- Private buyers also encounter a more difficult buying process.
- Manufacturers' strategies may have been shaped more by the desire for quick fulfillment of MOA requirements than by long-term establishment of an EV market.

The Green Car Institute study will use standard automotive market research techniques to estimate the magnitude of the current and potential future markets for EVs. The variables will include current and future EVs with a variety of ranges, lease/sale prices and other attributes. Green Car Institute expects to be able to extrapolate the potential EV market and compare that with placement numbers required by the ZEV regulation. The study is expected to be completed prior to the September Board meeting.

7.3.3 Potential Market Applications

To attempt to provide useful information regarding the possible market in 2003, staff has investigated several applications that lend themselves well to being served by electric vehicles.

For this exercise we assume that the vehicle price would be roughly equivalent to similar conventional vehicles on a lifecycle cost basis. Manufacturers have argued that the price of EVs will need to be less than that of similar conventional vehicles, due to the limitations on EV driving range and recharge time. Ford commented that based on customer response to several different prices set for the Ranger EV, in order to meet a 4 percent mandate volume, Ford would have to set the price of the Ranger EV well below $200 per month. The $200 per month lease price corresponds to a manufacturers' suggested retail price (MSRP) of less than $10,000, as compared to the $14,000 MSRP of the conventional Ranger.

We recognize that at least in the initial years such pricing would not recover the cost of the vehicle. Consideration clearly must be given to how any additional costs would be borne. For our purposes here, however, we are investigating whether applications exist that could make use of the required number of vehicles, without regard to cost.

Fleet Vehicles.

Fleet sales include commercial, rental and governmental fleets. EVs are well suited to meet a variety of fleet applications. Fleet vehicles typically have well defined and consistent driving patterns and range requirements, and are centrally refueled.

Data from Automotive Fleet Magazine indicate that on a national basis, fleet sales make up about 20 percent of passenger car sales and 12 percent of truck sales. Fleet sales are 16 percent of the combined (cars plus trucks) total. Given California annual light duty vehicle sales of roughly 1,000,000 per year, a 16 percent sales fraction corresponds to a fleet market of about 160,000 vehicles per year. (Please note that this is a revised estimate as compared to the Preliminary Draft Staff Report, based on new information). Thus a 10 percent penetration of the fleet market, or 16,000 vehicles per year, would in and of itself almost be sufficient to meet our estimated "base case" four percent ZEV placement requirement.

Staff has attempted to gather more specific information as to the number of fleet vehicles purchased per year in California by various fleet operators. Information on such purchases is scattered, and to date staff has been unable to obtain precise estimates. The following represents the best available information available at this point.

Automotive Fleet Magazine data, again at the national level, indicate that governmental fleets make up 7 percent of passenger fleet sales, 12 percent of truck fleet sales, or 9 percent of total fleet sales. Using the 160,000 vehicle annual California fleet sales estimate noted above, 9 percent of that total is 14,400 vehicles per year.

Excluding special purpose vehicles such as those used by the California Highway Patrol, the State of California purchases roughly 1,500 passenger cars and light duty trucks per year. Based on 1991 survey results reported by the California Energy Commission, staff estimates that local governments (cities and counties) purchase roughly 14,000 light duty vehicles per year. This total does not include special purpose vehicles such as police cars. Taken together these state and local government fleet sales total more than 15,000 vehicles per year. This estimate is in general agreement with the 14,400 figure for governmental fleet sales derived above. If electric vehicles could serve one fourth of these governmental applications, it would result in a market of about 3,750 vehicles per year just for state and local public fleets.

Utility companies represent another ideal market. A representative of Southern California Edison testified at the March 2000 workshop that EVs already constitute more than 11 percent of their total light duty vehicle fleet, and more than 60 percent of some business units. SCE plans plan to add 200 vehicles per year. Staff estimates that by 2003 utility companies statewide could readily absorb 1,000 vehicles per year.

The federal government vehicle fleet and other large institutional fleets such as the US Postal Service also could readily use EVs. Staff does not have quantitative information at this point, but notes that it is reasonable to assume that other fleets could make use of EVs in a manner similar to utilities and governmental fleets.

Commuter Vehicles/Second Cars.

To attempt to quantify the number of households that could reasonably be expected to use an EV for commuting purposes, staff has adapted a methodology used by auto manufacturers. The elements of the calculation are as follows:

Number of owner-occupied households in California with two cars and garage	3,800,000
Percentage of above with annual household income greater than $75,000	x 17%
Result	646,000
Percentage of above with round trip commute of 40 miles or less	x 68%
Result	439,280
Percentage of above that purchase a vehicle in a given year	x 20%
Result	87,856

These assumptions are deliberately somewhat conservative. For example, households with annual income below $75,000 certainly purchase cars, and some fraction of them could be attracted to an EV. Even so, this calculation results in a target population of almost 88,000 households. If 5 percent of these households chose to lease an electric vehicle for commuting or second car purposes, it would result in a market of about 4,400 vehicles per year.

City Electric Vehicles.

Ford Motor Company, through its Th!nk subsidiary, plans to market the Th!nk City vehicle beginning in 2001. The market for City Electric Vehicles is promising but largely unexplored.

Low Speed Vehicles.

As discussed in Section 4 above, low speed vehicles are not passenger cars under federal law and do not need to meet the same Federal Motor Vehicle Safety Standards. These vehicles do, however, qualify for ZEV credit. The market for low speed vehicles in California also is unexplored at this point. Proponents have noted that there are large numbers of retirement communities, universities, business campuses, gated communities and other developments that provide a potential niche for this type of vehicle.

Summary

As the technology has advanced and vehicle makers have adapted to current circumstances, it appears that a wide range of vehicle types will be available in 2003. Staff has described various applications that lend themselves to being served by EVs. Staff acknowledges that the assumptions underlying these estimates may be deemed overly conservative or overly optimistic depending on one's point of view.

Manufacturers have commented that "potential applications" are not the same as "market demand". Manufacturers also stated in public comments that the staff estimate of potential market is not well supported by data. Staff recognizes that placement of the required number of vehicles in the possible applications noted above will be difficult, because customers have many attractive choices available that do not have the range, recharge time, and cost limitations associated with today's battery electric vehicles. Staff does not agree, however, that market demand is non-existent for competitively priced ZEVs.

7.4 Elements Needed for a Successful EV Market

This section outlines several elements that will be essential in order for the EV market to progress. Before listing these marketing needs, however, it is necessary to understand some of the unique attributes of the EV market that need to be taken into account.

7.4.1 Attributes of the EV Market

Real vs. Perceived Range Needs.

Many drivers remarked that when they first considered an EV, they had an estimate in mind regarding the portion of their driving that could be accommodated within the available range. After living with the vehicle, however, they learned that their actual driving patterns were less demanding than they had imagined, and therefore they were able to use the EV far more than they had anticipated. Drivers noted that this "mismatch" between perceived and actual range needs is an artificial barrier to more widespread demand for EVs. Public information would help in getting customers beyond this perceived barrier.

SCE has developed an innovative electronic mapping tool known as the Trip Planner to help address range concerns within its own fleet applications. The software allows local fleet users to map their daily routes and confirm that they are within the range of an EV. The trip planner has been very effective in breaking down internal employee reservations about EV use. Districts that were reluctant to use EVs used the trip planner to analyze their trips and routes, and are now successfully using EVs.

Consumer Decisionmaking Regarding Lifecycle Cost.

EVs will have a higher up-front cost, offset by savings over time in fuel cost and maintenance. Consumers generally have shown, however, that they value up front savings more than savings achieved over time, even if from an economic standpoint the alternatives are of equal cost. For example, consumers do not always favor energy-saving improvements that clearly will pay for themselves over time. This behavior, although "irrational" in an economic sense, is real and must be addressed in order to achieve the full EV market potential.

Driving the Vehicle Increases Its Appeal.

Many members of the general public have preconceived notions regarding EVs--they are considered "golf carts" with limited driving appeal. At the March workshop drivers testified that once they had an opportunity to drive an EV, they were "sold". The customer satisfaction attributes noted above (smoothness, quiet, performance, fun to drive) can only be experienced in person. Staff has noted a similar phenomenon in the operation of the EV loan program. Once fleet users have had an opportunity to drive the vehicle their acceptance of its possible application to their fleet is enhanced.

Public Perception of Hybrid Electric Vehicles.

Many members of the public also have inaccurate perceptions of the relative environmental attributes of EVs and hybrid electric vehicles. Staff has noted that in most cases the public assumes that hybrid electric vehicles are as clean as EVs. They thus conclude that hybrids have more appeal because they are just as clean but offer unlimited range and do not need to be recharged. In fact, although the efficiency of hybrid electric vehicles offers CO_2 advantages when compared to a standard vehicle, today's hybrids can emit more smog forming pollutants than the most advanced conventional vehicles, let alone EVs. For example, the Honda Insight is certified to the ULEV level, while Honda sells an Accord that is certified to the SULEV level. The Toyota Prius is certified as a SULEV.

Many factors go into the choice of a vehicle, and staff does not mean to imply that purchasers of HEVs would instead all opt for EVs if they fully understood the relative environmental attributes of the various vehicles. A better public understanding of these points would, however, increase the relative appeal of EVs to those customers for whom "green car" attributes are important.

<u>Risk of New Technology</u>.

EVs feature cutting-edge technology. For some customers, this is a positive benefit. The manufacturer marketing strategies noted above recognized that "early adopters" and "techno champs" would be favorably disposed towards EVs for that reason. For other customers, however, the introduction of new technology is cause for hesitation. Such customers, who ultimately may be well suited to using EVs, will need additional information and consultation. Manufacturers have tried to address this issue through lease packages that offer unlimited free maintenance and remove all risk from the consumer.

Additionally, successive market years of experience will increase the acceptance of EVs as they pass their first years as a new technology. Those who avoid driving cars in the first model year of a new design will more readily consider EVs as their history on the market grows. This may help explain the apparent growth in interest in EVs in the past year as the MOA vehicles began to accumulate their third and fourth years of experience.

7.4.2 Marketing Needs

Much public comment has noted that the primary factors affecting the marketability of EVs are range, recharge time, infrastructure, and price. Staff agrees with this assessment, and in particular staff believes that in order for the market to succeed it will be necessary for EVs to be available to customers at prices that are competitive on a lifecycle cost basis to similar conventional vehicles. Staff notes that manufacturer testimony indicates that in their view this is overly optimistic; rather they believe that EVs will need to be offered at prices significantly below those of gasoline vehicles in order to achieve the volume required by the mandate. Assuming that at least in the short term EV costs will exceed costs for conventional vehicles, it will be necessary to consider some combination of government incentives and manufacturer subsidies to close the gap.

In addition to range, recharge time, infrastructure and price, the overall context in which customers are making their purchase decisions is also important. In that light, staff has identified several factors that are critical to the ongoing success of the EV market.

Continuity.

Perhaps the single greatest need is for a smooth, orderly buildup from the current base of activity towards 2003. For the ZEV regulation to achieve its goals there must be a well defined path towards greater and greater fleet penetration. A great deal of effort has been expended to bring us to where we are today from the standpoint of infrastructure development, dealership training, public outreach, and other factors. At the moment, however, there is a large gap between the completion of the MOA placements and the beginning of the 2003 requirement, and few if any vehicles are available to customers.

During the 1996 Biennial Review, the transition between the MOA program, which ends in the year 2000, and the ZEV regulation, which begins in 2003, was the subject of much discussion. Some parties argued for specific percentage phase-in requirements for 2000 through 2002. The manufacturers resisted any pre-defined ramp-up requirements, arguing that flexibility was needed to accommodate differing manufacturer technical approaches and development timing. In the end, a flexible approach was adopted. Manufacturers have produced the required MOA vehicles, and there was a period of several years during which those vehicles were readily available. As the MOA obligations have been satisfied, however, product availability has declined. Today, despite waiting lists for vehicles, the flexibility provided in the ZEV regulation has resulted in only limited product being available.

In most cases, there is no evidence that manufacturers plan to produce additional vehicles, particularly for lease to the general public, between now and 2003. On the bright side, Ford is gearing up to market the Think City EV in 2001, and has already begun to run television advertisements. Ford also has indicated that it will continue to produce lead acid Ranger EVs. Toyota has stated that it will continue to produce the RAV4 EV, and is taking fleet orders for next year's production (the current year production is sold out). For the remaining manufacturers, however, staff is not aware at this point of any firm commitment to produce additional vehicles prior to 2003.

Staff is concerned that a "boom and bust" cycle could wipe out the progress that has been made, and create an irreversible impression in the public's mind that EV technology is a thing of the past rather than a preview of the future.

Mainstream Vehicle Platforms.

As noted above, staff recognizes that the choice of vehicle platform was the subject of a great deal of analysis and research by the manufacturers. It is noteworthy, however, that at present there is no four door, five passenger sedan available. In order to achieve ongoing annual market penetration at the required level, staff believes that it will be necessary to have additional vehicle platforms available. In their public comments, manufacturers argued that the addition of a five passenger, four door sedan would not significantly increase ZEV volumes, but rather would take volume away from other offerings. They also note that adding new vehicle platforms will increase costs, due to large fixed costs for design, development, validation, manufacturing, and marketing.

Public Education.

We have noted that EV customers likely will need information above and beyond what is typically required for a vehicle purchase. Topics to be addressed include typical real world range needs and driving patterns, the benefits of a lifecycle cost approach, and the environmental superiority of pure electric vehicles. Customers also are likely to require more extended test drives than are typically offered. Staff notes that the Toyota Prius marketing plan calls for “demonstrator” vehicles to be available to interested customers for an overnight loan. Manufacturers have emphasized demonstration vehicles in their fleet marketing approach for EVs. A similar approach to retail EV sales will likely be necessary.

A public education campaign would require significant investment.

Market to Retail Customers.

As noted above, several auto manufacturers restricted their sales and marketing efforts to fleet customers only. During the MOA period, this approach had certain advantages, and allowed those manufacturers to limit their training, service and support needs, provide more targeted customer service, and focus on a better defined and more predictable set of driving patterns. In order to achieve the required 2003 placement levels and have a sustainable market over the long term, staff believes that it will be necessary for all manufacturers to market to retail as well as fleet customers.

Broader marketing will, however, result in added expenses for marketing, advertising, dealership training, sales and service, and infrastructure.

8 COST ESTIMATES

8.1 Introduction

The preliminary draft version of this Staff Report outlined a methodology for calculating comparative lifecycle cost estimates for battery electric vehicles and near-term partial ZEV vehicles (hybrid electric vehicles and SULEV internal combustion engine vehicles). Examples were given that showed the application of the methodology for given sets of assumptions.

Staff now presents estimates of likely costs for several representative vehicle types. These estimates draw upon the work of the Battery Technical Advisory Panel, comments received on the panel report, comments received on the draft Staff Report, and other sources.

The cost estimates presented here include the cost of the battery, charging equipment, any unique EV, HEV or PZEV components, fuel, and maintenance for each vehicle type. It should be noted that in order to simplify the calculations and their presentation, this analysis only considers a subset of vehicle operating costs--those expected to vary significantly across vehicle types. Therefore, the estimates reported here are not directly comparable to other reported estimates of lifecycle cost per mile. Our methodology is intended to provide a relative sense of the lifecycle cost difference across different vehicle types, rather than an absolute estimate of operating cost per mile.

Estimates are provided for incremental initial cost (incremental cost of the vehicle plus the battery pack and charger) and for lifecycle cost per mile. Cost estimates are derived for freeway capable battery electric vehicles, city electric vehicles, gasoline-electric power assist hybrid vehicles, and PZEV gasoline ICE vehicles. Results are shown for 2003 production volumes, and for future high volume production (100,000+ units). Low speed electric vehicles are discussed qualitatively but no cost per mile figures are generated.

The vehicle types noted above are included because they are expected to be available in the 2003 timeframe. Because examples of these vehicles are in production today, more reliable cost information is available for them. Cost information for other advanced vehicles not expected to be in production in 2003 (e.g. fuel cells, or hybrids with all-electric range) generally is far more tentative at this point, and no estimates of such costs are developed in this document.

8.1.1 Cost, Not Price

Staff emphasizes that this methodology seeks to estimate the incremental <u>cost</u> of vehicle production and the cost of operation. This is not the same as estimating the <u>price</u> at which various vehicles would be offered for sale. Price is set in a competitive environment, and can differ from cost for a variety of reasons. In some circumstances companies may choose to set a price that is lower than their cost in order to encourage sales of a particular vehicle. Several possible reasons for such an approach were noted in a study by EPRI entitled Pricing for Success: EV Costing and Pricing. Companies may establish a price that encourages sales of a particular vehicle in order to:

- Foster a cutting edge or environmentally sensitive image.
- Capture customers from particular demographic segments.
- Improve the corporate average fuel economy (CAFE) result.
- Expand market share, overall and in particular market segments (e.g. fleets).
- Introduce new technology in a limited, controlled fashion.

8.1.2 Previous Analyses

The most recent detailed ARB assessment of electric vehicle operating cost was prepared in 1994 to support that year's Biennial Review. That assessment concluded that "the net present value of the battery and operating cost of an electric vehicle using a high-energy battery (in volume production) can be comparable to the net present value of the cost to operate a conventional compact car." Although certain assumptions are handled differently, from a methodological standpoint the cost calculations in this section follow the approach used in 1994.

Other analyses have also attempted to estimate the lifecycle cost of various vehicle types. A Review of Electric Vehicle Cost Studies: Assumptions, Methodologies, and Results (Lipman, 1999) critically reviewed eight EV cost studies performed from 1994 to 1999. This report summarized that "The EV cost studies…report somewhat disparate results. All studies conclude that EV costs will be higher than conventional vehicle costs in the near term, but a few studies suggest that EV costs could relatively quickly drop to levels comparable to those of conventional vehicles, particularly on a lifecycle basis. Most studies suggest that EV purchase costs are expected to remain a few to several thousand dollars higher than conventional vehicle costs, with lifecycle costs also remaining somewhat higher. Finally, one study concludes that EV purchase prices are likely to remain much higher than conventional vehicle prices, through 2010". In the critical review, Lipman notes various limitations in many of the studies reviewed, including the two that showed rapidly declining cost and the one that showed much higher EV cost.

The report went on to note that "Some of the variation in the reported results of EV manufacturing costs can be explained by considering the vehicle classes, production volumes, and battery types considered in the various analyses. However, aside from these critical study parameters, considerable variation remains in the vehicle purchase price and lifecycle cost estimates reported here. Uncertain parameters that help to account for the remaining differences in cost estimates include the assumed performance of the vehicle…, the cost of the assumed battery type, and costs of accessories and additional equipment needed for the EV".

Two additional studies have been published subsequent to the completion of the Lipman review. The first is entitled Evaluation of Electric Vehicle Production and Operating Costs (Cuenca, Gaines, and Vyas, November 1999), prepared by the Center for Transportation Research at Argonne National Laboratory. With regard to initial cost, this study concludes that "The initial cost of the EV is projected to be higher than that of the CV, even under the most favorable assumptions. The basic EV (excluding battery) could possibly be produced at a slightly lower cost than the CV, but the high cost of the battery pack contributes substantially to the EV's cost." The conclusion of the Cuenca study with respect to lifecycle cost is that "The long-term operating cost of the EV would be comparable with that of the CV, despite the projected low fuel prices. … Although the energy cost is much lower for the EV, the battery replacement cost would more than offset this advantage. Only after a decade or more of continuous development and volume building would the EV be able to show a slight advantage over the CV with respect to operating costs."

The second recent analysis is the Motor Vehicle Lifecycle Cost and Energy-Use Model (Delucchi, 2000), prepared for the Air Resources Board by the Institute of Transportation Studies, University of California, Davis. This model "designs" a vehicle to meet range and performance requirements specified by the modeler, and then calculates the initial retail cost and total lifecycle cost of the designed vehicle. The model uses detailed assessments of vehicle cost and weight, vehicle energy use, and periodic ownership and operating costs. The model calculates the performance and cost of twelve kinds of light-duty motor vehicles. For battery electric vehicles, results are presented for two kinds of vehicles (Ford Escort and Ford Taurus) and four kinds of batteries (lead acid, NiMH Gen2, Li-Ion, and NiMH Gen4).

With regard to initial vehicle cost, in all cases analyzed in the Delucci study the retail cost of the EV is higher than the retail cost of the comparison ICEV Taurus or the comparison ICEV Escort. The report notes that "the higher initial cost of the EV is due mainly to the high cost of the battery". From a lifecycle cost standpoint, one scenario (next generation NiMH battery, 100 mile range) resulted in a lifecycle cost competitive with that of the ICE vehicle. In the other cases analyzed, using this study's methodology, the cost of the battery resulted in a higher EV lifecycle cost.

The existing studies do not provide a consistent framework for assessing and reporting comparative vehicle lifecycle cost, nor do they report similar results, particularly for long term prospects. This lack of consistency underscores the difficulty and uncertainty associated with projecting future costs for evolving technology.

8.1.3 Methodology

The lifecycle cost analyses used in this report focus on a subset of vehicle operating costs—those costs expected to vary across vehicle types, and to have a significant effect on the total. Thus many other costs are not included, such as the cost of the basic vehicle platform, insurance, or vehicle registration. Because this analysis does not address all aspects of building and operating a vehicle, the estimates developed here are not directly comparable to other reported estimates of lifecycle operating cost per mile.

At the May workshop an automaker commented that the "base case" for cost comparison should be a SULEV vehicle rather than a PZEV vehicle, because the SULEV more closely represents the typical 2003 fleet vehicle. This suggestion has been adopted.

Staff's analysis takes into account the following costs, aggregated over a ten-year vehicle life:

Battery electric vehicle:
Battery pack cost
EV incremental cost (incremental cost of unique EV components other than the battery, as compared to a SULEV)
Fuel cost (electricity)
Maintenance cost
Charging equipment cost

Power assist hybrid electric vehicle:
Battery pack cost
HEV incremental cost (incremental cost of unique HEV components other than the battery, as compared to a SULEV)
Fuel cost (gasoline)
Maintenance cost

Internal combustion engine vehicle:
PZEV incremental cost (incremental cost of unique PZEV components other than the battery, as compared to a SULEV)
Fuel cost (gasoline)
Maintenance cost

The identified costs are totaled over the ten-year life of the vehicle, then discounted back to present dollars. This discounted sum is then divided by the number of miles traveled to give a net present value cost per mile. In this analysis, we assume 10-year lifetime vehicle miles traveled of roughly 117,000 miles, based on the standard ARB emission inventory estimate, for all vehicles other than city EVs. Lifetime vehicle miles traveled for city EVs is assumed to be 75 percent of that for freeway capable vehicles, or about 88,000 miles.

This approach does not take into account possible variations in vehicle acceleration or other performance attributes. Rather, all vehicle operating characteristics are expressed in terms of two measures--battery pack capacity (for electric vehicles), and vehicle efficiency.

Even this simplified analysis requires the use of a number of assumptions:

- Battery pack capacity
- Battery cost per kWh, new and replacement
- Battery life
- Battery salvage value
- Incremental cost of EV components
- Incremental cost of HEV components
- Incremental cost of PZEV components
- Charging equipment cost
- Price of electricity
- Price of gasoline
- BEV efficiency
- HEV efficiency
- PZEV efficiency
- Maintenance cost, BEV
- Maintenance cost, HEV
- Maintenance cost, PZEV
- Inflation rate
- Discount rate

8.2. Cross-Cutting Assumptions

As noted above, a number of assumptions must be made in order to perform cost calculations. Many of these assumptions are “cross-cutting” in that they apply to all vehicles within a category (EV, HEV, or PZEV). Table 8-1 below presents the various cross-cutting assumptions, and staff’s estimate for each, for 2003 and for eventual volume production. The basis for staff’s estimates is further discussed below.

Table 8-1
Cross-Cutting Assumptions

Assumption	2003	Volume Production
NiMH battery initial cost		
Module cost	$300 per kWh	$235 per kWh
Added cost for pack	$40 per kWh	$20 per kWh
Multiplier for indirect cost	1.15	1.15
Cost as installed in vehicle	$391 per kWh	$293 per kWh
NiMH battery life [a, b]	6 years	10 years
NiMH battery salvage value	$40 per kWh	$40 per kWh
NiMH battery replacement cost		
Module cost	$267 per kWh	Not Applicable
Added cost for pack	$30 per kWh	Not Applicable
Multiplier for indirect cost	1.15	Not Applicable
Uninstalled cost	$342 per kWh	Not Applicable
Handling and installation	$500 per pack	Not Applicable
PbA battery initial cost		
Module cost	$135 per kWh	$100 per kWh
Added cost for pack	$40 per kWh	$20 per kWh
Multiplier for indirect cost	1.15	1.15
Cost as installed in vehicle	$201 per kWh	$138 per kWh
PbA battery life [a, b]	3 years	5 years
PbA battery salvage value	$3 per kWh	$3 per kWh
PbA battery replacement cost	$	
Module cost	$118 per kWh	$100 per kWh
Added cost for pack	$30 per kWh	$20 per kWh
Multiplier for indirect cost	1.15	1.15
Uninstalled cost	$170 per kWh	$138 per kWh
Handling and installation	$500 per pack	$500 per pack
Vehicle Incremental Cost		
2 passenger freeway BEV	$9,500	$1,500
4 passenger freeway BEV/pickup	$8,000	$0
City EV	$5,000	$0
HEV	$2,500	$500
PZEV	$500	$500
Charging equipment, installed	$1,500	$750
Price of electricity [c]	$0.05 per kWh	$0.05 per kWh
Price of gasoline [d]	$1.26 per gallon	$1.26 per gallon
Maintenance cost		
Freeway capable EV	$0.04 per mile	$0.04 per mile
City EV	$0.035 per mile	$0.035 per mile
HEV	$0.075 per mile	$0.075 per mile
ICE	$0.06 per mile	$0.06 per mile
Inflation rate	3 percent	3 percent
Discount rate	8 percent	8 percent

a. For 2003 vehicles, an alternative scenario is also calculated that assumes extended battery life.
b. HEV batteries are assumed to last the life of the vehicle in all cases.
c. Excludes tax. For comparison purposes, an alternative scenario is also calculated using $0.075 per kWh, to take into account the effect of daytime charging.
d. Excludes tax; equivalent to $1.75 per gallon retail. For comparison purposes, an alternative scenario is also calculated using the after-tax gasoline price of $1.75.

<u>Battery Initial Cost</u>

In this analysis, the battery initial cost represents the cost of the battery pack as installed in the vehicle. Several parties stated in public comments that an additional cost factor should be added to the cost of the battery as paid by the automaker to the battery manufacturer, in order to account for shipping and manufacturer indirect costs. This comment has been adopted. Thus the battery initial cost used here is the sum of three components: (1) the per module price charged by the battery manufacturer, (2) the cost of assembling modules into a battery pack, and (3) a markup factor to capture additional costs to the vehicle manufacturer. Each is discussed in turn.

<u>Per module battery cost</u> is taken from the draft Final Report of the Year 2000 Battery Technical Advisory Panel, and further discussion with Panel members. For NiMH batteries, the Panel reports projected cost for 2003 volume (20,000 packs per year) of $300 per kWh, and projected cost in volume production (100,000 packs per year) of $225-250 per kWh. Staff uses a midrange estimate of $235. For PbA batteries, the panel provides a range of $100 to $150 per kWh at MOA volume levels. No estimated is provided for production volume greater than 25,000 packs per year. Staff assumes $135 per kWh for year 2003 and $100 per kWh for volume production.

<u>Pack cost</u> also is taken from the Battery Technical Advisory Panel report. As described by the Panel, an EV battery pack consists of a number of modules connected together to provide the desired system voltage and energy storage capacity. The pack will also have a thermal management system, as well as electrical and electronic controls to regulate charge and discharge, assure safety, and prevent electrical abuse. The Panel makes a rough estimate that the cost of assembling battery modules into a complete pack is at least $1200 per pack ($40 per kWh) at 2003 volume and about half of that at volume production levels. Staff uses a fixed additional cost (not adjusted for pack size) of $40 per kWh for 2003, and $30 per kWh for replacement packs, and $20 per kWh for volume production.

A <u>markup factor</u> is needed to account for overhead, dealer support, and other costs that are added to manufacturing costs as part of the cost structure for vehicle production. Specific cost structure information is proprietary and difficult to obtain. The Delucchi and the Cuenca cost reports referenced above each have a discussion of possible cost factors. Staff has adopted the cost factor used in the Cuenca report. The base case analysis in that report uses a 1.15 multiplier, described as "optimistic", that accounts only for marketing cost and profit. This approach is described as similar to that used in aircraft assembly or heavy duty truck manufacturer, in which expensive engines procured from outside suppliers are used with a relatively low markup. The report also provides results for an alternative scenario, using a 1.3 multiplier that accounts for dealer support, distribution, marketing, a small part of corporate overhead, and profit. Staff follows the Cuenca analysis and uses a 1.15 multiplier, but recognizes that this represents an optimistic scenario.

To illustrate how these three components are combined, the $391 per kWh cost estimated for 2003 NiMH batteries is arrived at by first adding together (1) a $300 per kWh cost at the module level, plus (2) a $40 per kWh cost for assembly into a pack. This total, $340 per kWh, is then multiplied by (3) the markup factor of 1.15, to arrive at the total of $391 per kWh as shown in Table 8-1.

Battery Pack Life

Battery life has a significant effect on lifecycle cost. Staff's assessment of battery pack life is based on the work of the Battery Technical Advisory Panel, and on comments provided by battery manufacturers and other parties.

For 2003, staff assumes that battery pack life for PbA batteries is 3 years, and for NiMH batteries is 6 years. Although not yet fully demonstrated in real world driving, this level of durability appears to be well within the reach of the most recent battery technologies.

Data exists which suggests that longer battery lives are possible. For example, the Battery Technical Advisory Panel reported that "bench tests and recent technology improvements in charging efficiency and cycle life at elevated temperature indicate that NiMH batteries have realistic potential to last the life of an EV, or at least ten years and 100,000 vehicle miles". Bench test data for the Panasonic PbA batteries installed in the GM EV1 indicate that the battery maintains more than 80 percent of its capacity for more than 1000 cycles, equivalent to more than 50,000 miles. Because real world data is not available to demonstrate this performance with the reliability needed for large scale introduction in motor vehicles, staff is reluctant to assume such levels for 2003. To provide a complete picture of possible outcomes, however, we also provide an alternative cost analysis for 2003 that assumes a 5 year life for PbA batteries and a 10 year life for NiMH batteries. We also assume 5 and 10 year lifetimes for batteries used in future volume production.

Because the assumed life of the vehicle is 10 years, when replacement packs are needed some allowance must be made to account for unused battery life at the end of the 10 year period. For example, if battery life is 6 years and a new pack is installed in year 7, at the end of year 10 the pack still has 2 years of useful life. In such instances we increase the "salvage value" in year 10 to account for the remaining battery life. For example, if the cost of a 6 year NiMH battery pack is $13,260, and at the end of year 10 the pack has two years of useful life remaining, we add one-third of the battery pack cost, or $4,420, to the salvage value of the battery in year 10.

Manufacturers noted in public comment that the assumption of linear depreciation was too optimistic in that vehicles lose much of their value in the first few years. Staff believes that the value of the battery pack is based strictly on its capacity, and therefore has retained the original method.

<u>Battery Pack Salvage Value</u>

Staff assumes that the salvage value for EV batteries will be $40 per kWh for NiMH batteries and $3 per kWh for lead acid batteries. This amount, which accounts for the value of the battery for secondary uses (NiMH) or material recycling (PbA), is in addition to any credit for remaining battery life as discussed above.

Batteries for electric vehicles generally are considered to have reached the end of their useful life when their capacity has dropped by 20 percent. Staff notes that for NiMH batteries, even a 30 percent reduction in capacity would still allow vehicles to have adequate range for many applications.

However "useful life" is defined, it is clear that a somewhat depleted NiMH EV battery still has significant capacity available for use in less-demanding applications. Battery manufacturers and utility companies are investigating possible secondary markets for used vehicle batteries, which generally involve supplying power in remote or distributed locations where the long life of advanced batteries could provide a significant maintenance cost advantage. A secondary market that provides a salvage value for vehicle batteries will effectively reduce the battery cost. EPRI has work underway to better estimate the value of NiMH secondary uses. Their results are not yet available. In the absence of more specific information, staff assumes $40 per kWh.

The existence of a secondary market for PbA batteries at meaningful volume levels is in staff's view more speculative. The $3 estimate for PbA represents the value of the materials in the battery.

Battery Replacement Cost

Two opposing factors affect battery replacement cost. First, due to technical improvement and increased volume, it is likely that in the early years of production the module cost of a replacement pack will be less than the module cost of the pack it replaces. On the other hand, due to the cost of distribution, dealer support and on-site installation, the actual installed cost of a replacement battery pack will be more than the cost of a battery pack installed at the factory.

In our calculations, we assume that for 2003 vehicles the uninstalled cost of the replacement pack is halfway between the 2003 cost and the "volume production" cost. (For volume production vehicles we assume that the per module cost is the same for the original pack as for the replacement pack.) We also assume that handling and installation total $500 per pack, which covers shipping, storage, testing, and installation of the replacement pack. For example, for a 2003 NiMH vehicle, the uninstalled cost of a replacement pack is $342 per kWh, halfway between the $391 per kWh cost of the original pack and the $293 per kWh cost of the pack in volume production. The cost of the replacement pack is then increased by $500 to give the installed cost.

Vehicle Incremental Cost

Freeway Battery Electric Vehicles. The incremental cost of the vehicle means the cost of an EV, minus the battery, as compared to the cost of a baseline SULEV ICE vehicle. Please note that in the preliminary draft Staff Report the baseline comparison vehicle was a PZEV rather than a SULEV. This was changed in response to public comment.

The incremental cost is highly dependent on production volume. Although staff provides estimates for both low and high volume production, for purposes of cost comparison to other vehicle types it is appropriate to use the long-term, learned out cost in volume production.

Staff has developed two estimates of incremental cost for each production level—one for the 4 passenger vehicles, and a higher estimate for the highly efficient 2 passenger commuter vehices. The latter are modeled after the EV1 and make use of lightweight components.

In order to estimate incremental costs, staff reviewed the cost analyses prepared by Cuenca et al and by Delucchi. For low volume production (roughly equivalent to 2003 levels) Cuenca provides estimates for several different manufacturing methods (based on existing vehicle, based on new design, assembled from glider, conversion from a conventional vehicle). These estimates range from $1,300 for glider assembly to $4,300 for an EV based on a new design. These estimates do not, however, include any volume-related additional cost for the drivetrain. Rather, the authors assume aggregate demand would be sufficient to have high volume production levels and costs for the EV drivetrain.

Delucchi provided ARB staff with unpublished model runs that calculate an incremental cost for low volume production of roughly $8,000 to $14,000 depending on the vehicle characteristics. Confidential information from vehicle manufacturers shows higher estimated costs.

Staff assumes $8,000 for the 4 passenger vehicles, at the low end of the Delucchi range and close to the low end of the manufacturer information.

For high volume production both the Delucchi and the Cuenca studies conclude that the vehicle minus the battery will cost roughly the same as the equivalent ICE vehicle. In our site visits, auto manufacturers generally maintained that due to the need for additional components (e.g. electric power steering, electric heating and air conditioning, regenerative brakes) the non-battery portion of an electric vehicle was likely to always have some cost premium. Several manufacturers also stated, however, that in volume production such a premium would be small relative to the extra cost of the battery. Staff assumes no additional cost in volume production for the 4 passenger battery electric vehicles, excluding the cost of the battery.

For the 2 passenger vehicles, which are assumed to make extensive use of aluminum, staff uses an added cost of $1,500 for both 2003 and for volume production. This estimate, which should be considered an approximation, is based on work by the Office of Technology Assessment. In their report Advanced Automotive Technology that Office estimated that the additional cost in 2005 for a first generation aluminum vehicle would be on the order of $1,200 to $1,500 per vehicle, with about $800 in materials cost and the balance in handling and manufacturing cost.

City Electric Vehicles. The incremental cost for a city EV, minus the battery, is assumed to be $5,000 at 2003 production levels and $0 in large volume. Staff is not aware of published estimates that focus on City EV manufacturing cost. In the absence of more specific information, we assume 2003 incremental cost slightly lower than that for freeway capable EVs. Large volume production incremental cost is treated the same as for freeway capable EVs.

Hybrid Electric Vehicles. The incremental cost of HEV components, excluding the battery pack, is assumed to be $2,500 in 2003 and $500 in volume production. This results in a total incremental cost, including the battery pack, of about $3,300 in 2003 and $1,100 in volume production. The 2003 level corresponds to manufacturer published announcements regarding desired incentive levels to encourage the purchase of HEVs. A modest cost premium is assumed even or volume production because a hybrid electric vehicle needs all of the components of an ICE vehicle, plus components unique to a hybrid.

PZEV Vehicles. Staff assumes an incremental cost for PZEVs of $500 in 2003 and in volume production, which is in the middle of the range estimated by staff during the LEV II rulemaking. In the LEV II staff analysis, the incremental cost to the consumer of a conventional gasoline vehicle that qualifies to receive 0.2 partial ZEV credit (e.g. Nissan Sentra CA) relative to a gasoline SULEV vehicle was estimated to be in the range of $385 to $800. Staff estimated that PZEV vehicles would incur additional costs in the following three categories compared to a SULEV:

a) Additional emission control hardware such as a HC adsorber or additional catalyst loading may be required in larger six-cylinder or difficult to control four-cylinder engines to ensure continued compliance with emission standards for 150,000 miles vs. 120,000 miles.

b) All PZEV gasoline vehicles are required to be equipped with fuel systems certified to the zero-fuel evaporative emission standards for 150,000 miles. The use of advanced fuel/evaporative systems that are capable of eliminating fuel evaporative emissions would be required for compliance with the zero-fuel evaporative standards. Some of these systems include a sealed fuel system, a pressurized fuel system and upgraded joint hardware and lines. The costs of such systems have been estimated to be in the range of $50 to $150.

c) For PZEV vehicles, all emission-related malfunctions detected by the vehicle's OBD II system must fixed under warranty up to 15-years/150,000 miles, whichever occurs first. This requirement is significantly more stringent than the 3-year or 50,000 mile (7-years/70,000 miles for high cost components) emission warranty requirement applicable to SULEVs. As a result, staff believes that virtually every PZEV gasoline vehicle would require some amount of warranty work over its useful life. Accordingly, staff estimated the increased warranty costs to be between $300 to $500 per vehicle.

An additional ten- percent was added to these costs to account for cost of capital recovery, dealership costs and other miscellaneous costs.

Charging Equipment Cost

The cost estimation methodology outlined in the Preliminary Draft staff report did not include the cost of electric vehicle charging equipment. Public comment has pointed out that the cost of a charger should be included, and staff agrees. Staff has reviewed several published estimates of the equipment and installation cost for the off-board portion of vehicle charging equipment. (The cost of the on-board components is included in the estimate of vehicle incremental cost). Delucchi estimates near-term cost of $1,200 for a dedicated high power circuit plus the off board charger, and long-term cost of $400. The long-term cost assumes the use of an integrated conductive charger at a cost of $250, and $150 on average for installation of the dedicated circuit. Cuenca estimates a lifecycle added cost of $0.005 to $0.01 per mile initially, and half that at high production volume. Using our cost estimation methodology, $0.01 per mile lifecycle cost is the equivalent of $1,200 in initial cost. In addition to these published estimates, automaker comments stated that chargers can cost $1,500 or more, not including installation.

Staff assumes 2003 cost for charging equipment will average $1,500, including installation. This assumes minor improvement in both component and installation cost over current levels, and is in the same range as the Delucchi and Cuenca estimates. Staff assumes volume production cost of $750, based on the Delucchi estimate but increased to allow for higher average installation costs.

Price of Electricity

Staff assumes that the price of electricity for EV charging will be $0.05 per kWh, which assumes 90 percent off-peak charging. To allow consideration of other scenarios, under which a lower proportion of charging may occur off-peak due to daytime use of convenience chargers, or workplace charging, we also present an alternative case using an average electricity price of $0.075 per kWh.

Electric vehicles that charge with off-peak power have a fuel cost advantage over gasoline fueled vehicles. Off-peak electricity is cheaper than gasoline from an energy content standpoint, and electric vehicles use their energy very efficiently. The size of the fuel cost differential between electric and gasoline vehicles will vary according to the relative fuel prices.

The electricity prices used in this analysis exclude taxes. Taxes are likewise excluded from gasoline prices. This approach is taken because taxes on electricity and gasoline are “transfer payments” used for other social purposes and are not truly a part of the cost of the product. (In economic terms, transfer payments are transfers of money or economic value from one party to another without an exchange of goods or services in return, and are not included within costs or benefits.) In Sacramento, which staff believes is representative of the rest of the state, electricity is assessed a 7.5 percent local use tax plus a 2 mil per kWh state surcharge.

Price of Gasoline

Staff assumes a gasoline price of $1.26 per gallon, which excludes taxes. As noted above, a similar approach is taken with respect to electricity prices. Federal and state fuel excise taxes currently total $0.363 per gallon. In addition, a sales tax of between 7.25 percent and 8.25 percent is assessed on the total cost of the sale. At current gasoline prices of about $1.75 per gallon, tax included, these taxes account for about $0.49 of the $1.75.

Because hybrid electric vehicles are more efficient than conventional ICE vehicles, they will have a fuel cost advantage over gasoline fueled vehicles. The size of the cost advantage will vary according to the price of gasoline.

Consumers, of course, pay fuel prices that include tax. Thus in assessing the cost faced by a driver and its effect on a purchase or lease decision, the full price with tax included should be used. The base case staff calculations assume prices without tax but staff provides alternative calculations that include tax.

Maintenance Cost

Maintenance costs are assumed to be as follows:

Freeway Capable Battery EV	\$0.04
City EV	\$0.035
HEV	\$0.075
ICE	\$0.06

The Automobile Club of Southern California publishes estimates of driving cost based on regional data. These costs have been calculated by averaging the owning and operating expenses of three 1999 car makes--the Chevrolet Cavalier LS, the Ford Taurus SE, and the Mercury Grand Marquis LS. For these 1999 vehicles the club estimates maintenance expenses of \$0.04 per mile and tire expenses of \$0.017 per mile. Staff rounds the total to \$0.06 per mile and uses this figure as the estimate for conventional internal combustion engine vehicles.

Due to the different technologies employed, maintenance costs for electric vehicles may differ from those for gasoline vehicles. Several of the studies discussed in Section 8.1.1 above have attempted to estimate electric vehicle maintenance costs. Staff has also received public comment regarding maintenance costs experienced by utility company EV fleets. Based on the available information, in this analysis staff assumes that EV maintenance costs will be about \$0.04 per mile, roughly one-third less than ICE maintenance costs. This estimate takes into account the fact that EV tires, which are optimized for low rolling resistance, are more expensive.

City EV maintenance cost is assumed to be \$0.035 per mile, somewhat less than for freeway capable EVs. This reduction is due to the smaller size and weight of the vehicles.

Maintenance costs for hybrid electric vehicles may differ from those for gasoline or battery electric vehicles. Because hybrid vehicles employ both a conventional and an electric drive system, staff assumes that maintenance cost for hybrids will be higher than for gasoline or electric vehicles. In the absence of more specific information staff assumes that hybrid electric vehicle maintenance costs will be 25 percent higher than for ICE vehicles, or \$0.075 per mile.

Inflation Rate

Annual inflation is assumed to be 3 percent. Ongoing costs such as maintenance and fuel can be expected to increase over time with inflation. Staff is not aware of information that would justify assigning separate inflation rates to the different categories. Therefore a single rate is assumed to apply to all future costs, other than battery pack replacement and battery pack salvage value. Because staff expects battery costs to decline over time, these costs are not inflated.

Discount Rate

The assumed discount rate is 8 percent. The rationale for using a discount rate when considering the value of future costs and benefits is discussed in A Guide for Reviewing Environmental Policy Studies—A Handbook for the California Environmental Protection Agency (M Cubed, 1994). This report notes that "A discount rate is used to calculate the present discounted value of future benefits and costs….The farther in the future benefits are received, the less value they have compared to receiving the same benefits today. The discount rate reflects the time value of money and the risk associated with future benefits and costs."

The higher the discount rate, the lower the value, in today's dollars, of costs or payments which occur in future years. Battery electric vehicles typically will have higher initial costs, offset by fuel cost savings over a period of years. Therefore the discount rate used will affect their lifecycle cost relative to internal combustion vehicles, which have lower initial costs but higher fuel costs over time.

The Cal/EPA guidelines for economic analysis recommend that the discount rate used in an analysis should equal "the interest rate on United States Treasury Securities with a maturity that most closely approximates the project [time] horizon, plus two percent." In this instance, the time horizon of the cost analysis is ten years. Therefore according to the Cal/EPA guidelines the resulting discount rate should equal the current interest rate on 10-year Treasury Securities (around 6 percent) plus 2 percent, or 8 percent total.

The discount rates used here are assumed to include inflation. In other words, a nominal discount rate of 8 percent, as used here, equates to a "real" discount rate of 5 percent given the assumed inflation rate of 3 percent.

Value of EV Connection to Utility

At the May workshop one commenter suggested that EV battery packs could provide distributed energy services to electric utilities. In this scenario, a computer controlled bi-directional power interface would allow power to be stored in or withdrawn from EV battery packs as needed, given time-of-day system capacity and demand. EV battery packs could be used to provide peak power, reactive power, or spinning reserves to the utility. Initial calculations estimate that the value of such an arrangement could be possibly $10 per month per kWh of battery capacity, with a net present value reported at $125 to $565 per kWh. Building on such distributed energy arrangements, researchers have presented long term visions of an electricity supply system without central generators, with generation provided exclusively by customer owned fuel cell EVs. Alternatively or in combination, the electric supply system could use a high proportion of intermittent renewable energy sources, buffered by distributed storage in the battery EV fleet.

Staff recognizes the potential value of such distributed energy services. The real-world practicality of such mechanisms must be further assessed, however, and staff has not assigned any dollar value to distributed energy services in its cost calculation methodology.

8.3 Assumptions--Freeway Capable Battery Electric Vehicles

This section presents the vehicle-specific assumptions used to derive cost estimates for freeway capable battery electric vehicles. Several different vehicle types are considered. In this context the range figures provided represent real-world driving range. Cost estimates are developed for both NiMH and PbA versions of most these vehicles.

The specific attributes of each vehicle type are listed in Table 8-2 and discussed in more detail below.

Table 8-2
Vehicle-Specific Assumptions
Freeway Capable Battery Electric Vehicles

Vehicle Type	Battery Type	Pack Capacity (kWh)	Vehicle Efficiency (kWh/mile)	Range (miles)[b]
2003				
MOA 2 passenger	NiMH	33.4	.373	145
MOA 2 passenger	PbA	19.1	.248	81
MOA 4 passenger	NiMH	31.5	.476	73
MOA 4 passenger	PbA	17.6	.438	40
MOA fleet/pickup	NiMH	32.0	.539	64
MOA fleet/pickup	PbA	19.1	.511	37
Volume production				
MOA 4 passenger	NiMH	31.5	.380	90
HE[c] 2 passenger, 60 mile	NiMH	10.2	.187	60
HE 2 passenger, 60 mile	PbA	10.5	.177	60
HE 2 passenger, 100 mile	NiMH	17.4	.191	100
HE 2 passenger, 100 mile	PbA	18.5	.186	100
HE 2 passenger, 150 mile	NiMH	28.8	.198	150
HE 4 passenger, 60 mile	NiMH	14.8	.271	60
HE 4 passenger, 60 mile	PbA	15.2	.256	60
HE 4 passenger, 100 mile	NiMH	25.2	.277	100
HE 4 passenger, 100 mile	NiMH	22.5	.249	100

a. Total of vehicle incremental cost, initial battery pack, and charging equipment.
b. Real-world driving range.
c. High efficiency.

Vehicle Efficiency and Battery Pack Capacity

Estimates were determined by calculating vehicle performance under steady-state (freeway) driving conditions at 70 mph. Unlike conventional non-hybrid gasoline automobiles, EVs demonstrate improved efficiency when operated under low-speed urban driving cycles and are less efficient when operated at high speeds. Real life estimates of current and projected EV performance should therefore be based on conditions that are challenging to EVs and that best agree with MOA-era real life EV experience.

The 2003 vehicles are assumed to be identical in efficiency to the MOA vehicles that have been placed as part of the demonstration program. Efficiency ratings are based upon EV America and SCE test results. The lower efficiency shown for NiMH vehicles as compared to PbA is due to their reduced charging efficiency at high temperatures and the energy needed for battery thermal management.

The “base case” volume production 4 passenger EV, which we describe as “MOA 4 passenger”, is a MOA type vehicle with minor efficiency improvements over today’s technology. The assumed efficiency is taken from the A.D. Little work on full fuel cycle vehicle energy efficiency. Staff is confident that this efficiency level would be achieved in vehicles brought to market in the volume production timeframe.

Staff also provides cost estimates for several configurations of “high efficiency” volume production EVs. These examples are provided in order to illustrate the effect of efficiency improvement on vehicle initial cost and lifecycle cost. Increased efficiency allows the use of a smaller battery pack. For example, the most efficient 100 mile 4 passenger volume production NiMH vehicle assumes a pack size of 22.5 kWh, as compared to 31.5 kWh for the MOA type volume production vehicle. Use of a smaller pack reduces both initial cost and lifecycle cost.

The high efficiency vehicles are assumed to be 2nd or 3rd generation versions of OEM ZEVs with improvements over MOA-era vehicles in several of their efficiency-related attributes. These improvements include aerodynamic drag reduction, lower loss tires, higher efficiency drive systems, and substantial improvements in charging efficiency. More specifically, the 2-seat commuter vehicles incorporate an 88 percent efficient drive system (roughly 10 percent more efficient than that used in MOA vehicles), a considerable improvement in charging efficiency (from 46 percent to 73 percent), but no aerodynamic improvements. The 4 passenger vehicles incorporate all of these commuter improvements, and also assume a design with substantial aerodynamic drag reduction resulting in a drag coefficient of 0.2.

The final 4 passenger volume production vehicle is a sedan that takes advantage of all of the 4 passenger vehicle improvements noted above, but in a smaller vehicle with a frontal area of only 2.07 square meters.

Staff notes that these hypothetical vehicles do not assume efficiency improvements as radical as those demonstrated on actual state-of-the-art prototype ZEVs and HEVs. Chassis mass reductions requiring composite materials were not incorporated, and battery specific energy was assumed to remain at 35 whr/kg for PbA batteries and 70 whr/kg for NiMH. Reductions in battery pack mass to obtain commuter EVs were considered without corresponding reductions in chassis structural mass. It may be desirable to offer a platform with multiple battery pack versions where a short-range, 60 mile (real-life) EV would be burdened with an over-designed chassis, but could be made less expensive by sharing components and development costs with its longer-range versions.

<u>Cost of Sales</u>.

In public comments, an automaker stated that EVs have a higher "cost of sales" due to additional time demands on dealership staff, and suggested that staff's cost model specifically account for this cost. Staff recognizes that EVs do require additional effort from sales staff. Because our cost model is primarily focused on hardware cost, however, staff has not adopted this suggestion.

8.4 Assumptions--City Electric Vehicles

This section presents the vehicle-specific assumptions used to derive cost estimates for City electric vehicles. Staff develops calculations for NiMH and PbA versions for 2003 and for volume production. Again the range estimates shown are for real-world driving.

The specific attributes of each vehicle type are listed in Table 8-3 and discussed in more detail below.

Table 8-3
Vehicle-Specific Assumptions
City Electric Vehicles

Vehicle Type	**Battery Type**	**Pack Capacity (kWh)**	**Vehicle Efficiency (kWh/mile)**	**Range (miles)[a]**
2003				
City EV	NiMH	9.1	.250	36
City EV	PbA	5.3	.250	21
Volume production				
City EV	NiMH	9.1	.180	50
City EV	PbA	5.3	.180	29

a. Real world driving range.

Please note that in the City EV lifecycle cost calculations the lifetime vehicle miles traveled is assumed to be 75 percent of that for the other vehicles, or about 88,000 miles over ten years.

<u>Vehicle Efficiency and Battery Pack Capacity</u>

Vehicle efficiency and battery pack capacity estimates for 2003 are based on published specifications of existing city EVs. Modest efficiency improvement is assumed for future volume production vehicles.

8.5 Low Speed Vehicles

Low speed vehicles are on the market today, at prices of around $7,000. These prices appear to cover the cost of production plus manufacturer profit. Because these vehicles are aimed at entirely different market niches from the other battery electric and PZEV vehicles, there is no need to calculate how their lifecycle cost compares. Therefore staff has not developed cost comparison ranges for low speed vehicles.

8.6 Assumptions--Power Assist Hybrid Electric Vehicles

This section presents the vehicle-specific assumptions used to derive cost estimates for power assist hybrid electric vehicles. Several different vehicle types are considered, which are intended to be comparable to the freeway capable electric vehicles discussed above. The specific attributes of each vehicle type are listed in Table 8-4 and discussed in more detail below.

Table 8-4
Vehicle-Specific Assumptions
Power Assist Hybrid Electric Vehicles

Vehicle Type	Battery Type	Pack Capacity (kWh)	Vehicle Efficiency (miles/gallon)
2003			
2 passenger	NiMH	2.0	70
4 passenger	NiMH	2.0	45
Fleet/pickup	NiMH	2.0	30
Volume production			
2 passenger	NiMH	2.0	80
4 passenger	NiMH	2.0	55
Fleet/pickup	NiMH	2.0	35

<u>Vehicle Efficiency</u>.

Vehicle efficiency for 2003 passenger HEVs is based upon published mile per gallon figures for currently available hybrids. The fleet/pickup mileage is based upon an assumed 25 percent improvement over the gasoline version. Modest further improvements are assumed for volume production.

8.7 Assumptions--Internal Combustion Engine Vehicles

This section presents the vehicle-specific assumptions used to derive cost estimates for internal combustion engine Partial Zero Emission Vehicles (PZEVs). Once again the vehicles considered are intended to be comparable to the freeway capable electric vehicles discussed above. The specific attributes of each vehicle type are listed in Table 8-5 and discussed in more detail below.

Table 8-5
Vehicle-Specific Assumptions
PZEV Vehicles

Vehicle Type	**Vehicle Efficiency (miles/gallon)**
2003	
2 passenger	40
4 passenger	30
Fleet/pickup	20
Volume production	
2 passenger	45
4 passenger	35
Fleet/pickup	25

Vehicle Efficiency.

Vehicle efficiency for 2003 is based upon current mileage for subcompact, compact and pickup vehicles. Again a modest improvement is assumed for future production.

8.8 Cost Calculations

This section presents the results of staff calculations using the assumptions outlined above. Cost estimates are first presented for 2003, then for future volume production. The 2003 estimate assumes volume of roughly 20,000 to 30,000 vehicles per year. In public comment manufacturers have noted that because each individual manufacturer will produce only a portion of the statewide total, their costs will be based on smaller production runs. Other commenters have noted, however, that vehicles will be produced for other states and countries as well as for California, and that the aggregate demand will be higher than the California-only figure. Taking into account both factors, staff continues to use assumed volume of 20,000 to 30,000. Staff agrees that if the actual number of vehicles produced in 2003 is significantly less than this number, due to early introduction or other factors, battery cost and the overall cost per vehicle will increase.

Within each time period, similar vehicles are presented together (2 passenger, 4 passenger, pickup/fleet).

For each vehicle type we present the following:

Incremental initial cost, which includes the incremental cost for that vehicle as compared to the baseline SULEV vehicle, plus, where necessary, the cost of the initial battery pack and charging equipment.

Incremental lifecycle cost per mile, which is the present discounted value, per mile, of the sum of incremental initial cost plus operating cost over the life of the vehicle.

A discussion of the various results is provided in Section 8.9 after all results have been tabulated.

8.8.1 Cost Estimates for 2003

This section presents cost calculations for 2003, first for the base case and then for the alternative scenarios.

Base Case.

Results for the base case are shown in Table 8-6 below. The base case assumes battery life of 6 years for NiMH and 3 years for PbA, and a pre-tax gasoline price of $1.26 per gallon. Alternative scenarios follow, which assume longer battery life, increased gasoline prices, and increased electricity prices.

Please note that the various battery electric vehicles shown have different range and therefore are not directly comparable. (The assumed range for each vehicle is noted under Vehicle Specific Assumptions above). Later on we show the results of an equal-mileage comparison between NiMH and PbA vehicles.

A printout of the complete calculation for Vehicle 1 (MOA 2 passenger NiMH vehicle) follows Table 8-6.

Table 8-6
2003 Vehicles
Base Case Cost Estimates

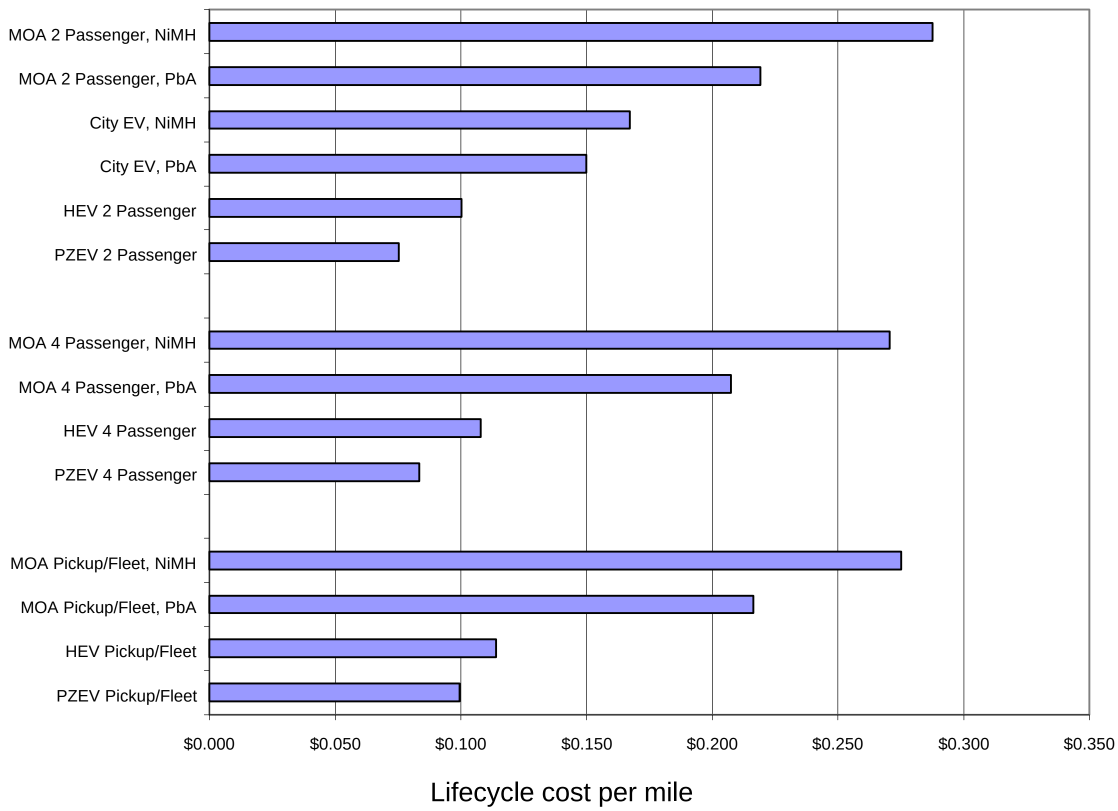
Vehicle Type	Battery Type	Charger Cost	Initial Pack Cost	Vehicle Incremental Cost	Total Incremental Cost	Lifecycle Cost per Mile
2 Passenger						
MOA 2 Passenger	NiMH	$1,500	$13,059	$9,500	$24,059	$0.288
MOA 2 Passenger	PbA	$1,500	$3,839	$9,500	$14,839	$0.219
City EV	NiMH	$1,500	$3,558	$5,000	$10,058	$0.167
City EV	PbA	$1,500	$1,065	$5,000	$7,565	$0.150
HEV 2 Passenger	NiMH	$0	$782	$2,500	$3,282	$0.100
PZEV 2 Passenger	NA	$0	$0	$500	$500	$0.075
4 Passenger						
MOA 4 Passenger	NiMH	$1,500	$12,317	$8,000	$21,817	$0.270
MOA 4 Passenger	PbA	$1,500	$3,538	$8,000	$13,038	$0.208
HEV 4 Passenger	NiMH	$0	$782	$2,500	$3,282	$0.108
PZEV 4 Passenger	NA	$0	$0	$500	$500	$0.083
Pickup/fleet						
MOA Pickup/Fleet	NiMH	$1,500	$12,512	$8,000	$22,012	$0.275
MOA Pickup/Fleet	PbA	$1,500	$3,839	$8,000	$13,339	$0.216
HEV Pickup/Fleet	NiMH	$0	$782	$2,500	$3,282	$0.114
PZEV Pickup/Fleet	NA	$0	$0	$500	$500	$0.099

Present Value Calculation--Vehicle 1

Discount rate:			8%				
Battery cost, $ per kWh:			$391				
Pack capacity, kWh:			33.4				
Initial pack cost:			$13,059				
Pack life, years:			6				
Replacement pack cost, $ per kWh:			$342				
Replacement pack cost, uninstalled			$11,423				
Replacement pack handling/install			$500				
Replacement pack cost, installed:			$11,923				
Pack salvage value, $ per kWh:			$40				
Pack salvage value, total:			$1,336				
Replacement pack cost, minus salvage:			$10,587				
Electricity cost, $ per kWh:			$0.05				
EV component & charger cost:			$11,000				
kWh per mile:			0.373				
Maintenance, $ per mile:			$0.040				
Inflation rate:			1.03				
			Components				
Year	Mileage	Pack Cost	& charger	Elect. Price	Fuel	Maintenance	Total
0	0	$13,059	$11,000				$24,059
1	13,352	$0	$0	$0.050	$249	$534	$783
2	12,948	$0	$0	$0.052	$249	$533	$782
3	12,556	$0	$0	$0.053	$248	$533	$781
4	12,176	$0	$0	$0.055	$248	$532	$780
5	11,808	$0	$0	$0.056	$248	$532	$779
6	11,450	$10,587	$0	$0.058	$248	$531	$11,365
7	11,104	$0	$0	$0.060	$247	$530	$778
8	10,768	$0	$0	$0.061	$247	$530	$777
9	10,442	$0	$0	$0.063	$247	$529	$776
10	10,126	-$5,144	$0	$0.065	$246	$528	-$4,369
Total	116,730	$18,503	$11,000		$2,477	$5,313	$37,292
NPV of total		$17,348	$11,000		$1,663	$3,568	$33,579
$ per mile		$0.149	$0.094		$0.014	$0.031	$0.288

Graph 8-1 on the next page shows incremental lifecycle cost per mile for the various vehicles.

Graph 8-1
2003 Vehicles
Estimated Incremental Lifecycle Cost per Mile



Alternative Scenarios.

Next we present the results of three alternative scenario, which assume (1) longer battery life (10 year for NiMH and 5 years for PbA), (2) higher gasoline prices (using the nominal gasoline price of $1.75 per gallon rather than the pre-tax price of $1.26 per gallon), and(3) higher electricity prices ($0.075 per kWh average rather than $0.05 per kWh). Tables 8-7, 8-8 and 8-9 present the results for these scenarios.

As is shown in the tables, the increased battery life decreases the lifecycle cost for the freeway capable battery electric vehicles by about 15 percent. The City EVs show a smaller change due to the relatively smaller size of their battery pack. The increased cost of gasoline increases the lifecycle cost of the HEVs by some 5 to 9 percent, and increases lifecycle cost for the PZEVs by about 12 to 19 percent. The impact on HEVs is less due to their greater fuel economy. Increased electricity prices have only a minor effect, increasing lifecycle cost by about 2 to 5 percent.

Table 8-7
2003 Vehicles
Alternative Scenario Cost Estimates
(Increased Battery Life)

	Incremental Lifecycle Cost Per Mile			
Vehicle Type	Base Case	Increased Battery Life	Difference	Percent
2 Passenger				
MOA 2 Passenger, NiMH	$0.288	$0.246	-$0.042	-14.6%
MOA 2 Passenger, PbA	$0.219	$0.188	-$0.031	-14.0%
City EV, NiMH	$0.167	$0.149	-$0.018	-10.7%
City EV, PbA	$0.150	$0.133	-$0.016	-11.0%
HEV 2 Passenger	$0.100	$0.100	$0.000	0.0%
PZEV 2 Passenger	$0.075	$0.075	$0.000	0.0%
4 Passenger				
MOA 4 Passenger, NiMH	$0.270	$0.231	-$0.040	-14.7%
MOA 4 Passenger, PbA	$0.208	$0.179	-$0.029	-13.8%
Hybrid 4 Passenger	$0.108	$0.108	$0.000	0.0%
PZEV 4 Passenger	$0.083	$0.083	$0.000	0.0%
Pickup/fleet				
MOA Pickup/Fleet, NiMH	$0.275	$0.235	-$0.040	-14.7%
MOA Pickup/Fleet, PbA	$0.216	$0.186	-$0.031	-14.2%
Hybrid Pickup/Fleet	$0.114	$0.114	$0.000	0.0%
PZEV Pickup/Fleet	$0.099	$0.099	$0.000	0.0%

Table 8-8
2003 Vehicles
Alternative Scenario Cost Estimates
(Increased Gasoline Price)

	Incremental Lifecycle Cost Per Mile			
Vehicle Type	**Base Case**	**Increased Gas Price**	**Difference**	**Percent**
2 Passenger				
MOA 2 Passenger, NiMH	$0.288	$0.288	$0.000	0.0%
MOA 2 Passenger, PbA	$0.219	$0.219	$0.000	0.0%
City EV, NiMH	$0.167	$0.167	$0.000	0.0%
City EV, PbA	$0.150	$0.150	$0.000	0.0%
HEV 2 Passenger	$0.100	$0.106	$0.005	5.3%
PZEV 2 Passenger	$0.075	$0.085	$0.009	12.4%
4 Passenger				
MOA 4 Passenger, NiMH	$0.270	$0.270	$0.000	0.0%
MOA 4 Passenger, PbA	$0.208	$0.208	$0.000	0.0%
Hybrid 4 Passenger	$0.108	$0.116	$0.008	7.7%
PZEV 4 Passenger	$0.083	$0.096	$0.012	15.0%
Pickup/fleet				
MOA Pickup/Fleet, NiMH	$0.275	$0.275	$0.000	0.0%
MOA Pickup/Fleet, PbA	$0.216	$0.216	$0.000	0.0%
Hybrid Pickup/Fleet	$0.114	$0.125	$0.011	9.4%
PZEV Pickup/Fleet	$0.099	$0.118	$0.019	18.8%

Table 8-9
2003 Vehicles
Alternative Scenario Cost Estimates
(Increased Electricity Price)

	Incremental Lifecycle Cost Per Mile			
Vehicle Type	**Base Case**	**Increased Elect. Price**	**Difference**	**Percent**
2 Passenger				
MOA 2 Passenger, NiMH	$0.288	$0.295	$0.007	2.5%
MOA 2 Passenger, PbA	$0.219	$0.224	$0.005	2.2%
City EV, NiMH	$0.167	$0.172	$0.005	2.9%
City EV, PbA	$0.150	$0.155	$0.005	3.4%
HEV 2 Passenger	$0.100	$0.100	$0.000	0.0%
PZEV 2 Passenger	$0.075	$0.075	$0.000	0.0%
4 Passenger				
MOA 4 Passenger, NiMH	$0.270	$0.280	$0.010	3.5%
MOA 4 Passenger, PbA	$0.208	$0.216	$0.008	4.1%
Hybrid 4 Passenger	$0.108	$0.108	$0.000	0.0%
PZEV 4 Passenger	$0.083	$0.083	$0.000	0.0%
Pickup/fleet				
MOA Pickup/Fleet, NiMH	$0.275	$0.285	$0.010	3.6%
MOA Pickup/Fleet, PbA	$0.216	$0.226	$0.010	4.5%
Hybrid Pickup/Fleet	$0.114	$0.114	$0.000	0.0%
PZEV Pickup/Fleet	$0.099	$0.099	$0.000	0.0%

8.8.2 Cost Estimates for Volume Production

This section presents cost calculations for volume production, once again for a base case and for an alternative scenario. The assumptions used are detailed in Cross-Cutting Assumptions and Vehicle Specific Assumptions above.

Base Case.

Results for the base case are shown in Table 8-10 below. The base case assumes battery life of 10 years for NiMH and 5 years for PbA, a pre-tax gasoline price of $1.26 per gallon, and an electricity price of $0.05 per kWh. Alternative scenarios follow that use the after-tax gasoline price of $1.75 and an increased electricity price of $0.075.

The first results listed in the Table 8-10 are for “standard vehicles”, which include PZEVs, HEVs, and what we describe as the “MOA 4 passenger” battery electric vehicle. The latter is a MOA type vehicle with minor efficiency improvements over today’s technology. The assumed efficiency of .380 kWh per mile is taken from the A.D. Little work on full fuel cycle vehicle energy efficiency. Staff is confident that this efficiency level would be achieved in vehicles brought to market in the volume production timeframe.

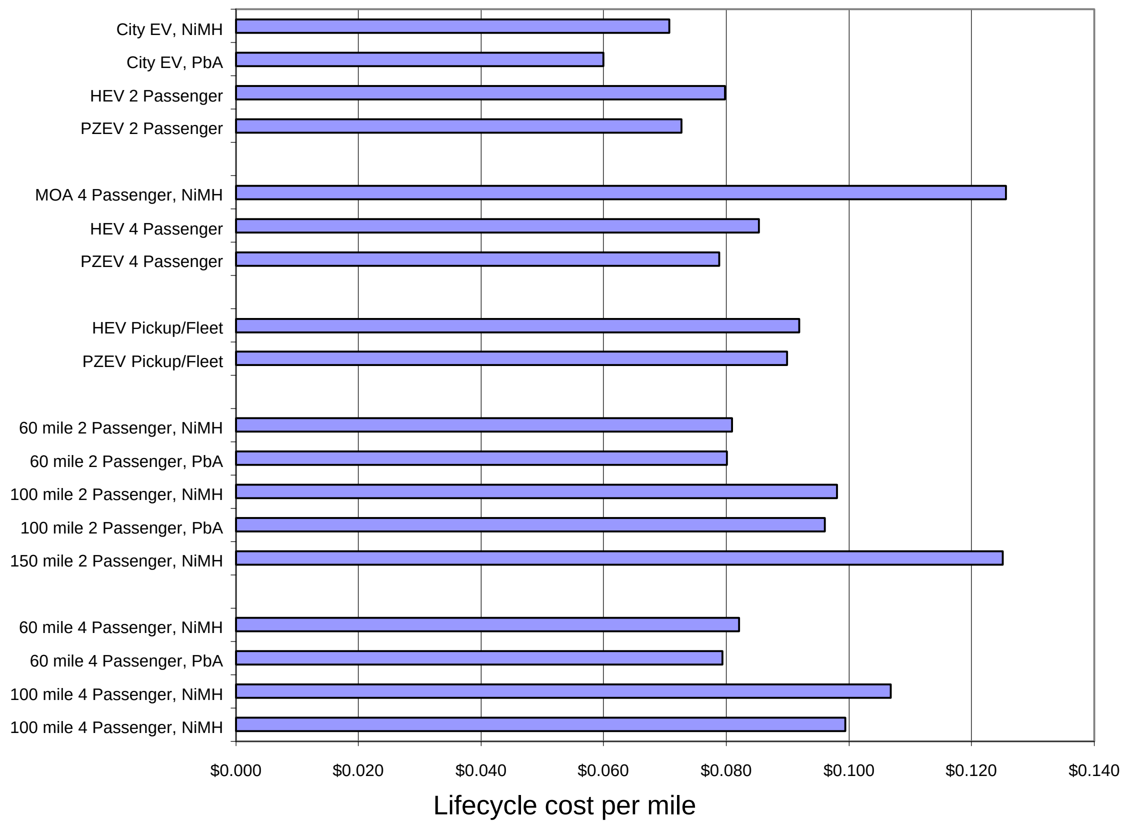
Following the results for the standard vehicles, Table 8-10 shows results for several configurations of high efficiency vehicles. As described in Section 8.3 above, the high efficiency vehicles are assumed to be 2nd or 3rd generation versions of OEM ZEVs with improvements over MOA-era vehicles in several of their efficiency-related attributes. These examples are provided in order to illustrate the effect of efficiency improvement and the resulting reduced battery pack size on vehicle initial cost and lifecycle cost.

Table 8-10
Volume Production Vehicles
Base Case Cost Estimates

Vehicle Type	Battery Type	Charger Cost	Initial Pack Cost	Vehicle Incremental Cost	Total Incremental Cost	Lifecycle Cost per Mile
(Standard Vehicles)						
2 Passenger						
City EV	NiMH	$750	$2,666	$0	$3,416	$0.071
City EV	PbA	$750	$731	$0	$1,481	$0.060
HEV 2 Passenger	NiMH	$0	$586	$500	$1,086	$0.080
PZEV 2 Passenger	NA	$0	$0	$500	$500	$0.073
4 Passenger						
MOA 4 Passenger	NiMH	$750	$9,230	$0	$9,980	$0.126
HEV 4 Passenger	NiMH	$0	$586	$500	$1,086	$0.085
PZEV 4 Passenger	NA	$0	$0	$500	$500	$0.079
Pickup/Fleet						
HEV Pickup/Fleet	NiMH	$0	$586	$500	$1,086	$0.092
PZEV Pickup/Fleet	NA	$0	$0	$500	$500	$0.090
(High Efficiency Vehicles)						
2 Passenger						
60 mile 2 Passenger	NiMH	$750	$2,989	$1,500	$5,239	$0.081
60 mile 2 Passenger	PbA	$750	$1,449	$1,500	$3,699	$0.080
100 mile 2 Passenger	NiMH	$750	$5,098	$1,500	$7,348	$0.098
100 mile 2 Passenger	PbA	$750	$2,553	$1,500	$4,803	$0.096
150 mile 2 Passenger	NiMH	$750	$8,438	$1,500	$10,688	$0.125
4 Passenger						
60 mile 4 Passenger	NiMH	$750	$4,336	$0	$5,086	$0.082
60 mile 4 Passenger	PbA	$750	$2,098	$0	$2,848	$0.079
100 mile 4 Passenger	NiMH	$750	$7,384	$0	$8,134	$0.107
100 mile 4 Passenger	NiMH	$750	$6,593	$0	$7,343	$0.099

Graph 8-2 displays the incremental lifecycle cost for these vehicles.

Graph 8-2
Volume Production Vehicles
Estimated Incremental Lifecycle Cost per Mile



Alternative Scenarios.

Next we present the results of two alternative scenarios. Similar to the alternative scenarios shown for 2003, these scenarios look at higher gasoline prices (using the nominal gasoline price of $1.75 per gallon rather than the pre-tax price of $1.26 per gallon) and higher electricity prices ($0.075 per kWh rather than $0.05 per kWh). Because in future volume production we already assume longer battery life, a separate alternative scenario for battery life is not needed. The results of these scenarios are presented in Tables 8-11 and 8-12.

As is shown in the tables below, the increased price of gasoline increases the lifecycle cost of the HEVs by some 6 to 10 percent, and increases lifecycle cost for the PZEVs by 11 to 17 percent. The increased price of electricity increases lifecycle cost for the battery electric vehicles by about 3 to 6 percent. These results are similar to those reported for the 2003 vehicles.

Table 8-11
Volume Production Vehicles
Alternative Scenario Cost Estimates
(Increased Gasoline Price)

	Incremental Lifecycle Cost Per Mile			
Vehicle Type	**Base Case**	**Increased Gas Price**	**Difference**	**Percent**
(Standard Vehicles)				
2 Passenger				
City EV, NiMH	$0.071	$0.071	$0.000	0.0%
City EV, PbA	$0.060	$0.060	$0.000	0.0%
HEV 2 Passenger	$0.080	$0.085	$0.005	5.9%
PZEV 2 Passenger	$0.073	$0.081	$0.008	11.4%
4 Passenger				
MOA 4 Passenger, NiMH	$0.126	$0.126	$0.000	0.0%
HEV 4 Passenger	$0.085	$0.092	$0.007	8.0%
PZEV 4 Passenger	$0.079	$0.090	$0.011	13.6%
Pickup/Fleet				
HEV Pickup/Fleet	$0.092	$0.101	$0.009	10.2%
PZEV Pickup/Fleet	$0.090	$0.105	$0.015	16.7%
(High Efficiency Vehicles)				
2 Passenger				
60 mile 2 Passenger, NiMH	$0.081	$0.081	$0.000	0.0%
60 mile 2 Passenger, PbA	$0.080	$0.080	$0.000	0.0%
100 mile 2 Passenger, NiMH	$0.098	$0.098	$0.000	0.0%
100 mile 2 Passenger, PbA	$0.096	$0.096	$0.000	0.0%
150 mile 2 Passenger, NiMH	$0.125	$0.125	$0.000	0.0%
4 Passenger				
60 mile 4 Passenger, NiMH	$0.082	$0.082	$0.000	0.0%
60 mile 4 Passenger, PbA	$0.079	$0.079	$0.000	0.0%
100 mile 4 Passenger, NiMH	$0.107	$0.107	$0.000	0.0%
100 mile 4 Passenger, NiMH	$0.099	$0.099	$0.000	0.0%

Table 8-12
Volume Production Vehicles
Alternative Scenario Cost Estimates
(Increased Electricity Price)

	Incremental Lifecycle Cost Per Mile			
Vehicle Type	**Base Case**	**Increased Elect. Price**	**Difference**	**Percent**
(Standard Vehicles)				
2 Passenger				
City EV, NiMH	$0.071	$0.074	$0.003	4.6%
City EV, PbA	$0.060	$0.063	$0.003	5.2%
HEV 2 Passenger	$0.080	$0.080	$0.000	0.0%
PZEV 2 Passenger	$0.073	$0.073	$0.000	0.0%
4 Passenger				
MOA 4 Passenger, NiMH	$0.126	$0.133	$0.007	5.9%
HEV 4 Passenger	$0.085	$0.085	$0.000	0.0%
PZEV 4 Passenger	$0.079	$0.079	$0.000	0.0%
Pickup/Fleet				
HEV Pickup/Fleet	$0.092	$0.092	$0.000	0.0%
PZEV Pickup/Fleet	$0.090	$0.090	$0.000	0.0%
(High Efficiency Vehicles)				
2 Passenger				
60 mile 2 Passenger, NiMH	$0.081	$0.085	$0.004	5.0%
60 mile 2 Passenger, PbA	$0.080	$0.083	$0.003	3.7%
100 mile 2 Passenger, NiMH	$0.098	$0.102	$0.004	4.0%
100 mile 2 Passenger, PbA	$0.096	$0.100	$0.004	4.1%
150 mile 2 Passenger, NiMH	$0.125	$0.129	$0.004	3.1%
4 Passenger				
60 mile 4 Passenger, NiMH	$0.082	$0.087	$0.005	5.9%
60 mile 4 Passenger, PbA	$0.079	$0.084	$0.005	5.7%
100 mile 4 Passenger, NiMH	$0.107	$0.112	$0.005	4.8%
100 mile 4 Passenger, NiMH	$0.099	$0.104	$0.005	4.6%

8.9 Discussion

This section provides an overview discussion of the cost results for the various scenarios, and also looks at the results for comparable-range lead acid and NiMH vehicles.

8.9.1 2003 Cost Estimates

For 2003, in all cases the incremental initial cost of battery electric vehicles is significantly greater than the incremental initial cost for similar configuration HEVs or PZEVs. The incremental initial cost varies from about $7,500 for City EVs (which have no directly comparable ICE vehicle) to more than $20,000 for freeway capable vehicles with NiMH batteries. By comparison the incremental initial cost is about $3,300 for HEVs and $500 for PZEVs.

On a lifecycle cost per mile basis similar results are obtained—the near-term EVs are significantly more expensive. Looking first at 2 passenger vehicles, the lowest cost is the PZEV at $0.075 per mile. The lowest cost EV is a PbA City EV, which at $0.15 per mile is twice the incremental cost. The freeway capable vehicles have higher costs still.

For 4 passenger vehicles, the NiMH and PbA MOA type vehicles have estimated incremental lifecycle costs of $0.27 and $0.208 per mile respectively. (Please note that these vehicles have different ranges (73 vs. 40 miles) so the costs are not directly comparable. The relative cost of comparable-range NiMH and PbA vehicles is discussed separately below). The cost per mile for the 4 passenger HEVs and PZEVs is estimated at $0.108 and $0.083.

The incremental lifecycle cost per mile for the 2003 EV fleet/pickup vehicles likewise significantly exceeds that of the HEV or PZEV alternatives.

Under alternative scenarios, we assume longer battery life and higher gasoline prices. In that instance, the cost gap narrows. Even with both of these factors taken into account, however, the 2003 battery vehicles are estimated to have a significantly higher lifecycle cost per mile than their conventional counterparts. An increased price of electricity slightly increases the battery vehicle cost premium.

8.9.2 Volume Production Cost Estimates

For future, optimized volume production a different picture emerges. Incremental cost for the EVs is reduced significantly, ranging from about $1300 for a PbA City EV to about $10,000 for a 150 mile freeway capable vehicle. This stems from a reduction in per module battery cost, reduced pack sizes due to more efficient vehicle design, and elimination of the incremental cost associated with the rest of the vehicle.

The estimated incremental lifecycle cost per mile is heavily dependent on the assumed efficiency of the vehicle. The “base case” MOA type four passenger vehicle, which assumes only modest efficiency improvement over today’s vehicles, has an estimated incremental lifecycle cost per mile of $0.126. This is about 60 percent more expensive than the 4 passenger PZEV at $0.079.

If, however, vehicles are built with the efficiency improvements assumed in the other vehicles considered, then several of the battery EVs are roughly comparable to PZEVs on a lifecycle cost basis. For example, in our base case analysis the NiMH and PbA versions of the 2 passenger 60 mile vehicle are \$0.081 and \$0.080 per mile respectively, while the PZEV is \$0.073. The 2 passenger 100 mile vehicles are \$0.098 and \$0.096 per mile for NiMH and PbA, roughly 35 percent more expensive than the PZEV. The 4 passenger 60 mile EVs are \$0.082 per mile for NiMH and \$0.079 for PbA and the 4 passenger 100 mile EVs are \$0.107 and \$0.099 per mile, while the PZEV is \$0.079. The City EVs, at \$0.071 and \$0.060 per mile, are the least expensive of all vehicles considered in the volume production scenario.

Under an alternative scenario, which considers the after-tax gasoline price actually paid by consumers, the lifecycle cost of the 60 mile freeway capable vehicles is equal to or in some cases less than the lifecycle cost of the similar conventional vehicle.

Thus using optimistic but nevertheless plausible assumptions, in volume production the battery EVs could become cost-competitive with conventional vehicles on a lifecycle cost per mile basis.

8.9.3 NiMH Compared to Lead-Acid

In those cases where PbA and NiMH vehicles with the same range are compared, the PbA vehicles have a very minor cost advantage. Table 8-13 below shows the base case cost for three comparable vehicle types, in volume production.

Table 8-13
Incremental Lifecycle Cost per Mile
Same-Range NiMH and PbA Vehicles

Vehicle	**Battery Type**	**Lifecycle Cost per Mile**
60 mile 2 passenger	NiMH	.081
	PbA	.080
100 mile 2 passenger	NiMH	.098
	PbA	.096
60 mile 4 passenger	NiMH	.082
	PbA	.079

In the 2003 calculations, the PbA vehicles are less expensive than the similar NiMH vehicles on both an initial cost and a lifecycle cost basis. However, in these instances the PbA vehicles and the NiMH vehicles are not directly comparable because the NiMH vehicles have greater range.

8.9.4 Relative Significance of Various Factors

Staff has performed a limited “sensitivity analysis” to identify how changes in the various assumptions for EVs affect the net present value cost per mile.

Assuming that vehicle performance is held constant, vehicle efficiency has the greatest impact on net present value cost per mile. This is because increased vehicle efficiency allows the use of a smaller battery pack to achieve a given range, and also results in lower fuel costs. For example, in volume production a 50 percent increase in vehicle efficiency, if used to reduce battery pack size by 50 percent, results in about a 50 percent reduction in net present value cost per mile. (The exact magnitude of the change varies according to the starting assumptions used). This example does not consider “second-order” effects, such as the further increase in range made possible by a lighter vehicle weight, which would allow a still smaller battery pack. Such iterative improvements would increase the overall benefit of efficiency gains. In 2003 the impact of a similar efficiency improvement is somewhat diluted, to about 30 percent, due to the large fixed cost associated with vehicle components.

The parameters associated with battery cost also have a significant impact. For example, in volume production a 50 percent increase in battery cost per module results in roughly a 30 percent increase in the net present value cost per mile. Once again the impact is reduced in 2003, to about 16 percent, due to the effect of vehicle incremental cost. Battery life also is important. As was shown in Table 8-7 above, increasing the assumed NiMH battery life from 6 to 10 years results in about a 15 percent reduction in net present value cost per mile. Increasing the assumed life for PbA from 3 to 5 years likewise reduces net present value cost per mile by about 15 percent.

The only other factor with a significant effect is EV incremental cost. Increasing the assumed EV incremental cost by $3,000 results in about an 8 percent increase in net present value cost per mile in 2003, and a 20 percent increase in volume production. Maintenance cost has an intermediate impact. A 50 percent increase in assumed maintenance cost results in roughly a 5 percent increase in net present value cost per mile in 2003 and 12 percent in volume production. The remaining parameters (battery salvage value, electricity cost, inflation rate, discount rate) all have a relatively minor impact.

8.9.5 Conclusions

This section presents incremental cost estimates for a wide variety of vehicle types. For 2003, battery EVs are significantly more expensive than conventional vehicles on both an initial and lifecycle cost basis. This holds true even under alternative scenarios with increased battery life and increased gasoline price.

For volume production, the base case MOA type vehicle is about 60 percent more expensive on a lifecycle cost per mile basis than a comparable PZEV. Highly efficient BEVs, however, can be comparable to conventional vehicles on a lifecycle cost basis.

When volume production NiMH and PbA vehicles with the same range are compared, the PbA vehicles have a very slight cost advantage.

9 ENVIRONMENTAL, ENERGY AND ECONOMIC BENEFITS

9.1 Introduction

ZEVs have the capability to provide comprehensive environmental, energy and societal benefits. As noted above, ZEVs are the “gold standard” with respect to reducing emissions of smog forming pollutants. ZEVs also provide reductions in the emissions of toxic air contaminants from motor vehicles. High-efficiency ZEVs and hybrid electric near-ZEVs also will result in significant reductions in emissions of CO_2 and other greenhouse gases. Vehicles powered by grid electricity will increase the diversity of California’s fuel supply and reduce our dependence on imported oil. Electric drive vehicles have the potential to be powered by renewable sources of energy such as wind, hydropower, or solar energy. ZEVs also can benefit California’s economy as well as our public health. Because of their high-technology leadership, California companies have the technical and scientific capability to play a significant role in the design, development and production of advanced technology zero emission components and vehicles.

Participants at both public workshops urged that staff fully consider a wide range of environmental benefits from ZEVs. From an air quality standpoint, they recommended additional focus on “real world” emissions, which they contend can be higher than the estimates provided by ARB emission models. They also recommended full consideration of upstream emissions (emissions from refining, transport and refueling) for gasoline vehicles, and a similar emphasis on toxic emissions. They noted that toxic emissions from motor vehicles, fueling infrastructure and refining can have a disproportionate impact on nearby populations, and stated that ARB should recognize the resulting environmental justice implications. Finally, they asked staff to fully consider the CO_2 emissions from internal combustion vehicles and the resulting contribution to global climate change.

Commenters also asked that staff consider multimedia environmental impacts, such as the damage to water quality caused by leaking underground fuel tanks. Commenters also urged ARB to pay attention to the energy diversity implications of different fuel choices. This chapter addresses these issues and quantifies to the extent possible the relative environmental impacts of ZEVs.

9.2 Air Quality Benefits

Due to the ever-increasing growth in vehicle miles traveled, new, extremely clean vehicle technologies are necessary if California is to meet health-based air quality standards. This section documents the need for further improvements, then discusses the air quality impacts that result from the use of electric and other vehicle technologies in the South Coast Air Basin. Information is presented for smog precursors, toxic air contaminants, and carbon dioxide.

This complete analysis of vehicle emissions covers both direct and indirect emissions on a per vehicle basis and for the vehicle fleet as a whole. The information is drawn from two main data sources. The ARB EMFAC2000 motor vehicle emission inventory provides the basis for estimates of direct emissions at both the individual vehicle and the fleet level. Please note that the evaporative emission results reflect revisions to the evaporative model to reflect new data and analysis not included in the published version. Staff will be seeking Board approval for these minor revisions.

Our estimates of per vehicle indirect emissions are based on contract work performed by A.D. Little (formerly Acurex Environmental). The fleet-wide indirect emission estimate uses both sources--per vehicle indirect estimates from A.D. Little are multiplied by fleet activity estimates taken from the emission inventory.

9.2.1 The Need for Air Quality Improvements

Although significant strides have been made toward improving California's air quality, health-based state and federal air quality standards continue to be exceeded in regions throughout California. Areas exceeding the federal 1-hour ozone standard include the South Coast Air Basin, San Diego County, the San Joaquin Valley, the Southeast Desert, the Broader Sacramento area and Ventura County. With promulgation of the new federal eight-hour ozone standard, more areas of the State are likely to be designated as nonattainment.

Ozone, created by the photochemical reaction of reactive organic gases and oxides of nitrogen, leads to harmful respiratory effects including lung damage, chest pain, coughing, and shortness of breath, especially affecting children and persons with compromised respiratory systems. Other environmental effects from ozone include agricultural crop damage. In addition, because ozone precursors, such as NOx, also react in the atmosphere to form particulate matter (PM), reductions in NOx will be crucial to meet existing state and federal PM_{10} standards, as well as the new federal standards for fine particulate matter ($PM_{2.5}$). Thus, even though direct emissions of particulate matter are negligible for both EVs and gasoline vehicles, reductions in NOx brought about by EVs will help address the particulate matter problem. Toxic air contaminants are substances that may cause or contribute to an increase in cancer or serious illness, such as respiratory disease. The sources of toxic emissions include many products, services, industrial processes, and motor vehicles. The high potential of the ZEV program to reduce toxic emissions, and a focus on ARB's mission to promote and protect public health, are an impetus for ARB staff to begin quantifying the releases of toxic air contaminants from various vehicle technologies.

California's plan for achieving the federal 1-hour ozone standard is contained in the California State Implementation Plan (SIP) that was approved by the Board in 1994. A significant part of the SIP pertains to the control of mobile sources, which are estimated to account for approximately 60 percent of ozone precursors statewide. The SIP calls for new measures to cut ozone precursor emissions from mobile sources to half of what the emissions would be under existing regulations. Specific control measures to reduce emissions from most types of motor vehicles, including light duty vehicles, are included in the SIP. The SIP calls for additional motor vehicle emission reductions in the South Coast Air Basin of approximately 75 tons per day reactive organic gases (ROG) plus NOx (these emission reductions are referred to as the mobile source “Black Box”). Specific approaches to fully achieve these additional emission reductions have not yet been identified.

One purpose of the ZEV program is to address the requirements of California’s SIP by introducing advanced technology measures to achieve additional emission reductions needed for the South Coast Air Basin. The reductions will help ensure continued statewide progress toward meeting state and federal air quality standards for ozone and particulate matter. The ZEV program will help achieve and maintain the federal one-hour ozone standard in regions such as the San Joaquin Valley and the Sacramento area, the federal eight-hour ozone and particulate matter standards in a number of areas, and the State ozone and particulate matter standards throughout California.

9.2.2 Per Vehicle Emissions

This section compares the direct and indirect emissions, at the per vehicle level, that result from several different vehicle technologies. Information is presented here for NMOG, NOx, and toxic air contaminants. (CO_2 emissions are discussed in Section 9.4 below.) ARB recognizes the importance of including toxic air contaminants when evaluating motor vehicle emission impacts. Various interested parties emphasized this need during both public workshops.

Historically, when assessing the impact of motor vehicles and developing regulations, the ARB only evaluated direct vehicle emissions. The introduction of the ZEV requirement in 1990 brought a fundamental change in the way vehicle technologies are compared due to the shift in emissions away from the vehicle. Any comparison of ZEV technology with conventional vehicles must include both direct and indirect emissions (e.g. power plant emissions associated with a battery electric vehicle, and refinery and refueling emissions from gasoline vehicles) to accurately assess a vehicle’s overall environmental impact.

While ARB staff recognizes that the vehicles analyzed would be used throughout California, all comparisons are restricted to the South Coast Air Basin. Due to the information available, this provides the fairest possible comparison.

Vehicle Technologies Evaluated

In comparing per-vehicle direct and indirect emissions, ARB staff has included several vehicle technologies that could be available to meet the ZEV requirements in 2003. These technologies represent a plausible mix of vehicles for 2003 (auto manufacturers have indicated that they plan to produce a combination of gasoline-fueled vehicles and battery electric vehicles to meet the early ZEV requirements). The vehicle types evaluated include:

- Battery electric vehicle
- Gasoline vehicle eligible for 0.2 partial ZEV allowance (PZEV SULEV)
- Gasoline non-grid connected HEV eligible for 0.3 partial ZEV allowance (PZEV HEV non-grid)
- Non-PZEV SULEV vehicle (SULEV)
- Non-PZEV SULEV vehicle with higher in-use deterioration (SULEV with high LEV II deterioration rates)
- Average model year 2002 vehicle (MY 2002 vehicle)

Direct Emissions

Direct emissions include tailpipe and evaporative emissions from the vehicle itself. EMFAC2000 was used to provide the average lifetime direct emissions of NMOG and NOx. As noted above, the evaporative results presented here reflect revisions to the published version. Table 9-1 provides the direct emissions that result from each vehicle technology, presented on a gram per mile basis. As is shown in Table 9-1, BEVs are truly the "gold standard" for direct emissions.

Table 9-1
Estimated Direct Emissions Per Vehicle
(Tailpipe and Evaporative)

Vehicle Type	Tailpipe (g/mi)			Evaporative (g/mi)	
	NMOG	NOx	Toxics	NMOG	Toxics
BEV	0	0	0	0	0
PZEV SULEV	0.0067	0.024	0.0025	0.020	0.0007
PZEV HEV non-grid	0.0067	0.024	0.0025	0.020	0.0007
SULEV	0.0073	0.025	0.0027	0.032	0.0011
SULEV with LEV II DR	0.0150	0.030	0.0056	0.032	0.0011
MY 2002 vehicle	0.0620	0.173	0.0230	0.049	0.0016

Indirect Emissions

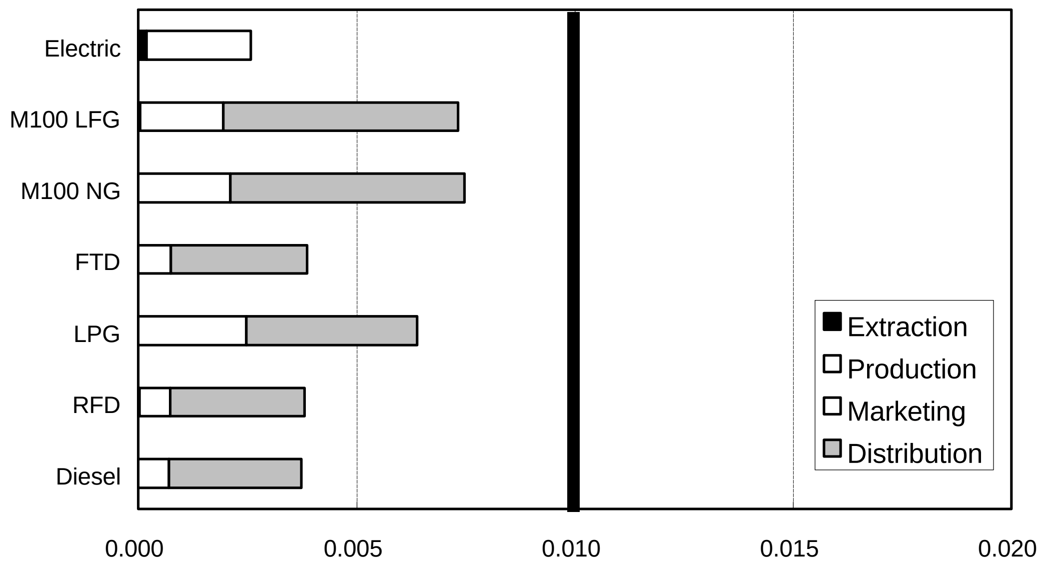
As direct emissions from motor vehicles are reduced, the indirect emissions that result from vehicle refueling, fuel transportation, fuel processing, and feedstock extraction represent a larger share of the total emissions that are attributed to vehicle operation. To quantify these indirect emissions, ARB contracted with

Acurex Environmental in 1993 (now part of A. D. Little) to examine the full fuel cycle emissions for a variety of fuels. The final report, entitled "Evaluation of Fuel-Cycle Emissions on a Reactivity Basis," was completed in September 1996. The fuels evaluated included conventional gasoline, Phase 2 reformulated gasoline, diesel, liquefied petroleum gas (LPG), methanol from natural gas, M85 from biomass, ethanol, compressed natural gas, liquefied natural gas, hydrogen, and electricity.

In November 1998, the ARB adopted the LEV II regulations that, in part, allow vehicles that use fuels with extremely low fuel-cycle emissions to receive an additional ZEV allowance of up to 0.2. As noted above, the fuel-cycle emissions upon which this ZEV allowance is based include all emissions associated with the production, marketing, and distribution of a fuel. To receive this additional partial ZEV credit, the marginal NMOG emissions associated with a fuel used by a vehicle must be lower than or equal to 0.010 grams per mile. The results of the Acurex report were used to determine whether a vehicle using a certain fuel is eligible to receive additional credit toward the ZEV requirement.

To refine the results for several fuels that were found to have NMOG emissions not significantly above or below the 0.010 grams per mile cutpoint, the ARB again contracted with the same consultants, now part of A.D. Little, in 1999. The objective of this study was to refine the emissions estimates on a per-vehicle-mile basis for diesel fuel and LPG for internal combustion vehicles, and methanol for fuel cell powered vehicles. As shown in Figure 9-1, the marginal NMOG emissions for each of the fuels evaluated is lower than 0.010 grams per mile. Consequently, vehicles using these fuels and meeting the applicable partial ZEV requirements would received the additional ZEV allowance of 0.2.

Figure 9-1
Marginal NMOG Emissions in the South Coast



M100 LFG: Methanol from landfill gas
M100 NG: Methanol from natural gas
FTD: Fischer-Tropsch diesel
LPG: Liquefied petroleum gas
RFD: Reformulated diesel

Table 9-2 provides estimates of the indirect emissions for the vehicle technologies examined above. The emission estimates in Table 9-2 represent the marginal emissions expected in the South Coast Air Basin (SCAB) in 2010. Of the three scenarios presented in the 1996 A.D. Little report that evaluated the marginal emissions in the SCAB in 2010, ARB staff chose to include the middle estimates in Table 9-2. The report did not assess vehicle exhaust emissions (other than CO_2 which is proportional to fuel consumption) or vehicle evaporative emissions.

Table 9-2
Estimated Indirect Emissions Per Vehicle
South Coast Air Basin in 2010

Vehicle Type	Fuel Cycle (g/mi)		
	NMOG	NOx	Toxics1
BEV	0.0020	0.003	0.0010
PZEV SULEV	0.0310	0.016	0.0060
PZEV HEV non-grid	0.0210	0.011	0.0040
SULEV	0.0310	0.016	0.0060
SULEV with LEV II DR	0.0310	0.016	0.0060
MY 2002 vehicle	0.0310	0.016	0.0060

1. Toxic weighting: Formaldehyde 1.0; Acetaldehyde 0.5; Benzene 4.8; 1,3 Butadiene 28.0

As Table 9-2 shows, per vehicle indirect emissions from BEVs are significantly lower than the indirect emissions from all other vehicle technologies evaluated. NMOG emissions are reduced by at least a factor of 10, NOx emissions are reduced by more than two-thirds, and toxic emissions are reduced by nearly three-quarters.

<u>Total Emissions</u>

Table 9-3 below presents the estimated total (direct plus indirect) per-vehicle emissions that result from the operation of the various vehicle types.

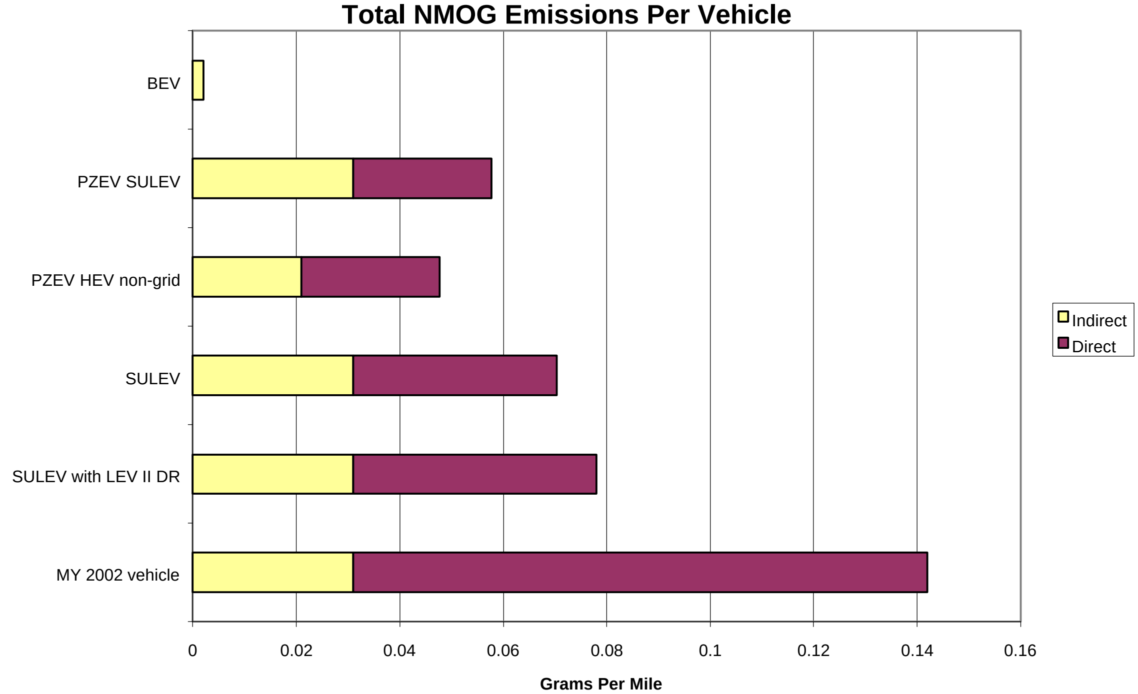
Table 9-3
Total Emissions Per Vehicle
(Grams per mile)

Vehicle Type	NMOG	NOx	Toxics
BEV	0.0020	0.003	0.0010
PZEV SULEV	0.0577	0.040	0.0092
PZEV HEV non-grid	0.0477	0.035	0.0072
SULEV	0.0703	0.041	0.0098
SULEV with LEV II DR	0.0780	0.046	0.0127
MY 2002 vehicle	0.1420	0.189	0.0306

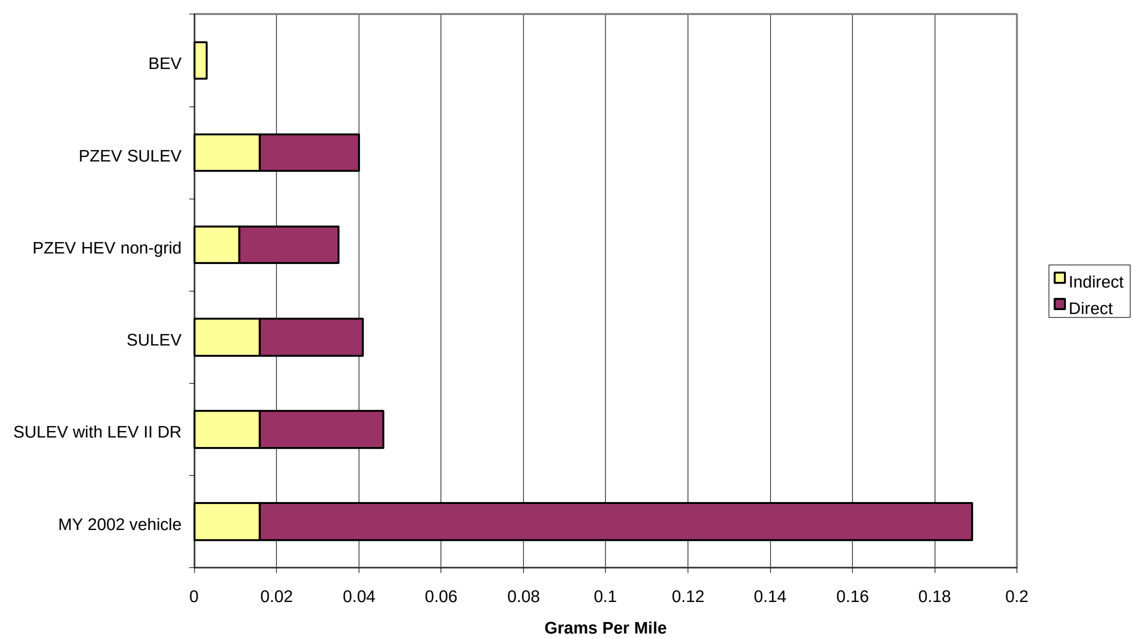
As Table 9-3 illustrates, taking into account both direct and indirect emissions, the per-vehicle emission reductions associated with BEVs are even more dramatic and occur across all pollutants. NMOG emissions are about 96 percent lower than those from the cleanest gasoline vehicle, NOx emissions are about 91 percent lower, and toxic emissions are reduced by more than 86 percent.

Graphs 9-1 through 9-3 show this information in graphic form.

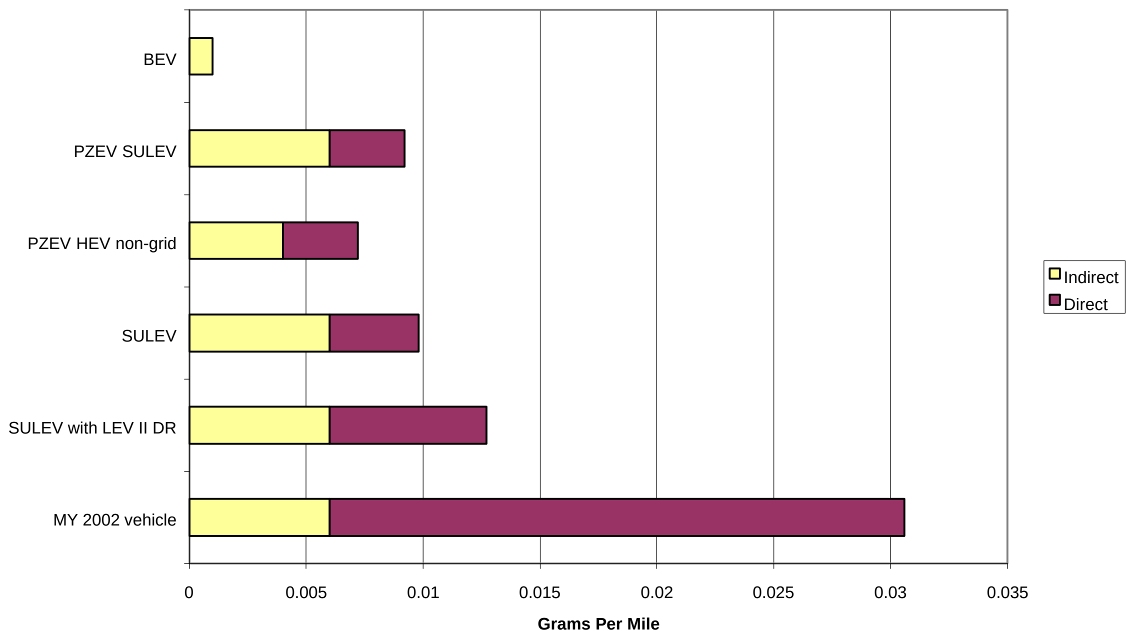
Graph 9-1
Total NMOG Emissions Per Vehicle



Graph 9-2
Total NOx Emissions Per Vehicle



Graph 9-3
Total Air Toxics Emissions Per Vehicle



9.2.3 Fleet-Wide Emissions

To assess and update the fleet-wide emissions benefit of the current ZEV program, ARB staff conducted an emissions impact analysis using the updated on-road emissions inventory model, EMFAC2000. The ARB approved this version of the model on May 25, 2000. As noted above, the evaporative results presented here reflect changes from the published version. The results of the analysis represent various implementation scenarios in the South Coast Air Basin and include the emissions from passenger cars and light-duty trucks weighing less than 3,501 pounds gross vehicle weight.

<u>2010 Scenarios</u>

The analysis compares the emissions from three potential scenarios to a baseline scenario. These scenarios quantify the 2010 emissions in the South Coast Air Basin from light-duty vehicles sold in the years 2003 through 2010. Older vehicles are excluded from this calculation.

- The baseline scenario examines the emissions that would result if no pure ZEVs are sold. Instead, the overall fleet average standard is met with a mix of conventional vehicles.

- Scenario 1 assumes that 10 percent of all vehicles sold during the 2003 to 2010 timeframe are pure ZEVs. Thus in this scenario there are no “multipliers” for vehicle range.

- Scenario 2 represents the introduction of fewer ZEVs (less than 10 percent). This scenario assumes that the average ZEV has an all-electric range of 125 miles. Current regulations provide additional credit for vehicles that have more than 100 miles of all-electric range through model year 2007. The 125 mile range assumption decreases the number of vehicles placed to 3.3 percent from 2003 through 2005, 6.7 percent in 2006 and 2007, and 10 percent in 2008 through 2010.

- Scenario 3 assumes that automakers meet the 4 percent pure ZEV requirement with electric vehicles having an average range of 125 miles (thus reducing the numbers of vehicles required) and the remaining 6 percent requirement with PZEV technologies.

Direct Emissions. Table 9-4 provides estimates of direct fleet-wide tailpipe and evaporative vehicle emissions for the scenarios described above.

Table 9-4
Direct Vehicle Emissions
South Coast Air Basin in 2010
(Tons per day)*

Scenario	ROG Exhaust	ROG Evap	NOx	Total ROG+NOx
Baseline--No ZEVs	4.45	3.67	12.82	20.94
1. 10% ZEVs, no multipliers	4.33	3.30	11.82	19.45
2. 10% ZEVs, with multipliers	4.35	3.47	12.20	20.02
3. 4% ZEVs, 6% PZEVs, with multipliers	4.28	3.42	11.53	19.23

*Estimates include only those vehicles sold in model-years 2003 to 2010; other vehicles excluded

Table 9-5 below presents the reduction in emissions for each scenario as compared to the baseline. As shown in Table 9-5, the reduction in total emissions for each scenario ranges from 0.92 to 1.71 tons per day. Staff notes that scenario 3 (4 percent ZEVs, 6 percent PZEVs, with multiple credits) actually results in greater emission reductions than scenario 2 (10 percent ZEVs, with multiple credits). This does not mean that PZEVs are cleaner than ZEVs. As was shown above, ZEVs are dramatically cleaner on a per-vehicle basis. Rather, these scenario results show the effect of large numbers of PZEVs replacing “fleet average” vehicles. Because PZEVs only generate 0.2 ZEV credit, at least 5 PZEVs are needed to offset 1 ZEV. In addition, because a 125 mile ZEV generates 2.67 credits per vehicle in 2003, each 2003 ZEV is the equivalent of 13 PZEVs (5 x 2.67). Thus reducing the number of ZEVs results in the need for large numbers of PZEVs, which replace vehicles that otherwise would have higher emission levels.

The consistency of the fleet totals across the various scenarios reflects the truly remarkable conventional vehicle emission reductions that have been achieved to date and are projected for the future, in particular as a result of the LEV II regulations.

Table 9-5
Reduction in Direct Vehicle Emissions As Compared to Baseline
South Coast Air Basin in 2010
(Tons per day)*

Scenario	ROG Exhaust	ROG Evap	NOx	Emission Reductions
1. 10% ZEVs, no multipliers	0.12	0.37	1.00	1.49
2. 10% ZEVs, with multipliers	0.10	0.20	0.62	0.92
3. 4% ZEVs, 6% PZEVs, with multipliers	0.17	0.25	1.29	1.71

* Estimates include only those vehicles sold in model-years 2003 to 2010; other vehicles excluded

The estimates in Table 9-5 provide a comparison of direct vehicle emissions and their overall fleet impact. As was noted above, the emission reductions for scenario 3 are similar to scenario 1 and greater than scenario 2 due the high number of PZEVs (30 percent of total production) required to meet the 6 percent ZEV requirement.

<u>Indirect and Total Emissions</u>. To provide a comprehensive evaluation of the benefits of the ZEV program, these emissions must be added to the indirect emissions quantified by A.D. Little. Table 9-6 presents total (direct plus indirect) emissions for the three scenarios compared to the baseline. As shown in Table 9-6, due to upstream emissions, the total emissions from the baseline scenario are 27.45 tons per day in the South Coast Air Basin.

Table 9-6
Total Fleet Emissions
South Coast Air Basin in 2010
(Tons per day)*

Scenario	ROG Exhaust	ROG Evap	ROG Upstream	NOx	NOx Upstream	Total ROG+NOx
Baseline--No ZEVs	4.45	3.67	4.29	12.82	2.22	27.45
1. 10% ZEVs, no multipliers	4.33	3.30	3.89	11.82	2.04	25.38
2. 10% ZEVs, with multipliers	4.35	3.47	4.01	12.20	2.09	26.12
3. 4% ZEVs, 6% PZEVs, with multipliers	4.28	3.42	4.18	11.53	2.16	25.57

* Estimates include only those vehicles sold in model-years 2003 to 2010; other vehicles excluded

Table 9-7 below presents the emission reduction for each scenario as compared to the baseline. As is shown in the table, scenarios 1, 2 and 3 result in emission reductions of 2.07, 1.33 and 1.88 tons per day respectively as compared to the baseline.

Table 9-7
Reduction in Total Vehicle Emissions As Compared to Baseline
South Coast Air Basin in 2010
(Tons per day)*

Scenario	ROG Exhaust	ROG Evap	ROG Upstream	NOx	NOx Upstream	Total ROG+NOx
1. 10% ZEVs, no multipliers	0.12	0.37	0.40	1.00	0.18	2.07
2. 10% ZEVs, with multipliers	0.10	0.20	0.28	0.62	0.13	1.33
3. 4% ZEVs, 6% PZEVs, with multipliers	0.17	0.25	0.11	1.29	0.06	1.88

* Estimates include only those vehicles sold in model-years 2003 to 2010; other vehicles excluded

In public comments, automakers have stated that the air quality benefits of the ZEV program are relatively minor. Staff recognizes that in the near term, due to the small amount of ZEV penetration and the significant improvement in conventional vehicle emissions resulting from LEV II, fleet-wide benefits are modest. To place these emissions reductions in context, however, it is important to note that on a per-vehicle basis ZEVs are significantly cleaner than even the cleanest conventional alternative. Thus, they offer great potential for significant emission reductions over time, as large numbers of ZEVs enter the fleet. The next section explores this issue in more detail.

Long-Term Scenario (2020)

As discussed above, new vehicle technologies are necessary if California is to meet health-based air quality standards. When the ZEV program was adopted in

1990, the intent of the Board was to provide the regulatory push needed for environmentally beneficial technologies to compete in a mature and extremely competitive industry. Even then, the Board and staff acknowledged that for the program to have a significant contribution in helping California meet state and federal air quality standards, much larger percentages of vehicles introduced must be ZEVs. In keeping with this vision, staff modeled the emission benefits that would result in 2020 if 50 percent of all passenger and light-duty vehicles on the road in 2020 were ZEVs. Scenario 4 assumes a ZEV ramp-up beginning in 2003 and further assumes that automakers produce 25% SULEVs during the 2010 to 2020 timeframe, regardless of the NMOG fleet average standard.

Note that these estimates are for direct vehicle emissions only, and do not include upstream emissions. Staff does not have information to support an upstream emission analysis at this time. As was shown for 2010 fleet emissions, however, upstream emissions have a sizable impact on the total. Therefore the results shown here are conservative and do not fully account for all ZEV benefits.

Table 9-8 presents the results of this scenario, along with estimates of the 2020 emissions for the three scenarios discussed above. These results illustrate the importance of pursuing a future in which California fundamentally changes the technology used for personal transportation.

Table 9-8
Direct Fleet Emissions in 2020*
South Coast Air Basin
(Tons per day)*

Scenario	ROG Exhaust	ROG Evap	NOx	Total ROG+NOx
Baseline--No ZEVs	6.73	14.86	17.02	38.61
1. 10% ZEVs, no multipliers	6.44	13.38	15.34	35.16
2. 10% ZEVs, with multipliers	6.43	13.72	15.54	35.69
3. 4% ZEVs, 6% PZEVs, with multipliers	6.41	13.55	15.18	35.14
4. 50% ZEV fleet penetration	4.37	11.80	10.69	26.86

* Estimates include only those vehicles sold in model-years 2003 to 2020; other vehicles excluded

Table 9-9 below presents the difference in emission benefits for each scenario as compared to the baseline.

Table 9-9
Reduction in Direct Vehicle Emissions As Compared to Baseline
South Coast Air Basin in 2020
(Tons per day)*

Scenario	ROG Exhaust	ROG Evap	NOx	Total ROG+NOx
1. 10% ZEVs, no multipliers	0.29	1.48	1.68	3.45
2. 10% ZEVs, with multipliers	0.30	1.14	1.48	2.92
3. 4% ZEVs, 6% PZEVs, with multipliers	0.32	1.31	1.84	3.47
4. 50% ZEV fleet penetration	2.36	3.06	6.33	11.75

* Estimates include only those vehicles sold in model-years 2003 to 2020; other vehicles excluded

As is shown in Table 9-9, the total NMOG plus NOx benefit of Scenario 4 when compared to the "no ZEV" baseline scenario is 11.75 tons per day in the South Coast. This is a reduction of more than 30 percent from the baseline level, illustrating the gains that are possible with significant levels of ZEV introduction.

9.2.4 Community Level Impacts

At the public workshops, commenters also urged that staff consider the environmental justice implications of toxic emissions from motor vehicles and refineries. Staff recognizes that mobile source pollution from highway traffic may disproportionately affect nearby inner city and low-income neighborhoods. For example, the Multiple Air Toxics Exposure Study conducted in the South Coast Air Basin found that mobile sources were the greatest contributor to carcinogenic risk in the basin. At sites with the greatest risk levels, the dominance of mobile sources was even greater than at the other sites. Refineries and other production and distribution facilities may have similar effects on nearby communities. Reductions in toxic emissions from motor vehicles and related fueling infrastructure can thus help address community level public health concerns.

The Board has recently announced the formation of a new Community Health Program to address how exposure to numerous air toxic sources affects specific neighborhoods. For the first time, the ARB will address strategies to reduce the cumulative effects of exposure from multiple sources of air toxics.

9.3 Releases to Other Environmental Media

Above and beyond their air pollution benefits, ZEVs can make significant positive contributions in other environmental areas. Just as the gasoline refining, marketing and distribution system results in air pollution emissions, it likewise results in water pollution due to fuel leakage and wastewater discharges, and is a source of hazardous waste.

The fuel distribution system in California is tightly regulated. Nevertheless, given the enormous quantities of fuel involved (roughly 40 million gallons of gasoline sold per day in California) it is inevitable that leakage occurs. The impact of such leaks can be significant.

One example is the contamination of groundwater by leaking underground storage tanks. Certainly the most well known recent case involves the contamination of drinking water supplies by MTBE. It is important to bear in mind, however, that in addition to MTBE gasoline contains numerous other toxic compounds, including benzene, toluene, and 1,3 butadiene. Therefore the removal of MTBE from gasoline will not eliminate the danger of water pollution from fuel leakage.

In addition to the threat posed by leaking storage tanks, the fuel distribution system also introduces water pollution in the form of point source discharges from refineries. According to figures reported by industry as part of the annual Toxic Release Inventory (TRI) program, there are 22 facilities in California that fall under Standard Industrial Classification Code 2911, petroleum refining. For the 1998 reporting year, 10 of these 22 facilities reported discharges to surface water, totaling more than 7.3 million pounds. Chemicals released included nitrate compounds, MTBE, and methanol. In that same reporting year, 13 of the 22 facilities reported releases to publicly owned treatment works (wastewater treatment facilities). Chemicals released included phenol, MTBE and methanol, and total releases were almost 1.5 million pounds.

The fuel production and distribution system also results in the generation of hazardous waste. According to manifest data from the Department of Toxic Substances Control, the 22 refineries noted above generated more than 103,000 tons of hazardous waste in 1998.

Because the use of battery electric vehicles and hybrid electric vehicles reduces gasoline demand, widespread adoption of these technologies would have a positive impact on water quality and hazardous waste generation.

Although not directly related to the fuel distribution system, motor oil from internal combustion engine vehicles is also a significant source of water pollution. Motor oil contains polycyclic aromatic hydrocarbons (PAHs), which are a major water toxicity problem in urban areas. Motor oil is released to the environment during the normal operation of internal combustion engine vehicles, and also when used motor oil is improperly disposed. Electric vehicles do not need motor oil and therefore do not contribute to this problem.

9.4 Energy Diversity and Energy Demand Benefits

Reducing demand for gasoline can have important benefits for California. First, a reduction in demand could help eliminate shortages of cleaner-burning California gasoline that have lead to rapid price increases. Second, a successful effort to reduce gasoline demand also would reduce the need for additional refining, transportation and distribution facilities, thus reducing air and water pollution as noted above.

The Task Force on California Gasoline Prices, convened by the Attorney General, recently examined gasoline supply and demand issues as they relate to gasoline price increases. The Attorney General, in his comments on the Task Force work, noted that high gasoline prices erode the competitiveness of California's industries and reduce the real income of our citizens.

Gasoline demand can be reduced by increasing the efficiency with which gasoline is used, and by the use of alternative fuels. Advanced vehicle design, lightweight components, aerodynamic advances and the use of electric drivetrains all result in increased vehicle efficiency. EVs and hybrid electric vehicles typically take advantage of such measures and, as a result, achieve higher efficiencies. Battery EVs, which use electricity as a fuel, provide significant alternative fuel benefits because electricity can be produced from a variety of non-petroleum energy resources. Moreover, because both electricity and hydrogen can be produced from renewable resources such as solar, wind or hydropower, or biomass feedstocks, these technologies can help pave the way towards a sustainable energy future.

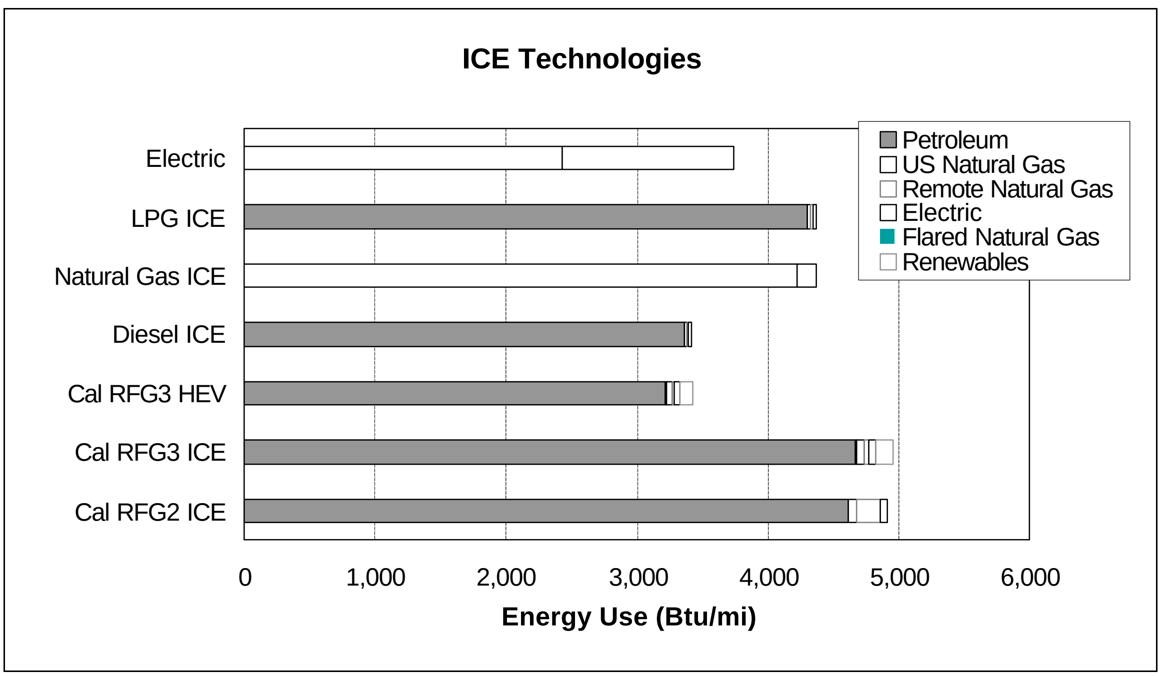
The Task Force formed a Conservation Work Group that looked specifically at conservation and efficiency measures that can reduce demand for gasoline. The Conservation Work Group agreed that the Task Force should recommend policies to encourage vehicle efficiency, fuel substitution, and alternative modes of transportation. The Conservation Work Group further agreed that the state should examine its environmental and energy programs and give preference to programs that simultaneously address environmental problems and reduce gasoline consumption. Task Force members generally agreed that conservation measures are worthy of further analysis and debate.

The Attorney General recommended that the State take aggressive steps to increase fuel economy and the use of alternative fuels, and supports taking steps to ensure the state optimizes conservation and alternative fuel opportunities. Such actions, by reducing the pressure on supplies of clean-burning California gasoline, would help mitigate shortages and the resulting price spikes. ARB staff concurs that EVs and high efficiency hybrid vehicles provide important energy supply and diversity advantages.

To quantify the relative efficiencies of current and future technologies, the ARB and the Energy Commission contracted with A.D. Little to perform an analysis of the full fuel cycle energy efficiency of various vehicle technologies. A technical advisory committee with members from each of the affected fuels was established to provide additional expertise and guidance. This work would also serve to quantify the relative global greenhouse gas benefits of each technology by quantifying total carbon dioxide emissions. Energy conversion efficiency of a fuel was determined for the fuel production and energy conversion portions of the fuel cycle, including fuel acquisition and refining, distribution, refueling, and in-vehicle consumption

The A.D. Little study determined that, at the vehicle level, battery electric vehicles had the highest "miles per equivalent gallon" energy efficiency of all vehicle types analyzed, followed by hydrogen fuel cell and methanol fuel cell vehicles and hybrid electric vehicles. However, on a total fuel-cycle energy use basis, diesel internal combustion engine vehicles and gasoline hybrid electric vehicles used the least energy per mile, followed by electric vehicles. When compared to conventional vehicles, electric vehicles consume approximately 25 percent less energy on a full fuel cycle basis. It should be noted that there was significant debate between technical advisory committee members on the estimated electric vehicle efficiency in 2010. ARB staff believes these results conservatively represent the overall energy use of electric vehicles. These results are presented in Figure 9-4.

Figure 9-4
Energy Consumption Results



LPG: Liquefied Petroleum Gas
Cal RFG2: Phase 2 reformulated gasoline
Cal RFG3: Phase 3 reformulated gasoline

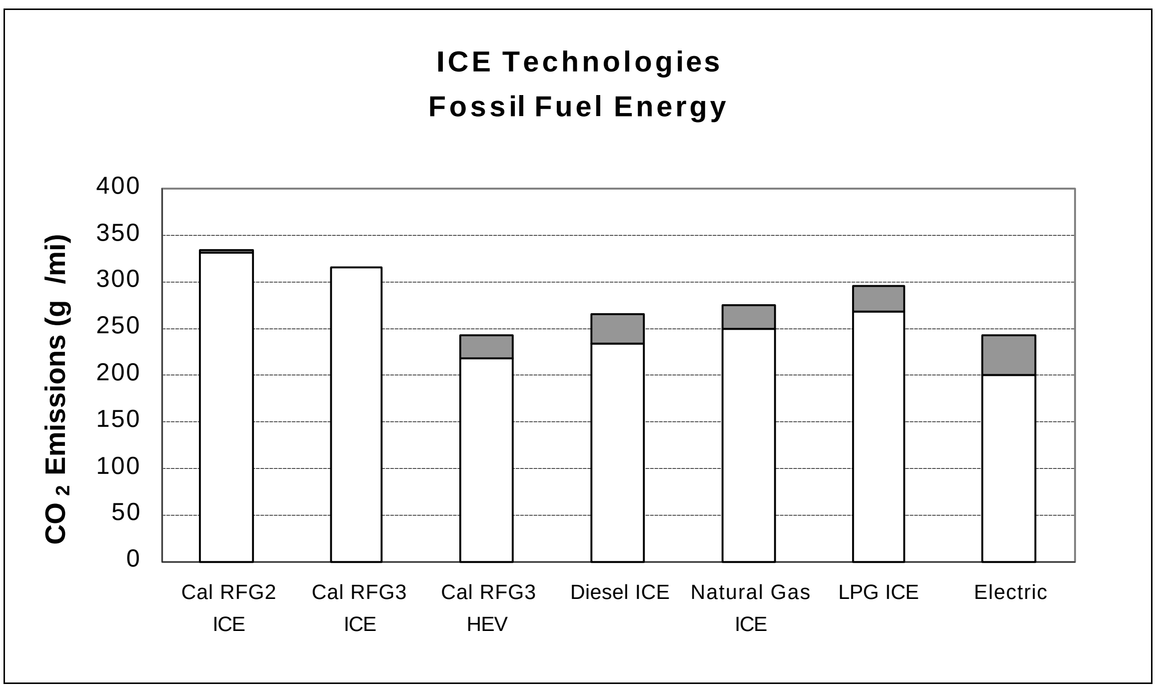
Emissions of greenhouse gases from vehicle exhaust and the energy conversion efficiency of the vehicle were calculated directly from vehicle fuel economy, carbon weight percentage of the fuel, fuel energy, and fuel density.

There are several other general conclusions that can be drawn from the report:

- Vehicle energy consumption has the largest effect on total fuel cycle and vehicle energy and CO_2 emissions.
- Energy demand and CO_2 emissions for EVs are strongly driven by the new California generation mix.
- Marginal energy assumptions are consistent with electric power generation mix from new natural gas combined cycle power plants.
- Fuel cell technologies, electric vehicles, and gasoline HEVs result in similar CO_2 emissions.

As shown in Figure 9-5, electric vehicles have the lowest carbon dioxide emissions of the technologies evaluated.

Figure 9-5
CO_2 Emissions Comparison



9.5 Secondary Economic Benefits

ARB currently has contract work underway to identify and assess the secondary economic benefits of the ZEV regulations, especially to California. Such secondary benefits include:

- the economic activity generated by automaker efforts to meet the ZEV requirement with pure EVs,
- improvements in technology spurred by the ZEV requirement but applied to products other than pure EVs, and
- the benefits of those applications to the economy and to consumers of products other than EVs.

Staff expects that information from this study will be available for consideration by the Board at the September Board meeting.

10 CONCLUSION

10.1 A Blueprint for Further Progress

In order to successfully place the vehicles required under the ZEV program regulations, and achieve the resulting long-term air quality and other environmental benefits, several things need to be in place.

First, the technology must have arrived at the point where reliable vehicles are available, with performance characteristics sufficient to meet a range of market applications. Based on the investigation discussed in this report, staff concludes that today's EVs clearly meet this test. Although real world vehicle range is limited and long recharge times are necessary, a variety of attractive platforms are available and vehicles are in everyday use in many different circumstances across the state. All evidence and testimony points to the fact that those who are using today's EVs are very pleased with their performance. With regard to PZEVs, manufacturers have testified that it will be difficult for some automakers to take full advantage of the PZEV option in 2003, due to the lead time necessary to convert a significant portion of the fleet to PZEV status.

Second, market applications must exist that can absorb the necessary number of vehicles. Although this portion of the analysis is necessarily more speculative than the technology review, as reported in the EV Market section staff has identified a number of applications that are well suited to the use of ZEVs. Staff recognizes that actual placement of vehicles in these possible applications will be challenging given the competing choices available.

Third, the vehicles must be available at prices that are competitive to conventional vehicles on a lifecycle cost basis. Our cost analysis concludes that in the 2003 time frame, both the initial and the lifecycle cost of battery electric vehicles will significantly exceed that of comparable conventional vehicles. In volume production (100,000 units per year), it is possible that battery electric vehicles could be competitive with conventional vehicles on a lifecycle cost basis.

The near-term cost premium is not surprising, given that each incremental step towards more stringent air pollution controls provides additional benefits, but at additional cost. The ZEV program, meanwhile, is not a typical incremental step but rather a visionary approach that will transform our vehicle pollution control strategy and bring with it comprehensive multimedia environmental and energy benefits. Given the sweeping nature of its effects it is reasonable to expect that the program will be more expensive in its early years than other more limited measures. Various means are available to close this cost gap. Ultimately, the decision as to what costs are reasonable and how they should be borne is a policy matter for the Board to determine.

The above three conditions are necessary to ensure successful implementation of the ZEV regulation. Other factors can ease the transition. As discussed in the EV market section, continuity between today and 2003 is vital. At the moment, however, there is a large gap between the completion of the MOA placements and the beginning of the 2003 requirement.

Finally, there will need to be teamwork among the interested parties who follow the ZEV issue. The auto manufacturers will benefit from the assistance of others. Areas where cooperative efforts would be helpful include the provision of incentives, development of the fleet market, and public education.

11 REFERENCES

Publicly Available Reports:

Anderman, Menahem, Kalhammer, Fritz and MacArthur, Donald, *Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost and Availability*, The Year 2000 Battery Technology Advisory Panel, June 22, 2000.

Attorney General Bill Lockyer, *Report on Gasoline Pricing in California,* Attorney General's Task Force on California Gasoline Prices Staff Report, May 2000.

Blair, Peter, et al*, Advanced Automotive Technology: Visions of a super efficient family car*, Office of Technology Assessment, September 1995

Cuenca, R.M, Gaines, L.L., and Vyas, A.D., *Evaluation of Electric Vehicle Production and Operating Costs*, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, November 1999.

Delucchi, M., Burke, Any, Lipman, Tim, Miller, Marshall, *Electric and Gasoline Vehicle Lifecycle Cost and Energy-Use Model*, Institute of Transportation Studies, University of California, Davis, March 2000.

Jennings, Christina, P.E., *Pacific Gas and Electric Company's Electric Vehicle Research*, Pacific Gas and Electric Company, San Francisco, California (Undated submittal to EVS 17)

Lipman, T., *A Review of Electric Vehicle Cost Studies: Assumptions, Methodologies, and Results*, Institute for Transportation Studies, University of California, Davis, February 1999

Montano, M., S. Unnasch, and P. Franklin, *Reclamation of Automotive Batteries: Assessment of Health Impacts and Recycling Technology*, prepared by ARCADIS Geraghty & Miller for the California Air Resources Board, April 1999

Moss, S., McCann, R. and Feldman, M., *A Guide for Reviewing Environmental Policy Studies: A Handbook for the California Environmental Protection Agency*, M Cubed

Nesbitt, K., *An Organizational Approach to Understanding the Incorporation of Innovative Technologies into the Fleet Vehicle Market with Direct Application to Alternative Fuel Vehicles*, Ph.D. Dissertation, Institute of Transportation Studies, University of California, Davis, 1996

Planning Center, The, *EV Fleet Issues: Perspectives of Fleet Managers*, (Sponsored by Southern California Edison), June 2000

Unnasch, Stefan, Browning, Louis, and Montano, Michelle, *Evaluation of Fuel-Cycle Emissions on a Reactivity Basis*, Prepared for the California Air Resources Board, Acurex Environmental Corporation, September 1996.

Unnasch, Stefan, and Browning, Louis, *Fuel Cycle Energy Conversion Efficiency Analysis—Status Report*, Prepared for the California Energy Commission and the California Air Resources Board, ARCADIS Geraghty & Miller, Inc., May 2000.

Unnasch, Stefan, and Browning, Louis, *Refinement of Selected Fuel-Cycle Emissions Analyses*, Prepared for the California Air Resources Board, Arthur D. Little, Inc., February 2000.

Vyas, et al., *Electric and Hybrid Electric Vehicles: A Technology Assessment Based on a Two-Stage Delphi Study*, ANL/ESD-36, Argonne National Laboratory, U.S. Department of Energy, Argonne, December (1997)

Vyas, A., Cuenca, R. and Gaines, L., *An Assessment of Electric Vehicle Life Cycle Costs to Consumers*, Proceedings of the 1998 Total Life Cycle Conference, SAE International Report, Warrendale, PA.

Confidential Submittals from Auto Manufacturers:

Product Plans

1999 MOA Product Plan Report, DaimlerChrysler Corporation, October 29, 1999

ZEV Product Plan, Ford Motor Company, October 4, 1999

MOA Status Report Related To Zero Emission Vehicle Product Plans, General Motors, November 1, 1999

Second Biennial ZEV Product Planning Report, American Honda Motor Company, October 27, 1999

MOA 1999 Zero Emission Vehicle Product Plan, Mazda Motor Corporation, October 26, 1999

Nissan 1999 Zero Emission Vehicle Product Plan, Nissan North America, Inc., November 1, 1999

Toyota ZEV Product Plan, Toyota Technical Center USA, October 29, 1999

Summaries of Marketing Efforts and Approaches

DaimlerChrysler ZEV Marketing Efforts, DaimlerChrysler Corporation, October 28, 1999

Ford Ranger EV Sales and Marketing Report, Ford Motor Company, November 16, 1999

General Motors Corporation Zero Emission Vehicle (ZEV) Marketing Activities Report to the California Air Resources Board, General Motors, November 22, 1999

Honda EV Plus Marketing Plan and Implementation: A Special Report to the California Air Resources Board, American Honda Motor Company, November 15, 1999

Nissan Altra EV Marketing Activities, Nissan Research and Development, November 12, 1999

Toyota Marketing Strategy for Advanced Battery EVs, Toyota Technical Center USA, November 24, 1999

<u>1999 MOA Annual Reports</u>

1999 Calendar Year Annual MOA Report, Toyota Technical Center USA, March 29, 2000

1999 Calendar Year Annual Report, DaimlerChrysler Corporation, March 24, 2000

1999 Calendar Year MOA Annual Report, Ford Motor Company, March 27, 2000

1999 Calendar Year MOA Report, General Motors, March 29, 2000

Honda ZEV Annual Report to CARB, American Honda Motor Company, March 27, 2000

MOA 1999 Calendar Year Annual Report, Mazda Motor Corporation, March 30, 2000

Zero Emission Vehicle Annual Report for 1999, Nissan Research and Development, March 31, 2000

APPENDIX A

**EXECUTIVE SUMMARY,
DRAFT REPORT OF THE 2000 BATTERY TECHNOLOGY ADVISORY PANEL**

Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost, and Availability

DRAFT

June 22, 2000

**Prepared for
State of California Air Resources Board
Sacramento, California**

By

The Year 2000 Battery Technology Advisory Panel

**Menahem Anderman
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DISCLAIMER

The findings and conclusions in this report are those of the authors and not necessarily those of the State of California Air Resources Board. The mention of commercial products in connection with the material presented herein is not to be construed as actual or implied endorsement of such products.

EXECUTIVE SUMMARY

When the California Air Resources Board began to consider battery-powered EVs as a potentially major strategy to reduce vehicle emissions and improve air quality, it did so with the view that the broadest market would be served by electric vehicles with advanced batteries, and it structured its ZEV credit mechanisms to encourage the development and deployment of EVs with such batteries. Consistent with this view, the Air Resources Board defined the scope of work for the first Battery Technical Advisory Panel study to focus on advanced batteries.

Five years after the modification of the 1991 Zero Emission Vehicle regulation, and after a period of intensive effort to develop, deploy and evaluate advanced electric vehicles, one key remaining question is whether batteries can be available in 2003 that would make electric vehicles acceptable to a large number of owners and operators of automobiles. The answer to this question is an important input to the California Air Resources Board's year 2000 Biennial ZEV regulation review. The authors of this report were asked to assist ARB in developing an answer, working together as a new Battery Technical Advisory Panel (BTAP 2000).

The Panel concentrated its investigation on candidate EV-battery technologies that promise major performance gains over lead-acid batteries, appear to have some prospects for meeting EV-battery cost targets, and are now available from low-volume production lines or, at least, laboratory pilot facilities. In the view of the Panel, other types of advanced batteries not meeting these criteria are highly unlikely to be introduced commercially within the next 5-7 years. While the focus of BTAP 2000 like the first battery panel was to be on advanced batteries because of their basic promise for superior performance and range, ARB asked the Panel to also briefly review the lead-acid battery technologies used in some of the EVs deployed in California. This request recognized that EVs with lead-acid batteries were introduced in the 1990s by several major automobile manufacturers beginning with General Motors' EV1, and that EVs equipped with recently developed lead-acid batteries were performing significantly better than earlier EVs.

The Panel's approach was similar to that of the 1995 BTAP: visits to the leading developers of advanced batteries and to major automobile manufacturers engaged in electric-vehicle development, EV deployment, and in the evaluation of EV batteries; follow-on discussions of the Panel's observations with these organizations; Panel-internal critical review of information and development of conclusions; and preparation of this report. To assist the Panel members with the development of judgment and perspective, they were given business-confidential technical and strategic information by nearly all of the Panel's information sources. This report, however, contains unrestricted material only. The Panel's findings and conclusions are as follows.

The improved lead-acid EV batteries used in some of the EVs operating in California today give these vehicles better performance than previous generations of lead acid batteries. However, even these batteries remain handicapped by the low specific energy that is characteristic of all lead-acid batteries. If EV trucks or representative 4-5 passenger EVs could be equipped with lead-acid batteries of sufficient capacity to provide a practical range of 75-100 miles on a single charge, batteries would represent 50% or more of the total vehicle weight. The specific costs of these batteries produced in volumes of 10,000-25,000 packs per year are projected to be between $100/kWh and $150/kWh, about 30-50% of the cost projected for advanced batteries produced in comparable volume. On the other hand, the life of lead-acid batteries remains a serious concern because the high cost of battery replacement might well offset the advantage of lower first costs.

Nickel-metal hydride (NiMH) batteries, employed in more than 1000 vehicles in California, have demonstrated promise to meet the power and endurance requirements for electric-vehicle (EV) propulsion. Bench tests and recent technology improvements in charging efficiency and cycle life at elevated temperature indicate that NiMH batteries have realistic potential to last the life of an EV, or at least ten years and 100,000 vehicle miles. Several battery companies now have limited production capabilities for NiMH EV batteries, and plant commitments in 2000 could result in establishment of manufacturing capacities sufficient to produce the quantities of batteries required under the current ZEV regulation for 2003. Current NiMH EV-battery modules have specific energies of 65 to 70Wh/kg, comparable to the technologies of several years ago—reported in the BTAP 1995 report (1)—and major increases are unlikely. If NiMH battery weight is limited to an acceptable fraction of EV total weight, the range of a typical 4/5-passenger EV in real-world driving appears limited to approximately 75 to 100 miles on a single charge.

Despite extensive cost reduction efforts by the leading NiMH EV-battery developers, NiMH battery cost remains a large obstacle to the commercialization of NiMH-powered EVs in the near term. From the cost projections of manufacturers and some carmakers, battery module specific costs of at least \$350/kWh, \$300/kWh and \$225-250/kWh can be estimated for production volumes of about 10k, 20k and 100k battery packs per year, respectively. To the module costs, at least \$1,200 per battery pack (perhaps half of that sum in true mass production) has to be added for the other major components of a complete EV-battery, which include the required electrical and thermal management systems. On that basis, and consistent with the Panel’s estimates, NiMH batteries for the EV types now deployed in California would cost EV manufacturers between \$9,500 and \$13,000 in the approximate quantities (10k-

20k packs per year) required to implement the year 2003 ZEV regulation, and approximately $7,000 to $9,000 at production levels exceeding one hundred thousand packs per year.

Lithium-ion EV batteries are showing good performance and, up to now, high reliability and complete safety in a limited number of EVs. However, durability test data obtained in all major lithium-ion EV-battery development programs indicate that battery operating life is typically only 2-4 years at present. Li Ion EV batteries exhibit various degrees of sensitivity when subject to some of the abuse tests intended to simulate battery behavior and safety under high mechanical, thermal or electrical stresses. Resolution of these issues, the production of pilot batteries and their in-vehicle evaluation, and fleet testing of prototype Li Ion batteries meeting all critical requirements for EV application are likely to require at least three to four years. Another two years will be required to establish a production plant, verify the product, and scale up to commercial production. Based on several (albeit not all) of the cost estimates provided by developers and on the Panel's own estimates, these batteries will be significantly more expensive than NiMH batteries at a production volume of around 10,000 packs per year. Even in much larger production volumes, Li Ion EV batteries will cost less than NiMH only if substantially less expensive materials become available, and after manufacturing technologies combining high levels of automation, precision and speed have been developed.

Lithium-metal polymer EV batteries are being developed in two programs aimed at technologies that might cost $200/kWh or less in volume production. However, these technologies have not yet reached key technical targets, including most notably cycle life, and they are in the pre-prototype cell stage of development. It is unlikely that the steps required to achieve commercial availability of Li Polymer batteries meeting the performance and life requirements, as well as the cost goals for EV propulsion, can be completed in less than 7 to 8 years.

Battery developers, USABC, and the six major automobile manufacturers serving the California market have invested extensive financial and talent resources in developing a diversity of EV batteries and evaluating them in electric vehicles. Battery performance and reliability has been excellent in many, and generally adequate in nearly all, of the more than 1400 EVs deployed to date with advanced batteries, most of them of the NiMH-type. However, advanced battery costs will exceed by about $7,000 to $9,000 in the nearer term, and about $5,000 at automotive-mass-production levels, the cost goals derived for EV batteries by postulating comparable life-cycle costs for broadly comparable electric and ICE-powered vehicles.

These cost projections assume reductions arising from incremental technological advances as well as cost reductions resulting from the economies of scale of materials procurement and high-volume manufacturing. In the Panel's assessment, major technology advances or breakthroughs would be required to reduce advanced battery costs substantially below current projections; the Panel considered this unlikely for the next 6-8 years. In addition, the practical range provided by the batteries of current EVs is limited. For applications where increased range is desired, the resulting larger-capacity batteries would aggravate the advanced-battery cost problem in proportion, and they would raise increasingly serious volume and weight issues.

All major carmakers are now actively pursuing other advanced-technology vehicles—such as hybrid and mini EVs—to achieve emission reductions. Like conventional EVs, HEVs and mini-EVs depend on improved batteries for their technical and cost feasibility. However, they require only a fraction of an EV's battery capacity—between 5% and 50%, depending on HEV technology and application. Battery cost is thus substantially reduced, and thereby one of the largest barriers to the commercial viability of these new automotive products. The Panel was made aware of the impressive battery technology progress achieved in this area by several of the EV-battery developers. There is little doubt that the development of NiMH and Li Ion battery technologies for HEV and mini-EV applications has benefited directly and substantially from EV-battery development. Conversely, the successful commercialization of HEVs, and possibly mini-EVs, in the coming years can be expected to result in continued improvements of advanced battery technologies. Over the longer term, these advances—together with likely advances in electric drive technologies and reductions in vehicle weight—might well increase performance and range, and reduce costs, to the point, where electric vehicles could become a widely accepted product.

Establishing New Fuel Pathways under the California Low Carbon Fuels Standard

Procedures and Guidelines for Regulated Parties

Concept Paper: August 4, 2009

I. Introduction

On April 23, 2009 the Air Board (ARB/Board) approved the California Low Carbon Fuel Standard (LCFS).[1] The LCFS establishes a compliance schedule which requires fuel providers to reduce the carbon intensity of the fuels they provide each year between 2011 and 2020. The 2020 carbon intensity level is ten percent below the baseline 2010 level. "Carbon intensity" is the total greenhouse gas emissions from the production, transport, storage, dispensing and use of a fuel. It is expressed as grams of carbon dioxide (CO_2) -equivalent per mega joule of fuel energy (gCO_2e/mg). In the context of the LCFS, the term 'carbon intensity' usually refers to the full lifecycle greenhouse gas emissions associated with a specific fuel 'pathway.'

The LCFS requires regulated fuel providers to determine the carbon intensity of the fuel they provide, and to report that information, for compliance determination purposes, to ARB. Regulated parties must report the carbon intensities based on values appearing in a table of Board-approved values found in §95486(b)(1) of the LCFS Regulation. As new and improved fuel pathways are developed, the carbon intensities of those pathways must be added to the lookup table. The guidelines below provide regulated parties with the information they need in order to work effectively with ARB to add additional fuel pathway data to the LCFS lookup table.

II. Establishing New Fuel Pathways

Regulated parties may use one of two methods to determine the carbon intensity of the transportation fuels they provide. Under Method 1, regulated parties select carbon intensity values from the fuel carbon intensity lookup table found in §95486(b)(1) of the LCFS Regulation. Under Method 2, regulated parties seek to have additional fuel pathways or sub-pathways added to the lookup table. If a proposed pathway or sub-pathway is approved, it is added to the lookup table, and becomes available to all regulated parties.

Method 2 is subdivided into Methods 2A and 2B. Method 2A provides regulated parties with a process whereby they may apply for the establishment of new sub-pathways. Sub-pathways are modified versions of pathways currently present in the lookup table. They are added when a fuel provider can demonstrate that a new or improved fuel production, transport, storage, and/or dispensing process significantly reduces the lifecycle carbon intensity of the existing fuel. Method 2B provides for the establishment of an entirely new fuel pathway. Such a pathway could yield an entirely new class of fuel, or it could describe an entirely new process for producing an existing fuel.

[1] CCR Title 17, §95480, 95480.1, 95481, 95482, 95483, 95484, 95485, 95486, 95487, 95488, and 95489

The purpose of this document is to provide regulated parties who wish to add new or modified pathways to the LCFS lookup table with the guidance they need to efficiently and effectively complete the application process. One of the stated goals of the LCFS is to incentivize the development of lower carbon fuels for the California transportation market. As those fuels become available, their pathways must be added to the lookup table before they can begin earning credits for fuel providers. As such, ARB staff has designed the application process to be as streamlined as possible, while retaining the necessary scientific and technical rigor. Regulated parties who closely follow these procedures can expect the full and timely cooperation of ARB staff in processing and evaluating their applications.

A. Overview of The Method 2A and 2B Application Processes

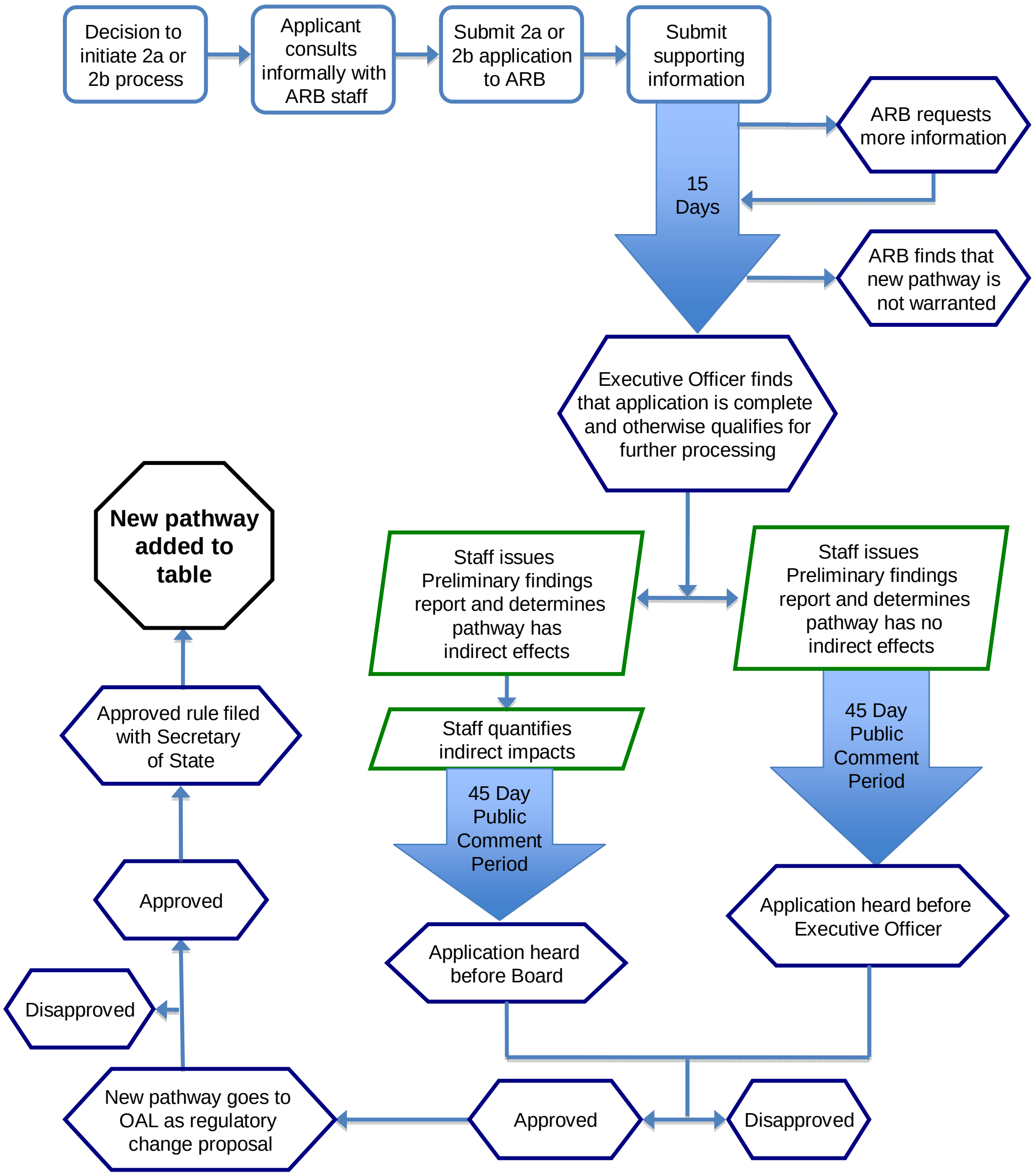
The LCFS fuel pathway lookup table is included in the LCFS regulation. The general process for revising or amending California regulations is as follows:

- Release the proposed changes to the public for a 45-day comment period;
- Conduct a public hearing to formally consider adoption of the proposed changes;
- If the proposed changes are approved by the rulemaking entity (the Board, in this case), they are forwarded to the Office of Administrative Law for consideration;
- Only after the Office of Administrative Law approves the proposed rules, and those rules are filed with the Secretary of State, do they become effective.

In the case of modifications to the LCFS lookup table, the Board has delegated certain authorities to the Executive Officer: so long as the proposed lookup table revisions do not involve indirect land use change emissions (or emissions from other indirect effects), the public hearing to consider those revisions may be held before the Executive Officer. A Method 2A application describing modifications to a primary pathway that includes land use change or other indirect effects can still be heard before the Executive Officer if the proposed modifications do not entail any changes to the indirect effects included for in the primary pathway. Whenever Method 2A or 2B applications involve new or changed indirect effects, including land use change, the regulatory hearing must be conducted before the Board, as described in Section III, below.

A schematic of the application and approval processes is shown in Figure 1.

Figure 1: Schematic of the Method 2A and 2B Application and Approval Process



B. Method 2A Application Procedures

Under Method 2A, regulated parties may apply for the establishment of a new fuel sub-pathway. The need for a sub-pathway is created when a fuel producer revises one or more components of an existing pathway. A process improvement in which natural gas or coal requirements are significantly reduced by a conversion to combined heat and power could, for example, produce the requisite reduction of five gCO_2e/MJ (see the section on substantiality requirements, below). A sub-pathway is created by re-calculating the lifecycle carbon intensity of an existing fuel pathway using one or more revised input values. Input values are revised so that they accurately describe the proposed new production process. The LCFS requires the use of the California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (CA-GREET) model to calculate what are referred to as 'direct' pathway emissions. Indirect effects, such as land use change, are evaluated according to the process described in section III, below. Sub-pathways are created by revising CA-GREET input values to reflect revised fuel production, transport, storage, and/or dispensing processes. Proposed modifications can only be approved if they are supported by appropriate scientifically defensible data and documentation and meet other criteria, described below.

The following discussion focuses primarily on the formal application, evaluation, and decision process. In order to expedite the application process, however, applicants are strongly urged to meet with ARB staff prior to initiating a Method 2A application. At a pre-application meeting, the prospective applicant can describe the proposed sub-pathway in detail to staff. The applicant may also submit preliminary documentation to staff for review. Staff, in turn, can begin to provide the applicant with a list of the specific types of information it will need in order to evaluate the applicant's proposal. Following the informal meeting, the applicant can continue to provide staff with additional information and to seek staff's guidance during the application development process.

(1) How to Apply

To apply for the establishment of a new sub-pathway, a fuel provider must:

- Fill out and submit a Method 2A application. The application form is a secure web-based application, available at http://www.arb.ca.gov/fuels/lcfs/.[2] It is designed to be completed and submitted on-line. The following information is required:
    - o Identification and contact information: the applicant's name, address, and LCFS organization code, as well as the phone numbers and e-mail addresses of those who will be working with ARB on the evaluation of the proposed new sub-pathway.
    - o The existing fuel pathway for which a new sub-pathway is being proposed.
    - o The revised CA-GREET input values that would be used to generate the carbon intensity value for the new sub-pathway.
    - o The carbon intensity value that results from running CA-GREET using the revised inputs specified in item c, above.
    - o A detailed discussion of how each revised CA-GREET input relates to the revised physical fuel pathway used to produce the fuel for which a new sub-pathway is being requested. This discussion should begin with a

[2] Application will be added to the web when Guidelines are approved.

clear and thorough overview of the revised production, storage, transport, and dispensing processes in the new sub-pathway. This overview should fully describe and identify all new equipment used in the proposed new processes.

- The annual volume of fuel that would be affected by the creation of the proposed new sub-pathway. The energy contained in that fuel must also be specified (in units of mega joules).

- Submit the necessary documentation in support of the establishment of the proposed new sub-pathway. The files submitted will be use to determine whether the proposed sub pathway meets ARB's minimum requirements for substantiality and scientific defensibility. Electronic files should be submitted using the secure LCFS file upload service available at the application web site (http://www.arb.ca.gov/fuels/lcfs/). ARB requests that as many files as possible be submitted in electronic form. Spreadsheets and similar files that contain calculated values must be submitted with all formulas intact and accessible to ARB evaluators. The files submitted will be preserved in their original forms for reference purposes. ARB evaluators will use copies of the original submissions in the evaluation process. Applicants are asked to submit the following documentation at a minimum. Additional documentation that directly supports the proposed new sub-pathway may also be submitted.
  - The official factory technical specifications of new equipment that contributes to the reported carbon intensity reductions.
  - Technical drawings, schematics, flow diagrams, maps, and other graphical representations describing the proposed process changes.
  - Technical papers reporting the results of pertinent greenhouse gas (GHG) emission studies. These could be articles from peer-reviewed journals, unpublished university or consulting reports, or studies that were prepared under contract to the applicant.
  - Emissions monitoring data not included in any of the studies submitted under item c, above. This could be data from governmental regulatory entities, or data collected by entities testing or using the proposed equipment and processes.
  - Spreadsheets, data files, and similar files documenting the quantitative lifecycle analysis behind the carbon intensity value for the proposed new pathway. Except where it is impossible to do so, the applicant must submit files of this type electronically, via the LCFS upload site. All such files must be submitted in a format that permits full and unimpeded access to all the data, formulas, and calculations they contain. In general, files of this type should be submitted in their native formats. CA-GREET files, in particular, must not be converted to any other format. If format conversions appear to be warranted in order to permit or improve access, the applicant must obtain ARB approval before proceeding with the proposed conversions.

  - A preliminary determination concerning the likelihood that the proposed sub-pathway will create significant land use change impacts or other indirect impacts. See section III, below, for a discussion of how to reach a preliminary indirect effects determination, and of ARB's process for evaluating that determination.

(2) Evaluation Criteria

The applicant's Method 2A submittal will be evaluated against the following criteria:

- *Substantiality*
  - The applicant must demonstrate his or her ability and willingness to produce more than ten million gasoline gallon equivalents per year (1,156 MJ) of the fuel covered by the new sub-pathway proposal. This requirement applies only when the total amount of the fuel sold in California by all providers of that fuel exceeds tem million gasoline gallon equivalents per year
  - The applicant must demonstrate that the proposed new sub-pathway will yield a carbon intensity improvement of at least five gCO_2e/MJ over the existing primary pathway. This carbon intensity improvement is calculated on a 'well-to-tank' (or 'source-to-tank') basis: all fuel lifecycle emissions except those resulting from the combustion of the fuel must be included.
- *Scientific Defensibility*
  - The minimum standard against which the Scientific Defensibility of a proposed new sub-pathway is measured is the robustness of the data and analysis on which the values existing lookup table are based. The LCFS regulation states, at §95486(e)(1)(A), that a new pathway is deemed to be scientifically defensible if the carbon intensity value it yields is at least as robust as the values currently in the lookup table. This robustness derives from the strength of the scientific and technical data behind the lookup table values.
  - The regulation provides an example of a method by which the scientific defensibility of a proposed new pathway can be demonstrated: publication of an article describing that pathway in a major, well-established and peer-reviewed scientific journal such as Science, Nature, Journal of the Air and Waste Management Association, or the Proceedings of the National Academies of Science (§95486(e)(1)(B)).
  - If the applicant does not publish a description of the proposed new sub-pathway, as described above, staff will evaluate the scientific defensibility of that pathway by, first, verifying all information submitted by the applicant for authenticity. This will consist of checking the information submitted against original sources wherever this is possible (e.g., confirming that

submitted articles were actually published, and checking with the authors of unpublished reports). Once the authenticity of all submissions has been verified, those submissions will be evaluated to determine whether they adequately support the creation of the proposed new fuel sub-pathway. All calculations will be replicated and evaluated for appropriateness; selected results will be sent to expert third-parties for evaluation; equipment manufacturers will be asked to confirm that the technical specifications submitted are current and still considered to be valid, etc. Because the burden of demonstrating scientific defensibility is on the applicant, issues that arise during the evaluation process will be referred to the applicant for resolution.

- *Other*
  - Before the proposed new sub-pathway can be approved, the Executive Officer must find that the pathway is not already present in the lookup table.
  - Before the proposed new pathway can be approved the, Executive Officer must reach a determination that CA-GREET is capable of being modified to accurately calculate the carbon intensity of the proposed new pathway. If the Executive Officer cannot reach such a finding, the applicant will be required to use Method 1 to determine the carbon intensity of the fuel.
  - The applicant must identify information it considers to be trade secrets in its Method 2A submittal. The pathway application and supporting documentation, except the information that the applicant identifies as consisting of trade secrets, are subject to public disclosure. The Executive Officer shall treat the trade secrets identified by the applicant in accordance with 17 CCR §§ 91000-91022 and the California Public Records Act (Government Code section 6250 et seq.). In deciding on what information to designate as secret, however, applicants must consider the public nature of the rulemaking process. New sub-pathways can be approved only if enough information is available publicly to justify that approval. Once a sub-pathway is approved and added to the lookup table, other regulated parties may use the new pathway to report their fuel carbon intensities if they can demonstrate that the new pathway best describes their processes. Such use by other regulated parties is unrestricted.
  - The Executive Officer can request additional information, as needed, in the evaluation of the Method 2A application.
  - Including carbon intensity values derived from a Method 2A application in an annual LCFS compliance report to ARB before the Board or the Executive Officer issues a formal written approval of the proposed new pathway is a violation of the LCFS.

(3) Completeness

The Executive Officer has 15 calendar days to determine whether a Method 2A application is complete enough to proceed to a full pathway evaluation. If the Executive Officer determines that an application is sufficiently complete to proceed to a full evaluation, the applicant will be notified of this determination. If an application is deemed to be incomplete, the Executive Officer will notify the applicant in writing of that determination. That notification will identify the deficiencies identified in the application. An applicant notified of a deficiency may submit the missing information. Upon receipt of that information, the Executive will, within 15 days, determine whether the newly submitted information renders the application sufficiently complete to proceed to a full evaluation. If the Executive Officer again finds the application to be incomplete, the notification/re-submittal/re-evaluation process can repeated. Otherwise, the application will move to the full pathway evaluation phase of the process.

Applications approved for a full pathway consideration are posted to ARB's LCFS web site for public review. The public review period will last a minimum of 30 calendar days.

(4) Preliminary Findings

Staff will evaluate the applicant's submittal package and prepare a set of preliminary findings. The preliminary staff report will cover the following points, at a minimum.

- The extent to which the proposed CA-GREET input changes accurately describe the process that will actually be used to produce the affected fuels
- The direction and magnitude of the proposed CA-GREET input changes are reasonable and are adequately supported by the information submitted.
- The applicant's ability to meet the substantiality requirements described above.
- The likelihood that the proposed sub-pathway will create land use change or other indirect impacts.

Once approved, the preliminary findings document will be released to the applicant for comment. If a final draft acceptable to both staff and the applicant can be prepared, that draft will serve as Initial Statement of Reasons in the subsequent public hearing process (as discussed in the following section III). The preliminary findings document will contain staff's findings concerning the indirect impacts (if any) associated with the proposed sub-pathway. If staff finds that the sub-pathway will involve indirect impacts, those impacts will be quantified using the Global Trade Analysis Project (GTAP) or an equivalent model, and the results will be added to the final draft of the Initial Statement of Reasons. If staff determines that the proposed sub-pathway will entail indirect impacts, the public hearing with be held before the Board rather than the Executive Officer.

(5) Public Hearing and Subsequent Rulemaking Process

Regardless of whether a Method 2A application is heard before the Executive Officer or the Board, the formal rulemaking process established in the California Administrative Procedures Act must be followed before the LCFS lookup table can be modified. The steps in the rulemaking process are the following:

- ARB publishes a notice of proposed rulemaking in the California Regulatory Notice Register. The publication of this notice initiates a 45-day comment period on the addition of the proposed sub-pathway to the LCFS lookup table.
- At the end of the 45-day comment period, ARB convenes a public hearing to consider the proposed sub-pathway. If the Initial Statement of Reasons (discussed in the previous section) found that the proposed sub-pathway does not entail indirect impacts, the proposal will be heard before the Executive Officer. If the Initial Statement of reasons found that indirect impacts would be involved, the proposal will be heard before the Board.
- The public hearing culminates with a decision on the part of either the Executive Officer or the Board concerning the proposed sub-pathway adoption. The possible decisions are approve, disapprove, and approve subject to specified revisions. The applicant will be notified of the outcome in writing, and the results will be posted to the LCFS web site. If an application is not approved, the letter informing the applicant of that finding will describe the basis of the disapproval.
- If approval comes with a requirement for substantive revisions to the sub-pathway proposal, staff must complete the required revisions, and initiate a 15-day comment period on those changes. A public hearing is not required following a 15-day comment period, but one may be held in some cases. ARB is obligated to fully consider all comments received during the comment period in deciding on the proposed revisions.
- ARB must respond to all comments received during the original 45-day comment period. Those responses are compiled into a document known as a Final Statement of Reasons.
- The Final Statement of Reasons, and other pertinent rulemaking documents, are submitted to the California Office of Administrative law, which is the body responsible for rendering a final decision on all proposed California regulations.
- Within 30 days the Office of Administrative Law must either approve the proposed rule and forward it to the Secretary of State for publication, or disapprove the proposal and return it to the ARB for correction.
- If the Office of Administrative Law rejects a proposed sub-pathway, ARB has 120 days to correct the problems that triggered the rejection. A 15-day comment period is automatically initiated in this case.

A schematic of the application and approval processes is shown in Figure 1.

C. Method 2B Application Procedures

Under Method 2B, regulated parties may apply to the Executive Officer for the establishment of an entirely new fuel pathway. New pathways are not modifications of existing pathways, as are Method 2A sub-pathways. Pathways approved under Method 2B are primary lookup table pathways, equivalent to the existing set of top-level pathways (electricity, average corn ethanol, hydrogen, compressed natural gas, etc.). Like Method 2A sub-pathways, Method 2B pathways are created using the ARB's carbon intensity determination tools: CA-GREET and GTAP (or an equivalent model).

The following discussion focuses primarily on the formal application, evaluation, and decision process. In order to expedite the application process, however, applicants are strongly urged to meet with ARB staff prior to initiating a Method 2B application. At a pre-application meeting, the prospective applicant can describe the proposed pathway in detail to staff. The applicant may also submit any preliminary documentation to staff for review. Staff, in turn, can begin to provide the applicant with a list of the specific types of information it will need in order to evaluate the applicant's proposal. Following the informal meeting, the applicant can continue to provide staff with additional information and to seek staff's guidance during the application development process.

A schematic of the application and approval processes is shown in Figure 1.

(1) How to Apply

The Method 2B application process is similar to the Method 2A process. Applicants must:

- Fill out and submit a Method 2B application. The application form is a secure web-based application, available at http://www.arb.ca.gov/fuels/lcfs/. It is designed to be completed and submitted on-line. The following information is required:
    - Identification and contact information: the applicant's name, address, and LCFS organization code, as well as the phone numbers and e-mail addresses of those who will be working with ARB on the evaluation of the proposed pathway.
    - A complete description of the proposed new pathway
        - The nature of the fuel (electricity, hydrogen, liquid alcohol, liquid hydrocarbon, compressed hydrocarbon gas, etc.) that would be produced using the proposed new pathway.
        - The fuel's production, transport, storage, and dispensing processes
        - Characteristics of the vehicles that will use the fuel.
        - Expected production volumes.

    - The CA-GREET input values that would be used to generate the carbon intensity value for the new sub-pathway.
  - A detailed discussion of how each CA-GREET input relates to the physical fuel pathway for which a new lookup table value is being requested.
  - The carbon intensity of the fuel that would be produced using this proposed new pathway, as estimated by CA-GREET.

- Submit the necessary documentation in support of the establishment of the proposed new pathway. The files submitted will be use to determine whether the proposed pathway meets the ARB's minimum requirements for scientific defensibility. Electronic files should be submitted using the secure LCFS file upload service available at http://www.arb.ca.gov/fuels/lcfs/. ARB requests that as many files as possible be submitted in electronic form. All spreadsheets and similar files that contain calculated values must be submitted with all formulas intact and accessible to ARB evaluators. The files submitted will be preserved in their original forms for reference purposes. ARB evaluators will use copies of the original submissions in the evaluation process. Applicants are asked to submit the following documentation at a minimum. Additional documentation that directly supports the proposed new pathway may also be submitted.
  - The official factory technical specifications of new equipment that contributes to the GHG reductions from the proposed new pathway.
  - Technical drawings, schematics, flow diagrams, maps, and other graphical representations describing the proposed process change.
  - Technical papers reporting the results of pertinent GHG emission studies. These could be articles from peer-reviewed journals, unpublished university or consulting reports, or studies that were prepared under contract to the applicant.
  - Emissions monitoring data not included in any of the studies submitted under item c, above. This could be data from governmental regulatory entities, or data collected by entities testing or using the proposed equipment and processes.
  - Spreadsheets, data files, and similar files documenting the quantitative lifecycle analysis behind the carbon intensity value for the proposed new pathway. Except where it is impossible to do so, the applicant must submit files of this type electronically, via the LCFS upload site. All such files must be submitted in a format that permits full and unimpeded access to all the data, formulas, and calculations they contain. In general, files of this type should be submitted in their native formats. CA-GREET files, in particular, must not be converted to any other format. If format conversions appear to be warranted in order to permit or improve access, the applicant must obtain ARB approval before proceeding with the proposed conversions.

- A preliminary determination concerning the likelihood that the proposed sub-pathway will create significant land use change impacts or other indirect impacts. See section III, below, for a discussion of how to reach a preliminary indirect effects determination, and of ARB's process for evaluating that determination.

(2) Evaluation Criteria

The applicant's Method 2B submittals will be evaluated against the following criteria:

- *Scientific Defensibility:*
  - The minimum standard against which the Scientific Defensibility of a proposed new sub-pathway is measured is the robustness of the data and analysis on which the values existing lookup table are based. The LCFS regulation states, at §95486(e)(1)(A), that a new pathway is deemed to be scientifically defensible if the carbon intensity value it yields is at least as robust as the values currently in the lookup table. This robustness derives from the strength of the scientific and technical data behind the lookup table values.
  - The regulation provides an example of a method by which the scientific defensibility of a proposed new pathway can be demonstrated: publication of an article describing that pathway in a major, well-established and peer-reviewed scientific journal such as Science, Nature, Journal of the Air and Waste Management Association, or the Proceedings of the National Academies of Science (§95486(e)(1)(B)).
  - If the applicant does not publish a description of the proposed new pathway, as described above, staff will evaluate the scientific defensibility of a proposed new pathway by, first, verifying all information submitted by the applicant for authenticity. This will consist of checking the information submitted against original sources wherever this is possible (e.g., confirming that submitted articles were actually published, and checking with the authors of unpublished university and consulting reports). Once the authenticity of all submissions has been verified, those submissions will be evaluated to determine whether they adequately support the creation of the proposed new fuel pathway. All calculations will be replicated and evaluated for appropriateness; selected results will be sent to expert third-parties for evaluation; equipment manufacturers will be asked to confirm that the technical specifications submitted are current and still considered to be valid, etc. Because the burden of demonstrating the scientific defensibility is on the applicant, issues that arise during the evaluation process will be referred to the applicant for resolution.
  - In order for the Board or the Executive Officer to approve the proposed new pathway, ARB must reach a finding that the proposed CA-GREET input changes accurately describe the process that will actually be used to

produce the affected fuels, and that the direction and magnitude of the proposed input changes are reasonable and adequately supported by the information submitted. That finding, if reached, will be documented, and a copy of the document provided to the applicant.

- *Other*
  - Before the proposed new pathway can be approved the Executive Officer must find that the pathway is not already present in the lookup table.
  - Before the proposed new pathway can be approved the Executive Officer must reach a determination that CA-GREET is capable of being modified to accurately calculate the carbon intensity of the proposed new pathway. If the Executive Officer cannot reach such a finding, the applicant will be required to use either Method 1 or Method 2A to determine the carbon intensity of the fuel.
  - The applicant must identify information it considers to be trade secrets in its Method 2B submittal. The pathway application and supporting documentation, except the information that the applicant identifies as consisting of trade secrets, are subject to public disclosure. The Executive Officer shall treat the trade secrets identified by the applicant in accordance with 17 CCR §§ 91000-91022 and the California Public Records Act (Government Code section 6250 et seq.). In deciding on what information to designate as secret, however, applicants must consider the public nature of the rulemaking process. New sub-pathways can be approved only if enough information is available publicly to justify that approval. Once a sub-pathway is approved and added to the lookup table, other regulated parties may use the new pathway to report their fuel carbon intensities if they can demonstrate that the new pathway best describes their processes. Such use by other regulated parties is unrestricted.
  - The Executive Officer can request additional information, as needed, during the evaluation of the Method 2B application.
  - Including carbon intensity values derived from a Method 2B application in an annual LCFS compliance report to the ARB before the Board or the Executive Officer issues a formal written approval of the proposed new pathway is a violation of the LCFS.
  - Unlike Method 2A applications, Method 2B applications are not subject to substantiality requirements.

(3) Completeness

The Executive Officer has 15 calendar days to determine whether a Method 2B application is complete enough to proceed to a full pathway evaluation. If the Executive Officer determines that an application is sufficiently complete to proceed to a full evaluation, the applicant will be notified of this determination. If an application is deemed to be incomplete, the Executive Officer will notify the applicant in writing of that determination. That notification will identify the deficiencies identified in the application. An applicant notified of a deficiency may submit the missing information. Upon receipt of that information, the Executive will, within 15 days, determine whether the newly submitted information renders the application sufficiently complete to proceed to a full evaluation. If the Executive Officer again finds the application to be incomplete, the notification/re-submittal/re-evaluation process can repeated. Otherwise, the application will move to the full pathway evaluation phase of the process.

Applications approved for a full pathway consideration are posted to ARB's LCFS website for public review. The public review period will last a minimum of 30 calendar days.

(4) Preliminary Findings

Staff will evaluate the applicant's submittal package and prepare a set of preliminary findings. The preliminary staff report will cover the following points, at a minimum.

- The extent to which the proposed CA-GREET input changes accurately describe the process that will actually be used to produce the affected fuels
- The direction and magnitude of the proposed CA-GREET input changes are reasonable and are adequately supported by the information submitted.
- The likelihood that the proposed pathway will create land use change or other indirect impacts.

Once approved, the preliminary findings document will be released to the applicant for comment. If a final draft acceptable to both staff and the applicant can be prepared, that draft will serve as Initial Statement of Reasons in the subsequent public hearing process (as discussed in the following section). The preliminary findings document will contain staff's findings concerning the indirect impacts (if any) associated with the proposed sub-pathway. If staff finds that the sub-pathway will involve indirect impacts, those impacts will be quantified using the GTAP or an equivalent model, and the results will be added to the final draft of the Initial Statement of Reasons. If staff determines that the proposed sub-pathway will entail indirect impacts, the public hearing with be held before the Board rather than the Executive Officer.

(5) Public Hearing and Subsequent Rulemaking Process

Regardless of whether a Method 2B application is heard before the Executive Officer or the Board, the formal rulemaking process established in the California Administrative Procedures Act must be followed before the LCFS lookup table can be modified. The steps in the rulemaking process are the following:

- ARB publishes a notice of proposed rulemaking in the California Regulatory Notice Register. The publication of this notice initiates a 45-day comment period on the addition of the proposed pathway to the LCFS lookup table.
- At the end of the 45-day comment period, ARB convenes a public hearing to consider the proposed pathway. If the Initial Statement of Reasons (discussed in the previous section) found that the proposed pathway does not entail indirect impacts, the proposal will be heard before the Executive Officer. If the Initial Statement of reasons found that indirect impacts would be involved, the proposal will be heard before the Board.
- The public hearing culminates with a decision on the part of either the Executive Officer or the Board concerning the proposed pathway adoption. The possible decisions are approve, disapprove, and approve subject to specified revisions. The applicant will be notified of the outcome in writing, and the results will be posted to the LCFS web site. If an application is not approved, the letter informing the applicant of that finding will describe the basis of the disapproval
- If approval comes with a requirement for substantive revisions to the pathway proposal, staff must complete the required revisions, and initiate a 15-day comment period on those changes. A public hearing is not required following a 15-day comment period, but one may be held in some cases. ARB is obligated to fully consider all comments received during the comment period in deciding on the proposed revisions.
- ARB must respond to all comments received during the original 45-day comment period. Those responses are compiled into a document known as a Final Statement of Reasons.
- The Final Statement of Reasons, and other pertinent rulemaking documents, are submitted to the California Office of Administrative law, which is the body responsible for rendering a final decision on all proposed California regulations.
- Within 30 days the Office of Administrative Law must either approve the proposed rule and forward it to the Secretary of State for publication, or disapprove the proposal and return it to ARB for correction.
- If the Office of Administrative Law rejects a proposed pathway, ARB has 120 days to correct the problems that triggered the rejection. A 15-day comment period is automatically initiated in this case.

A schematic of the application and approval processes is shown in Figure 1.

III. Land Use Change and Other Indirect Effect Determination Process

Applicants for new pathways and sub-pathways are required to submit a preliminary determination concerning the likelihood that the proposed pathway will create significant land use change impacts or other indirect impacts. To make this determination, the applicant shall consult section IV, below. If the primary pathway from which the sub-pathway is being derived involves land use change impacts, but the proposed sub-pathway does not alter those existing impact levels, the sub-pathway is not subject to a land use change evaluation. The Executive Officer will evaluate the applicant's land-use-change findings, and take appropriate action. The Executive Officer's findings are not constrained by the applicant's findings: if the two are not in agreement, the Executive Officer's findings shall supersede the applicant's. If the Executive Officer determines that significant land use change impacts are likely, the formal Board Hearing process will be initiated.

IV. Fuels Deemed to Have Negligible or No Land Use Change or Other Indirect Effects

On April 23, 2009, the Board approved staff's proposed Low Carbon Fuel Standard, but directed staff to prepare several revisions to that rule, and to take various other actions relative to rule implementation. Among the actions staff was directed to take was the creation of an informal set of "criteria and a list of specific biofuel feedstocks that are expected to have no or inherently negligible land use effects on carbon intensity" (Air Resources Board Resolution 09-31, April 23, 2009, p. 15). The overriding criterion that must be met before a fuel can be included on this list is that production of its feedstock must not compete with the production food. A recent paper published in *Science* (Tillman et al., 2009) also recommends this approach. It places the fuels that meet this criterion into five basic categories:

- Fuel feedstock crops grown on abandoned farmland that is current degraded. Crops grown in this way do not compete with food crops, but they could also prove to be environmentally beneficial. In addition to their potential to improve wildlife habitat and water quality, perennial feedstock crops could increase soil carbon sequestration.
- Crop residues. Although crop residues increase soil fertility, decrease erosion, and improve soil carbon stores when left on fields, some residues can be removed without compromising these benefits. The removable fraction is capable of supporting the production of significant quantities of biofuels.
- Sustainably harvested wood and forest residues. These include the slash that is currently left in place after timber harvesting, residues from milling and pulp production, thinnings from fire prevention operations, as well as wastes from management operations undertaken to reduce competition and hasten the growth of marketable trees. In approving the LCFS, the Board directed the Executive Officer to work with stakeholders to define the terms "biomass" and "renewable biomass." As part of that effort, the Executive Officer is to assess the effects of incentivizing the use of forest biomass as a fuel feedstock, as well as the protections that would be necessary to ensure the sustainable and

environmentally beneficial use of forest biomass. The goal of this effort would be to certify pathways for fuels produced from forest biomass, should the use of this feedstock be found to be sustainable and environmentally beneficial. In addition to this state-level effort, Congress is also considering the advisability of forest biomass as a feedstock as it debates a new energy bill3. Staff's recommendation to the Board will take into consideration the results of these and other relevant inquiries.

- Double and mixed cropping. Biofuel crops that can be grown and harvested between existing food cropping cycles (and which do not interfere with those cycles) meet the criterion established above. The same is true for crops that can be grown along with food crops (such as between food crop rows).
- Municipal and industrial waste streams. Waste streams that include paper products, yard waste, construction wastes, and plastics are viable sources of feedstocks that do not entail land use change impacts.

Table 1 contains both fuels that meet these criteria, as well as other fuels that staff has determined to entail no significant indirect effects. Regulated parties wishing to apply for new pathways or sub-pathways for the fuels in this table can report on their Method 2A and 2B applications that those pathways will entail no land use change impacts. In support of that conclusion, applicants should cite Table 1.

Table 1: Fuels Expected to Have No or Inherently Negligible Land Use Effects on Carbon Intensity

Fuel	Feedstock	Conditions/Restrictions
Biodiesel	Used cooking oil	
	Algae	Specific conditions of operation are to be determined to assess land use impacts if any. There may be a need to demonstrate sustainable production of algae without displacement of crop land..
Renewable Diesel (RD)	Inedible Tallow (sourced in the United States)	
Fischer–Tropsch Diesel	Gasification of Forest Waste, MSW, Medical Waste, Dedicated crops (such as Poplar-see "Forest Waste" and "Dedicated Crops" under "Cellulosic Ethanol," below)	
	LFG and Digester Gas	
Cellulosic Ethanol	Municipal Solid Waste	
	Food and yard waste	

[3] See for example, the renewable biomass definition in H.R. 2452, The "American Clean Energy And Security Act of 2009," drafted by Congressmen Waxman and Marky.

Fuel	Feedstock	Conditions/Restrictions
	Switchgrass	If grown on land unsuitable for crops, then impacts are zero. Also, if grown between traditional crop growing periods, impacts from Land Use Change should be zero. Verification will be required.
	Industrial Waste	
	Perennial plants lands not suitable for agricultural use	Needs verification of land type.
	Crop Residue (stover from corn, straw from rice and wheat)	No impacts if enough residues are left on fields to ensure soil and crop health (only sustainable quantities are utilized for fuel). Requires verification.
	Vineyard Prunings	
	Forest Waste (thinnings)	Criteria Under Development
	Double cropped or mixed cropping	When a feedstock is harvested between traditional food crop plantings. This must be verified.
	Lumberyard mill residues	
	Dedicated crops (such as Poplar) on land unsuitable for food crop cultivation	Needs verification that land is unsuitable for food crop cultivation.
CNG/LNG	Landfill Gas	
	Dairy Digester Gas	
Electricity	Derived from new Solar, Wind, Hydro, or Biomass sources.	
	Derived from LFG or Digester Gas	
Hydrogen	Derived from LFG or Digester Gas using electricity from renewable sources	
	Derived from electrolysis with electricity from renewable source	

V. Future Certification Program.

In its approval of the Low Carbon Fuel Standard, the Board directed the Executive Officer to work with stakeholders to develop “robust, transparent, and specific criteria for conducting Carbon Intensity Lookup Table modifications through a certification process” (Resolution 09-31, April 23, 2009, page 18). The most effective approach to designing a certification process is to base that process upon the experience gained working with regulated parties to develop new pathways and sub-pathways. As the Executive Officer and staff gain experience assisting applicants, evaluating applications, responding to comments, and holding hearings, they will be applying that experience on an ongoing basis to the development of a pathway certification process proposal. Such a process would be similar to the existing ARB fuel additive certification process: proposed additives are subjected to a set of standardized evaluations that are comprehensively described in a certification procedures manual. In order to develop an LCFS fuel pathway certification process, staff will consciously work to systematize and standardize the application evaluation process. This should result in an increasingly streamlined, efficient, and clearly defined process—one that can be readily transformed into a certification process. Staff will report to the Board in December of 2009 on its progress developing a formal certification process.

When a pathway certification process proposal has been drafted, staff will seek Board approval to formally integrate that process into the LCFS regulation. If approved, that process will replace the one described herein.

VI. References

Tilman, David, Robert Socolow, Jonathon A. foley, Jason Hill, Eric Larson, Lee Lynd, Stephen Pacala, John Reilly, Tim Searchinger, Chris Somerville, and Robert Williams. "Beneficial Biofuels—The Food, Energy, and Environment Trilemma." *Science* 325:270-271. July 17, 2009.

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Atmospheric Chemistry and Physics

N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels

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Abstract. The relationship, on a global basis, between the amount of N fixed by chemical, biological or atmospheric processes entering the terrestrial biosphere, and the total emission of nitrous oxide (N_2O), has been re-examined, using known global atmospheric removal rates and concentration growth of N_2O as a proxy for overall emissions. For both the pre-industrial period and in recent times, after taking into account the large-scale changes in synthetic N fertiliser production, we find an overall conversion factor of 3–5% from newly fixed N to N_2O-N. We assume the same factor to be valid for biofuel production systems. It is covered only in part by the default conversion factor for "direct" emissions from agricultural crop lands (1%) estimated by IPCC (2006), and the default factors for the "indirect" emissions (following volatilization/deposition and leaching/runoff of N: 0.35–0.45%) cited therein. However, as we show in the paper, when additional emissions included in the IPCC methodology, e.g. those from livestock production, are included, the total may not be inconsistent with that given by our "top-down" method. When the extra N_2O emission from biofuel production is calculated in "CO_2-equivalent" global warming terms, and compared with the quasi-cooling effect of "saving" emissions of fossil fuel derived CO_2, the outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), depending on N fertilizer uptake efficiency by the plants, can contribute as much or more to global warming by N_2O emissions than cooling by fossil fuel savings. Crops with less N demand, such as grasses and woody coppice species, have more favourable climate impacts. This analysis only considers the conversion of biomass to biofuel. It does not take into account the use of fossil fuel on the farms and for fertilizer and pesticide production, but it also neglects the production of useful co-products. Both factors partially compensate each other. This needs to be analyzed in a full life cycle assessment.

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1 Introduction

N_2O, a by-product of fixed nitrogen application in agriculture, is a "greenhouse gas" with a 100-yr average global warming potential (GWP) 296 times larger than an equal mass of CO_2 (Prather et al., 2001). As a source for NO_x, i.e. NO plus NO_2, N_2O also plays a major role in stratospheric ozone chemistry (Crutzen, 1970). The increasing use of biofuels to reduce dependence on imported fossil fuels and to achieve "carbon neutrality" will further cause atmospheric N_2O concentrations to increase, because of N_2O emissions associated with N-fertilization. Here we propose a global average criterion for the ratio of N to dry matter in the plant material, which indicates to what degree the reduced global warming ("saved CO_2") achieved by using biofuels instead of fossil fuel as energy sources is counteracted by release of N_2O. This study shows that those agricultural crops most commonly used at present for biofuel production and climate protection can readily lead to enhanced greenhouse warming by N_2O emissions.

2 A global factor to describe N_2O yield from N fertilization

We start this study by deriving the yield of N_2O from fresh N input, based on data compiled by Prather et al. (2001) and Galloway et al. (2004) with some analysis of our own. Fresh fixed N input includes N, which is produced by chemical, biological and atmospheric processes. The pre-industrial, natural N_2O sink and source at an atmospheric mixing ratio of 270 nmol/mol is calculated to be equal to 10.2 Tg N_2O-N/yr (Prather et al., 2001), which includes marine emissions. By the start of the present century, at an atmospheric volume mixing ratio of 315 nmol/mol, the stratospheric photochemical sink of N_2O was about 11.9 Tg N_2O-N/yr. The total N_2O source at that time was equal to the photochemical sink (11.9 Tg N_2O-N/yr) plus the atmospheric growth rate (3.9 Tg N_2O-N/yr), together totalling 15.8 Tg N_2O-N/yr (Prather et al., 2001). The anthropogenic N_2O source is the difference between the total source strength, 15.8 Tg N_2O-N/yr, and the current natural source, which is equal to the pre-industrial source of 10.2 Tg N_2O-N/yr minus an uncertain 0–0.9 Tg N_2O-N, with the latter number taking into account a decreased natural N_2O source due to 30% global deforestation (Klein Goldewijk, 2001). Thus we derive an anthropogenic N_2O source of 5.6–6.5 Tg N_2O-N/yr. To obtain the agricultural contribution, we subtract the estimated industrial source of 0.7–1.3 Tg N_2O-N/yr (Prather et al., 2001), giving a range of 4.3–5.8 Tg N_2O-N/yr. This is 3.8–5.1% of the anthropogenic "new" fixed nitrogen input of 114 Tg N/yr for the early 1990s; the input value is derived from the 100 Tg of N fixed by the Haber-Bosch process, plus 24.2 Tg of N fixed due to fossil fuel combustion and 3.5 Tg difference from biological N fixation, BNF, between current and pre-industrial times (Galloway et al., 2004), reduced by the 14 Tg of Haber-Bosch N not used as fertilizer (Smeets et al, 2007). (This total of 114 Tg N is very similar to the sum of the different values for N from fertilizer and BNF given by Smeets et al.: 81+38=119 Tg.) In an earlier study (Mosier et al., 1998) the source of N_2O from agriculture was estimated to be even larger, 6.3 Tg N_2O-N, giving an N_2O yield of 5.5%. In comparison, the N_2O-N emission estimated by Prather et al. (2001) is 2.9–6.3 Tg N_2O-N/yr, or 3.4–6.8 Tg N_2O-N/yr if we also include biomass and biofuel burning (which we consider an agricultural source), leading to N_2O-N yields of 2.6–5.5% or 3.0–6.0%, respectively.

Because of good knowledge of the chemical processing of N_2O in the atmosphere and its tropospheric concentrations, obtained from air enclosure in ice cores, its natural sources and sinks are well known and can be calculated with models. Thus, pre-industrial, natural conditions provide additional information on the yield of N_2O from fixed N input. For that period, the global source and sink of N_2O was 10.2 Tg N_2O-N/yr with 6.2–7.2 Tg N_2O-N/yr coming from the land and coastal zones (Prather et al., 2001), derived from a fresh fixed N input of 141 Tg N/yr (Galloway et al., 2004), giving an N_2O-N yield of 4.4–5.1%. Both for the pre-Haber-Bosch natural terrestrial emissions and the agricultural emissions in the Haber-Bosch era, we find that the ratio y=N_2O output/fresh fixed N input is 3–5%. This is a parametric relationship, based on the global budgets of N_2O and fixed N input, and atmospheric concentrations and known lifetime of N_2O, and thus is not dependent on detailed knowledge of the terrestrial N cycle. We assume that this global ratio will be the same in agro/biofuel production systems. This is a reasonable assumption, as similar agricultural plants are currently used as feedstocks for biofuel production as those grown in regular agriculture. Some correction is needed for the use of animal manure in biofuel crop production, but this is quite small: Cassman et al. (2002) noted that approximately 11% of total N input to world's cropland came from animal manures.

A comparison of our "top-down" estimates of N_2O emissions from inputs of newly fixed N with the "bottom-up" estimates that are made with the IPCC inventory methodology (Mosier et al., 1998; IPCC, 2006) is presented in Appendix A. A key feature of our methodology is that the 114 Tg of newly fixed N entering agricultural systems (synthetic fertilizer N and N from biological nitrogen fixation (BNF)) is regarded as the source of all agriculture related N_2O emissions.

3 N_2O release versus CO_2 saved in biofuels

As a quick indicator to describe the consequence of this "background" N_2O production we compare its global warming with the cooling due to replacement of fossil fuels by biofuels. Here we will only consider the climatic effects of conversion of biomass to biofuel and not a full life cycle, leaving out for instance the input of fossil fuels for biomass production, on the one hand, and the use of co-products on the other hand.

We assume that the fixed nitrogen which is used to grow the biofuels is used with an average efficiency of 40% (see below) and that this factor determines how much newly fixed N must be supplied to replenish the fields over time. We also obtain the fossil CO_2 emissions avoided from the carbon processed in the harvested biomass to yield the biofuel. With these assumptions, we can compare the climatic gain of fossil fuel-derived CO_2 "savings", or net avoided fossil CO_2 emissions, with the counteracting effect of enhanced N_2O release resulting from fixed N input. Our assumptions lead to expressions per unit mass of dry matter harvested in biofuel production to avoid fossil CO_2 emissions, "saved CO_2",(M), and for "equivalent CO_2", (Meq), the latter term accounting for the global warming potential (GWP) of the N_2O emissions. We derive M from carbon contained in biomass as the lower heat value per carbon, and consequently the CO_2 emissions per energy unit, are almost identical for the fossil fuels and biofuels discussed here (JRC, 2007):

$$\mathrm{M} = r_{\mathrm{C}} * \mu_{\mathrm{CO2}} / \mu_{\mathrm{C}} * cv \quad (1)$$

$$\mathrm{Meq} = r_{\mathrm{N}} * y * \mu_{\mathrm{N2O}} / \mu_{\mathrm{N2}} * \mathrm{GWP} / e \quad (2)$$

In these formulae r_{C} is in g carbon per g dry matter in the feedstock; r_{N} is the mass ratio of N to dry matter in g N/kg;

Table 1. Relative warming derived from N_2O production against cooling by "saved fossil CO_2" by crops as a function of the actual nitrogen content $r_{N\,(actual)}$. Uncertainty ranges presented derive from the uncertainty of the yield factor y (see text).

Crop	$r_{N(actual)}$ (g N/kg dry matter)	Relative warming (Meq/M) (N-efficiency e=0.4)	Type of fuel produced
Rapeseed	39	1.0–1.7	Bio-diesel
Maize	15	0.9–1.5	Bio-ethanol
Sugar cane	7.3	0.5–0.9	Bio-ethanol

cv is the mass of carbon in the biofuel per mass of carbon in feedstock biomass (maize, rapeseed, sugar cane); e is a surrogate for the uptake efficiency of the fertilizer by the plants; y=0.03–0.05, the range of yields of N_2O-N from fixed N application; GWP=296; μ_{CO2}/μ_C=44/12, μ_{N2O}/μ_{N2}=44/28, where the μ terms are the molar weights of N_2O, N_2, CO_2, and C.

Inserting these values in Eqs. (1) and (2) we thus obtain, with expressions in parentheses representing ranges,

$$\mathrm{M}=3.667.cv.r_C \quad (3)$$

$$\mathrm{Meq}=(14-23.2)r_N/e \quad (4)$$

$$\mathrm{Meq/M}=(3.8-6.3)r_N/(e.cv.r_C) \quad (5)$$

The latter term is the ratio between the climate warming effect of N_2O emissions and the cooling effect due to the displacement of fossil fuels by biofuels.

These equations are valid for all above-ground harvested plant material, and separately also for the products and residues which are removed from the agricultural fields. If Meq>M, there will be net climate warming, the greenhouse warming by increased N_2O release to the atmosphere then being larger than the quasi-cooling effect from "saved fossil CO_2". There will neither be net climate warming nor cooling by biofuel production when Meq=M, which occurs for

$$r_N=(0.158-0.263).(e.cv.r_C) \quad (6)$$

Under current agricultural practices, worldwide, the average value for e ≈0.4 (or 40%) (Cassman et al., 2002; Galloway et al., 2003; Balasubramanian et al., 2004). This value reflects the considerable amounts of N lost to the atmosphere via ammonia volatilization and denitrification (N_2) and by leaching and runoff to aquatic systems. Fertilizer N use efficiency much higher than this (e.g. Rauh and Berenz, 2007) is certainly possible when fertilizer N is made available according to plant uptake requirements, but this does not reflect the agricultural practice in many countries of the world.

Nonetheless, we recognise the possibility of better efficiencies in future, as has been possible in special circumstances on a research basis. Below we derive values for r_N based on both e=0.4 and e=0.6.

The data (and their sources) used to calculate the carbon contents, r_C, and the conversion efficiency factors, cv, and the calculations themselves, are given in Appendix B. As r_C we use 0.61, 0.44 and 0.43 for rapeseed, maize, and sugar cane, respectively. We derive values of cv=0.58 for rapeseed bio-diesel, cv=0.37 for maize bio-ethanol, and cv=0.30 for sugar cane ethanol production.

Consequently, for e=0.4,
r_N=22.3–37.2 g N/kg dry matter for rapeseed bio-diesel,
r_N=10.3–17.1 g N/kg dry matter for maize bio-ethanol
r_N=8.1–13.6 g N/kg dry matter for sugar cane bio-ethanol.
Similarly, for e=0.6,
r_N=33.5–55.8 g N/kg dry matter for rapeseed bio-diesel,
r_N=15.4–25.7 g N/kg dry matter for maize bio-ethanol
r_N=12.2–20.4 g N/kg dry matter for sugar cane bio-ethanol.

For each of these biofuels, a larger value of r_N in the plant matter than this range implies that use of the fuel causes a net positive climate forcing.

Note that our analysis only considers the conversion of biomass to biofuels, emphasizing the role of N_2O emissions. It does not take into account the supply of fossil fuel for fertilizer production, farm machinery and biofuel process facility, which require a considerable fraction of the energy gained (Hill et al., 2006). Furthermore, we assume that biofuel production is based on mineral fertilizer only (substitution of manure for synthetic fertilizer would offset our result by the percentage of synthetic fertilizer that is not used). The energy content gained from by-products will largely be offset from additional energy needed to produce it (Hill et al., 2006), here we also neglect its potential to replace other animal feed crops (and the associated N_2O emissions). We are aware that integrated processes exist which better connect biofuel production with animal husbandry, but we believe this cannot be taken for granted on a global scale.

4 Results and discussion

4.1 Nitrogen content in biofuels

Data on r_N for several agricultural products, in g (N)/kg dry matter (Velthof and Kuikman, 2004; Biewinga and van der Bijl, 1996), are presented in Table 1, together with results on

Table 2. Sensitivity analysis, showing the impact on relative warming (Meq/M) resulting from changes to parameters used for Table 1. The calculations depend on assumptions made about the global agricultural practice of biofuel production. In each column, values differ from those presented in Table 1 by one parameter only as indicated in the relevant column heading.

Crop	Increased N-efficiency (e=0.6)	High share of manure (20%) in fertilizer for biofuels	Efficient use of by-products: Considerable fraction (50%) of N harvested for biofuel production replaces crops that would need N fertilizer
Rapeseed	0.7–1.2	0.8–1.4	0.5–0.9
Maize	0.6–1.0	0.7–1.2	0.4–0.7
Sugar cane	0.4–0.6	0.4–0.7	0.3–0.4

"relative warming". They show net climate warming, or considerably reduced climate cooling, by fossil fuel "CO_2 savings", due to N_2O emissions. The r_N value for maize is equal to 15 g N/kg dry matter, leading to a relative climate warming of 0.9–1.5 compared to fossil fuel CO_2 savings. The effect of the high nitrogen content of rapeseed is particularly striking; it offsets the advantages of a high carbon content and energy density for biodiesel production. World-wide, rapeseed is the source of >80% of bio-diesel for transportation, and has been particularly promoted for this purpose in Europe. For bio-diesel derived from rapeseed, this analysis indicates that the global warming by N_2O is on average about 1.0–1.7 times larger than the quasi-cooling effect due to "saved fossil CO_2" emissions. For sugar cane / ethanol the relative warming is 0.5–0.9, based on a r_N value of 7.3 g N/kg dry matter (Isa et al., 2005), causing climate cooling with respect to N_2O (not necessarily for the whole process, as fossil energy input is not considered).

Although there are possibilities for improvements by increasing the efficiency, e.g. for the uptake of N fertilizer by plants (Cassman et al., 2002) – which is much needed in regular agriculture as well – on a globally averaged basis the use of agricultural crops for energy production, with the current nitrogen use efficiencies, can readily be detrimental for climate due to the accompanying N_2O emissions, as indicated here for the common biofuels: rapeseed / bio-diesel, and maize / ethanol. However, if nitrogen use efficiency can be increased to e=0.6, then as the calculations above and in Table 2 show, maize / ethanol and rapeseed / biodiesel may be climate-neutral or beneficial. Also the effect of other assumptions on our result (substitute manure; replace other crops) is tested in Table 2.

More favourable conditions for bio-energy production, with much lower nitrogen to dry matter ratios (Tillman et al., 2006), resulting in smaller N_2O emissions, exist for special "energy plants", for instance perennial grasses (Christian et al., 2006) such as switch grass (*Panicum virgatum*) and elephant grass (*Miscanthus* × *giganteus* hybrid), with a r_N of 7.3 g N/kg dry matter. The production of biofuel from palm oil, with a r_N of 6.4 g N/kg dry matter (Wahid et al., 2005), may also have moderately positive effects on climate, viewed solely from the perspective of N_2O emissions. Other favourable examples are ligno-cellulosic plants, e.g. eucalyptus, poplar and willow.

The importance of N_2O emissions for climate also follows from the fact that the agricultural contribution of 4.3–5.8 Tg N_2O-N/yr gives the same climate radiative forcing as that provided by 0.55–0.74 Pg C/yr, that is 8–11% of the greenhouse warming by fossil fuel derived CO_2. Increased emissions of N_2O will also lead to enhanced NO_x concentrations and ozone loss in the stratosphere (Crutzen, 1970). Further, NO is also produced directly in the agricultural N cycle. Adopting the relative yield of NO to N_2O of 0.8 (Mosier et al., 1998), and the agricultural contribution to the N_2O growth rate of 4.3–5.8 Tg N_2O-N/yr, the global NO production from agriculture is equal to 3.4–4.6 Tg N/yr, about 20% of that caused by fossil fuel burning (Prather et al., 2001), affecting tropospheric chemistry in significant ways.

4.2 Potential impact on life cycle analysis

An abridged analysis as presented above, yielding N/C ratios to indicate whether biofuels are GHG-positive or GHG-negative, can not replace a full life cycle assessment. In recent years, a number of such assessments have become available (Adler et al., 2007; Kaltschmitt et al., 2000; von Blottnitz et al., 2006; Farrell et al., 2006; Hill et al., 2006). At this stage, we can not discuss the differences between these respective approaches, which also affect conclusions. But we may look into the release rate of N_2O-N used, presented as a function of applied fertilizer N. In these life cycle studies, release rates typically are based on the default values estimated by IPCC (2006) for "direct" emissions which were derived from plot-scale measurements (1% of the fertilizer N applied, or, in a previous version, 1.25%). Only a few studies (Adler et al., 2007) also incorporate the corresponding default values for "indirect" emissions also specified by IPCC (totalling less than 0.5% and which, together with the direct emissions, add up to c. 1.5% of fertilizer N), whereas our global analysis indicates a value of 3–5%. Past studies seem to have underestimated the release rates of N_2O to the atmosphere, with great potential impact on climate warming. The effect of applying higher N_2O yields can be assessed using the openly accessible EBAMM model (Farrell et al., 2006).

5 Conclusions

As release of N_2O affects climate and stratospheric ozone chemistry by the production of biofuels, much more research on the sources of N_2O and the nitrogen cycle is needed. Here we have shown that the yield of N_2O-N from fixed nitrogen application in agro-biofuel production can be in the range of 3–5%, 3–5 times larger than assumed in current life cycle analyses, with great importance for climate. We have also shown that the replacement of fossil fuels by biofuels may not bring the intended climate cooling due to the accompanying emissions of N_2O. There are also other factors to consider in connection with the introduction of biofuels. Here we concentrated on the climate effects due only to required N fertilization in biofuel production and we have shown that, depending on N content, the current use of several agricultural crops for energy production, at current total nitrogen use efficiencies, can lead to N_2O emissions large enough to cause climate warming instead of cooling by "saved fossil CO_2". What we have discussed is one important step in a life cycle analysis, i.e. the emissions of N_2O, which must be considered in addition to the fossil fuel input and co-production of useful chemicals in biofuel production. We have not yet considered the extent to which any loss by volatilisation of part of the fertilizer N may stimulate CO_2 uptake from the atmosphere, following deposition on natural ecosystems; estimates for this effect are very uncertain (de Vries et al., 2006; Magnani et al., 2007; Hyvönen et al., 2007). We conclude that the relatively large emission of N_2O exacerbates the already huge challenge of getting global warming under control.

Appendix A

Comparison between the present and the IPCC method to estimate the global N_2O yields

The basis of our methodology is that the newly fixed N entering agricultural systems (synthetic fertilizer N and N from biological nitrogen fixation (BNF)) is regarded as the source of all related N_2O emissions, and furthermore these emissions may not all happen in the season of application, but involve longer cycling times (which are nonetheless short compared with the lifetime of N_2O in the environment). These emissions can be conveniently considered in three categories:

- direct emissions from N-fertilized soils;
- "secondary" emissions resulting from the complex transformations of N compounds in the various flows within agricultural systems; and
- indirect emissions (in the IPCC meaning of the phrase) arising from leached N leaving agricultural fields and entering water systems, and from volatilized N deposited onto natural ecosystems.

Examples of the "secondary" emission sources are:

- crop residues ploughed in as fertilizer for a successor crop;
- dung and urine from livestock (both grazing and housed) fed variously on N-fertilized grain crops, feeds containing BNF-N (e.g. soya bean meal, alfalfa, clover-rich pasture and silage in Europe, and tropical grasses with *Azospirillum* associations in Brazil); and
- N mineralized from soil organic matter and root residues following cultivation or grassland renewal.

In contrast, in the IPCC approach, emissions from crop residues and mineralization are included in the "direct" emissions and have the same emission factor (*EF*); separate *EF*s are used for emissions from grazing animals, and the N source here is quantified on the basis of the N excreted, and essentially is treated as a "new" N source, not as fertilizer- or BNF-derived N. The fractions of the N applied to fields that are lost by leaching, runoff and volatilization have additional *EF*s applied to them. The aggregate emissions from agriculture are arrived at by summing all these individual sources. The IPCC's 1% *EF* for direct N_2O emissions contains an uncertainty of one-third to 3 times the default value. The default EF for emissions from cattle, poultry and pigs is 2% of the N excreted, with a range of 0.7% to 6% – again, from one-third to 3 times the default value. The EFs for N derived from N volatilization and re-deposition and N derived from leaching and runoff are 1% (uncertainty range 0.2–5%) and 0.75% (0.05–2.5%), respectively. At default volatilization fractions of 10% (mineral fertilizer) or 20% (animal manure), and default leaching fraction of 30%, indirect emissions amount to 0.35–0.45% of N applied. Each of the source terms in the bottom-up, IPCC method is very uncertain. However, their sum is not inconsistent with the total derived by the top-down methodology.

Appendix B

Calculation of cv values

a) Bio-ethanol production from maize:

Yield=2.66 US gallons per US bushel (mean of values for wet and dry milling processes) (USDA 2002, cited in UK Dept for Transport, 2006)

=2.66×3.785=10.07 l ethanol/25.4 kg maize
≡7.945 kg ethanol/25.4 kg maize
=0.313 kg ethanol/kg maize.

C content of ethanol (C_2H_5OH, mol. wt. 46) by weight=24/46=522 g/kg.
C content of maize (r_C)≅0.44 g/g≅440 kg/t.

cv=(0.313×522)/440=0.37.

b) Bio-diesel production from rapeseed:

– the average oil yield is 45% (450 kg/t rapeseed) (Elaine Booth, SAC Aberdeen, personal communication)

– the average composition of the oil is adequately represented by the triglyceride of the dominant fatty acid, erucic acid, i.e. $(C_{22}H_{41}O_2)_3(C_3H_5)$, mol. wt. 1052, then

C content of the oil by weight=828/1052=0.787 kg/kg.

Thus the C content of the oil=(450×0.787)=354 kg/t rapeseed.

The conversion to bio-diesel involves conversion to the methyl ester:

$(C_{22}H_{41}O_2)_3(C_3H_5) \rightarrow 3C_{22}H_{41}O_2CH_3$

but the C content of the bio-diesel is almost unchanged from that of the natural oil:

mol. wt. of methyl ester=352, and
C content=(276/352)×450=353 kg/t rapeseed.

Oil content of original rapeseed=45% (450 kg/t), and non-oil components ≅550 kg/t, of which

– protein is 40% (≡220 kg/t original rapeseed), with a C content of 510 g/kg;

– the remainder (60%, ≡330 kg/t original rapeseed) is dominantly carbohydrate,

(Colin Morgan, SAC Edinburgh, personal communication)

Thus the C content of the protein fraction in the original rapeseed =220×510/1000=112 kg/t; and
the C content of the carbohydrate fraction (for which a C content of 440 g/kg can be adopted, as for grains)=330×440/1000=145 kg/t.
The overall C content of the original rapeseed ($r_C=C_{oil}+C_{protein}+C_{CHO}$) =354+112+145=612 kg/t.

cv=353/612=0.58.

c) Bio-ethanol production from sugar cane:

Yield is 86 l dry ethanol (density 0.79 kg/l) per tonne sugar cane harvested at a water content of 72.5%, or 247 kg ethanol per tonne dry sugar cane (Macedo et al., 2004, as cited by JRC, 2007).

C content of ethanol (C_2H_5OH, mol. wt. 46) by weight=24/46=522 g/kg.
C content of dry sugar cane is determined by its structural material, cellulose, and its sugar content (polysaccharides: 440 g/kg; saccharose: 420 g/kg), we use r_C=430 g/kg

cv=(0.247 × 522)/430=0.30.

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References

Adler, P. R., Del Grosso, S. J., and Parton, W. J.: Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems, Ecol. Appl., 17, 675–691, 2007.
Balasubramanian, V., Alves, B., Aulakh, M., Bekunda, M., Cai, Z., Drinkwater, L., Mugendi, D., van Kessel, C., and Oenema O.: Crop, environmental, and management factors affecting nitrogen use efficiency, in: Agriculture and the Nitrogen Cycle, edited by: Mosier, A. R., Syers, J. K., and Freney, J., SCOPE 65, 19–33, Island Press, Washington, Covelo, London, 2004.
Biewinga, E. E. and van der Bijl, G.: Sustainability of energy crops in Europe, Centre for Agriculture and Environment (CLM), Utrecht, The Netherlands, 1–209, 1996.
Cassman, K. G., Dobermann, A., and Walters, D. T.: Agroecosystems, nitrogen-use efficiency, and nitrogen management, Ambio, 31, 132–140, 2002.
Christian, D. G., Poulton, P. R., Riche, A. B., and Yates, N. E.: The recovery over several seasons of ^{15}N-labelled fertilizer applied to Miscanthus x giganteus ranging from 1 to 3 years old, Biomass Bioenerg., 30, 125–133, 2006.
Crutzen, P. J.: The influence of nitrogen oxides on the atmospheric ozone content, Q. J. Roy. Meteor. Soc., 96, 320–325, 1970.
de Vries, W., Reinds, G.J., Gundersen, P., Sterba, H.: The impact of nitrogen deposition on carbon sequestration in European forests and forest soils, Global Change Biol., 12, 1151–1173, 2006.
Farrell, A. E., Plevin, R. J., Turner, B. T., Jones, A. D., O'Hare, M., and Kammen, D. M.: Ethanol Can Contribute to Energy and Environmental Goals, Science, 311, 506–508, 2006.
Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., Asner, G. P., Cleveland, C. C., Green, P. A., Holland, E. A., Karl, D. M., Michaels, A. F., Porter, J. H., Townsend, A. R. and Vörösmarty, C. J.: Nitrogen cycles: Past, present, and future, Biogeochemistry, 70, 153–226, 2004.

Galloway, J. N., Aber, J. D., Erisman, J. W., Seitzinger, S. P., Howarth, R. H., Cowling, E. B., and Cosby B. J.: The nitrogen cascade, Bioscience, 53, 341–356, 2003.

Hill, J., Nelson, E., Tilman, D., Polasky, S., and Tiffany, D.: Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels, Proc. Nat. Acad. Sci., 103, 11 206–11 210, 2006.

Hyvönen, R., Persson, T., Andersson, S., Olsson, B., Ågren, G. I., and Linder, S.: Impact of long-term nitrogen addition on carbon stocks in trees and soils in northern Europe, Biogeochemistry, online edition, doi:10.1007/s10533-007-9121-3, 2007.

IPCC: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, prepared by the National Greenhouse Gas Inventories Programme, edited by: Eggleston, H.S, Buendia, L., Miwa, K., Ngara, T. and Tanabe, K., Volume 4, Chapter 11, N_2O emissions from managed soils, and CO_2 emissions from lime and urea application, IGES, Hayama, Japan, 2006.

Isa, D. W., Hofman, G., and van Cleemput, O,: Uptake and balance of fertilizer nitrogen applied to sugarcane, Field Crop. Res., 95, 348–354, 2005.

JRC: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. Well-to-Tank report, version 2c, Joint Research Centre, Ispra, Italy, March 2007.

Kaltschmitt, M., Krewitt, W., Heinz, A., Bachmann, T., Gruber, S., Kappelmann, K.-H., Beerbaum, S., Isermeyer, F., and Seifert, K.: Gesamtwirtschaftliche Bewertung der Energiegewinnung aus Biomasse unter Berücksichtigung externer und makroökonomischer Effekte (Externe Effekte der Biomasse), Final Report (in German), IER, University of Stuttgart, Germany, 2000.

Klein Goldewijk, C. G. M.: Estimating global land use change over the past 300 years: The HYDE data base, Global Biogeochem. Cy., 15, 415–434, 2001.

Magnani, F., Mencuccini, M., Borghetti, M., et al.: The human footprint in the carbon cycle of temperate and boreal forests, Nature, 447, 848–850, 2007.

Mosier, A., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S., and van Cleemput, O.: Closing the global N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle, Nutr. Cycl. Agroecosyst., 52, 225–248, 1998.

Prather, M., Ehhalt, D., et al.: Atmospheric chemistry and greenhouse gases, in: Climate Change 2001: The Scientific Basis, edited by: Houghton, J. T., Ding, Y., Griggs, D. J., et al., 239–287, Cambridge University Press, Cambridge, UK, 2001.

Rauh, S. and Berenz, S.: Interactive comment on "N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels" by: P.J. Crutzen et al., Atmos. Chem. Phys. Discuss., 7, S4616–4619, 2007.

Smeets, E., Bouwman, A. F., and Stehfest, E.: Interactive comment on "N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels" by P.J. Crutzen et al., Atmos. Chem. Phys. Discuss., 7, S4937–4941, 2007.

Tillman, D., Hill, J., and Lehman, C.: Carbon-negative biofuels from low-input high-diversity grassland biomass, Science, 314, 1598–1600, 2006.

UK Department for Transport, International resource costs of bio-diesel and bio-ethanol, published 26 January 2006, http://www.dft.gov.uk/pgr/roads/environment/research/cqvcf/internationalresourcecostsof3833, 2006.

Velthof, G. L. and Kuikman, P. J.: Beperking van lachgasemissie uit gewasresten, Alterra rapport 114.3 (in Dutch), Wageningen, The Netherlands, 2004.

von Blottnitz, H., Rabl, A., Boiadjiev, D., Taylor, T., and Arnold, S.: Damage Costs of Nitrogen Fertilizer in Europe and their Internalization, J. Environ. Plan. Manage., 49, 413–433, 2006.

Wahid, M. B., Abdullah, S. N. A., and Henson, I. E.: Oil palm – achievements and potential, Plant Prod. Sci., 8, 288–297, 2005.

Life-cycle energy use and greenhouse gas emission implications of Brazilian sugarcane ethanol simulated with the GREET model

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abstract

By using data available in the open literature, we expanded the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory to include Brazilian-grown sugarcane ethanol. With the expanded GREET model, we examined the well-to-wheels (WTW) energy use and greenhouse gas (GHG) emissions of sugarcane-derived ethanol produced in Brazil and used to fuel light-duty vehicles in the United States. Results for sugarcane ethanol were compared with those for petroleum gasoline. The sugarcane-to-ethanol pathway evaluated in the GREET model comprises fertilizer production, sugarcane farming, sugarcane transportation, and sugarcane ethanol production in Brazil; ethanol transportation to U.S. ports and then to U.S. refueling stations; and ethanol use in vehicles. Our analysis shows that sugarcane ethanol can reduce GHG emissions by 78% and fossil energy use by 97%, relative to petroleum gasoline. The large reductions can be attributed to the use of bagasse in sugarcane mills, among other factors. To address the uncertainties involved in key input parameters, we developed and examined several sensitivity cases to test the effect of key parameters on WTW results for sugarcane ethanol. Of the total GHG emissions associated with sugarcane ethanol, the five major contributors are open-field burning of sugarcane tops and leaves, N_2O emissions from sugarcane fields, fertilizer production, sugarcane mill operation, and sugarcane farming. Brazil is going to phase out open-field burning in the future. This action will certainly help further reduce GHG emissions of sugarcane farming, together with reductions in emissions of criteria pollutants such as NO_x and particulate matter with diameters smaller than 10 microns. The eventual elimination of open-field burning in sugarcane plantations will result in additional GHG emission reductions by sugarcane ethanol of up to 9 percentage points.

Keywords: **greenhouse gases, life-cycle analysis, sugarcane ethanol, well-to-wheels analysis**

El ciclo de vida del uso de energía y las consecuencias de las emisiones de gas del etanol derivado de caña azucarera en Brasil, simulado con el modelo GREET

La utilización de datos disponibles en la literatura abierta al público, nos permitió extender el alcance del modelo GREET desarrollado por el Argonne National Laboratory (Laboratorio Nacional de Argonne) para abarcar el etanol de la caña azucarera cultivada en Brasil. Con el modelo GREET – cuyo nombre se deriva de Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (Gases de Invernadero, Emisiones Reguladas, y Uso de Energía en Transporte) - ampliado, hemos analizado el uso de energía desde el pozo a las ruedas (well-lo-wheels o WTW) y las emisiones de gas de invernadero (greenhouse gas = GHG) del etanol derivado de caña de azúcar producido en Brasil y que se utiliza como combustible para vehículos livianos en los Estados Unidos. Los resultados obtenidos para el etanol de caña fueron comparados con los de la gasolina de petróleo. La ruta que enlaza la caña de azúcar y el etanol, fue evaluada en el modelo GREET e incluye el estudio de la producción de fertilizante, el cultivo de la caña, el transporte de la caña, y la producción de etanol de caña en Brasil; el transporte de etanol a puertos de los Estados Unidos y de ahí a estaciones de abastecimiento en EE.UU.; y el uso de etanol para vehículos de transporte. Nuestro análisis muestra que, cuando se compara con la gasolina derivada del petróleo, el etanol proveniente de caña de azúcar puede reducir las emisiones GHG en un 78% y el uso de energía fósil en un 97%. Estas reducciones considerables pueden ser atribuidas al uso del bagazo en los ingenios azucareros. Con el objetivo de hacer frente a las incertidumbres resultantes de los parámetros clave, hemos desarrollado y examinado varios casos de sensibilidad para estudiar el efecto de los parámetros clave sobre los resultados del WTW para el etanol derivado de la caña azucarera. Del total de emisiones de GHG asociadas con el etanol de caña de azúcar, los cinco contribuyentes principales son: la quema en campo abierto de los cogollos y hojas de la caña, las emisiones de N_2O proveniente de los campos de caña, la producción de fertilizante, la operación del ingenio azucarero, y el cultivo de la caña azucarera. Brasil tiene la intención de erradicar la práctica de quema en campo abierto en el futuro. Estas actividades ayudarán por seguro a la reducción de las emisiones de GHG en el cultivo de la caña de azúcar junto con la reducción de contaminantes importantes como el NO_x y la materia en partículas de diámetro menor de 10 micrones. Cuando se elimine la quema a campo abierto en la plantaciones de caña azucarera esto resultará en una reducción adicional de las emisiones de GHG por el etanol de la caña de azúcar, en aproximadamente nueve puntos porcentuales.

Lebenszyklus-Energieverbrauch und Treibhausgas-Emissionsimplikationen von brasilianischem Zuckerrohrethanol, simuliert mit dem GREET-Modell

Unter Hinzuziehung von in veröffentlichten Schriften enthaltenen Daten erweiterten wir das vom Argonne National Laboratory entwickelte GREET-Modell (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) um Zuckerrohrethanol aus brasilianischem Anbau. Mit dem erweiterten GREET-Modell untersuchten wir den WTW-Energieverbrauch (Well-to-Wheels = vom Brunnen zum Rad) und die Treibhausgas-Emissionen (GHG) von aus Zuckerrohr gewonnenem Ethanol, das in Brasilien produziert und zum Antrieb von leichten Nutzfahrzeugen in den USA verwendet wird. Die Ergebnisse für Zuckerrohrethanol wurden mit denen für Mineralölbenzin verglichen. Der im GREET-Modell evaluierte Weg von Zuckerrohr zu Ethanol umfasst die Düngemittelproduktion, den Zuckerrohranbau, den Zuckerrohrtransport und die Zuckerethanolproduktion in Brasilien, den Ethanoltransport zu US-amerikanischen Häfen und dann zu US-amerikanischen Tankstellen sowie die anschließende Ethanolnutzung in Fahrzeugen. Unsere Analyse zeigt, dass Zuckerrohrethanol, verglichen mit Mineralölbenzin, die GHG-Emissionen um 78% und den Fossilenergieverbrauch um 97% reduzieren kann. Die großen Reduktionen sind der Verwendung von Bagasse in den Zuckerrohrmühlen zuzuschreiben. Um Ungewissheiten bei den wichtigsten Eingabeparametern Rechnung zu tragen, entwarfen und untersuchten wir mehrere sensitive Fälle, um die Auswirkungen von Schlüsselparametern auf die WTW-Ergebnisse für Zuckerrohrethanol zu testen. Von den GHG-Gesamtemissionen, die mit Zuckerrohrethanol verbunden waren, waren die fünf Hauptbeitragsfaktoren: Verbrennung von Zuckerrohrblättern und Pflanzenteilen auf offenem Feld, N_2O-Emissionen der Zuckerrohrfelder, Düngemittelproduktion, Zuckerrohrmühlenbetrieb und Zuckerrohranbau. Brasilien beabsichtigt das Abrennen von Feldern allmählich einzustellen. Diese Maßnahme wird sicherlich – ebenso wie eine Reduktion der Emissionen von gefährlichen Schadstoffen (Criteria Pollutant Emissions) wie z.B. NO_x und Feststoffteilchen mit einem Durchmesser von unter 10 Mikrometer – dazu beitragen, die GHG-Emissionen des Zuckerrohranbaus weiter herabzusetzen. Das schließliche Ende des Abbrennens der Felder von Zuckerrohrplantagen wird weitere GHG-Emissionsreduktionen für Zuckerrohrethanol von bis zu 9 Prozentpunkten mit sich bringen.

Introduction

Brazil began its sugarcane fuel ethanol program in 1975 after the first oil crisis and has since expanded it significantly. Brazil is now the number two fuel ethanol producer and consumer after the United States. Ethanol has become a mainstream motor fuel in Brazil, accounting for 40% of its gasoline market. More than 80% of new cars sold in 2006 were ethanol flexible-fuel vehicles (FFVs).

Brazil has vast land available for sugarcane farming. About five million hectares of land are currently used for sugarcane farming in Brazil (Macedo 2005), and some in Brazil maintain that an additional five million hectares can be made available for sugarcane farming. Brazil expects that its sugarcane ethanol industry will continue to expand. In fact, companies from other countries are beginning to invest in the sugarcane ethanol industry in Brazil. In addition to its own consumption, Brazil seeks to export fuel ethanol to other countries, including the United States, the European Union, and Japan.

Biofuels are being promoted for their potential for reductions in greenhouse gas (GHG) emissions, relative to those of petroleum-based gasoline. Sugarcane-based ethanol has been reported to achieve more than 80% reductions in GHG emissions (see Macedo *et al.* 2004; International Energy Agency 2004; Concawe *et al.* 2007). However, systematic, detailed evaluation of sugarcane ethanol and comparison of it with other biofuels and alternative fuels are needed.

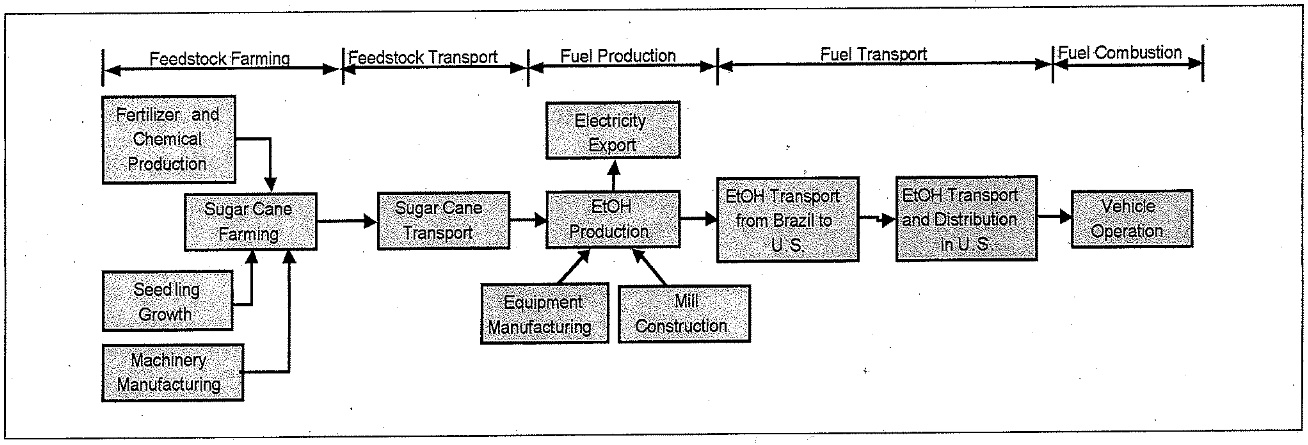
Argonne National Laboratory has been developing and applying the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to examine energy and emission benefits of advanced vehicle technologies and new transportation fuels (see Brinkman *et al.* 2005 for the GREET model and its applications). The GREET model features many fuel ethanol production pathways from feedstocks such as corn, fast-growing trees, switchgrass, crop residues, and forest residues. Through this study, we expanded the GREET model to include the production of sugarcane ethanol in Brazil and the use of it in the United States. Doing so enables GREET users (more than 4,000 of them as of December 2007) to examine sugarcane ethanol together with ethanol produced from other feedstocks and with other potential transportation fuels. We then used the expanded GREET model to systematically simulate energy and GHG emission effects of sugarcane ethanol.

System boundary and analysis cases for the sugarcane-to-ethanol pathway

The GREET model is a life-cycle, or well-to-wheels (WTW), analytical tool that parties can use to examine energy and emission effects of different vehicle/fuel options. Argonne National Laboratory has been developing and applying the model since 1995. The most recent version - GREET1.8a - was released in August 2007. The model and its major publications are posted at the GREET website (http://www.transportation.anl.gov/software/GREET/index.html). For a given vehicle and fuel system, GREET evaluates total energy use, fossil fuel use, natural gas (NG) use, coal use, and petroleum use; emissions of carbon dioxide (CO_2)-equivalent GHGs, including CO_2, methane (CH_4), and nitrous oxide (N_2O); and emissions of six criteria pollutants - volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO_x), particulate matter with diameters smaller than 10 microns (PM_{10}), particulate matter with diameters smaller than 2.5 microns ($PM_{2.5}$), and sulfur oxides (SO_x). The criteria pollutant emissions are further separated into total and urban emissions to reflect human exposure to air pollution caused by emissions of the six criteria pollutants.

We conducted a WTW analysis of Brazilian sugarcane-derived ethanol based on the system boundary depicted in Figure 1. The life cycle of sugarcane-derived ethanol begins with the manufacture of fertilizer and farming machinery and the preparation of cane setts for transplanting. Farming operations include chemical application, irrigation, tillage and harvest. The current sugarcane farming practice involves open-field burning of sugarcane leaves and tops before and after harvest to facilitate the manual harvest and to control disease. We included these factors in our analysis.

Figure 1. Stages of the sugarcane-to-ethanol pathway



Harvested sugarcane is transported via trucks to sugarcane mills. At sugarcane mills, sugarcane undergoes sugar juice extraction, followed by fermentation of juice for ethanol production (and/or sugar production). The residues from juice extraction - called "bagasse" - are combusted to generate steam and electricity to meet the demand for heat and power. Since 2000, sugarcane mills in Brazil have made major efforts to export their excess electricity to the electric grid.

Ethanol is then transported and distributed from plants to refueling stations. Ethanol is transported from sugarcane mills to Brazilian ports via rails and pipelines (as being practiced in Brazil now), to U.S. ports by ocean tankers, and then to U.S. refueling stations via trucks.

Finally, ethanol is used during vehicle operation. Ethanol can be used either in low-level blends such as E10 (mixture of 10% ethanol and 90% gasoline by volume) in regular gasoline vehicles or high-level blends such as E85 (mixture of 85% ethanol and 15% gasoline by volume) in FFVs.

In our analysis of sugarcane ethanol, we included energy and GHG emissions of the manufacture of farming machinery and sugarcane mill equipment and the construction of sugarcane mills. These so-called infrastructure-related activities are usually not included in WTW analyses.

The gasoline life cycle, on the other hand, begins with crude oil recovery in oil fields and ends in gasoline combustion in gasoline vehicles, a pathway that is already in the GREET model.

Our analysis targeted the timeframe of 2006-2010. With this time frame, many factors play a key role in determining the overall energy use and GHG emissions of sugarcane ethanol. We examined these factors by developing several sugarcane ethanol cases, all of which produce ethanol and export electricity to the electric grid. In addition, we included petroleum gasoline, corn ethanol, and switchgrass ethanol for comparison.

The base case established for sugarcane ethanol was production in Brazil with use in the United States. Other cases were developed to test the importance of the following parameters: (1) whether sugarcane ethanol is used in the United States or Brazil (to assess the contribution of ocean tanker transportation of ethanol), and (2) whether energy embedded in farming equipment manufacturing and sugarcane mill construction makes a significant contribution to the WTW results of sugarcane ethanol. The sugarcane (SC) cases and the petroleum gasoline, corn ethanol, and switchgrass ethanol cases were as follows:

- SC Case 1 (the base case for sugarcane ethanol): sugarcane ethanol is produced in Brazil and used in the United States; energy embedded in farming equipment manufacturing and sugarcane mill construction is not included. (This case is consistent with the petroleum gasoline pathway.)

- SC Case 2: same as SC Case 1 except that energy embedded in farming equipment manufacturing and sugarcane mill construction is included.

- SC Case 3: same as SC Case 1 except that energy embedded in farming equipment manufacturing is included.

- SC Case 4: same as SC Case 3 except that sugarcane ethanol is used in Brazil. (This case shows the contribution of ocean tanker transportation of ethanol.)

- Petroleum gasoline production and use in the United States, excluding energy embedded in all infrastructure-related activities.

- Corn ethanol production and use in the United States, including energy embedded in the farming machinery.

- Cellulosic ethanol production and use in the United States with switchgrass as the feedstock, including energy embedded in the farming machinery.

Data sources and GREET assumptions

Sugarcane farming

We analyzed energy use and emissions for activities involved in sugarcane farming, including fertilizer, lime, and chemical production; sugarcane setts preparation; farming operations; farming equipment manufacturing; and open-field burning of sugarcane leaves and straws.

Chemical and energy inputs for sugarcane farming

Once sugarcane setts have been planted on sugarcane farms, the sugarcane can be harvested for five to seven seasons. After that, sugarcane farms are replanted. Traditionally, sugarcane is harvested

Table 1. Fertilizer and chemical inputs for sugarcane farming in Brazil

Input	Assuncao (2000)[a]	Macedo *et al.* (2004)[b]	GREET[e]
N fertilizer			
kg/ha/yr	77.2	71.6[c]/75[d]	
g/MT of sugarcane	1,152.2	1,042.2[c]/1,091.7[d]	1,091.7
P_2O_5			
kg/ha/yr		40.8[c]/8.3[d]	
g/MT of sugarcane		593.9[c]/120.8[d]	120.8
K_2O			
kg/ha/yr		120[c]/13.3[d]	
g/MT of sugarcane		1,746.7[c]/193.6[d]	193.6
Lime ($CaCO_3$)			
kg/ha/yr		366.7	
g/MT of sugarcane		5,337.7	5,337.7
Herbicide use			
g/MT of sugarcane		26.9	26.9
Pesticide use			
g/MT of sugarcane		2.21	2.21

[a] Assuncao assumed a nitrogen application of 28 kg/ha for planting of sugarcane and 87 kg/ha for each harvest season. We assumed a cycle of 6 years with five cuts. He further assumed a sugarcane yield of 80.4 MT/ha/cut, resulting in 67 MT/ha/year over the 6-year period. These values were used to derive nitrogen application per hectare per year and per metric ton of sugarcane harvested.
[b] Macedo *et al.* (2004) used a sugarcane yield of 68.7 MT/ha/year over a 6-year sugarcane cycle. We used this value to derive nitrogen application rates per metric ton.
[c] For farms that do not use filter mud cake and vinasse (the residues left in a still following distillation).
[d] For farms that use filter mud cake and vinasse.
[e] For GREET simulations, weighted average values between sugarcane fields without and with use of filter mud and vinasse would be ideal. Because of the lack of data regarding breakdown of the two types of sugarcane plantations, we adopted the values for the fields with use of filter mud and vinasse.

Table 2. Inputs of energy use for farming operation, sugarcane sett preparation and farming machinery manufacturing for sugarcane farming (MJ/MT of sugarcane)

Activity	Assuncao (2000)	GTZ (2005)	Macedo *et al.* (2004)	GREET
Farming operation[a]	30.1	38	38	38
Sugar-cane seedling preparation	5.76	6	5.88	5.88
Energy embedded in farming machinery	33.1	N/A	29.1	29.1

[a] The farming energy data include energy use for sugarcane harvesting, as well as for other farming activities. Data from the three cited sources are for combinations of manual and mechanical harvest. Although manual harvest now accounts for more of the total harvest than mechanical harvest, in the long term, mechanical harvest will account for more. Energy use between the two harvest methods could be different, but no data showing the difference are available. The difference in harvest energy use may be small, because manual harvest collection and loading activities are still performed by machines to a large extent.

by laborers ("sugarcane cutters"); this harvest is often referred to as the "manual harvest." To ease cutters' efforts, sugarcane fields are burned before harvest. After harvest, the remaining tops are often burned to control disease and promote cane growth in the next season. Primarily because of concerns about air pollution caused by open-field burning, the state of Sao Paulo will phase out open burning completely by 2018. As a result, mechanical harvest will replace manual harvest. As of 2005, 65% of the sugarcane harvest in Brazil was manual, and 35% was mechanical (Macedo 2005).

Table 1 summarizes the application rates of nitrogen (N) and phosphate (P_2O_5) fertilizer, potash (K_2O), lime ($CaCO_3$), herbicide, and pesticide on Brazilian sugarcane farms. Fertilizer and chemical use are usually reported in kilograms per hectare per year (kg/ha/yr); however, for GREET simulations, we need to use kilograms or grams per metric ton (kg/MT) of sugarcane harvested. We converted the former by using a sugarcane yield of 68.6 MT/ha (Macedo *et al.* 2004). The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007).

For sugarcane farming, energy use includes diesel fuels used to power farming equipment, energy spent preparing sugarcane setts, and energy embedded in farming equipment manufacturing (Table 2). Although GREET WTW analyses generally do not include energy embedded in equipment, we included it to be consistent with the pathways for ethanol production from different feedstocks, which include this energy. Nonetheless, we designed an option in GREET for including or excluding the energy embedded in farming equipment manufacturing and associated emissions.

Open-field burning of sugarcane leaves and tops

Sugarcane leaves and tops are typically burned in the field before and after harvest. Macedo *et al.* (2004) reported a yield of 280 kg of leaves and tops (with 50% moisture content, or 140 kg of dry leaves and tops) per metric ton of sugarcane harvest. 80% of sugarcane farms in Brazil are assumed to practice open-field burning in 2010. Because open-field burning will be gradually phased out, in developing the sugarcane ethanol pathway in GREET, we assumed burning of 80% of leaves and tops for 2010 and 0% in 2020.

For the GREET simulation, we took into account emissions from open-field burning - in particular, emissions of two pollutants:

methane (CH_4) and nitrous oxide (N_2O). Emissions of carbon dioxide (CO_2) from open-field burning were not taken into account, because the CO_2 is taken from the air during sugarcane growth. Emissions from open-field burning of sugarcane leaves and tops were estimated by assuming a carbon content of leaves and tops of 50% on a dry-matter basis (Macedo *et al.* 2004).

Table 3 lists our estimates of emissions generated from open-field burning. These were based on three sources: summaries of Macedo *et al.* (2004) and Assuncao (2000); results in Andreae and Merlet (2001); and data included in the Intergovernmental Panel on Climate Change guidelines (IPCC 2006a). The average emission values from open-field burning of agricultural residues listed in the IPCC guidelines appear higher than those from other sources. We used the IPCC data as our base case for emission factors of CH_4, N_2O, CO, NO_x, and $PM_{2.5}$. For PM_{10}, we estimated emission factors on the basis of a ratio of 2:1 between PM_{10} and $PM_{2.5}$, which was derived from coal combustion emission factors in GREET. Therefore, we used a value of 7.8 g/kg of leaves and tops burned for PM_{10}. For VOC and SO_x emission factors, we used values estimated by Andreae and Merlet (2001).

N_2O emissions from sugarcane fields

A major source of N_2O emissions from sugarcane farming is nitrification and denitrification of nitrogen fertilizer applications. In Brazil, the most frequently used type of nitrogen fertilizers is urea (Macedo 2007), from which N_2O is emitted directly and indirectly. When applied to soil, nitrogen fertilizer is volatilized and converted to N_2O; when oxidized, some of it is emitted directly to the air as N_2O. A large amount of nitrogen fertilizer leaches to groundwater or rivers through surface runoff, during which some of it is converted to N_2O via microbial nitrification and denitrification. Macedo *et al.* (2004) estimated that on an annual basis, 75 kg of nitrogen in nitrogen fertilizer applied to a 1-ha sugarcane field resulted in 1.76 kg of N_2O emissions in the Central-South region of Brazil, which resulted in 1.5% in weight (wt%) of nitrogen in N_2O per weight unit of nitrogen in nitrogen fertilizer applied.

The N_2O emissions from soil are highly uncertain; they depend on various conditions such as the amount of nitrogen fertilizer applied, soil type, soil moisture content, and soil temperature. According to the IPCC guidelines (2006b), the following are the N_2O emission factors for nitrogen in N_2O generated from the nitrogen in nitrogen fertilizer for generic applications: 1% for direct N_2O-N emissions, with a range of 0.3–3%; 1% for N_2O emissions from volatilization, with a range of 0.2-5% and a volatilization rate for nitrogen input of 10%, with a range of 3-30%; and 0.75% N_2O emissions from leaching and runoff, with a range of 0.05-2.5% and a leaching and runoff rate for nitrogen input of 30%, with a range of 10-80%. Using the average values in the IPCC guidelines (2006b), we derived a total N_2O-N rate of 1.325% [1% + (1% x 10%) + (0.75% x 30%)], which is close to the value of 1.5% derived from Macedo et al. (2004). We used the rate of 1.5% in our analysis.

In contrast, Crutzen *et al.* (2007) estimated a conversion rate of 3-5%, based on a global N_2O balance. While the top-down approach adopted in Crutzen *et al.* is sound, especially for checking and verifying results with the bottom-up approach used by the IPCC and others, data for the top-down approach needs to be closely examined in order to generate reliable N_2O conversion factors. In particular, Crutzen *et al.* adopted the global N_2O emission balance from a 2001 study but nitrogen inputs from a separate 2004 study for deriving N_2O conversion factors. Furthermore, Crutzen *et al.* did not deal with agricultural subsystems (such as crop farming, animal waste management, and crop residual burning), which are required for generating N_2O conversion rates for the nitrogen inputs into crop farming. Their allocation of aggregate N_2O emissions (even after subtracting N_2O emissions from industrial sources) to the aggregate agricultural system could result in overestimation of N_2O conversion rates from nitrogen inputs into crop farming systems. Nonetheless, N_2O conversion rates, which are subject to great uncertainties, need to be reconciled between the bottom-up and the top-down approach.

The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007). A gram of urea (NH_2CONH_2) contains 0.2 g of carbon, resulting in 0.43 g of carbon per gram of nitrogen in urea. This composition results in 1.577 g of CO_2 per gram of nitrogen in urea. We included this CO_2 emission source in GREET simulations.

Table 3. Emission factors of open-field burning of sugarcane leaves and tops

	Emission factors (g/kg of dry leaves and tops burned)					
Pollutant	Andreae and Merlet (2001)	Macedo *et al.* (2004) Low value[a,b]	Macedo *et al.* (2004) High value[a,b]	Assuncao (2000)[a]	IPCC (2006a)	GREET
CO_2	1515 (±177)				1515 (±177)	NN[c]
CO	92 (±84)				92 (±84)	92
CH_4	2.7	0.1464	1.0214	0.2886	2.7	2.7
NO_x	2.5(±1)				2.5 (±1)	2.5
N_2O	0.07				0.07	0.07
$PM_{2.5}$	3.9					3.9
PM_{10}						7.8[d]
VOC	7.0					7.0
SO_x	0.4					0.4

[a] These sources reported CH_4 emissions in kg/MT of sugarcane harvested. We used the yield of 280 kg of sugar cane leaves and tops with 50% moisture content per MT of sugarcane harvested to convert the original values into values in g/kg of leaves and tops burned.
[b] Macedo *et al.* (2004) maintained that the low values represented the average Brazilian emission rates, and the high values were adopted from the IPCC guidelines.
[c] Data is not needed here. CO_2 emissions are calculated in GREET by using the carbon balance of sugar cane leaves and tops; see a section below.
[d] Data was not available. This value was estimated on the basis of the ratio of PM_{10} versus $PM_{2.5}$ for coal combustion.

Figure 2. Schematic representation of the sugarcane ethanol production process

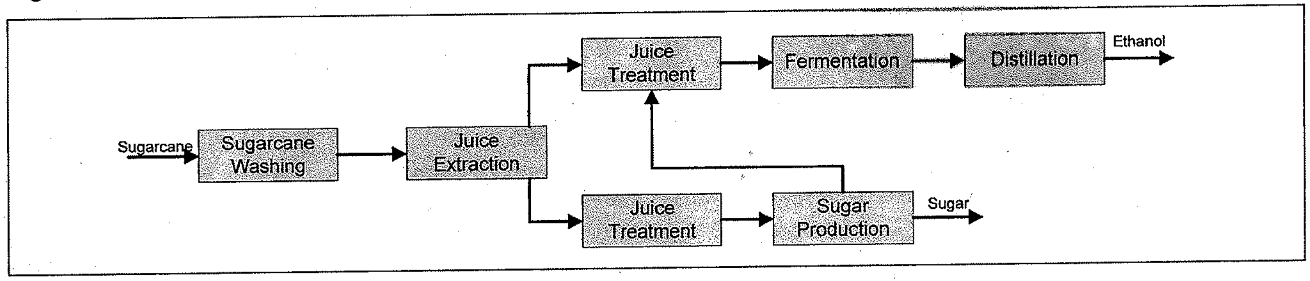


Table 4. Sugarcane composition

Parameter	Value (%)
Sucrose content	14.5
Fiber content	13.5
H_2O content	72.0

Source: Macedo *et al.* 2004.

Sugarcane transportation from farms to sugarcane mills

Harvested sugarcane contains about 70% water. Because sugarcane is bulky and heavy, sugarcane mills are built in the midst of sugarcane farms to minimize transportation distance. Sugarcane is transported via trucks an average one-way distance of 20 km (Macedo *et al.* 2004). The payload of a truck is 40-50 MT (Moreira and Goldemberg 1999). With these inputs, past studies in Brazil concluded that energy use for transporting sugarcane from farms to mills is 31-43 MJ/MT of sugarcane (Assuncao 2000; GTZ 2005; Macedo *et al.* 2004).

For GREET simulations, we assumed that sugarcane is transported by a diesel truck with a payload of 40 MT for a 20-km one-way trip from field to mill. Furthermore, we assumed a fuel economy of 4 miles per gallon (1.7 km/L) of diesel fuels for trucks transporting sugarcane. On the basis of these assumptions, the GREET model estimated an energy consumption of 24.4 MJ/MT of sugarcane transported. This value is lower than the values in the cited studies; those studies may have included direct energy use (as was the case in our estimate) and energy embedded in manufacturing the trucks.

Ethanol production in sugarcane mills

In sugarcane mills, sugarcane is washed and crushed, and cane juice is extracted. The juice is then treated to produce ethanol and/or sugar. The split between the two products is based on market demand. Table 4 presents the typical composition of sugarcane. The stream for ethanol production is then fermented, and the fermentation broth is subject to distillation, yielding product ethanol. CO_2 is emitted during fermentation. Figure 2 is a schematic of the sugarcane ethanol production process. To simplify this analysis, we assumed that a sugarcane ethanol mill is operated with 100% feed for ethanol production. The primary source of process fuel is bagasse with additional lubricant oil to support machinery operation.

Ethanol yield

Table 5 presents a summary of ethanol yield from several studies.

Table 5. Ethanol yields in sugarcane mills (liters per MT of sugarcane)[a]

Source	Ethanol yield	Notes
Moreira and Goldemberg (1999)	79.5	1996/97 season yield
Assuncao (2000)	73	1985 season yield
	85.4	2000 season yield
GTZ (2005)	80	
Macedo *et al.* (2004)	86	Average value
	91	Best value
GREET Input value	91	

[a] Assuming that all sugarcane goes to ethanol production, and sugarcane contains 72% of water.

We used a yield of 91 L of ethanol/MT of sugarcane, based on the best value reported in Macedo *et al.* (2004).

Energy requirements in sugarcane mills

Table 6 shows the amounts of electric, thermal, mechanical, and chemical energy required for production of ethanol in sugarcane mills. Sugarcane mills are self-sufficient in terms of thermal energy and electricity use. Heat demand represents the majority of energy use and is met through bagasse combustion. Most sugarcane mills generate their own electricity for internal use. The use of bagasse as the process fuel is discussed in a section below. We selected values for GREET input parameters on the basis of the latest data from the open literature. We estimated the total electricity use by the sugarcane mill to be 28.85 kWh/MT of sugarcane processed. Of this total, 16.84 kWh/MT is used to drive mechanical work with a conversion efficiency of 95% (Table 7).

We assumed that the thermal energy of 1,188 MJ per MT of sugarcane is supplied by bagasse combustion in a biomass boiler to produce steam with an efficiency of 80%. With these, about 1,485 MJ of bagasse is required per MT of sugarcane processed, which is about 16.3 MJ/L of ethanol produced (Table 7). A small amount of lubricants (6.36 MJ/MT of sugarcane) is used in sugarcane mills, which we assumed to be similar to residual oil in terms of energy and emission profiles.

Macedo *et al.* (2004) estimated a life-cycle energy use of 9.29 MJ/MT of sugarcane processed in construction of sugarcane mills and 24.16 MJ/MT in manufacture of sugarcane mill equipment (that is, embedded energy in mill equipment). We included these values in the GREET model. The equipment used was assumed to be 100% steel. Emissions from equipment manufacturing were estimated on the basis of process fuel shares for steel production as presented in the GREET model.

Bagasse as the process fuel in sugarcane mills

Bagasse is the residue of sugarcane after the juice has been extracted. Because of its high carbon content (46.3 wt% on a dry matter basis), it serves as an excellent source of process fuel in sugarcane mills. We assumed that bagasse is combusted in a biomass boiler to produce steam to meet the plant demand for steam and to generate electricity with a steam turbine to meet the plant requirement for electricity and for electricity export.

We used a bagasse yield of 280 kg (with 50% moisture content) per MT of sugarcane, which was reported by Macedo *et al.* (2004). The lower heating value (LHV) of bagasse in references ranged from 7.530 to 7.736 MJ/kg (with 50% moisture content, Macedo *et al.* 2004; Garcia 2007). One heating value reported by Assuncao (2000), 9.449 MJ/kg, was 2 MJ higher and was not specified as either high heating value (HHV) or LHV. We compared the data with the Chemical Engineers' Handbook (Perry and Green 1997), which lists an HHV of 8.37-11.63 MJ/kg for bagasse, suggesting that the value of 9.448 MJ/kg is most likely the HHV. For sugarcane ethanol simulations in GREET, we used a LHV of 7.53 MJ/kg (with 50% moisture content) for bagasse. On a dry-matter basis, the LHV for bagasse is 15.06 MJ/kg.

The steam and electricity balance for sugarcane ethanol processing is presented in Table 8. The total energy in bagasse, 23.17 MJ/L of ethanol produced, was determined by using a bagasse yield of 280 kg/MT sugarcane, bagasse energy content of 7.53 MJ/kg, and an ethanol yield of 91 L/MT of sugarcane. The steam needed for plant operation is 16.3 MJ/L of ethanol (Table 7).

We assumed the surplus energy, 6.87 MJ/L of ethanol, is used to generate electricity. With an electricity generation efficiency of 30% (the current Brazil industrial average), a total of 0.57 kWh of electricity can be generated for each liter of ethanol produced. After

Table 6. Energy consumption in sugarcane mills (MJ/MT of sugarcane processed)

Parameter	Energy use	Data source	GREET Input
Energy use			
Electricity	43.20	Macedo 2005	43.20
Mechanical energy	57.60	Macedo 2005	57.60
Thermal energy	1,188	Macedo 2005	1,188
Chemical and lubricant use			
Source 1	7.34	Assuncao 2000	
Source 2	6.00	GTZ 2005	
Source 3	6.36	Macedo *et al.* 2004	6.36
Energy embedded in sugar mill construction			
Average value	10.78	Assuncao 2000	
Average value	12.00	GTZ 2005	
Best value	8.07	Assuncao 2000	
Best value	9.00	GTZ 2005	
Average value	11.97	Macedo *et al.* 2004	
Best value	9.29	Macedo 2004	9.29
Energy embedded in sugar mill equipment			
Average value	27.96	Assuncao 2000	
Average value	31.00	GTZ 2005	
Best value	20.98	Assuncao 2000	
Best value	24.00	GTZ 2005	
Average value	31.07	Macedo *et al.* 2004	
Best value	24.16	Macedo *et al.* 2004	24.16

Table 7. Process energy use in sugarcane mills for ethanol production

	MJ/MT of sugarcane	kWh/MT of sugarcane	kWh/L of EtOH[a]	MJ/MT of sugarcane	MJ/L of EtOH[a]
Electricity	43.2[b]	12.00	0.132		
Mechanical	57.6[b]	16.84[c]	0.185		
Thermal	1,188[b]			1,485[d]	16.3
Lubricant oil	6.36[b]			6.36	0.070
Mill construction	9.29[b]				0.102
Equipment manufacturing	24.16[b]				0.265
Total		28.85	0.317		

[a] The conversion from sugarcane processed to ethanol produced is based on the ethanol yield of 91 L/MT of wet sugarcane.

[b] Data source: see Table 6.

[c] We assumed a conversion efficiency of 95% from electric energy to mechanical energy.

[d] This is the amount of energy in bagasse needed, which was estimated for a steam generation efficiency of 80%.

Table 8. Ethanol plant steam and electricity energy balance (per L of ethanol)

Bagasse energy yield (MJ)	Internal steam needs (MJ)	Extra energy for electricity generation (MJ)
23.17	16.3	6.87
Electricity generated from extra bagasse energy (kWh)	**Internal electricity needs (kWh)**	**Extra electricity for export (kWh)**
0.57	0.317	0.253

Table 9. Emission factors of bagasse combustion (g/1000 MJ of bagasse burned)

	From IPCC guidelines (2006b)			GREET input
	Low	Average	High	
CH_4	10.43	30.00	100.00	30.00
N_2O	1.50	4.00	15.00	4.00

Table 10. Average electricity generation mix in Brazil in 2004

	Electric generation share (%)
Petroleum	1.2
Natural gas	5.0
Coal	1.7
Biomass	4.2
Nuclear	3.0
Hydro	82.9
Others	2.0

Source: Ministry of Mine and Energy of Brazil (2005).

0.317 kWh (Tables 7 and 8) has been consumed in the process, an excess of 0.253 kWh/L of ethanol is available for export.

Bagasse combustion emissions

The IPCC guidelines (2006b) specify emission factors of CH4 and N2O from biomass combustion; see Table 9. Because of the large variations in the CH_4 and N_2O emission factors, we adopted the IPCC average values for GREET simulations.

Ethanol transportation from sugarcane mills to refueling stations

While some Brazilian sugarcane ethanol is exported to Japan, the European Union, and the United States, the majority of the sugarcane ethanol produced in Brazil is used in the Brazilian domestic market. We examined the case in which sugarcane ethanol is produced in Brazil and used in the United States market, so that we could compare its effects directly with those of ethanol production pathways already examined for the United States.

For the case of the domestic use of ethanol in Brazil, we assumed that ethanol is transported via pipeline and rail for 560 km (in each mode) from sugarcane mills to bulk terminals, then via truck for 130 km to refueling stations, where it is used either in its pure form or blended with gasoline.

For the case of ethanol exported to the United States, we accounted for ethanol transportation in both Brazil and the United States. Ethanol is first transported from mills to Brazilian ports in Southern Brazil. For this analysis we selected a representative port, Santos, a major port in Brazil. Most sugarcane mills are located in the two southern states near the Santos port, which provide about 50% of the nation's ethanol. In particular, we assumed that ethanol is transported via pipeline and rail on an average of 1290 km (in each mode) from sugarcane mills to the Santos port, where it is loaded onto ocean tankers for transport to the United States. We chose two U.S. ports, New York and Los Angeles, as entry points for Brazilian ethanol to the U.S. market. We used the average distance of 12,000 km from Santos to New York and from Santos to Los Angeles (see www.distance.com). Inside the United States, we assumed that ethanol is distributed regionally on the East and West Coasts, while the rest of the country receives domestic corn ethanol from the U.S. Midwest. In particular, we assumed that the imported ethanol is transported 160 km by truck to blending and storage facilities and further distributed to refueling stations.

Extraction and production of process fuels and electricity generation mix

For individual stages of the sugarcane ethanol pathway in Brazil, such as sugarcane farming, cane transportation, ethanol production, and ethanol transportation to U.S. ports, the energy use and emissions of primary energy recovery and processing, including coal, natural gas, and oil, were not available at the time of this study. We used GREET default values, which are based on U.S. industry averages. These values may be updated once Brazilian data become available.

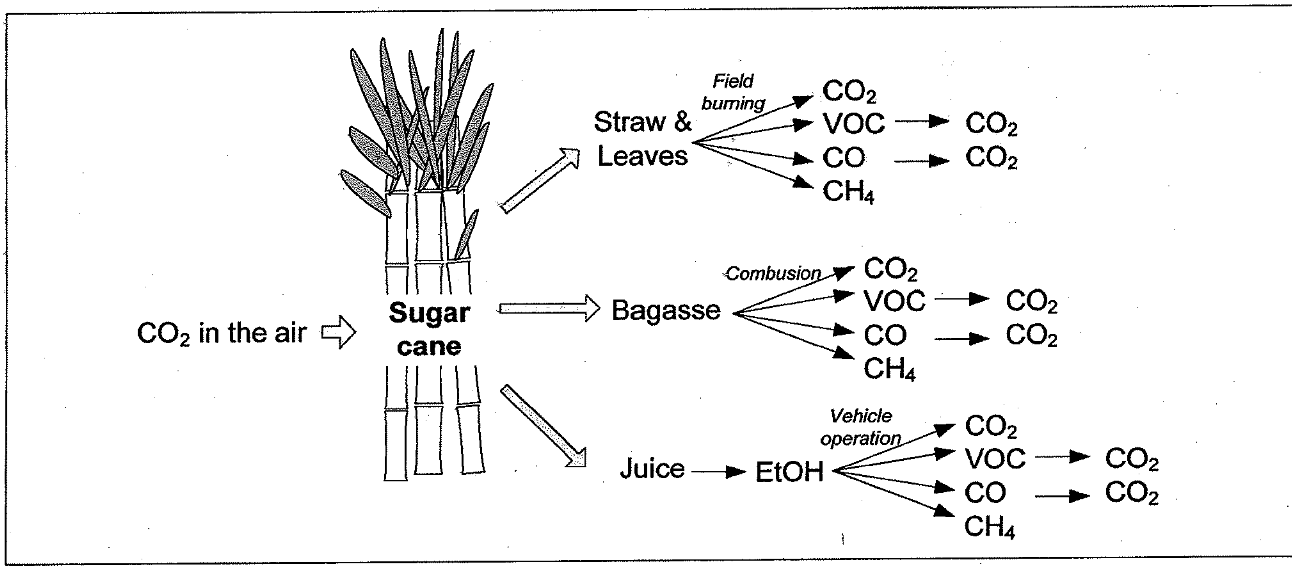
To estimate energy and emission credits of the exported electricity generated at sugarcane mills in Brazil, energy and emissions associated with electricity use in Brazil were estimated by assuming the electricity exported from sugarcane mills would replace electricity generation in natural gas plants. It is believed that the electric generation share of natural-gas power plants is marginal in Brazil. Table 10 shows the average power generation mix in Brazil.

Key issues in life-cycle analysis of sugarcane ethanol

CO_2 credits

During growth, sugarcane plants take CO_2 from the air for the photosynthesis process. The carbon taken in by sugarcane plants resides in them and is further converted to carbon in CO_2, CO, VOC, and CH_4, which are generated through various chemical and biological routes (fermentation, combustion, and the like) when sugarcane is processed to produce ethanol. The CO_2 from sugarcane that is emitted through a combustion process or through ethanol combustion in vehicles is considered zero CO_2 emissions to the air, since this is the carbon from the air that is taken in during sugarcane plant

Figure 3. Fate of renewable carbon in the sugarcane ethanol pathway



growth. In this case, the renewable carbon from sugarcane, rather than fossil fuel carbon, is used for combustion. Similarly, direct CO_2 emissions from sugar fermentation to ethanol are considered to be zero CO_2 emissions to the air.

We examined the fate of the renewable carbon in sugarcane, beginning with harvested sugarcane, by making several assumptions. First, all carbon in sugarcane plants is from atmospheric CO_2. Second, emissions from carbon in sugarcane plants end in four sources: CO_2, CO, VOC, and CH_4. Third, CO and VOC, which are emitted to the air during combustion of sugarcane tops and leaves in sugarcane fields and combustion of bagasse in ethanol plants, are converted to CO_2 in the air in a short time; these CO2 sources, together with direct CO_2 emissions from these combustion processes, are not included in CO_2 emission calculations for sugarcane ethanol, since they are ultimately from the air. Fourth, CH_4 from these combustion processes remains in the air for a long time, and these CH_4 emissions are accounted for as a GHG emission source for sugarcane ethanol. Finally, the organic carbon content of soil in sugarcane farms remains constant; however, this condition may not be the case if sugarcane ethanol production is expanded significantly and certain land uses are changed to accommodate such expansion.

Figure 3 is a schematic diagram of the fate of atmospheric carbon in the sugarcane ethanol pathway. The renewable carbon in sugarcane is utilized (combusted) in the sugarcane-to-ethanol pathway via three major routes: open-field burning of sugarcane leaves and tops, bagasse combustion in ethanol plants, and ethanol combustion during vehicle operation. All four forms of carbon emissions from these sources - CO_2, CO, VOC, and CH_4 - originate in carbon uptake from the air by sugarcane plants during growth. Among them, CO and VOC typically are oxidized to CO_2 within a few days after being released to the air. The amount of CO_2 generated is basically the carbon transformed from atmospheric CO_2; that is, the CO_2 emission sources shown in Figure 3 are actually CO_2 from the air during sugarcane growth.

Energy and emission credits of exported electricity

Bagasse is combusted to provide steam for meeting process heat requirements at sugarcane mills, and excess steam generates electricity to satisfy plant internal power demand. Excess power could be exported to the electric grid. In this case, we assumed that electricity generated from sugarcane mills displaces electricity generated with natural-gas electric power plants. On the other hand, if the exported electricity is assumed to displace the electricity with the Brazilian average electric generation mix, which is largely hydropower (82.9%, see Table 10), the energy and emission credits of the exported power would be smaller. In other words, the fact that the renewable power generated from bagasse displaces another primary renewable power reduces the benefit of the exported electricity from sugarcane ethanol plants.

Potential land use changes

It has been debated recently whether potential land use changes to be induced by large-scale biofuel production could result in significant changes in soil carbon and, therefore, could affect WTW GHG emission results of biofuels. This issue is especially relevant to GHG results of corn ethanol, sugarcane ethanol, soybean biodiesel, rapeseed biodiesel, and palm oil biodiesel, as their production is rapidly expanded.

Land use changes induced by biofuel production can be separated into direct and indirect components. Direct land use changes concern displacement of original land use directly by farming of feedstocks for biofuel production. Indirect land use changes concern secondary effects on land use changes by biofuel production. For example, as corn ethanol production may be increased significantly in the U.S., additional corn will be farmed in the land that is currently used for farming of soybeans and other crops (the direct land use change). In addition, corn use for ethanol production in the U.S. will result in reductions in U.S. corn export and in use of corn as a direct animal feed and for other purposes. The reductions in U.S. corn export, in the U.S. soybean production (as a switch of some soybean farms to corn farms), and in animal feed supply can result in an increase in production of corn and other agricultural commodities in some other parts of the world.

Limited efforts have been made to address direct land use

Figure 4. WTW fossil energy and petroleum reductions by ethanol relative to petroleum gasoline

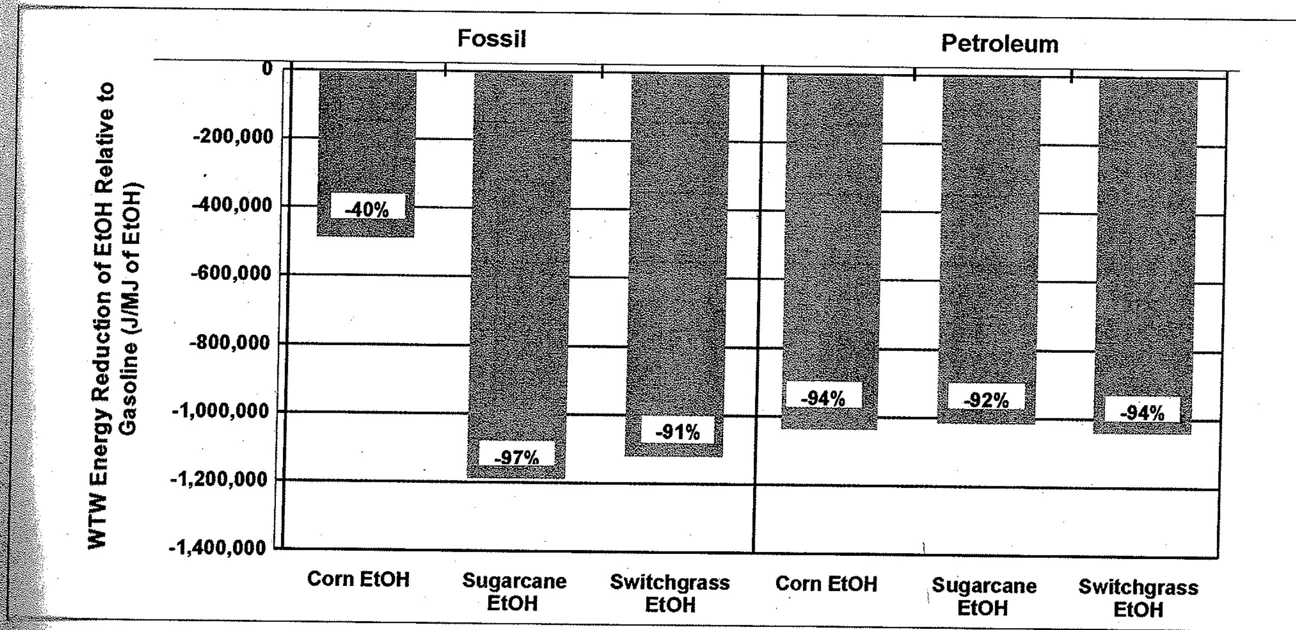
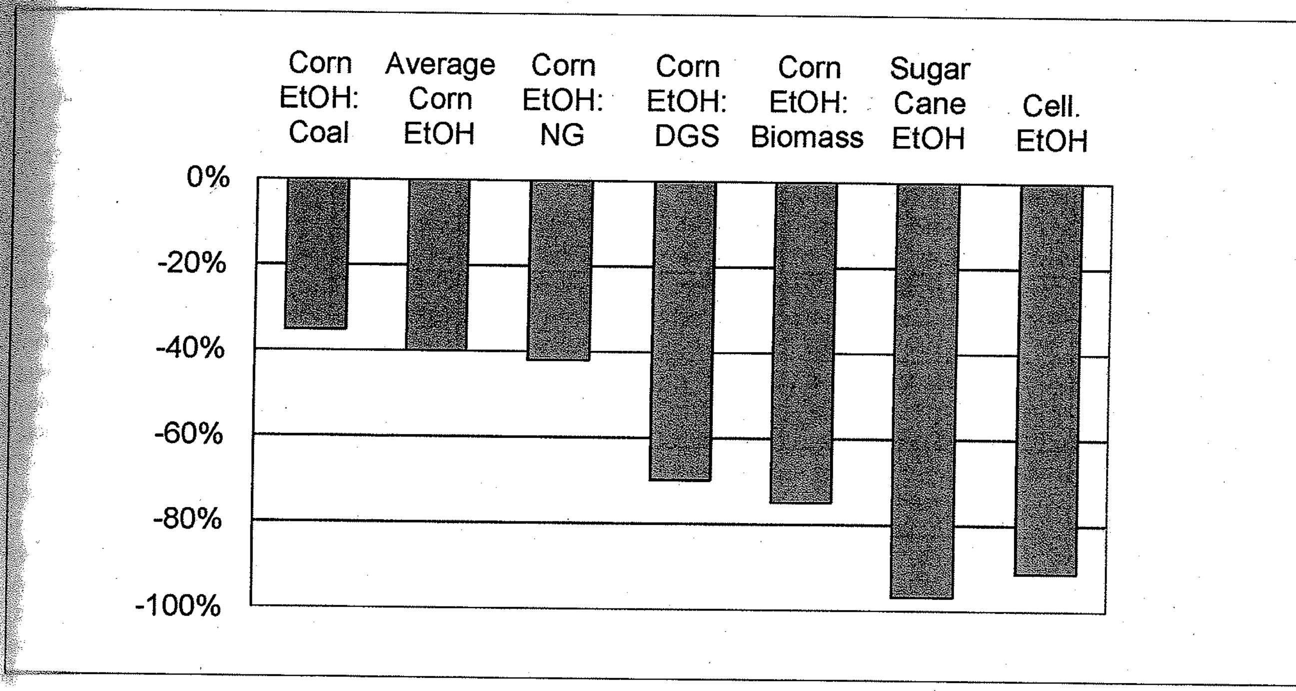


Figure 5. WTW fossil energy reductions of various ethanol production options relative to petroleum gasoline (NG = natural gas, DGS = distiller's grains and solubles)



changes from production of corn ethanol and cellulosic ethanol in the U.S. Results of those efforts were incorporated in life-cycle analyses of corn and cellulosic ethanol in the U.S. However, as corn ethanol production in the U.S. is to increase dramatically, those past results no longer reflect what will happen in the future regarding direct land use changes to be caused by corn ethanol production. On the other hand, we have not found any studies on potential direct land use changes caused by sugarcane ethanol production in Brazil.

Indirect land use changes are much more difficult to model. To do so requires use of general equilibrium models to take into account supply and demand of agricultural commodities, land use patterns, and land availability (all at the global scale), among many other factors. Efforts began only very recently to address both direct and indirect land use changes together with general equilibrium models or partial equilibrium models. It will be awhile before definitive results can be obtained. Nonetheless, land use changes could be a significant factor to determine GHG emission effects of certain biofuel types.

Results and discussion

As indicated in a section above, we established a base case for

Figure 6. Net energy balance of ethanol and petroleum gasoline

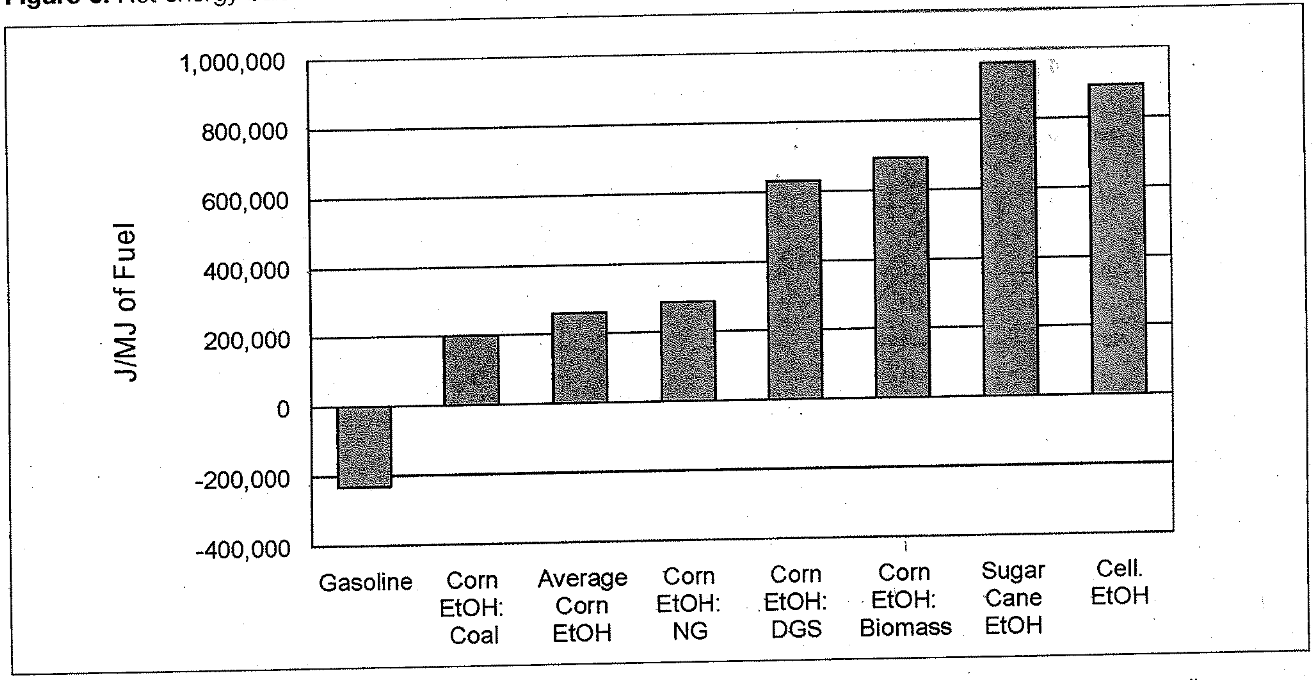


Figure 7. WTW GHG emission reductions by various ethanol production options relative to petroleum gasoline

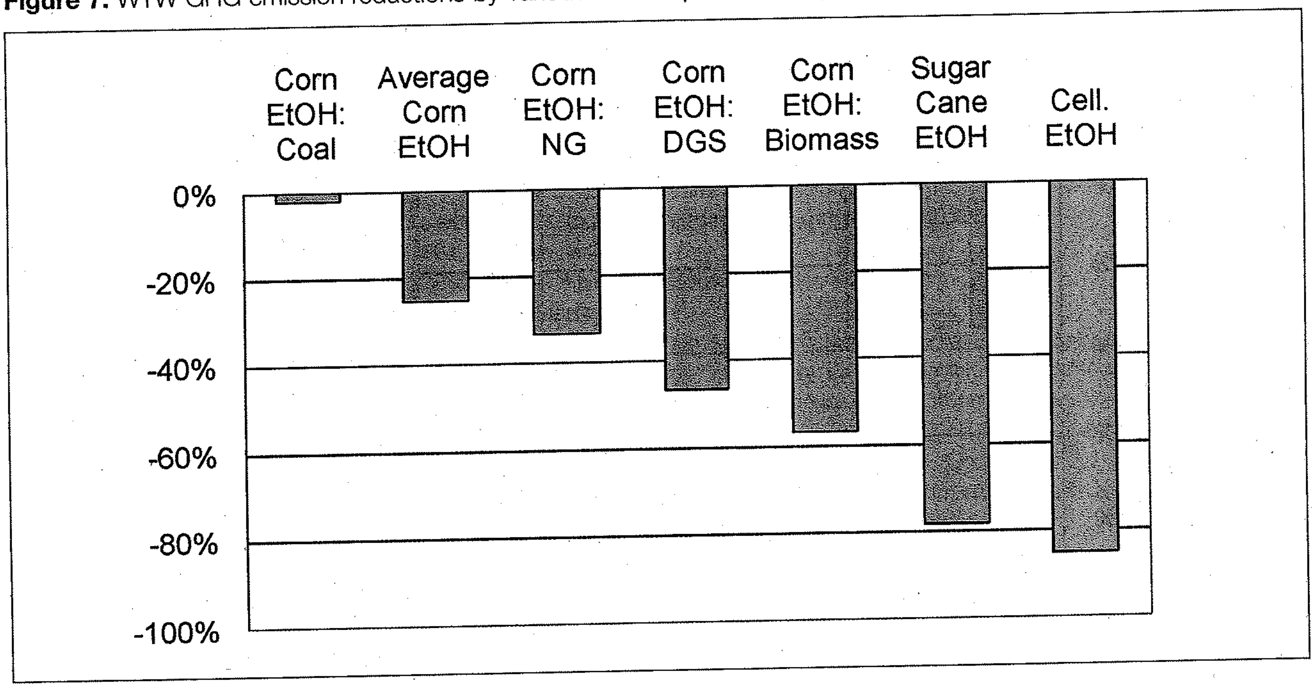


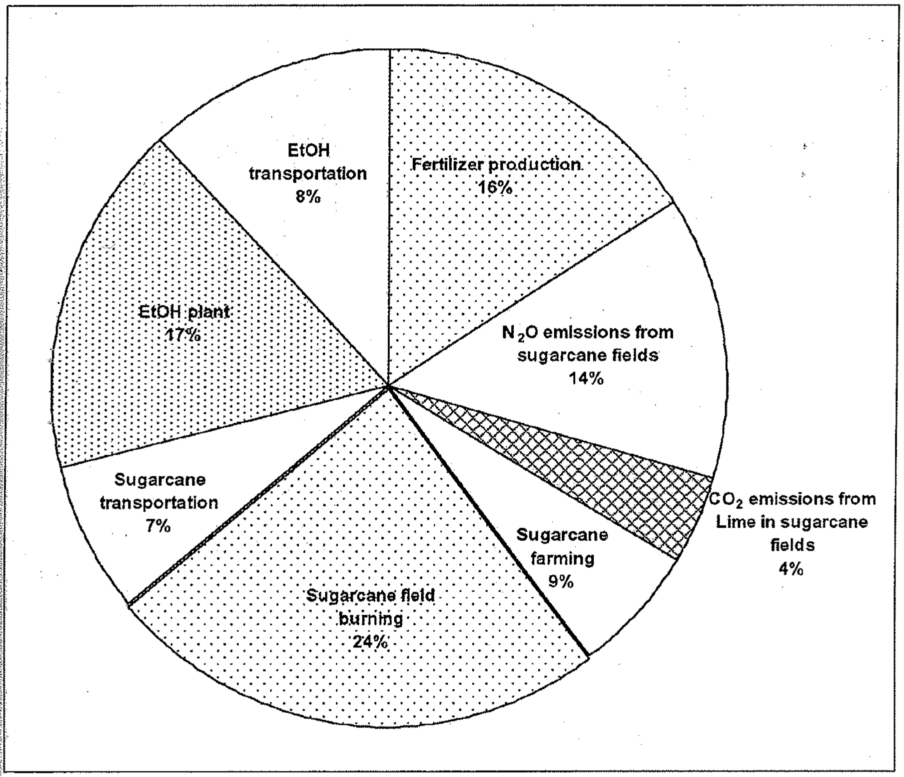
Table 11. WTW fossil energy use for ethanol (J/MJ of ethanol)

Fossil energy	Corn EtOH	Sugarcane EtOH
Natural gas	468,358	–96,097[a]
Coal	200,115	42,675
Petroleum	70,180	92,596
Total	738,653	39,174

[a] The negative value represents the reduction of natural-gas-based electricity generation that is displaced with the electricity exported from sugar cane mills.

production of sugarcane ethanol in Brazil and its use in the United States (SC Case 1). Three sensitivity cases were developed from the base case. For comparison, we selected the base case to compare sugarcane ethanol with corn ethanol, switchgrass-based cellulosic ethanol, and petroleum gasoline, since evaluation of these three cases does not include energy embedded in corn ethanol plants and

Figure 8. Shares of GHG emissions of sugarcane ethanol pathway activities



petroleum refineries. The WTW results of energy use and GHG emissions are presented in Figures 4-10 and in Table 11. Energy and GHG emission results are expressed for each MJ of fuel produced and used.

Energy use results for sugarcane ethanol, corn ethanol, and cellulosic ethanol are presented together in this section. While results for sugarcane and corn ethanol are based on operational data of many plants, results for cellulosic ethanol from switchgrass are based on projections and engineering simulations of switchgrass growth and cellulosic ethanol production. That is, in terms of commercial readiness, cellulosic ethanol is not at the same stage of development as sugarcane and corn ethanol.

Fossil and petroleum energy use results

Ethanol produced from Brazilian sugarcane achieves substantial reductions in fossil energy use (97%) relative to petroleum gasoline (Figure 4). The reductions are 2.6 times as much as those by corn ethanol. Fossil energy includes petroleum, natural gas, and coal energy; thus, the petroleum energy use presented here is a subset of fossil energy use.

Figure 4 shows that ethanol can provide reductions of more than 90% in petroleum energy compared to gasoline, regardless of the feedstocks for ethanol production (corn, sugarcane, or switchgrass). Figure 5 compares sugarcane ethanol with various ethanol production and feedstock options. Among the options evaluated, fossil energy reduction by sugarcane ethanol is similar to that by cellulosic ethanol. Figure 6 presents the net energy balance values of various ethanol production options and petroleum gasoline per MJ of fuel produced. The net energy balance (NEB) is the difference between the energy content of a fuel and the fossil energy input to the fuel production pathway. A positive value for the NEB represents an energy surplus for a fuel, while a negative value shows an energy deficiency. All the ethanol options show positive NEB values. For each MJ of ethanol produced from sugarcane grown in Brazil and utilized in the United States, there is a net gain of 0.96 MJ, in contrast to a net gain of 0.26 MJ for corn ethanol and 0.89 MJ for switchgrass-derived ethanol.

The unique advantage of the sugarcane ethanol pathway is that ethanol production in sugarcane mills is self-sustaining in terms of energy need: the juice is used for ethanol production, and the bagasse is used for heat and power generation. As a result, ethanol production requires 16.3 MJ of heat demand and 0.317 kWh of electricity per liter of ethanol. In addition, renewable power at the rate of 0.253 kWh can be exported to the electric grid for each liter of ethanol produced. This reduction in fossil energy use is the main cause of the marked difference in WTW results between sugarcane ethanol and corn ethanol. Table 11 indicates that approximately 564,453 J of natural gas and 157,740 J of coal per MJ of ethanol are saved by sugarcane ethanol production compared to corn ethanol. Recently, designers and operators started to address the issue of process fuel demand in corn ethanol plants by considering renewable sources such as wood chips or distiller's grains and solubles (DGS). With these renewable energy sources, corn ethanol could reduce an additional 30% (DGS as the process fuel) or 35% (wood chips as the process fuel) of fossil energy use (Figure 5).

Sensitivity analysis with the four sugarcane ethanol production options (as presented earlier) indicates that (a) energy embedded in sugarcane mills contributes 0.3% of total fossil energy use; (b) energy embedded in farming equipment contributes 2.3%; and (c) transportation of ethanol from Brazil to the United States contributes 3.0%.

Greenhouse gas emission results

Figure 7 shows WTW GHG emission reductions by sugarcane ethanol and several other ethanol production options, compared to petroleum gasoline. The GHG emission reductions by sugarcane ethanol are 3.1 times as much as those by corn ethanol and rank second only to those by cellulosic ethanol.

For the five corn ethanol production options, GHG emission changes range from a 2% reduction to a 57% reduction, depending on the process fuel used.

We examined key stages of the sugarcane ethanol pathway for their contributions to total GHG emissions. Similar to that for cellulosic ethanol, the sugarcane ethanol pathway generates heat and power from bagasse in sugarcane mills to displace natural gas or coal use. However, sugarcane farming differs considerably from cellulosic

Figure 9. Fossil energy reductions by four sugarcane ethanol cases relative to petroleum gasoline

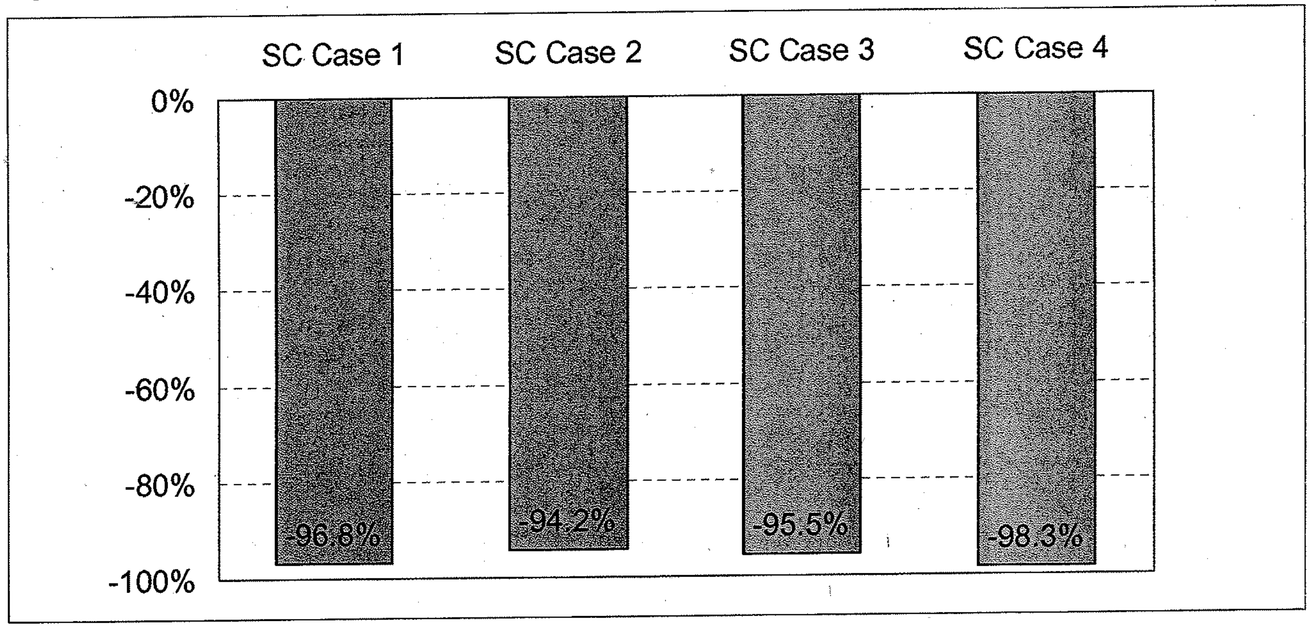
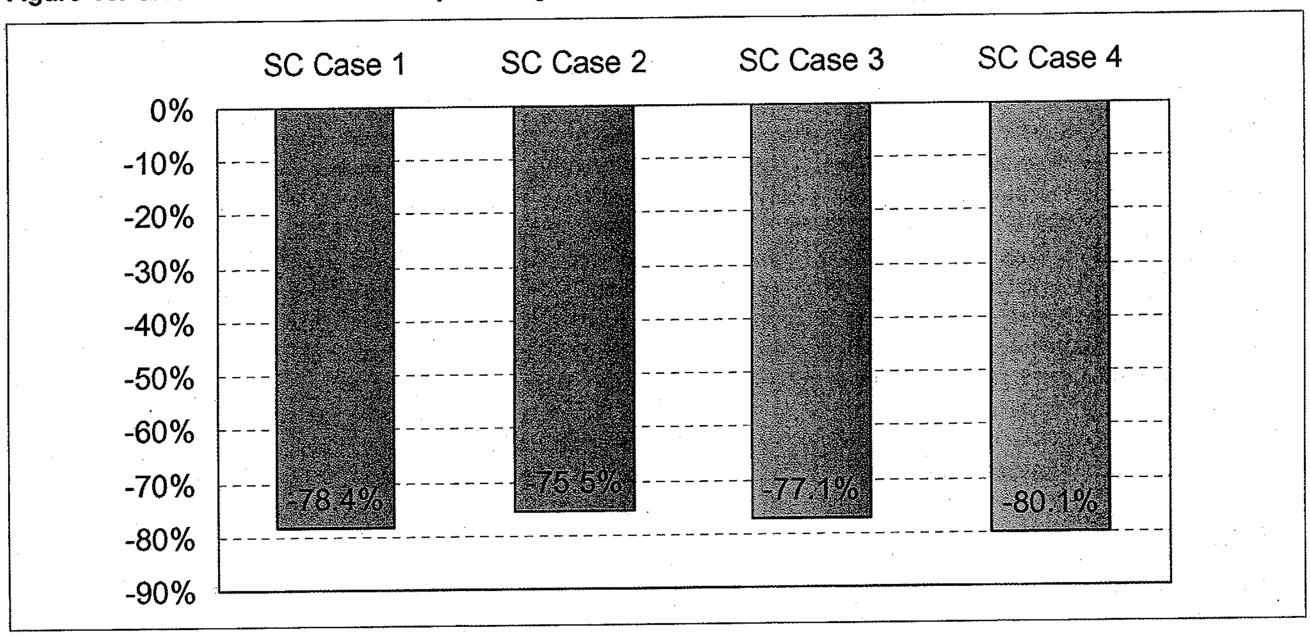


Figure 10. GHG emission reductions by four sugarcane ethanol cases relative to petroleum gasoline



biomass farming. For example, sugarcane farming is associated with open-field burning of sugarcane tops and leaves, a practice not used in either corn farming or cellulosic biomass farming. CH_4 and N_2O emissions from open-field burning alone are responsible for 24% of total GHG emissions for sugarcane ethanol (Figure 8). In particular, the five major contributors to sugarcane ethanol GHG emissions are open-field burning (24%), N_2O emissions from sugarcane fields (14%), fertilizer production (16%), GHG emissions from sugarcane mills (17%), and sugarcane farming (9%); together these make up 80% of the total WTW GHG emissions of sugarcane ethanol.

Sensitivity cases of sugarcane ethanol

We developed four sugarcane ethanol cases in this study to show variations in energy and GHG emission effects of sugarcane ethanol. The difference between Cases 1 and 2 shows the contribution of energy embedded in farming equipment production and sugarcane mill construction; that between Cases 1 and 3 shows the contribution of energy embedded in farming equipment production; and that between Cases 1 and 4 shows the contribution of transporting ethanol from Brazil to the United States.

Figures 9 and 10 show the effects of these factors. In particular, inclusion of energy embedded in farming equipment and sugarcane mill construction lowers fossil energy reductions by sugarcane ethanol by 2.6 percentage points and GHG emission reductions by 2.9 percentage points. Inclusion of energy embedded only in farming equipment lowers fossil energy reductions by 1.3 percentage points and GHG reductions by 1.3 percentage points. These results imply that energy embedded in farming equipment and sugar cane mills contributes in equal proportion to total sugarcane ethanol results.

The difference between Cases 1 and 4 indicates that transportation of sugarcane ethanol from Brazil to the United States contributes to a 1.5-percentage-point difference in fossil energy use and a 1.7-percentage-point difference in GHG emissions for sugarcane ethanol.

We also analyzed two cases for open-field burning - one with 100% burning and the other with 0% burning (this is compared with the assumed 80% open-field burning for all four sugarcane ethanol cases examined in this study). The results of the two cases showed a difference in GHG emission reductions of 9 percentage points. Brazil is going to phase out open-field burning in the future, which will certainly help further reduce GHG emissions of sugarcane farming, together with reductions in emissions of criteria pollutants such as NO_x and PM_{10}.

CH_4 emissions from open-field burning are subject to great uncertainty (Table 3). Use of a CH_4 emission factor of 0.15 g/kg of biomass instead of 2.7 g/kg helps increase GHG emission reductions of sugarcane ethanol by 5.2 percentage points.

We assumed in our analysis that the exported electricity from sugarcane ethanol plants will displace electricity generated in natural-gas electric power plants, which are believed to be the marginal electric power mix in Brazil. On the other hand, if the exported electricity displaces the average electricity in Brazil (83% of which is from hydro power), the GHG emission benefits of sugarcane ethanol would be reduced by up to 8 percentage points.

Conclusions

By using the GREET model to conduct a WTW analysis of the pathway of producing ethanol from sugarcane in Brazil and using it in the United States, we reached the following conclusions. Sugarcane ethanol could achieve fossil energy reduction as much as 97% relative to petroleum gasoline. The large reduction is a result of use of bagasse in sugarcane mills in place of coal or natural gas to generate the heat and power needed for plant operation. This and other factors such as low use of energy and fertilizer for sugarcane farming contribute to a positive net energy balance of 0.96 MJ per MJ of ethanol produced.

Sugarcane ethanol could achieve a reduction of 78% in GHG emissions relative to those of petroleum gasoline. This reduction is similar to that of cellulosic ethanol. Even when energy embedded in farming equipment and sugarcane mills is included, GHG emission reductions by sugarcane ethanol are still more than 75%. The large reductions can be attributed to the use of bagasse in sugarcane mills, among other factors. Of the total GHG emissions associated with sugarcane ethanol, the five major contributors are open-field burning of sugarcane tops and leaves, N_2O emissions from sugarcane fields, fertilizer production, sugarcane mill operation, and sugarcane farming.

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References

Andreae, M.Q. and Merlet P. (2001) Emission of trace and aerosols from biomass burning. *Global Biogeochemical Cycles,* 15 pp. 955-966.

de Assuncao, J.V. (2000) *Life cycle analysis of sugar cane ethanol in relation to greenhouse gases emissions.* The 93rd Meeting and Exhibition of the Air and Waste Management Association, Salt Lake City, Utah, June 18-22.

Brinkman, N., Wang M., Weber T. and Darlington T. (2005) *Well-to-wheels analysis of advanced fuel/vehicle systems - a North American study of energy use, greenhouse gas emissions, and criteria pollutant emissions.* General Motors Corporation and Argonne National Laboratory, May.

Concawe, EUCAR, EU JRC (2007) *Well-to-wheels analysis of future automotive fuels and powertrains in the european context.* WTW Report 220104, Brussels, Belgium, March.

Crutzen, P.J., Mosier A.R., Smith K.A. and Miniwarter W. (2007) N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics,* 7 pp. 11191-11205.

Garcia, J., Sao Paulo State of University, Sao Paulo (2007) Personal communication via e-mail, February.

German Technology Corporation (GTZ) (2005) *Liquid transportation fuels in Brazil: Potentials and implications for sustainable agriculture and energy in 21st century.* Prepared by BMVEL, November.

Intergovernmental Panel on Climate Change (IPCC) (2006a) *2006 IPCC guidelines for national greenhouse gas inventories, Volume 4: Agriculture, forestry, and other land use.* Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC) (2006b) *2006 IPCC guidelines for national greenhouse gas inventories, Volume 2: Energy.* Hayama, Japan.

International Energy Agency (IEA) (2004) *Biofuels for transport: An international perspective.* Paris, France, April.

Macedo I.D.C., Leal M.R.L.V. and Seabra J.E.A. (2004) *Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil.* Prepared for the State of Sao Paulo, Brazil, March.

Macedo I.D.C. (2005) *Sugar cane's energy: Twelve studies on Brazilian sugar cane agribusiness and its sustainability.* Sao Paulo Sugar Cane Agroindustry Union (UNICA), Sao Paulo, Brazil.

Macedo I.D.C. (2007) Personal communications via e-mail, March.

Ministry of Mine and Energy of Brazil (2005) *National energy balance 2005 (or Balanço Energético Nacional 2005)* (in Portuguese).

Moreira, J.R. and Goldemberg J. (1999) The Brazilian alcohol program. *Energy Policy,* 27 pp. 229-245.

Perry, R.H. and Green D.W. (1997) *Perry's Chemical Engineers' Handbook, 7th Edition,* McGraw-Hill.

Wang M., Wu M. and Hong H. (2007) Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types. *Environmental Research Letter,* 2 pp. 024001 (13 pages).

Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Brazilian Sugarcane Ethanol Production Simulated by Using the GREET Model

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Abstract

By using data available in the open literature, we expanded the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory to include Brazil-grown sugarcane ethanol. With the sugarcane ethanol pathway added to the GREET model, we examined the well-to-wheels (WTW) energy use and greenhouse gas (GHG) emissions of sugarcane-derived ethanol produced in Brazil and used to fuel light-duty vehicles in the United States. Results for sugarcane ethanol were compared with those for petroleum gasoline. This paper documents the development of the sugarcane-to-ethanol pathway in the GREET model. The pathway comprises fertilizer production, sugarcane farming, sugarcane transportation, and sugarcane ethanol production in Brazil; ethanol transportation to U.S. ports and then to U.S. refueling stations; and ethanol use in vehicles. We developed and examined several sensitivity cases to test the effect of key parameters on WTW results for sugarcane ethanol. Our analysis revealed that sugarcane ethanol can reduce GHG emissions by 78% and fossil energy use by 97%, relative to petroleum gasoline.

1. Introduction

Brazil began its sugarcane fuel ethanol program in 1975 after the first oil crisis and has since expanded it significantly. Brazil is now the number 2 fuel ethanol producer and consumer after the United States. Ethanol has become a mainstream motor fuel in Brazil, accounting for 40% of its gasoline market. More than 80% of new cars sold in 2006 were ethanol flexible-fuel vehicles (FFVs).

Brazil has vast land available for sugarcane farming. About five million hectares of land are currently used for sugarcane farming in Brazil (Macedo 2005), and some in Brazil maintain that an additional five million hectares can be made available for sugarcane farming. Brazil expects that its sugarcane ethanol industry will continue to expand. In fact, companies from other countries are beginning to invest in the sugarcane ethanol industry in Brazil. In addition to its own consumption, Brazil seeks to export fuel ethanol to other countries, including the United States, the European Union, and Japan.

With the support of the U.S. Department of Energy (DOE), Argonne National Laboratory has been developing and applying the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to examine energy and emission benefits of advanced vehicle technologies and new transportation fuels (see Brinkman et al. 2005 for the GREET model and its applications). The GREET model features many fuel ethanol production pathways from feedstocks such as corn, fast-growing trees, switchgrass, crop residues, and forest residues. As part of this effort, we added the production of sugarcane ethanol in Brazil and use of it in the United States to the GREET model.

2. System Boundary and Analysis Cases for the Sugarcane-to-Ethanol Pathway

We conducted a well-to-wheels (WTW) analysis of Brazilian sugarcane-derived ethanol based on the system boundary depicted in figure 1. The sugarcane-to-ethanol pathway simulated in this study comprises the following stages:

- Fertilizer production
- Sugarcane farming and harvesting
- Sugarcane transportation
- Ethanol production
- Ethanol transportation from sugarcane mills in Brazil to U.S. ports
- Ethanol transportation and distribution from ports to refueling stations within the United States
- Ethanol use in U.S. vehicles

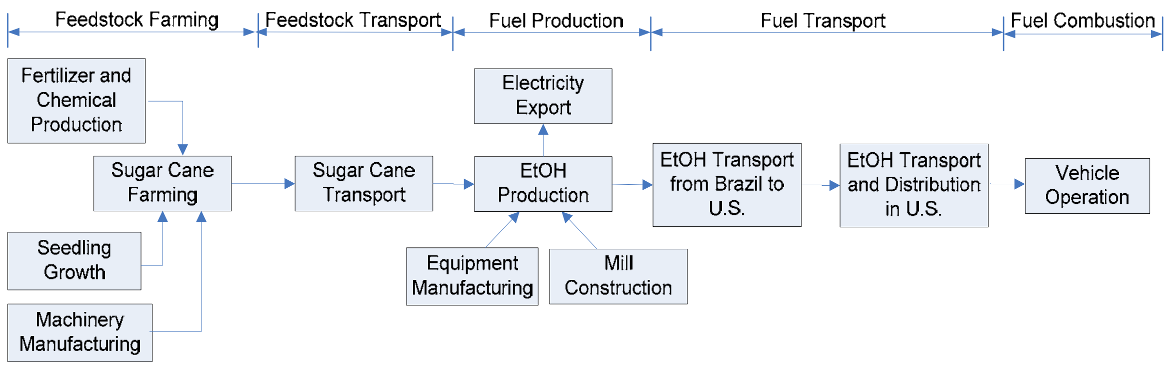


Figure 1. Stages of the Sugarcane-to-Ethanol Pathway

The life cycle of sugarcane-derived ethanol begins with the manufacture of fertilizer and farming machinery and the preparation of cane seedlings. Farming operations include chemical application, irrigation, tillage, and harvest. The current sugarcane farming practice involves open-field burning of sugarcane leaves and straws before and after harvest to facilitate the manual harvest and to control disease. Harvested sugarcane is transported via trucks to sugarcane mills, where it undergoes sugar juice extraction, followed by fermentation of juice for ethanol production (and/or sugar production).

The residues from juice extraction — called "bagasse" — are combusted in sugarcane mills to generate steam and electricity to meet the demand for heat and power. Since 2000, sugarcane mills have made major efforts to export their excess electricity to the electric grid. In addition to the manufacture of farming machinery and sugarcane mill equipment, construction of sugarcane mills was included in this analysis.

Ethanol is transported from sugarcane mills to Brazilian ports via rails and pipelines, to U.S. ports by ocean tankers, and then to U.S. refueling stations via trucks. Ethanol is used either in low-level blends such as E10 (mixture of 10% ethanol and 90% gasoline by volume) in regular gasoline vehicles or high-level blends such as E85 (mixture of 85% ethanol and 15% gasoline by volume) in FFVs.

The gasoline life cycle, on the other hand, begins with crude oil recovery in oil fields and ends in gasoline combustion in gasoline vehicles, a pathway that is already in the GREET model.

In this near-term (2006–2010) analysis of the sugarcane ethanol life cycle, many factors play a key role in determining the overall energy use and greenhouse gas (GHG) emissions of sugarcane ethanol. We examined these factors by developing several sugarcane ethanol cases, all of which produce ethanol and export electricity to the electric grid. In addition, we included petroleum gasoline, corn ethanol, and switchgrass ethanol for comparison.

The base case established for sugarcane ethanol was production in Brazil and use in the United States. Other cases were developed to test the importance of the following parameters: (1) whether sugarcane ethanol is used in the United States or Brazil (to assess the contribution of ocean tanker transportation of ethanol), and (2) whether energy embedded in farming equipment manufacturing and sugarcane mill construction makes a significant contribution to the WTW results of sugarcane ethanol. The sugarcane (SC) cases and the petroleum gasoline, corn ethanol, and switchgrass ethanol cases were as follows:

- SC Case 1 (the base case for sugarcane ethanol): sugarcane ethanol is produced in Brazil and used in the United States; energy embedded in farming equipment manufacturing and sugarcane mill construction is not included (This case is consistent with the petroleum gasoline pathway.)

- SC Case 2: same as SC Case 1 except that energy embedded in farming equipment manufacturing and sugarcane mill construction is included

- SC Case 3: same as SC Case 1 except that energy embedded in farming equipment manufacturing is included

- SC Case 4: same as SC Case 3 except that sugarcane ethanol is used in Brazil (This case shows the contribution of ocean tanker transportation of ethanol.)

- Petroleum gasoline production and use in the United States excluding energy embedded in all infrastructure-related activities

- Corn ethanol production and use in the United States, including energy embedded in farming machinery

- Cellulosic ethanol production and use in the United States with switchgrass as the feedstock and including energy embedded in farming machinery manufacture

3. Data Sources and GREET Assumptions

To develop the sugarcane ethanol pathway in GREET, we collected data for the activities associated with the sugarcane ethanol pathway from the open literature. The data were processed to derive input parameters for GREET.

Previous studies have been conducted to evaluate the GHG emission effects of sugarcane ethanol. Macedo et al. (2004) conducted a detailed analysis of the energy and emission effects associated with the production and use of sugarcane ethanol in Brazil. A study by Concawe et al. (2007) included sugar cane ethanol among many other transportation fuels; it relied on data developed by Macedo et al. and other studies.

3.1. Sugarcane Farming

We analyzed energy use and emissions for activities involved in sugarcane farming, including fertilizer, lime, and chemical production; sugarcane seedling preparation; farming operations; farming equipment manufacturing; and open-field burning of sugarcane leaves and straws.

3.1.1. Chemical and Energy Inputs for Sugarcane Farming

Once sugarcane seedlings have been planted on sugarcane farms, the sugarcane can be harvested for five to seven seasons. After that, sugarcane farms are replanted. Table 1 presents the typical composition of sugarcane. Traditionally, sugarcane is harvested by laborers (“sugarcane cutters”); this harvest is often referred as to the manual harvest. To ease cutters’ efforts, sugarcane fields are burned before harvest. After harvest, the remaining stalks are often burned to control disease and promote seedling growth in the next season. Primarily because of concerns about air pollution caused by open-field burning, the state of Sao Paulo will phase out open burning completely by 2018. As a result, mechanical harvesting will replace manual harvesting. As of 2005, 65% of the sugarcane harvest in Brazil was manual and 35% was mechanical (Macedo 2005).

Table 1. Sugarcane Composition

Parameter	Value (%)
Sucrose content	14.5
Fiber content	13.5
H_2O content	72.0

Source: Macedo et al. 2004.

Table 2 summarizes the application rates of nitrogen (N) and phosphate (P_2O_5) fertilizer, potash (K_2O), lime ($CaCO_3$), herbicide, and pesticide on Brazilian sugarcane farms. Fertilizer and chemical use are usually reported in kilograms per hectare per year (kg/ha/yr); however, for GREET simulations, we need to use kilograms or grams of per metric ton (kg/MT) of sugarcane harvested. We converted the value by using a sugarcane yield of 68.6 MT/ha (Macedo et al. 2004). The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007).

Table 2. Fertilizer and Chemical Inputs for Sugarcane Farming in Brazil

Input	Assuncao (2000)[a]	Macedo et al. (2004)[b]	GREET[e]
N fertilizer			
kg/ha/yr	77.2	71.6[c]/75[d]	
g/MT of sugarcane	1,152.2	1,042.2[c]/1,091.7[d]	1,091.7
P_2O_5			
kg/ha/yr		40.8[c]/8.3[d]	
g/MT of sugarcane		593.9[c]/120.8[d]	120.8
K_2O			
kg/ha/yr		120[c]/13.3[d]	
g/MT of sugarcane		1,746.7[c]/193.6[d]	193.6
Lime ($CaCO_3$)			
kg/ha/yr		366.7	
g/MT of sugarcane		5,337.7	5,337.7
Herbicide use			
g/MT of sugarcane		26.9	26.9
Pesticide use			
g/MT of sugarcane		2.21	2.21

[a] Assuncao assumed a nitrogen application of 28 kg/ha for planting of sugarcane and 87 kg/ha for each harvest season. We assumed a cycle of 6 years with five cuts. He further assumed a sugarcane yield of 80.4 MT/ha/cut, resulting in 67 MT/ha over the 6-year period. These values were used to derive nitrogen application per hectare per year and per metric ton of sugarcane harvested.
[b] Macedo et al. (2004) used a sugarcane yield of 68.7 MT/ha over a 6-year sugarcane cycle. We used this value to derive nitrogen application rates per metric ton.
[c] For farms that do not use filter mud cake and vinasse (the residues left in a still following distillation).
[d] For farms that use filter mud cake and vinasse.
[e] For GREET simulations, weighted average values between sugarcane fields without and with use of filter mud and vinasse would be ideal. Because of the lack of data regarding breakdown of the two types of sugarcane plantations, we adopted the values for the fields with use of filter mud and vinasse.

For sugarcane farming, energy use includes diesel fuels used to power farming equipment, energy spent preparing sugarcane seedlings, and energy embedded in farming equipment manufacturing (Table 3). Although GREET WTW analyses generally do not include energy embedded in equipment, we included it to be consistent with the pathways for ethanol production from different feedstocks, which include this energy. Nonetheless, we designed an option in GREET for including or excluding the energy embedded in farming equipment manufacturing and associated emissions.

Table 3. Inputs of Energy Use for Farming Operation, Seedling Preparation, and Farming Machinery Manufacturing for Sugarcane Farming

Input	Assuncao (2000)	GTZ (2005)	Macedo et al. (2004)	GREET
Farming operation[a]				
MJ[b]/MT of sugarcane	30.1	38	38	
Btu[b]/MT of sugarcane	28,531	36,019	36,019	36,019
Sugar cane seedling preparation				
MJ/MT of sugarcane	5.76	6	5.88	
Btu/MT of sugarcane	5,460	5,687	5,573	5,573
Energy embedded in farming machinery				
MJ/MT of sugarcane	33.1		29.1	
Btu/MT of sugarcane	31,346		27,583	27,583

[a] The farming energy data include energy use for sugarcane harvesting, as well as for other farming activities. Data from the three cited sources are for combinations of manual and mechanical harvest. Although manual harvest now accounts for more of the total harvest than mechanical harvest, in the long term, mechanical harvest will account for more. Energy use between the two harvest methods could be different, but no data showing the difference are available. The difference in harvest energy use may be small, because manual harvest collection and loading activities are still performed by machines to a large extent.

[b] MJ = millijoules; Btu = British thermal unit.

3.1.2. Open-Field Burning of Sugarcane Leaves and Tops

Sugarcane leaves and tops are typically burned in the field before and after harvest. Macedo et al. (2004) reported a yield of 280 kg of leaves and tops (with 50% moisture content, or 140 kg of dry leaves and tops) per metric ton of sugarcane harvest. At present, 80% of sugarcane farms in Brazil practice open-field burning. Because open-field burning will be gradually phased out, in developing the sugarcane ethanol pathway in GREET, we assumed burning of 80% of leaves and tops at present and 0% in 2020.

For the GREET simulation, we took into account emissions from open-field burning — in particular, emissions of two pollutants: methane (CH_4) and nitrous oxide (N_2O). Emissions of carbon dioxide (CO_2) from open-field burning were not taken into account, because the CO_2 is uptaken during sugarcane growth. Emissions from open-field burning of sugarcane leaves and tops were estimated by assuming a leaf and top moisture content of 15%, which is similar to that of corn stover and switchgrass. The carbon content of leaves and tops is 50% on a dry-matter basis (Macedo et al. 2004).

Table 4 lists our estimates of emissions generated from open-field burning. These were based on three sources: summaries of Macedo et al. (2004) and Assuncao (2000); results in Andreae and Merlet (2001); and data included in the Intergovernmental Panel on Climate Change guidelines (IPCC 2006a). Average emissions values from open-field burning of agricultural residues listed in the IPCC guidelines appear higher than those from other sources. We used IPCC data as our base case for emission factors of CH_4, N_2O, carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter measuring

2.5 micrometers or less ($PM_{2.5}$). For PM_{10} (particulate matter measuring 10 micrometers or less), we estimated emission factors on the basis of a ratio of 2:1 between PM_{10} and $PM_{2.5}$, which was derived from coal combustion emission factors in GREET. Therefore, we used a value of 7.8 g/kg of leaves and tops burned for PM_{10}. For volatile organic compound (VOC) and sulfur oxides (SO_x) emission factors, we used values estimated by Andreae and Merlet (2001).

Table 4. Emission Factors of Open-Field Burning of Sugarcane Leaves and Tops

	Emission Factors (g/kg of dry leaves and tops burned)					
		Macedo et al. (2004)				
Pollutant	Andreae and Merlet (2001)	Low Value[a,b]	High Value[a,b]	Assuncao (2000)[a]	IPCC (2006a)	GREET
CO_2	1515 ($\pm$177)				1515 ($\pm$177)	NN[c]
CO	92 ($\pm$84)				92 ($\pm$84)	92
CH_4	2.7	0.1464	1.0214	0.2886	2.7	2.7
NO_x	2.5($\pm$1)				2.5 ($\pm$1)	2.5
N_2O	0.07				0.07	0.07
$PM_{2.5}$	3.9					3.9
PM_{10}						7.8 [d]
VOC	7.0					7.0
SO_x	0.4					0.4

[a] These sources reported CH_4 emissions in kg/MT of sugarcane harvested. We used the yield of 280 kg of sugar cane leaves and tops with 50% moisture content per MT of sugarcane harvested to convert the original values into values in g/kg of leaves and tops burned.
[b] Macedo et al. (2004) maintained that the low values represented the average Brazilian emission rates, and the high values were adopted from the IPCC guidelines.
[c] Data are not needed here. CO_2 emissions are calculated in GREET by using the carbon balance of sugar cane leaves and tops; see Section 4.1.
[d] Data were not available. This value was estimated on the basis of the ratio of PM_{10} versus $PM_{2.5}$ for coal combustion.

3.1.3. N_2O Emissions from Sugarcane Fields

A major source of N_2O emissions from sugarcane farming is nitrification and denitrification of nitrogen fertilizer applications. In Brazil, the most frequently used type of nitrogen fertilizers is urea (Macedo 2007), from which N_2O is emitted directly and indirectly. When applied to soil, nitrogen fertilizer is volatilized and converted to N_2O; when oxidized, some of it is emitted directly to the air as N_2O. A large amount of nitrogen fertilizer leaches to groundwater or rivers through surface runoff, during which some of it is converted to N_2O via microbial nitrification and denitrification. Macedo et al. (2004) estimated that on an annual basis, 75 kg of nitrogen in nitrogen fertilizer applied to a 1-ha sugarcane field resulted in 1.76 kg of N_2O emissions in the Central-South region of Brazil, which resulted in 1.5% in weight (wt%) of nitrogen in N_2O per weight unit of nitrogen in nitrogen fertilizer applied.

N_2O emissions from soil are highly uncertain; they depend on various conditions such as the amount of nitrogen fertilizer applied, soil type, soil moisture content, and temperature. According to the IPCC guidelines (2006b), the following are the N_2O emission factors for nitrogen in N_2O generated from the nitrogen in nitrogen fertilizer for generic applications: 1% for direct N_2O-N emissions, with a range of 0.3–3%; 1% for N_2O emissions from volatilization, with a range of 0.2–5% and a volatilization rate for nitrogen input of 10%, with a range of 3–30%; and 0.75% N_2O emissions from leaching and runoff, with a range of 0.05–2.5% and a leaching and runoff rate for nitrogen input of 30%, with a range of 10–80%. Using the average values in the IPCC guidelines (2006b), we derived a total N_2O-N rate of 1.325% (1% + 1% × 10% + 0.75% × 30%), which is close to the value of 1.5% derived from Macedo et al. (2004). We used the rate of 1.5% in our analysis.

The types of nitrogen fertilizer used are 85% urea and 15% ammonium nitrate and sulfate together (Macedo 2007). A gram of urea (NH_2CONH_2) contains 0.2 g of carbon, resulting in 0.43 g of carbon per gram of nitrogen in urea. This results in 1.577 g of CO_2 per gram of nitrogen in urea. We included this CO_2 emission source in the GREET simulation.

3.1.4. Sugarcane Transportation from Farms to Sugarcane Mills

Harvested sugarcane contains about 70% water. Because sugarcane is bulky and heavy, sugarcane mills are built in the midst of sugarcane farms to minimize transportation distance. Sugarcane is transported via trucks (see figure 2) an average one-way distance of 20 km (Macedo et al. 2004). The payload of a truck is 40–50 MT (Moreira and Goldemberg 1999). With these inputs, past studies in Brazil concluded that energy use for transporting sugarcane from farms to mills is 31–43 MJ/MT of sugarcane (Assuncao 2000; GTZ 2005; Macedo et al. 2004).

Figure 2. A Truck Carrying Sugarcane to Sugarcane Mill

For GREET simulations, we assumed that sugarcane is transported by a diesel truck with a payload of 40 MT for a 20-km one-way trip from field to mill. Furthermore, we assumed a fuel economy of 4 miles per gallon of diesel fuels for trucks transporting sugarcane. On the basis of these assumptions, the GREET model estimated an energy consumption of 24.4 MJ/MT of sugarcane transported. This value is lower than the values in the cited studies; those studies may have included direct energy use (as was the case in our estimate) and energy embedded in manufacturing the trucks.

3.2. Ethanol Production in Sugarcane Mills

In sugarcane mills, sugarcane is washed and crushed, and cane juice is extracted. The juice is then treated to produce ethanol and/or sugar. The split between the two products is based on market demand. The stream for ethanol production is then fermented, and the fermentation broth is subject to distillation, yielding product ethanol. CO_2 is emitted during fermentation. Figure 3 is a schematic of the sugarcane ethanol production process. To simplify this analysis, we assumed that a sugarcane ethanol mill is operated with 100% feed for ethanol production. The primary source of process fuel is bagasse with additional lubricant oil to support machinery operation.

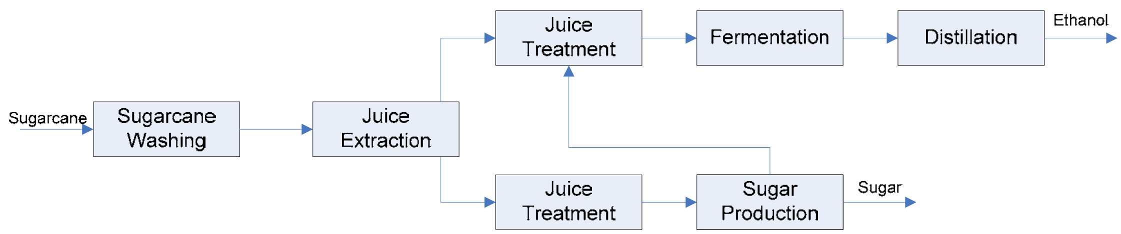


Figure 3. Schematic Representation of the Sugarcane Ethanol Production Process

3.2.1. Ethanol Yield

Table 5 presents a summary of ethanol yield from several studies. We used a yield of 91 L of ethanol/MT of sugarcane, based on the best value reported in Macedo et al. (2004).

Table 5. Summary of Ethanol Yield in Sugarcane Mills[a]

Source	Ethanol Yield (L/MT)	Notes	GREET Input (L/MT)/(gal/MT)[b]
Moreira and Goldemberg (1999)	79.5	1996/97 season yield	
Assuncao (2000)	73 85.4	1985 season yield 2000 season yield	
GTZ (2005)	80		
Macedo et al. (2004)	86 91	Average value Best value	 91/24

[a] Assuming that all sugarcane goes to ethanol production.
[b] Based on wet metric ton of sugarcane.

3.2.2. Energy Requirements in Sugarcane Mills

Table 6 shows the amounts of electric, thermal, mechanical, and chemical energy required for production of ethanol in sugarcane mills. Sugarcane mills are self-sufficient in terms of thermal energy and electricity use. Heat demand represents the majority of energy use and is met through bagasse combustion. Most sugarcane mills generate their own electricity for internal use. The use of bagasse as the process fuel is discussed in Section 3.2.4. We selected values for GREET input parameters on the basis of the latest data from the open literature. We estimated total electricity use by the sugarcane mill to be 28.85 kWh/MT of sugarcane processed. Of this total, 16.84 kWh/MT is used to drive mechanical work with a conversion efficiency of 95% (Table 7).

Table 6. Energy Consumption in Ethanol Production Process

Parameter	MJ/MT of Sugarcane	Data Source	GREET Input (MJ/MT of Sugarcane)
Energy Use			
Electricity	43.20	Macedo 2005	43.20
Mechanical energy	57.60	Macedo 2005	57.60
Thermal energy	1,188.00	Macedo 2005	1,188.00
Chemical and Lubricant Use			
	7.34	Assuncao 2000	
	6.00	GTZ 2005	
	6.36	Macedo et al. 2004	6.36
Energy Embedded in Sugar Mill Construction			
Average value	10.78	Assuncao 2000	
Average value	12.00	GTZ 2005	
Best value	8.07	Assuncao 2000	
Best value	9.00	GTZ 2005	
Average value	11.97	Macedo et al. 2004	
Best value	9.29	Macedo, 2004	9.29
Energy Embedded in Sugar Mill Equipment			
Average value	27.96	Assuncao 2000	
Average value	31.00	GTZ 2005	
Best value	20.98	Assuncao 2000	
Best value	24.00	GTZ 2005	
Average value	31.07	Macedo et al. 2004	
Best value	24.16	Macedo et al. 2004	24.16

We assumed that the thermal energy (1,188 MJ, or 1.126 million Btu, per MT of sugarcane) is supplied by bagasse combustion in a biomass boiler to produce steam with an efficiency of 80%. There is 1.408 million Btu of bagasse per MT of sugarcane, or 58,546 Btu/gal of ethanol produced (Table 7). A small amount of lubricants (6.36 MJ/MT of sugarcane) is used in sugarcane mills, which we assumed to be similar to residual oil in terms of energy and emission profiles. Therefore, we approximated the energy use of lubricant oil to that of residual oil.

Table 7. Process Energy Use in Sugarcane Mills for Ethanol Production

	MJ/MT of Sugar cane	KWh/MT of Sugarcane	KWh/gal of EtOH[a]	Btu/MT of Sugarcane	Btu/gal of EtOH[a]
Electricity	43.2[b]	12.00	0.50		
Mechanical	57.6[b]	16.84[c]	0.70		
Thermal	1,188[b]			1,407,583	58,546
Lubricant oil	6.36[b]			6,028	251
Mill construction	9.29[b]				366
Equipment manufacturing	24.16[b]				953
Total		28.85	1.20		

[a] The conversion from sugarcane processed to ethanol produced is based on the ethanol yield of 91 L/MT of wet sugarcane.
[b] Data source: see Table 6.
[c] We assumed a conversion efficiency of 95% from electric energy to mechanical energy.

Macedo et al. (2004) estimated a life-cycle energy use of 9.29 MJ/MT of sugarcane processed in construction of sugarcane mills and 24.16 MJ/MT in manufacture of sugarcane mill equipment (that is, embedded energy in mill equipment). We included these values in the GREET model. The equipment used was assumed to be 100% steel. Emissions from equipment manufacturing were estimated on the basis of process fuel shares for steel production as presented in GREET 2.7.

3.2.3. Bagasse as the Process Fuel in Sugarcane Mills

Bagasse is the residue of sugarcane after the juice has been extracted. Because of its high carbon content (46.3 wt% on a dry matter basis), it serves as an excellent source of process fuel in sugarcane mills. We assumed that bagasse is combusted in a biomass boiler to produce steam to meet the plant demand for steam and to generate electricity with a steam turbine to meet the plant requirement for electricity and for electricity export.

We used a bagasse yield of 280 kg (50% moisture content) per MT of sugarcane, which was reported by Macedo et al. (2004). The lower heating value (LHV) of bagasse in references ranged from 7.530 to 7.736 MJ/kg (with 50% moisture content, Macedo et al. 2004; Garcia 2007). One heating value reported by Assuncao (2000), 9.449 MJ/kg, was 2 MJ higher and was not specified as either high heating value (HHV) or LHV. We compared the data with Perry's *Chemical Engineers' Handbook* (Perry and Green 1997) which listed an HHV of 8.37–11.63 MJ/kg for bagasse, suggesting that the value of 9.448 MJ/kg is most likely the HHV. For sugarcane ethanol simulations in GREET, we used a LHV of 7.53 MJ/kg (with 50% moisture) for bagasse. On a dry-matter basis, the LHV for bagasse is 15.06 MJ/kg, or 12,947,320 Btu/ton.

The steam and electricity balance for sugarcane ethanol processing is presented in Table 8. The total energy provided by bagasse, 83,124 Btu/gal of ethanol produced, was determined by using a bagasse energy yield of 280 kg/MT sugarcane × 7.53 MJ/kg at an ethanol yield of 0.024 gal/kg of sugarcane (91 L/MT). The steam needed for plant operation is 58,546 Btu/gal of ethanol, which is based on a boiler efficiency of 80% (Table 7).

We assumed the surplus steam, 24,578 Btu/gal of ethanol, is used to generate electricity. With an electricity generation efficiency of 30% (the current Brazil industrial average), a total of 2.16 kWh of electricity can be generated for each gallon of ethanol produced. After 1.20 kWh (Tables 7 and 8) has been consumed in the process, an excess of 0.96 kWh/gal of ethanol is available for export.

Table 8. Ethanol Plant Steam and Electricity Energy Balance (per gallon of ethanol)

Bagasse Energy Yield (Btu)	Internal Steam Needs (Btu)	Extra Btu for Electricity Generation (Btu)
83,124[a]	58,546	24,578
Electricity Generated from Extra Bagasse Energy (KWh)	Internal Electricity Needs (kWh)	Extra Electricity for Export (kWh)
2.16[b]	1.20	0.96

[a] This value is calculated as follows. One MT of sugarcane results in 280 kg of bagasse with 50% moisture content and 91 L of ethanol. Thus, a gallon of ethanol is associated with 11.66 kg of bagasse, which contains 87.70 MJ of energy, or 83,124 Btu of energy.
[b] Based on a power generation efficiency of 30%.

3.2.4. Bagasse Combustion Emissions

The IPCC guidelines (2006b) specify emission factors of CH_4 and N_2O from biomass combustion; see Table 9. Because of the large variations in the CH_4 and N_2O emission factors, we adopted the IPCC average values for GREET simulations.

Table 9. Emission Factors of Bagasse Combustion

Pollutant	Emission Factors (g/mm Btu of bagasse)			
	From IPCC Guidelines (2006b)			GREET Inputs
	Low	Average	High	
CH_4	11.00	31.65	105.50	31.65
N_2O	1,58	4.22	15.83	4.22

3.3. Ethanol Transportation from Sugarcane Mills to Refueling Stations

While some Brazilian sugarcane ethanol is exported to Japan, the European Union, and the United States, the majority of the sugarcane ethanol produced in Brazil is used in the Brazilian domestic market. For a U.S. perspective of Brazilian sugarcane ethanol, we examined the case in which sugarcane ethanol is produced in Brazil and used in the United States market so that we could compare its effects directly with those of ethanol production pathways already examined for the United States.

For the case of the domestic use of ethanol in Brazil, we assumed that ethanol is transported via pipeline and rail for 350 miles (in each mode) from sugarcane mills to bulk terminals and then via truck for 50 miles to refueling stations, where it is used either in its pure form or blended with gasoline.

For the case of ethanol exported to the United States, we accounted for ethanol transportation in both Brazil and the United States. Ethanol is first transported from mills to Brazilian ports in Southern Brazil. For this analysis we selected a representative port, Santos, a major port in Brazil. Most sugarcane mills are located in the two southern states near the Santos port that provide about 50% of the nation's ethanol. In particular, we assumed that ethanol is transported via pipeline and rail on an average of 500 miles (in each mode) from sugarcane mills to the Santos port, where it is loaded onto ocean tankers for transporting to the United States. We chose two U.S. ports, New York and Los Angeles, as entry points for Brazilian ethanol to the U.S. market. We used the average distance of 6,449 nautical miles from Santos to New York and from Santos to Los Angeles (see www.distance.com). Inside the United States, we assumed that ethanol is distributed regionally on the East and West Coasts, while the rest of the country receives domestic corn ethanol from the U.S. Midwest. In particular, we assumed that the imported ethanol is transported 100 miles by truck to blending and storage facilities and further distributed to refueling stations.

3.4. Extraction and Production of Process Fuels and Electricity Generation Mix

For individual stages of the sugarcane ethanol pathway in Brazil, such as sugarcane farming, cane transportation, ethanol production, and ethanol transportation to U.S. ports, the energy use and emissions of primary energy recovery and processing, including coal, natural gas, and oil, were not available at the time of this study. We used GREET default values, which are based on U.S. industry averages. These values may be updated once Brazilian data become available.

To estimate energy and emission credits of the exported electricity generated at sugarcane mills in Brazil, energy and emissions associated with electricity use in Brazil were estimated by assuming the electricity exported from sugarcane mills would replace electricity generation in natural gas plants. It is believed that natural gas power plants are marginal power plants in Brazil. In comparison, Table 10 shows the average power generation mix in Brazil.

Table 10. Average Electricity Generation Mix in 2004 in Brazil

Plant Fuel	Average Electricity Generation Mix in Brazil (%)
Petroleum	1.2
Natural gas	5.0
Coal	1.7
Biomass	4.2
Nuclear	3.0
Hydro	82.9
Others	2.0

Source: Ministry of Mine and Energy of Brazil (2005).

4. Key Issues in WTW Analysis of Sugarcane Ethanol

4.1. CO_2 Credits

During their growth, sugarcane plants take CO_2 from the air for the photosynthesis process. The carbon taken in by sugarcane plants resides in them and is further converted to carbon in CO_2, CO, VOC, and CH_4, which are generated through various chemical and biological routes (fermentation, combustion, and the like) when sugarcane is processed to produce ethanol. The CO_2 from sugarcane that is emitted through a combustion process or through ethanol combustion on vehicles is considered zero CO_2 emissions to the air, since this is the carbon from the air during sugarcane plant growth. In this case, the renewable carbon from sugarcane, rather than fossil fuel carbon, is used for combustion. Similarly, direct CO_2 emissions from sugar fermentation to ethanol are considered to be zero CO_2 emissions to the air.

We examined the fate of the renewable carbon in sugarcane beginning with harvested sugarcane by making several assumptions:

- All carbon in sugarcane plants is from atmospheric CO_2.
- Emissions from carbon in sugarcane plants end in four sources: CO_2, CO, VOC, and CH_4.
- CO and VOC, which are emitted to the air during combustion of sugarcane tops and leaves in sugarcane fields and combustion of bagasse in ethanol plants, are

converted to CO_2 in the air in a short time; these CO_2 sources, together with direct CO_2 emissions from these combustion processes, are not included in CO_2 emission calculations for sugar cane ethanol, since they are ultimately from the air.

- CH_4 from these combustion processes remains in the air for a long time, and these CH_4 emissions are accounted for as a GHG emission source for sugarcane ethanol.

- The organic carbon content of soil in sugarcane farms remains constant; however, this may not be the case if sugarcane ethanol production is expanded significantly and certain land uses are changed to accommodate such expansion.

Figure 4 is a schematic diagram of the fate of atmospheric carbon in the sugarcane ethanol pathway. The renewable carbon in sugarcane is utilized (combusted) in the sugarcane-to-ethanol pathway via three major routes: open-field burning of sugarcane leaves and tops, bagasse combustion in ethanol plants, and ethanol combustion during vehicle operation. All four forms of carbon emissions from these sources — CO_2, CO, VOC, and CH_4 — originate in carbon uptake from the air by sugarcane plants during growth. Among them, CO and VOC typically are oxidized to CO_2 within a few days after being released to the air. The amount of CO_2 generated is basically the carbon transformed from atmospheric CO_2; that is, the CO_2 emission sources shown in figure 4 are actually CO_2 from the air during sugarcane growth.

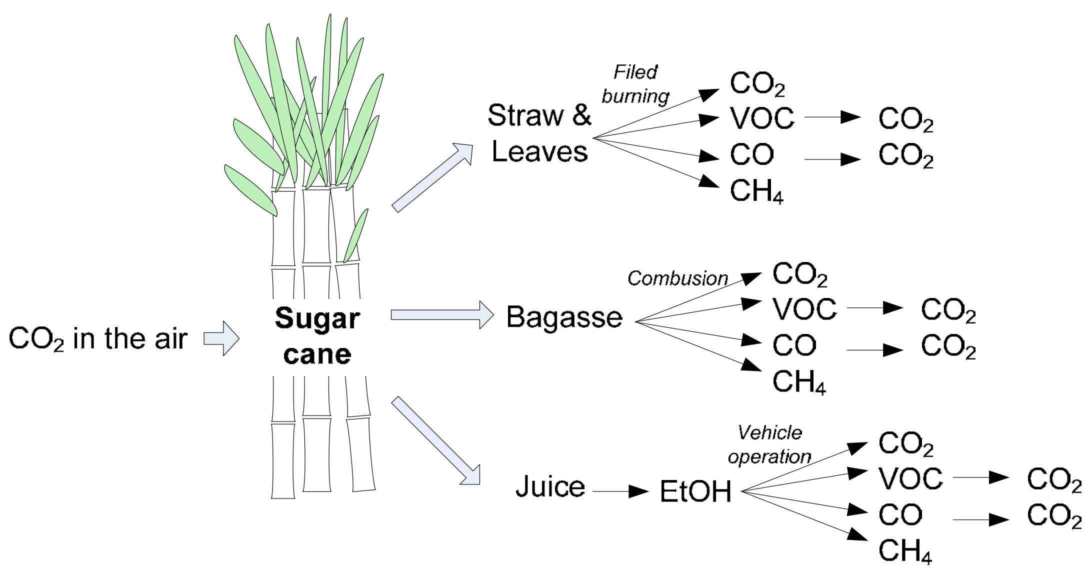


Figure 4. Fate of Renewable Carbon in the Sugarcane Ethanol Pathway

4.2. Energy and Emission Credits of Exported Electricity

Bagasse is combusted to provide steam for meeting process heat requirements at sugarcane mills, and excess steam generates electricity to satisfy plant internal power demand. Excess power could be exported to the electric grid. In some cases, mills may not be connected to the electric grid; thus, power export may not be an option. In the

GREET model, we designed two options for the sugarcane ethanol pathway: (1) ethanol production with no electricity export; and (2) ethanol production with excess electricity exported to the electric grid.

In the case in which excess electricity is exported to the electric grid (the case we considered in our simulations), electricity generated from sugarcane mills is assumed to displace electricity generated with natural gas electric power plants. On the other hand, if the exported electricity is assumed to displace the electricity with the Brazilian average electric generation mix, which is largely hydropower (82.9%, see table 10), the energy and emission credits of the exported power would be smaller. In other words, the fact that the renewable power generated from bagasse displaces another primary renewable power reduces the benefit of the exported electricity from sugarcane ethanol plants.

5. Results and Discussions

As indicated in Section 2, we established a base case for production of sugarcane ethanol in Brazil and use of it in the United States (SC Case 1). Three sensitivity cases were developed from the base case. For comparison, we selected the base case to compare sugarcane ethanol with corn ethanol, switchgrass-based cellulosic ethanol, and petroleum gasoline, since evaluation of these three cases does not include energy embedded in corn ethanol plants and petroleum refineries. WTW results of energy use and GHG emissions are presented in figures 5–11 and in Table 11. Energy and GHG emission results are expressed for each million Btu of fuel produced and used.

Energy use results for sugarcane ethanol, corn ethanol, and cellulosic ethanol are presented together in this section. While results for sugarcane and corn ethanol are based on operational data of many plants, results for cellulosic ethanol from switchgrass are based on projections and engineering simulations of switchgrass growth and cellulosic ethanol production. Note that in terms of commercial readiness, cellulosic ethanol is not at the same stage of development as sugarcane and corn ethanol.

5.1 Fossil and Petroleum Energy Use Results

Ethanol produced from Brazilian sugarcane achieves substantial reductions in fossil energy use (97%) relative to petroleum gasoline (Figure 5). The reductions are 2.6 times as much as those by corn ethanol. Fossil energy includes petroleum, natural gas, and coal energy; thus petroleum energy use presented here is a subset of fossil energy use.

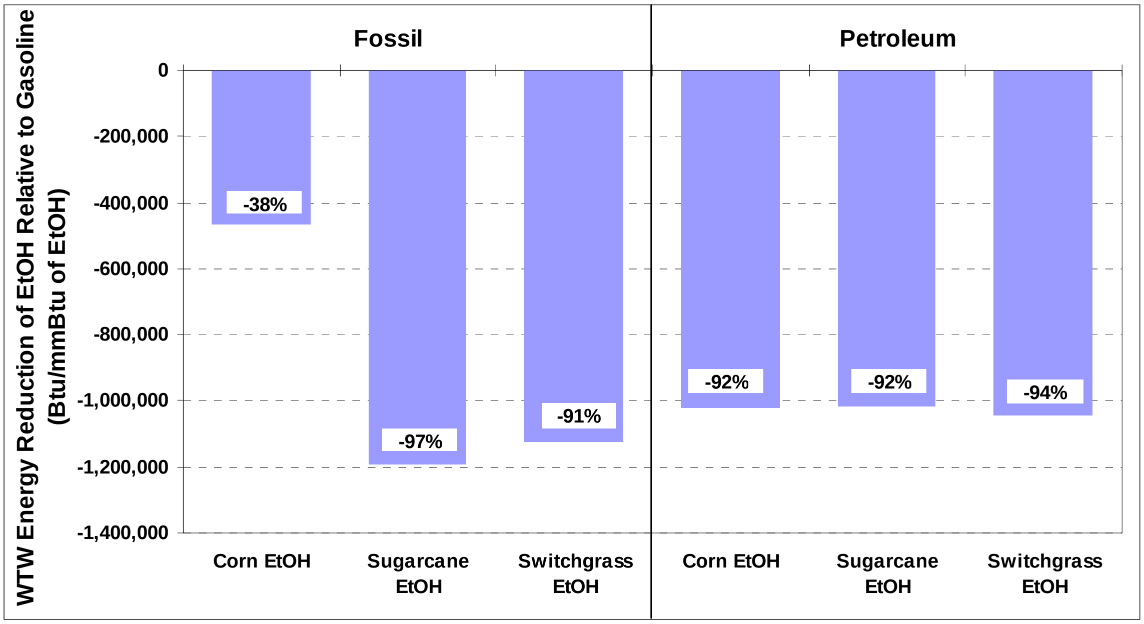
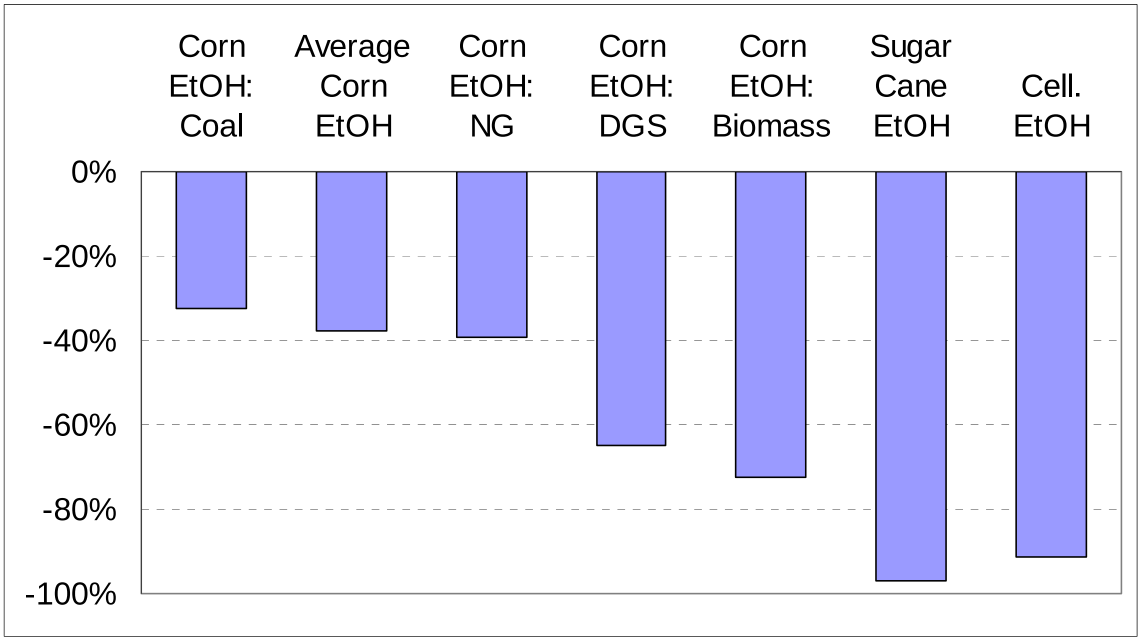


Figure 5. WTW Fossil Energy and Petroleum Reductions by Ethanol Relative to Petroleum Gasoline

Figure 5 shows that ethanol can provide reductions of more than 90% in petroleum energy compared to gasoline, regardless of the feedstocks for ethanol production (corn, sugarcane, or switchgrass). Figure 6 compares sugarcane ethanol with various ethanol production and feedstock options. Among the ethanol production and feedstock options evaluated, fossil energy reduction by sugarcane ethanol is similar to that by cellulosic ethanol. Figure 7 presents the net energy balance values of various ethanol production options and petroleum gasoline per million Btu of fuel produced. The net energy balance (NEB) is the difference between the Btu content of a fuel and the fossil Btu input to the fuel production pathway. A positive value of NEB represents an energy surplus for a fuel, while a negative value shows an energy deficiency. All the ethanol options show positive NEB values. For each million Btu of ethanol produced from sugarcane grown in Brazil and utilized in the United States, there is a net gain of 0.96 million Btu, in contrast to a net gain of 0.23 million Btu for corn ethanol and 0.89 million Btu for switchgrass-derived ethanol.



(Corn ethanol and cellulosic ethanol results are from Wang et al. (2007); each corn ethanol type represents the corn ethanol plants fueled with a given process fuel.)

Figure 6. WTW Fossil Energy Reductions of Various Ethanol Production Options Relative to Petroleum Gasoline

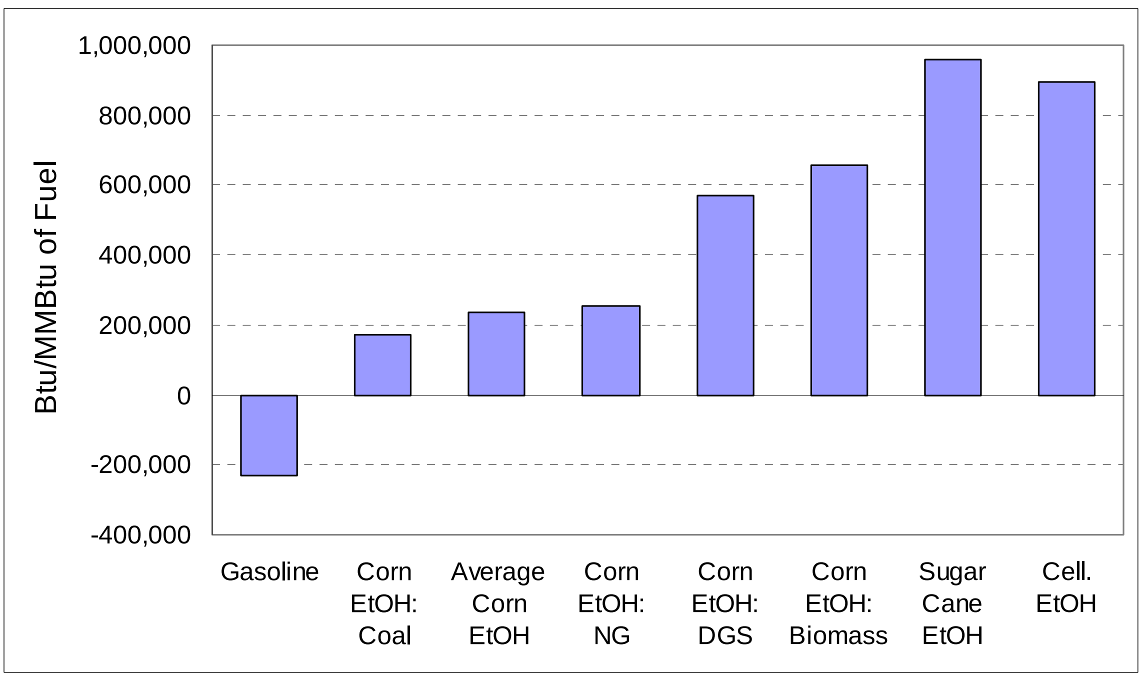


Figure 7. Net Energy Balance of Ethanol and Petroleum Gasoline:

The unique advantage of the sugarcane ethanol pathway is that ethanol production in sugarcane mills is self-sustaining in terms of energy need: the juice is used for ethanol production and bagasse is used for heat and power generation. As a result, ethanol production requires 58,546 Btu of heat demand and 1.20 kWh of electricity per gallon of ethanol. In addition, renewable power at the rate of 0.96 kWh can be exported to the electric grid. This reduction in fossil energy use is the main cause of the marked difference in WTW results between sugarcane ethanol and corn ethanol. Table 11 illustrates that approximately 100,785 Btu of natural gas and 163,609 Btu of coal per million Btu of ethanol are saved by sugarcane ethanol production compared to corn ethanol. Recently, designers and operators started to address the issue of process fuel demand in corn ethanol plants by considering renewable sources such as wood chips or distiller's grains and solubles (DGS). With these renewable energy sources, corn ethanol could reduce an additional 27% (DGS as the process fuel) or 34% (wood chips as the process fuel) of fossil energy use (Figure 6).

Table 11. WTW Fossil Energy Use for Ethanol (Btu/Million Btu of Ethanol)

Fossil Energy	Corn EtOH	Sugarcane EtOH
Natural Gas	468,709	–96,097[a]
Coal	206,284	42,675
Petroleum	90,398	92,596
Total	765,391	39,174

[a] The negative value represents the reduction of natural gas-based electricity generation that is displaced with the electricity exported from sugar cane mill.

Sensitivity analysis of sugarcane ethanol with the four sugarcane ethanol production options (as presented in Figure 10) indicates that (1) energy embedded in sugarcane mills contributes 0.3% of total fossil energy use; (2) energy embedded in farming equipment contributes 2.3%; and (3) transportation of ethanol from Brazil to the United States contributes 3.0%.

5.2. GHG Emissions Results

Figure 8 shows WTW GHG emission reductions by sugarcane ethanol and several other ethanol production options, compared to petroleum gasoline. The GHG emission reductions by sugarcane ethanol are 3.8 times as much as those by corn ethanol and rank second only to those by cellulosic ethanol.

For the five corn ethanol production options, GHG emission changes range from a 3% increase to a 52% reduction, depending on the process fuel used.

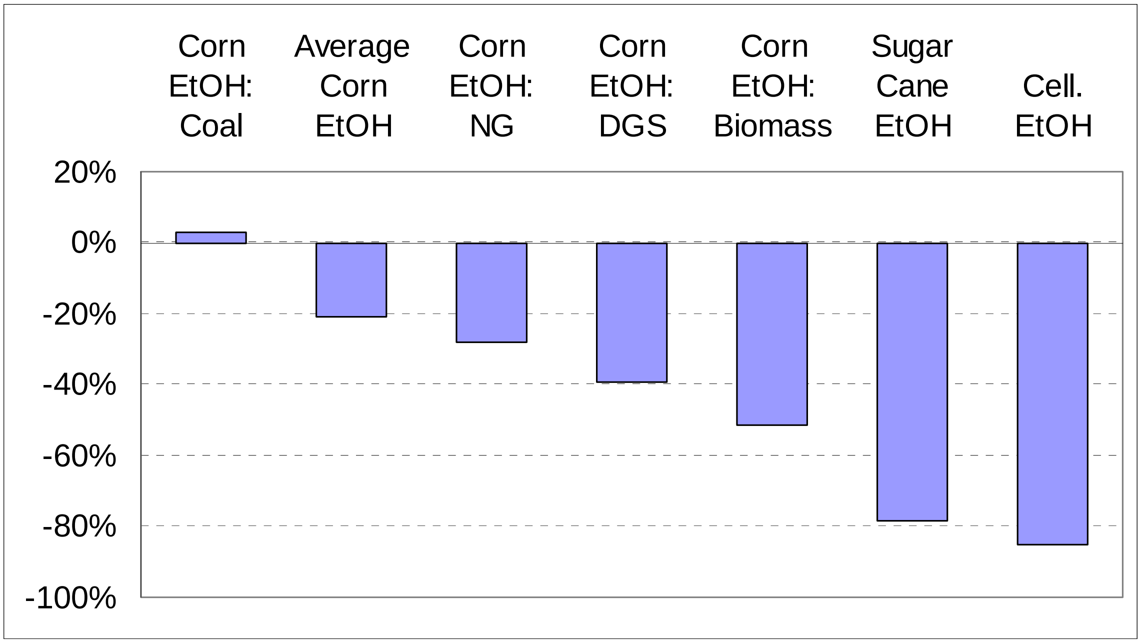


Figure 8. WTW GHG Emission Reductions by Various Ethanol Production Options Relative to Petroleum Gasoline

We examined key stages of the sugarcane ethanol pathway for their contributions to total GHG emissions. Similar to that for cellulosic ethanol, the sugarcane ethanol pathway generates heat and power from bagasse in sugarcane mills to displace natural gas or coal use. However, sugarcane farming differs considerably from cellulosic biomass farming. For example, sugarcane farming is associated with open-field burning of sugarcane tops and leaves, a practice not used in either corn farming or cellulosic biomass farming. CH_4 and N_2O emissions from open-field burning alone are responsible for 24% of total GHG emissions for sugarcane ethanol (Figure 9). In particular, the five major contributors to sugarcane ethanol GHG emissions are open-field burning (24%), N_2O emissions from sugarcane fields (14%), fertilizer production (16%), GHG emissions from sugarcane mills (17%), and sugarcane farming (9%); together these make up 80% of the total WTW GHG emissions of sugarcane ethanol.

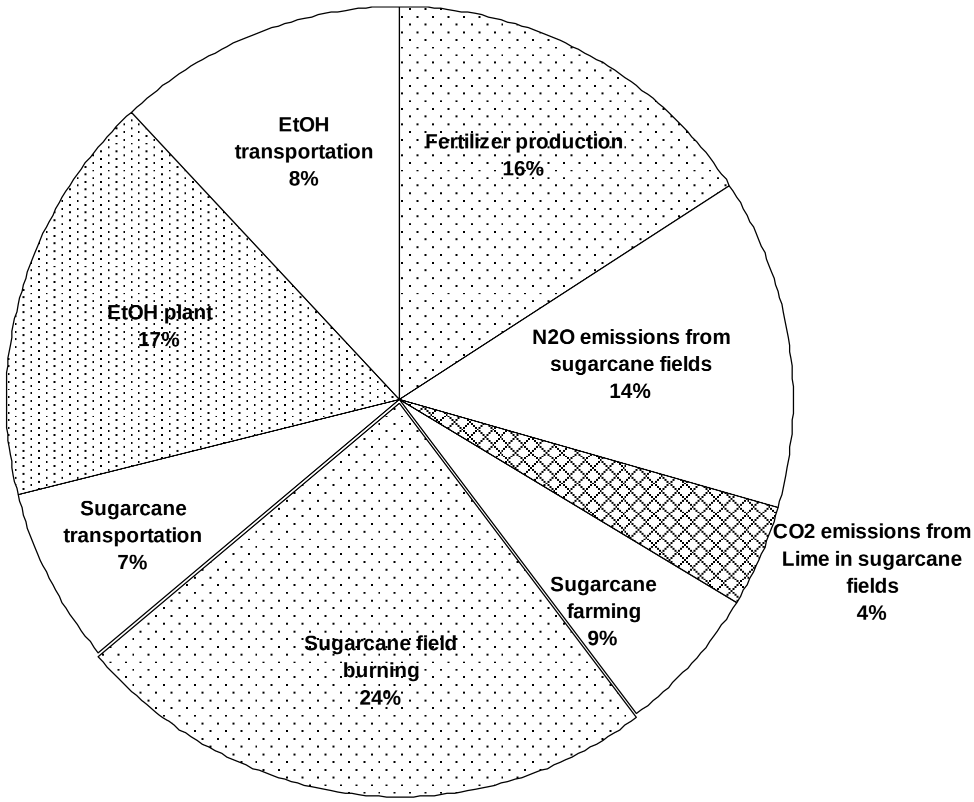


Figure 9. Shares of GHG Emissions of Sugarcane Ethanol Pathway Activities

5.3. Sensitivity Cases of Sugarcane Ethanol

We developed four sugarcane ethanol cases in this study to show variations in energy and GHG emission effects of sugarcane ethanol. The difference between Cases 1 and 2 shows the contribution of energy embedded in farming equipment production and sugarcane mill construction; that between Cases 1 and 3 shows the contribution of energy embedded in farming equipment production; and that between Cases 1 and 4 shows the contribution of transporting ethanol from Brazil to the United States.

Figures 10 and 11 show the effects of these factors. In particular, inclusion of energy embedded in farming equipment and sugarcane mill construction lowers fossil energy reductions by sugarcane ethanol by 2.6 percentage points and GHG emission reductions by 2.8 percentage points. Inclusion of energy embedded only in farming equipment lowers fossil energy reductions by1.3 percentage points and GHG reductions by 1.2 percentage points. These results imply that energy embedded in farming equipment and sugarcane mills contributes in equal proportion to total sugarcane ethanol results.

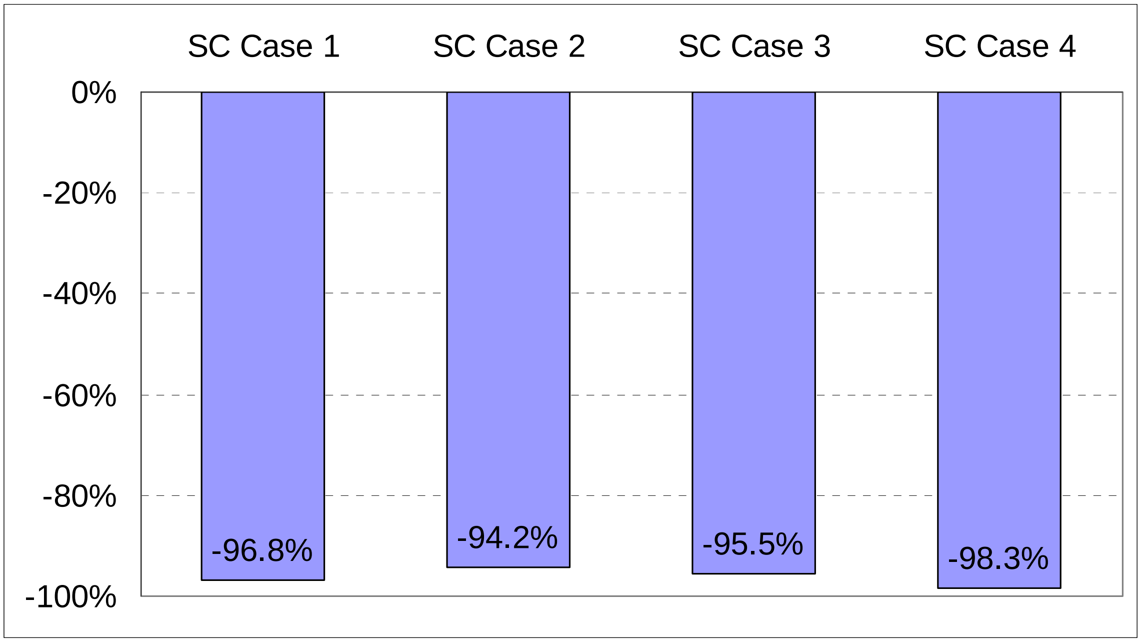


Figure 10. Fossil Energy Reductions by Four Sugarcane Ethanol Cases Relative to Petroleum Gasoline

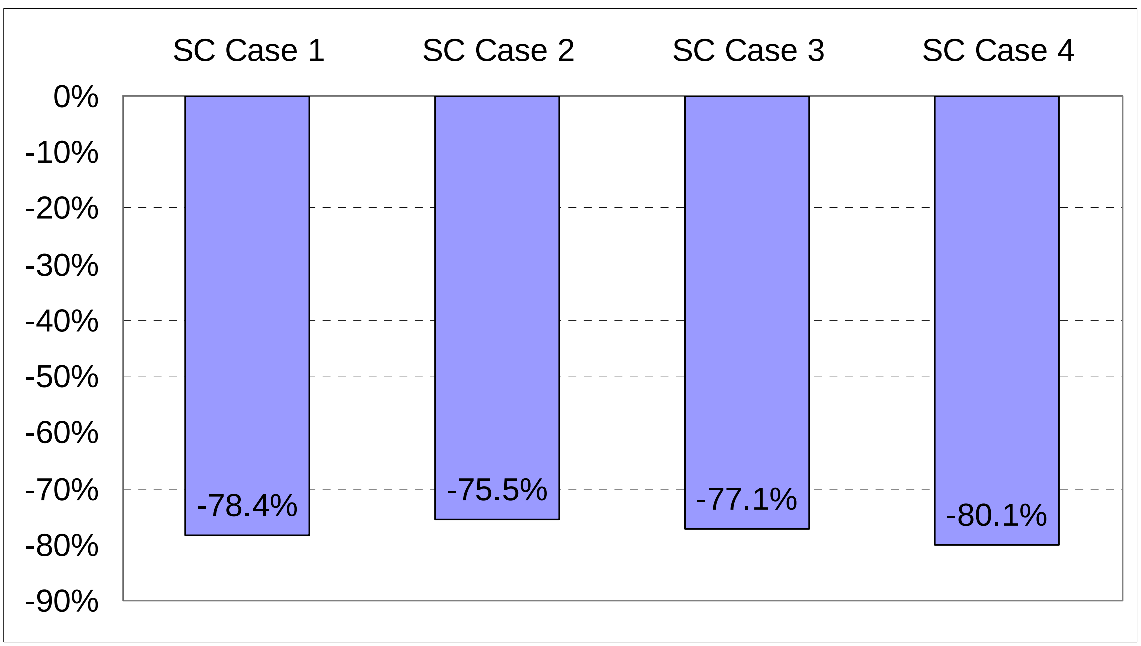


Figure 11. GHG Emission Reductions by Four Sugarcane Ethanol Cases Relative to Petroleum Gasoline

The difference between Cases 1 and 4 indicates that transportation of sugarcane ethanol from Brazil to the United States contributes to a 1.5-percentage-point difference in fossil energy use and a 1.7-percentage-point difference in GHG emissions for sugarcane ethanol.

We also developed two cases for open-field burning — one with 100% burning and the other with 0% burning (this is compared with the assumed 80% open-field burning for all four sugarcane ethanol cases examined in this study). The results of the two cases showed a difference in GHG emission reductions of 9 percentage points. Because Brazil is going to phase out open-field burning in the future, this will certainly help further reduce GHG emissions of sugarcane farming, together with reductions in emissions of criteria pollutants such as NO_x and PM_{10}.

CH_4 emissions from open-field burning are subject to great uncertainty (Table 4). Use of a CH_4 emission factor of 0.15 g/kg of biomass instead of 2.7 g/kg helps increase GHG emission reductions of sugarcane ethanol by 5.2 percentage points.

We assumed in our analysis that the exported electricity from sugarcane ethanol plants will displace electricity generated in natural gas electric power plants, which are believed to be the marginal electric power plants in Brazil. On the other hand, if the exported electricity displaces the average electricity in Brazil (83% of which is from hydro-power), GHG emission benefits of sugarcane ethanol are reduced by up to 8 percentage points.

6 Conclusions

By using the GREET model, our WTW analysis of the pathway of producing ethanol from sugarcane in Brazil and using it in the United States reached the following conclusions. Sugarcane ethanol could achieve fossil energy reduction as much as 97% relative to petroleum gasoline. The large reduction is a result of use of bagasse in sugarcane mills in place of coal or natural gas to generate the heat and power needed for plant operation. This and other factors such as low sugarcane farming energy and fertilizer use contribute to a positive net energy balance of 0.96 million Btu per million Btu of ethanol produced.

Sugarcane ethanol could achieve a reduction of 78% in GHG emissions relative to those of petroleum gasoline. This reduction is similar to that of cellulosic ethanol. Even when energy embedded in farming equipment and sugarcane mills is included, GHG emission reductions by sugarcane ethanol are still more than 75%. The large reductions can be attributed to the use of bagasse in sugarcane mills. Of the total GHG emissions associated with sugarcane ethanol, the five major contributors are open-field burning of sugarcane tops and leaves, N_2O emissions from sugarcane fields, fertilizer production, sugarcane mill operation, and sugarcane farming.

7. Acknowledgments

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8. References

Andreae MQ, Merlet P (2001): Emission of Trace and Aerosols from Biomass Burning. Global Biogeochem Cycles 15, 955–966

Assuncao JV de (2000): Life Cycle Analysis of Sugar Cane Ethanol in Relation to Greenhouse Gases Emissions. Presented at the 93rd Meeting and Exhibition of the Air and Waste Management Association, Salt Lake City, Utah, June 18–22

Brinkman, N., M. Wang, T. Weber, T. Darlington (2005): *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems — A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions*, General Motors Corporation and Argonne National Laboratory, May.

Concawe, EUCAR, EU JRC (2007): Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context, Brussels, Bulgium, March

Garcia J, Sao Paulo State of University, Sao Paulo (2007): Personal communication via e-mail to Mary Wu, Argonne National Laboratory, Argonne, IL, February

German Technology Corporation (GTZ) (2005): Liquid Transportation Fuels in Brazil: Potentials and Implications for Sustainable Agriculture and Energy in 21st Century, prepared by BMVEL, November

Intergovernmental Panel on Climate Change (IPCC) (2006a): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry, and Other Land Use. Hayama, Japan

Intergovernmental Panel on Climate Change (IPCC) (2006b): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy. Hayama, Japan

Macedo IDC, MRLV Leal, and JEA Seabra (2004): Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil, prepared for the State of Sao Paulo, Brazil, March

Macedo IDC (2005): Sugar Cane's Energy: Twelve Studies on Brazilian Sugar Cane Agribusiness and Its Sustainability, Sao Paulo Sugar Cane Agroindustry Union (UNICA), Sao Paulo, Brazil

Macedo IDC (2007): Personal communications via e-mail to May Wu, Argonne National Laboratory, Argonne, IL, March

Ministry of Mine and Energy of Brazil (2005): National Energy Balance 2005 (or Balanço Energético Nacional 2005) (in Portuguese)

Moreira JR, Goldemberg J (1999): The Brazilian Alcohol Program. *Energy Policy* 27, 229–245.

Perry, R.H. and D.W. Green (1997): Perry's Chemical Engineers' Handbook, 7th Edition, McGraw-Hill

Wang M, Wu M, Hong H (2007): Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types. Environ Res Lett 2, 024001 (13 pages)

ISSCT PROCESS WORKSHOP
Saint Denis, REUNION ISLAND
20 - 23 October 2008
"*Green cane impact on sugar processing*"

REPORT

By

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KEYWORDS: green cane, trash, extraneous matter, losses, workshop

Abstract

The ISSCT Process Section workshop held on Reunion Island was attended by 51 delegates from 10 countries. The theme was *Green cane impact on sugar processing*. The workshop provided a valuable and timely opportunity to review and discuss the impact on factory operations and performance from a green cane supply that could include significant levels of trash. It was particularly relevant to those mills that were considering options to boost their biomass intake for increased co-generation capacity. Several of the speakers related their experiences with processing 'whole of crop' cane supplies through the factory. Speakers detailed the problems and increased losses that were incurred when processing cane with high trash levels. The consensus of the delegates was that the best scenario would involve a cane cleaning plant at the factory so that only clean cane would be processes through the factory. The forum recommended that more research was required to address the issues of increased impurities in the process streams associated with high trash levels. Site visits to the two factories and a cane delivery station were arranged as part of the workshop.

Introduction

The Process Section Workshop was held at the Hotel Mercure Créolia, Saint Denis, Reunion Island from 19 to 23 October 2008 and hosted by CERF (Centre d'Essai de Recherche et de Formation).

The theme for the workshop was *Green cane impact on sugar processing*. The workshop provided a valuable and timely opportunity to review and discuss the impact on factory operations and performance from a green cane supply that could include significant levels of trash. It was particularly relevant to those mills that were considering options to boost their biomass intake for increased co-generation capacity.

It was attended by 51 delegates representing 10 countries including some delegates who had travelled from as far away as Brazil, Nicaragua and Japan for the workshop. All of the organisational matters for the workshop were handled extremely well by CERF and, in particular, by Laurent Corcodel and Carmille Roussel.

The program included the following activities:

Sunday, 19/10/2008	Visit to CERF facilities Welcoming cocktail function
Monday, 20/10/2009	Site visits to the Casernes cane delivery and transfer station, Le Gol Mill and the Centrale Thermique du Gol cogeneration plant

Tuesday, 21/10/2008	Session 1 – Sugar losses in storage: green cane versus burnt cane Session 2 – Mill detrashing equipment: design, operation and optimization Site visit to Bois Rouge Mill and Savanna Distillery
Wednesday, 22/10/2008	Session 3 – Effects of trash on factory operations Session 4 – Whole crop processing
Thursday, 23/10/2009	Session 5 – Forum review and discussion Close

The detailed workshop program is presented in Appendix A. The delegate list is attached as Appendix B.

Opening session

The opening session of the workshop included presentations by Jean-François Moser, President of CERF, and Laurent Corcodel.

Moser's presentation provided an insight into the sugar industry on Reunion Island and its significant importance to the local economy. He described how infrastructure had been developed to allow water collected on the eastern side of the island to be transferred to the western side to irrigate the crops. A modernisation program had resulted in the closure of all but two mills. Cogeneration plants using both bagasse and coal were established at each factory. The remaining two mills had been upgraded to handle the full crop. Cane delivery stations were developed in several areas (mostly on old mill sites) to allow farmers to deliver the cane to local collection points. Each load is sampled on arrival before being transferred to semi-trailers for transport to one of the mills.

Laurent Corcodel reviewed the performance of the cane sugar industry in Reunion since 1984. Some of the important changes to the industry have included:

· The sugar industry on Reunion Island was consolidated to two factories (Le Gol and Bois Rouge), each processing about 1,000,000 Mt per year between July and December and producing 100,000 t of raw sugar each.

· The cane crop comprises two main varieties; R570 (high trash) and R579 (self trashing);

· Each paddock can be rationed up to nine times;

· All cane is harvested green and much of the trash is included with the cane supplied to the factories;

· Cane is delivered to one of 12 transfer stations or direct to one of the two factories;

· Only 10-30 % is mechanically harvested;

· The true purity of the mixed juice ranges between 86 and 90;

· Ash % brix in mixed juice trends down from about 5 % at the start of the milling season in July to less than 4 % in December;

· Reducing sugars % brix range from about 3 % in July to 3.5 to 4.0 in December; and

· Plant reliability has improved significantly over the twenty year period from about 12 % downtime to an average of 4 % breakdown rate in 2007.

Technical sessions

Session 1 – Sugar losses in storage: green cane versus burnt cane

Determination of sucrose loss in storage of green billet cane (Michael Saska, Stuart Goudeau, Irina Dinu and Mike Marquette. Presented by Rod Steindl)

A series of tests was done to measure the sucrose loss during twenty-four hour storage of green billet cane. Several tests were also organized in a sugar factory where in addition to the storage on the ground, some damage or loss of cane may be expected from handling the cane with front end loaders. The mass loss of sucrose in storage of green billets of twenty four hours or less was found to be adequately represented by a linear model based on the length of time (hours) within three temperature ranges: <17 °C (63 °F), 17-27 °C (63-81 °F) and >27 °C (81 °F), representing cold, moderate and warm conditions. The predicted relative sucrose change (tons of sucrose lost or gained for each 100 tons of initial sucrose per hour) in the three temperature ranges are 0.022 (gain), -0.017 (loss) and -0.323 (loss), respectively.

An analogous model was found to apply to the cane weight loss during storage of green billet cane. The predicted relative cane weight loss (tons of cane per 100 tons initial per hour) in the three temperature ranges <17 °C, 17-27 °C and >27 °C was 0.02, 0.02 and 0.26 respectively. The six factory cane yard tests broadly agreed with the conclusions from the pilot storage tests done at ASI, indicating that the cane and sucrose mass losses from handling the cane in the cane yard were relatively small compared with the losses from the enzymatic and microbial action within the stored cane.

Whether the small sucrose gain predicted by their model for cold storage of green billets was related to enhanced activity of sucrose synthesizing enzymes or suppressed invertase activity in post-harvest cane as a reaction to low temperatures, or was rather an artefact of the experimental technique was uncertain.

The financial impact of the sucrose loss predicted for storage of cane at high temperatures (3.2% in ten hours at over 27 °C) is serious, and considerations should be given to improving through their design the natural or forced ventilation of cane wagons and piles, and to the scheduling of harvest and storage of cane.

Cane deterioration: Comparison green cane vs burnt cane – Research of green cane deterioration indicator (Camille Roussel, Arnaud Petit and Laurent Corcodel)

In the period 1990-1995, the Process Department of CERF carried out some studies on cane deterioration. The aims of those studies were to compare cane deterioration between whole cane and burnt cane and to find a criterion to gauge cane deterioration. Those studies showed that ethanol was a good criterion in burnt cane, but not in green cane. As cane is no longer burnt in Reunion Island, deterioration trials undertaken since 1995 have dealt only with green cane. Decreases in weight, sucrose content and purity meant that growers lost about €1/ton of cane per day from post-harvest delays.

As chemical inversion is not the only evolution during deterioration, biochemical measurements were undertaken in 2005 and 2007. In 2005, aconitic acid ratio appeared as a good deterioration criterion. In 2007, a preliminary trial was carried out to find other deterioration criteria using chromatography (HPIC and HPLC). Organic acids, polyols, and amino acids were measured. Of particular interest was 1-kestose, which increased linearly with post-harvest delays. Results showed also that citrate, alanine, proline, cysteine, isoleucine, and leucine (amino acid) correlated well with the post-harvest delay.

NIR evaluation of the post harvest deterioration of sugarcane quality (M. Ueno, E. Taira, Y. Kawamitsu, K. Kikuchi and Y. Komiya)

All of the sugarcane is harvested green, because burnt cane is not accepted by the mills in Japan. The trash is transported with the cane and separated at the factory. About 60% of the sugarcane is harvested manually. Mechanical harvesters included small machines that load billets into bags on the back of the harvester through to large machines that load directly into trucks. Manual harvesting requires a lot of labour, and is hard work. One to three weeks is required from harvesting to loading the transport truck. Therefore, deterioration occurred in the duration resulting in sugar losses. These deteriorated canes affect the milling process and lower the efficiency of the mill.

In order to measure the quality of sugarcane for payment, a 5 kg sample of cane is collected by the core sampler from every vehicle at the entrance of each factory. These samples are fibrated and near infrared spectrometer (NIR) is used to measure the pol in cane (PIC) as a quality index. If the mill staff can quickly and easily know the degree of deterioration, the information becomes very useful for process control. An NIR calibration equation to measure the ethanol content was investigated as an index of deterioration of cane. VIS/NIR absorbance spectra (570 to 1848 nm) were measured using an NIR instrument (Foss InfraXact), and the calibration equation for ethanol was developed by PLS regression analysis. As a result of PLS regression, the values of R square (r^2), standard error of calibration (SEC), and standard error of cross validation (SECV) were 0.908, 0.09 %, and 0.11 %, respectively. The developed calibration equation successfully measured the ethanol concentration of deteriorated cane with simultaneous measurement of PIC. Ethanol concentration was examined by the developed calibration equation after 0, 21, 28 and 36 days after harvesting. Although ethanol was not detected from fresh cane, the ethanol content increased dramatically as the delay increased. Ethanol content of all sugarcane samples of 11 sugar mills in Okinawa Prefecture were calculated by the developed calibration equation. The 5 % of all samples showed more than 1 % ethanol content. It was concluded that the NIR method gave information of the sugarcane deterioration to support the operation of all sugar mills in Okinawa without any chemicals or apparatus.

Session 2 – Mill de-trashing equipment: Design, operation, optimisation

The development of a prototype factory based trash separation plant (Phil Hobson. Presented by Rod Steindl)

Several sugarcane industries are actively seeking an efficient way of bringing the biomass to the factory to increase the co-generation potential. As well, some countries have or are about to ban the burning of cane. This has increased the interest in trash separation plants located either at the factory or in centralised locations closer to the cane supply areas. This presentation discussed investigations by SRI to separate the trash at the factory.

Trash left in the field after harvest constitutes a large, currently untapped source of available biomass. Harvesting the whole cane plant and subsequently separating the trash from the cane stalk in the cane supply entering the factory could potentially double the amount of fuel available for power generation. The Queensland Treasury (Office of Energy), Stanwell Corporation Ltd, and the NSW Sugar Milling Co-operative funded the development by SRI of a commercial scale prototype cane cleaning plant. Funding by the Australian Greenhouse Office assisted with the installation of a fully commercial cane cleaning plant at Condong Mill. Preliminary trials carried out at SRI in 2000 provided much of the basic information for the design of the prototype cleaning plant. Construction at Condong Mill of the prototype trash separation plant was completed by, and initial commissioning began, in early December 2000. Extensive testing and further development of the plant was continued through 2001. The performance testing program showed that the plant was able to achieve high levels of trash separation at low levels of cane loss (less than 1 %), at commercial pour rates. Trials with an industry standard shredder indicated that the shredder could reduce the trash to approximate bagasse like consistency, but with a power requirement of the order of 12 kW/t of trash per hour. Conventional cyclone technology was shown to remove at least 99 % of the air-borne trash which flowed from the cleaning chamber.

Cane field residues as supplementary boiler fuel (Kassiap Deepchand and A.F. Lau)

Cane field residues (CFR) consist of the dry cane trash and the green leaves left in the field after harvest and last for around six months of the year (June to Nov/Dec). The CFR confers a certain number of agronomic advantages such as soil moisture conservation in dry areas, control of soil erosion and maintenance of soil organic matter. But it also imparts a number of disadvantages in that it harbours pests and affects cane re-growth especially in areas with high rainfall. In an original approach, investment was made in a dry cane cleaning plant with a capacity of 150 tonnes of whole cane per hour and operated next to a sugar factory. The concept was to reduce sugar loss in bagasse and minimize sugar manufacture difficulties due to the CFR adhering/brought together with cane while at the same time targeting the long term additional CFR recovery to increase fuel availability for power plants and thus displace coal. Difficulties were encountered in continuous operation of the plant due to a lack of a constant flow of cane and of an inefficient separation of the trash from the long cane. Subsequently some modifications were made to the plant but it could not run beyond 90 t/h, although an improvement in the separation process was noted.

An alternative approach of using CFR as an additional fuel to bagasse is being looked into and the objective is to increase and extend electricity generation period from these resources by displacing coal. The total amount of CFR (which normally contains around 25 % moisture depending on climatic conditions prevailing at harvest and in the subsequent days) is around 15 t/ha. The project aims at collecting up to 50 % of the CFR from the fields under ratoon crop and almost all the CFR from fields which are to be replanted after 7-8 year crop cycle. Whereas equipment for collection (windrowing and baling – square or cylindrical) and transport are available for industrial applications, those for debaling/shredding have still to be identified or developed for such applications. The emphasis on current R&D has thus been focused on this particular aspect. Analysis of naturally dried CFR has revealed that it has a moisture content varying between 9 and 11 %. Its calorific value at 10 % moisture is around 15 000 kJ/kg. Industrial scale trials using existing conventional mills have shown that such naturally dried CFR can conveniently be burnt in existing boilers. However in view of the fact that the naturally dried CFR has a relatively higher ash content (8 %) compared to bagasse (2.5 %) it is proposed that it will, after preparation, be mixed with bagasse in a proportion of up to 25 %.

Preliminary estimates indicate that if 30 % of the CFR is collected, prepared and mixed with bagasse from an annual cane production of 5.0 million tonnes, it can potentially generate 250 GWh of electricity. In so doing this will replace 150 000 t of coal and avoid the generation of 400 000 t of CO_2 and 30 000 t of coal ash. In monetary terms, the foreign exchange saved will be US$30 million assuming a coal price of US$200/t as projected for the near future.

Session 3 – Effects of trash on factory operations

Ledesma's green cane project (Mario Rostagno, Carlos Bada, Federico Knauff, Miguel Ullivarri, Juan Carlos Mirande and Rodolfo Dofonzo. Presented by Rod Steindl)

Ledesma, a cane sugar factory in Argentina, has seen a significant increase in mechanised harvesting of cane in recent years. In 2007, 85 % of the cane was harvested mechanically. The progression to mechanised harvesting has seen the proportion of green cane delivered to the factory increase from 11 % of the crop in 2002 to more than 50 % in 2005. The proportion of green cane has remained static in the following years. As part of their effort to maintain factory efficiency and product quality, factory staff has undertaken a number of investigations to quantify the effects of the increased proportion of green cane in the raw sugar factory, refinery, distillery and on their energy production. During season 2005, some trials were undertaken to determine the green cane effect on milling capacity, sugar losses and bagasse moisture. The results can be summarised as follows:

- The final bagasse moisture increased by 7.3 %;
- There was an increased frequency in chute blockages along the milling tandem due to the extra trash;
- The pol loss in bagasse increased from 0.64 % to 0.70 %;
- The throughput capacity of the milling tandems decreased by 7 %;
- Although the molasses % cane remained relatively steady at about 3.66, the pol loss in molasses increased

by 8%;

· The raw sugar colour increased by 10 %; and

· Because of the higher starch content of the trash, the consumption of α-amylase increased from 40 kg/day to 120 kg/day.

In the refinery, the consumption of chemicals such as decolorant, phosphoric acid and filter aid increased significantly. In the distillery, the total production of ethanol increased by 5.8 % as a result of the higher sugar content in the molasses. However, the efficiency decreased to 79 % because of the problems associated with the higher ash levels in the fermentation broth. The additional bagasse for combustion allowed the factory to reduce its consumption of supplementary fuel (natural gas).

New laws in São Paulo State and a new agreement between the State and the mills have started a green revolution in the Brazil sugarcane business. By 2014, the cane fields where the harvesters will be able to operate must be harvested as green cane. By 2017, all the cane fields will be harvested as green cane and cane fires will be eliminated.

This green revolution which begins in the fields goes also to the mills. The crop of green cane has a strong impact in the agriculture and industry areas. The challenges for the agricultural sector will include:

· Varieties that withstand the impact of cutter blades on harvesters;
· Effects of trash blanketing on ratooning ability and pest activity;
· Increasing the row spacing to 1.5 m;

· Changes to farm implements to better cultivate the soil and apply fertiliser through the trash blanket; and
· Adoption of 100 % mechanical harvesting.

The impact on the factory processes will include:

· Increased impurity loading from the higher extraneous matter in the cane supply;
· Reduced milling throughput;
· Increased dirt loading in the bagasse going to the boilers;
· Potential for lower sugar quality;
· Higher costs for maintenance and chemicals; and
· Greater sugar losses in the mud and bagasse.

The option being favoured is to transport the cane and trash to the factory and separate the trash through dry cleaning plants. The cleaning plant is based on pneumatic separation of the trash followed by cleaning of the trash to remove soil and then shredding of the trash. However it was recognised that the cane cleaning technology was only at the beginning.

The two advantages of the trash supply are the increased biomass for cogeneration and as a feedstock for second generation fuels.

Clarification properties of stalk and trash tissues from U.S. sugarcane varieties (Gillian Eggleston and Michael Grisham. Presented by Barbara Muir)

The effect of the U.S. change from burnt to unburnt or “green” sugarcane harvesting on processing has not been fully characterized. Furthermore, the current trend to investigate sugarcane trash (leaves and tops) as biomass for the production of bio-products has made the processing quality of trash more important.

Sugarcane whole-stalks were harvested from the first ratoon crop of five commercial sugarcane varieties (LCP 85-384, HoCP 96-540, L 97-128, L 99-226, and L 99-233) with varying yield and harvest characteristics. Four replicated tissue samples of brown, dry leaves (BL), green leaves (GL), growing point region (GPR) or apical internodes, and stalk (S), were separated. Juice from each tissue type was clarified following a hot lime clarification process (operated by most U.S. factories). Only GPR and GL juices foamed on heating and followed the normal settling behaviour of global sugarcane juice, although GL was markedly slower than GPR. GPR juice was critical to clarification. S juice tended to “thin out” rather than follow normal settling, and much more upward motion of flocs was observed. Most varietal variation in settling and clarified juice characteristics occurred for GL.

The quality and not the quantity of impurities in the different tissues affected the volume of mud produced. Tissue juice brix (% dissolved solids) had no relationship with the amount of mud produced. After 30 min settling, mud volume per unit tissue juice brix varied markedly among the tissues (S=1.09, BL=11.3, GPR=3.0, and GL=3.1 mL/brix). Heat transfer properties of tissue juice and CJ were described. Clarification was unable to remove all BL cellulosic particles. GL and BL increased color, turbidity and suspended particles in the clarified juice with BL worse than GL. This would cause difficulty downstream in the factory boiling house and make the future attainment of Very Low Color (VLC) raw sugar more difficult. Strategies to reduce the delivery of green and, especially, brown leaves to the factory need to be urgently identified and implemented.

The effects of extraneous matter on factory operations (Rod Steindl)

The author provided a summary of several separate investigations that considered the effects of extraneous matter (tops, trash, roots and soil) on the composition of mixed juice and the downstream processes. The objectives in each case were to quantify the effects of green cane harvesting with increased levels of trash on factory throughput and sugar quality so that economic models could be developed. Although different methodologies were used, the outcomes were similar.

In the first investigation, estimates were determined for the composition of a cane stalk by separating the stalk into clean cane, trash, tops and top leaf components. The averaged values for a number of varieties were:

- Clean cane 81.2 %;
- Trash 7.1 %;
- Tops 6.1 %; and
- Top leaf 5.6 %.

It must be accepted that these quantities depend on many factors and can only be used as a guide. In a series of laboratory trials, composite samples of clean cane and added tops and trash were milled and samples of mixed juice and clarified juice were analysed. As expected, the samples of ‘dirty’ cane had higher levels of non-sugars, ash and colour. In another series of trials conducted at a factory, paired tests of dirty and clean cane were milled and the factory process streams were analysed to provide data to determine the economic impact of the trash content. Trash levels were up to 15 % of the cane supply. Some of the statistically significant effects included reductions in the sugar content for cane payment, crushing rates and syrup quality and an increase in the production of final molasses.

In a further series of factory trials, the harvesting operations were organised into clean and dirty cane periods of up to six days each and the effects measured in the factory operations. The main effects measured were statistically significant increases in the starch, phosphorus and mud solids content of juice from dirty cane. The filter cake % cane increased by up to 37 % and the pol loss in cake % pol in cane increased by 16 %. The A massecuite quantity dropped marginally while the B massecuite % cane increased by 7 % and the final molasses % cane increased by about 20 %.

Interestingly, there was no statistically significant difference in the quality of the sugar produced. It should be noted that the factories involved in these trials only produced raw sugar with a typical pol of 98.8 to 99.0.

Improving the exhaustion of C-sugar magma through on-line measurements of the crystal conten[t] (Teddy Libelle, Michael Benne, Bridgitte Grondin-Perez and Jean-Pierre Chabriat)

On-line measurements and supervision tools become essential tools when trying to optimize the boiling crystallization process and to limit the impact of the variability of incoming feed streams. This study presents the on-line measurement of the crystal contents of the sugar magma (massecuite). The measurement technique was simply based on the comparison between the brix of the massecuite (Bx_{MC}) and the brix of the mother liquor (Bx_{ML}). Thus, its implementation was simplified due to the fact that both these types of sensors are often present at industrial sites. The complete mass of crystals in the C-sugar magma, C_m, depends on the crystal contents. From industrial measurements collected at Bois Rouge sugar mill (La Reunion), we showed that C_m can either increase, decrease or be stable during a boiling crystallization. When analyzing the evolution of C_m , we can propose some methods to optimize the exhaustion of C-sugar magma.

Impact of trash and high fibre cane on sugar recovery: CERF preliminary results (Laurent Corcodel, Camille Roussel, Eslyne Lemoine, Audrey Thong Chane and Laurent Barau)

The effect of cane composition on sugar processing has been discussed worldwide. With the development of high fibre cane, an investigation into the high fibre effects on sugar processing was considered to be necessary. High fibre elite variety was at the end of the CERF breeding program and the effect of this variety on the sugar milling processes had to be investigated. Firstly, the theoretical impact in sugar plants (sugar losses and milling capacity) was described and secondly, laboratory extractability trials were done. Those experiments were conducted jointly between the CERF breeding department and the sugar processing department.

Different CERF cane varieties were pressed at different pressures (between 50 to 250 bar) by a hydraulic press to calculate their extraction rate. Results showed significant differences between those varieties which could be explained by their pith / fibre ratio. Those indicators will be studied further with the aim to integrate them into the CERF breeding program to select high fibre clones with a good milling ability.

Factory trials to determine the effect of green trash on downstream processing (Barbara Muir, Gillian Eggleston and Bryan Barker)

There is a worldwide shift to green cane from burnt cane harvesting. In South Africa 89% of the cane is still burnt and most of it is hand-cut. Certain areas are changing to green cane harvesting due to environmental pressures, increasing labour costs and the current trend to investigate sugarcane trash as biomass for the production of bio-products. This paper reports on the effects of harvesting green billeted and/or whole-stalk sugarcane compared to burnt billeted and/or whole-stalk sugarcane at three South African mills that operate either a tandem mill or diffusers. Sufficient cane of each treatment was harvested and processed at each mill to purge the extraction plant of other cane. Trash tissues, shredded cane, juice and bagasse samples in the front end were collected and analysed. A bulk sample of mixed juice was then transported to the SMRI in Durban and further processed in the SMRI pilot plant to clarified juice, syrup, "A" massecuites, molasses and raw sugar.

Some of the differences reported include:

- There was a six to ten fold increase in trash for mechanically harvested burnt and green cane over manually cut burnt cane;

- The cane and juice purities decreased with increasing trash content;

- RS/ash ratios in juice, syrup, massecuite and A molasses increased from burnt billets to green billets in some cases or were similar in other cases; and

- At one factory there was a slight increase (~10 %) in affined sugar colour while the samples from another factory showed a decrease of ~22 % in affined sugar colour from burnt to green cane.

Session 4 – Whole crops

Whole crop harvesting and processing (Michael Saska and Nicolas Gil Zapata. Presented by Rod Steindl)

This report presents results from tests done in 2006 in a Louisiana factory with harvesting and processing of the whole crop or "complete cane" (stalk plus trash). The objective was to determine if there was any benefit if the whole crop was harvested green and transported to the factory and then to process the cane with or without the extraneous matter.

For complete cane (CC), the mill harvested green cane with the extractor turned off on the harvester, and the normal green cane (NC) was harvested with the fans on as usual. On December 15, 2006, 367 tons of CC were processed in about 4.5 hours at an average of 82 t/h. Sampling of normal cane as a reference could not be done on the same day, because cane delivery problems delayed the start of processing the cane. Sampling of the normal cane (NC) was therefore done on December 20 for a total of seven hours. The mill operation was interrupted because of boiler problems for about 2 hours, about two hours into the test. Based on the information regarding the code and weight of the wagons that arrived at the mill, an estimated 974 tons of cane were processed within the period of the test, for an average rate of 139 t/h. The code, weight, and core lab analysis of the cane wagons delivered during each test were averaged and compared with the analysis of prepared cane taken at regular intervals during the test. Because of the time difference between the two tests, the variations reported here between NC and CC may be due in part to other factors than the trash content, e.g. cane and processing conditions, etc. Freezing temperatures at the start of December affected the cane quality, and the four day delay between the tests probably resulted in further deterioration of the freeze damaged cane and skewed the comparison between complete and normal cane.

No problems were noted when processing whole green cane although the mill operated well below capacity at the time of both tests for other reasons.

An Excel model was set up to estimate the economic viability of harvesting, transporting and processing cane with a variable amount of extraneous matter, including the case of whole crop processing, with co-generation with the extra bagasse. Other factors included in the model were the cane composition, sugar content and price, extra cane yield above the "normal cane" case, the power generation efficiency and sale price, and harvester fuel requirements, with the extractor fans either on or off. The field-to-factory distance and the fuel cost were the decisive factors whether whole-crop harvesting could be profitable. The model also shows the critical effect of pol in bagasse, when milling cane with increased amounts of extraneous matter.

***The experiences gained from whole crop milling (David Moller*)**

Whole cane milling (WCM) has been undertaken at two of the factories in the NSW Sugar Milling Co-operative to supply enough biomass to power a co-generation boiler of 30 MW during the six months of the non-crushing season. Whole crop milling is the supply of the whole crop (cane billets, leaves and trash) to the factory for processing through the milling tandem.

The initial plan was to transport the whole crop to the factory and then separate the leaf and trash material from the billets prior to milling. However the prohibitive capital costs were such that this proposal was later rejected. After a short trial it was decided that all the material would be processed through the milling train. This method of processing was trailed for three weeks during the 2007 crushing season before the factory returned to burnt cane processing.

In the 2008 crushing season the factory has been processing whole cane for the first eight weeks. Due to an extreme frost in the 2007 growing period, the cane supply during this eight week period has included approximately 30 % of frost affected cane. Assessing the effects of processing the whole crop has been complicated by the inclusion of this frosted cane. Processing whole cane has impacted on every part of the factory. Changes have been made in the feeding, milling and boiler stations, but no changes have been made to the clarification, evaporation, pan or fugal stages until the effects of whole crop processing can be better determined. The observed effects in the factory include:

- Cane feeding - lower bulk density, trash binds together more than billets alone;
- Milling – the fibre rate increased from 40 t/h to 77 t/h and greater variability;
- New cane payment formula needed;
- NIR system needed to measure fibre in each sample for cane payment;
- Clarification – lower settling rates, additional phosphate not effective in assisting clarification, and higher turbidity of clarified juice;
- Evaporation – poor HTC, faster scaling rate and scale harder to remove;
- Pan boiling – pans operating at only 60-70 %, poor circulation (it is possible that frost affected cane contributed to this);
- Sugar quality – higher colour in molasses layer, no real impact on refinery operations; and
- Recovery – pol recovery dropped by 9 %, bagasse loss increased by 4 %, and molasses loss increased by 5 %.

Composition of non-stalk components of sugarcane and field residues and their effects on composition of mixed juice (Michael Saska and Nicolas Gil Zapata. Presented by Rod Steindl)

This presentation summarised four independent investigations, carried out at different times and following somewhat differing methodologies. However, the objective was the same: add to the understanding of the composition of the various components of the sugarcane plant, with a focus on the effects of non-stalk components on the composition of the mixed juice, and to some degree on the potential new industrial uses for field residues after cane harvest, or after separation from stalk billets.

Specifically, the various facets of the work included the 2002 tests in Louisiana of the cane composition during the growth and harvest period, a one-time sampling and determination of composition in 2003 of non-sugars in a major sugar cane variety grown in Colombia, determination of the effects of a commonly used chemical ripener on non-sugar composition of the cane in 2005, and a four year (2002 to 2006) test to determine the chemical composition of both the biomass remaining in the field after harvest and the juice extracted from these field residues using laboratory milling equipment.

It is well known that the non-sucrose content of the juice (e.g. ash, reducing sugars, starch, and colorants) extracted from cane trash is higher when expressed on the dry solids basis, than in juice from clean stalk, and therefore the purity of the industrial mixed juice is lower than it would be if only clean stalks were milled. However, even though the present data are far from complete and may have been affected by various experimental factors, it is quite apparent that the ratio of reducing sugars over the sum of concentrations of potassium and aconitate (the two major contributors to ash in cane juices) tends to be larger in juices from tops and leaves, than in the juice in the clean billets. This would seem to indicate that cane trash (tops and leaves) in commercial cane supplies may increase the overall RS/Ash ratio and therefore lower the target molasses purity.

Session 5 – Forum review and discussion

Processing of green cane through sulphitation process (J.J. Bhagat)

The author provided an overview of the Indian sugar industry that included such topics as:

- The importance of the sugar industry to the national economy;
- Value-added products that are generated from the 260 Mt crop of sugarcane;
- The major constraints being faced by the industry; and
- Strategies being adopted to improve productivity including new varieties, sustainable farming systems, extensive upgrades and modernisation of factories and energy conservation, optimisation and power export.

Indian factories produce a bold grain sugar with a very low colour of 50-150 IU typically. The process includes double sulphitation and usually syrup clarification. Trash and other extraneous matter that would cause an increase in the sugar colour is avoided. Mixed juice colour can vary from about 14,000 IU for clean cane up to more than 30,000 IU for cane plus tops and trash.

Some of the disadvantages of the high extraneous matter present in the cane supply when all the biomass is delivered to the factory include:

- Reductions in grinding capacity and sucrose extraction;
- Mill efficiency reduces by 5 % and milling capacity by 10-15 %;
- Lower quality clear juice (increases in turbidity, residual CaO and PO_4, lower purity, and additional consumption of chemicals);
- The leaf matter introduces an extra high loading of colorants, ash and RS;
- Increases the purity of final molasses; and
- The net benefit to a factory processing 0.5 Mt of clean cane rather than cane with extra trash was estimated at US$1.3 M (without a co-generation facility).

Literature review of burnt / green cane effects on factory processing (Laurent Corcodel)

A brief summary of some papers to past ISSCT and SASTA conferences was presented. The summary highlighted the difficulties confronting current technologists when trying to reconcile the range of previous investigations because the focus of individual investigations is usually different and this makes comparisons difficult.

Poster papers

Technological measurement of sugarcane quality: Sugarcane variety extractability trials (Lauren Corcodel, E. Lemoine, G. Chabot, C. Soundron and Camille Roussel)

Cane constitution effect on sugar processing has been discussed worldwide. With the development of high fibre cane, investigations of fibre effect on sugar processing are necessary. High fibre elite is at the end of the CERF breeding program and before industrial plantation the effect of this variety on sugar processing has to be forecast. Firstly, the theoretical impact in sugar plants (sugar losses and milling capacity) is described and secondly, laboratory extractability trials are done. Those experiments are conducted between CERF breeding department and sugar processing department.

Different CERF cane varieties are pressed at different pressure (between 50 to 250 bar) by a hydraulic press, in order to calculate their extraction rate. Results show significant differences between those varieties which could be explained by their pith / fibre ratio. Those two indicators will be studied further with the aim to integrate them into the CERF breeding program to select high fibre clones with a good milling ability.

A pilot plant developed in house for yield and quality increasing of sugar crystallisation (Cédric Damour, Patrick Jeanty, Yannis Hoarau, Michel Benne, Brigitte Grondin-Perez and Jean-Pierre Chabriat)

Crystallization process is the key stage of sugar production. Increasing demands for yield and quality created a need for optimization and control of the process. To reduce the influence of variations in cane quality and changes in agro-climatic conditions on the process efficiency, it is essential to perform manufacturing protocols and to develop predictive control strategies. These steps require a series of experiments to reach the best trade-off. In an industrial context, each experiment could damage or stop the production. Development of a pilot offers the opportunity to run many tests and experiments in the same experimental conditions but at a reduced scale. This poster describes a 1:1 000 scale pilot plant for sugar crystallisation developed in house at the Laboratory of energetic electronic and processes (LE2P) at University of La Reunion. This pilot plant should allow us to test and implant some new advanced control methods that have not been tested *in situ*. Results obtained on C-sugar crystallisation and experimental design of the seeding point study justify the scientific interest in the pilot plant development.

Site visits

Casernes cane delivery and transfer station

Cane is delivered to one of the 11 transfer stations by the farmer, usually as single trailer loads towed by a tractor. A core sample is taken from each delivery to the station on arrival. The cane is then transferred to a stockpile if whole stick or transferred directly to a waiting 20 t trailer if billet cane. The core sample is then sub sampled into a 5 kg lot and analysed at the site. The subsample is shredded and a 1 kg aliquote is placed into a press at 200 bar for 90 s to provide a juice sample for pol and brix. The fibre is calculated from a regression equation and the weight of the press plug.

Le Gol Mill

Some of the factory data are:

- Factory stops every Sunday for maintenance including hammer change and evaporator boil using 28 % caustic for 10 h where caustic is recirculated around individual vessels;
- 4 MW electric drive on shredder, Hagglunds hydraulic drive on #1 mill and electric drives on #2, #3, #4 and #5 mills;
- 6 effect evaporation: #1 – semi-Kestner, #2 – falling film with 12 m tubes, #3, #4, #5 and #6 – Roberts but with floating calandrias;
- Extensive vapour bleeding: V6, V5 and V4 to primary heaters; V3 and V2 to secondary heaters; V2, V1 and LP to CJ heating to 112 °C in Barriquand heaters; V2 to pans; V3 to CVP;
- LP steam is about 100 kPa;
- Condensate from #2 effect used for MJ heating in Barriquand platular heater;
- CVP for A and C massecuites;
- A massecuite split between continuous and batch fugals;
- Raw sugar pol is 98-98.5 and special DC sugar pol is about 99.0;
- A high level of automation and centralised process control;
- Co-generation plant separated from factory;

- 3 x 125 t/h plus 1 x 114 t/h boilers on both bagasse and coal;
- 2 x 30 MW and 1 x 50 MW sets for cogeneration; and
- 150 kPa vapour in closed loop for 'pre-evaporator' to generate 100 kPa LP steam supply for factory.

Bois Rouge Mill

This factory was similar to Le Gol Mill but with the following exceptions:

- The initial mill is a 2 roll mill with electric drives and used as a 'pre-extractor' before a diffuser with the following objectives: (i) 75 % extraction, (ii) higher crushing rate, (iii) reduce imbibition rate, and (iv) reduce pol loss in bagasse.
- The diffuser has typical imbibition rates of 280-340 % on fibre;
- A belt press filter has been installed to assist with mud filtration;
- Molasses % cane is about 3.5; and
- A refinery is attached to the back-end of the factory.

Concluding forum

The forum discussed the use of the word 'trash' and what it represented. This arose because there were variations between research groups on what constituted trash and what was extraneous matter. The consensus within the workshop delegates was as follows:

- Trash – the fibrous non stalk material from the cane plant. This includes all leaf matter and the growing point of the cane stalk.

- Extraneous matter – everything left in the field or delivered to the factory that is not processable stalk.

There was general agreement that the best practice for factories to produce good quality sugar was to process clean cane. However it was also recognised that future economic conditions will dictate that factories will need to maximise the amount of biomass brought into the factory for energy and bio-commodities. Individual condition will define the most economical and sustainable balance for each organisation.

There was some discussion about future research needs. The papers delivered to the workshop identified a range of problems that factories have faced when processing cane with high levels of trash. The forum concluded that more research should be directed towards the following issues:

- An economical trash separation system to handle a cane supply with high levels of trash;

- Identify suitable chemicals that would assist to alleviate the problems associated with the additional impurities in trash when processing a 'whole of crop' cane supply through the factory; and

- Consider the idea of a joint workshop for both agricultural scientists and factory engineers to consider the operating constraints of each sector of the industry and to consider options that benefit the operations of both the field and the factory.

Acknowledgements

The contributions of CERF for hosting the workshop and the organisational efforts of the staff of CERF

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Sucrière de La Réunion,

Sucrerie de Bois Rouge,

SFSR (Sugar Producers Associations of Reunion Island)

ARTAS (Association of Sugarcane Technologists of Reunion Island)

REI (Réalisations Electroniques & Informatiques)

Departément de la Réunion

IRT (Ile de la Réunion Tourisme)

Appendix A Workshop Program

Sunday, October 19, 2008	
	Registration – Hotel Mecure Créolia
17:00	Depart for CERF
17:30	Visit to CERF - Visit of facilities (greenhouses and laboratories) - CERF presentation
18:30	Opening introduction – Jean-Françcois Moser and Bernard Siegmund
19:00	Welcoming cocktail – Sponsored by ARTAS
21:30	Depart for hotel
Monday, October 20, 2008	
07:00	Depart for site visits
08:30	Sugarcane delivery and sampling – Casernes Delivering Station
10:30	Coffee break – Le Gol Mill
11:00	Visit to Le Gol Mill
12:30	Lunch – sponsored by Le Gol Mill
14:30	Visit to co-generation plant – Centrale Thermique de Gol
15:30	Depart for hotel - tourist tour via volcano slides
Tuesday, October 21, 2008	
08:30	Introduction – Rod Steindl (Chairman)
08:50	The sugarcane industry in Reunion - Jean-Françcois Moser
09:20	A review of milling season in Reunion since 1984 – Laurent Corcodel
10:00	Coffee break
	Session 1 – Sugar losses in storage: green cane versus burnt cane
10:30	Determination of sucrose loss in storage of green billet cane – Michael Saska
11:10	Cane deterioration: Comparison green cane vs burnt cane / Research of green cane deterioration indicator – Camille Roussel
11:50	NIR evaluation of the post harvest deterioration of sugarcane – Masami Ueno and Koh Kikuchi
12:30	Lunch
	Session 2 – Mill de-trashing equipment: Design, operation, optimisation
14:00	The development of a prototype factory-based trash separation plant – Rod Steindl

14:40	Cane field residues as supplementary boiler fuel – Kassiap Deepchand
15:20	Coffee break
16:00	Depart for Bois Rouge Mill
16:30	Visit to Bois Rouge Mill and Savanna Distillery
19:00	Dinner – sponsored by Bois Rouge Mill
Wednesday, October 22, 2008	
	Session 3 – Effects of trash on factory operations
08:30	Ledesma's green cane project – Mario Rostagnos
09:10	Green revolution in the Brazil sugarcane business – Jean-Claude Religieux
09:50	Coffee break
10:20	Clarification properties of stalk and trash tissues from U.S. sugarcane varieties – Gillian Eggleston by Barbara Muir
11:00	The effects of extraneous matter on factory operations – Rod Steindl
11:40	Improving the exhaustion of C-sugar magma through online measurements of the crystal content – Teddy Libelle
12:30	Lunch
	Session 4 – Whole crops
14:00	Impact of trash and high fibre cane on sugar recovery: CERF preliminary results and future project – Laurent Corcodel
14:40	Factory trials to determine the effect of green trash on downstream processing – Barbara Muir
15:20	Coffee break
16:00	Whole cane processing – Michael Saska
16:40	The experiences gained from whole crop milling – David Moller
17:20	Composition of non-stalk components of sugarcane and field residues and their effects on composition of mixed juice – Michael Saska
18:30	Depart for Gala Dinner
19:00	Gala dinner – Villa du Département – Saint Denis
	Thursday, 23 October 2008
	Session 5 – Final forum discussion
08 :30	The Indian experience – J.J. Bhagat
09:20	Literature review of burnt/green cane effects on factory processing - Laurent Corcodel
10:00	Coffee break
10:30	Forum discussion – Rod Steindl and Laurent Corcodel
11:30	Close

Appendix B List of delegates

Delegate name	Company	Country	E-mail
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Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil

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Abbreviations		Units	
BEN	Balanço Energético Nacional (National Energy Balance)	**cv**	Metric horsepower (1cv = 0,7355 kW)
CMA	Controle Mútuo Agrícola (Agricultural Benchmark Program)	**GJ**	Gigajoule
CMI	Controle Mútuo Industrial (Industrial Benchmark Program)	**ha**	Hectare
CTC	Centro de Tecnologia Copersucar (Copersucar Technology Center)	**h**	Hour
C-S	Center-South region (Brazil)	**kcal**	Kilocalorie
IPCC	Intergovernmental Panel on Climate Change	**kg**	Kilogram
NIPE	Núcleo Interdisciplinar de Planejamento Energético – UNICAMP (Interdisciplinary Nucleus of Energy Planning – UNICAMP)	**kWh**	Kilowatt hour
PAMPA	Programa de Acompanhamento Mensal de Performance Agrícola (Agricultural Monthly Performance Follow up Program)	**l**	Liter
SP	São Paulo State	**MJ**	Megajoule
UNICAMP	Universidade de Campinas (University of Campinas)	**Pol**	Polarization (sucrose content)
GHG	Greenhouse gases	**t**	Metric ton
GWP	Global warming potential	**TC**	Metric ton of cane
HHV	Higher heating value	**TCH**	Metric ton of cane per hour
LHV	Lower heating value		
RS	Reducing sugars		

Chemical compounds

CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
H_2SO_4	Sulfuric acid
K_2O	Potassium fertilizers
N	Nitrogen
NH_4	Ammonium radical
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
P_2O_5	Phosphate fertilizers

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One of the main tasks of the Secretariat of the Environment of the State of São Paulo is the improvement of air quality in the State's urban areas. The addition to gasoline of 20-25% of ethanol is an important contribution to this end.

The substitution of gasoline by alcohol has another important consequence: the reduction of greenhouse gas emission (principally CO_2) provided that in the production of the ethanol, the fossil fuel contribution is minimized. This contribution stems from the energy needed to produce the raw materials used in farming and in the industrial process (fertilizers, lime, sulfuric acid, lubricants etc.) as well as electricity and fuels acquired by the producer (direct energy consumptions).

To consider ethanol as a renewable (or an "almost renewable") fuel, it is essential that the production fossil fuels' contribution is small, just as with the emission of greenhouse gases not directly associated with the use of fossil fuels in the entire cycle of production and usage.

Along the years evaluations of this contribution have been made by various groups of specialists, with highly encouraging results.

With the increase in the numbers of ethanol production units and with the advances of technology, the Secretariat of the Environment felt it to be necessary to seek from University of Campinas (UNICAMP) an updating of these evaluations. This update was carried out with data obtained also from the Copersucar Technology Center (CTC/Copersucar). This report is the result of this work.

Prof. José Goldemberg

Secretary of the Environment

Sugar cane energy products, ethanol and bagasse, have made a significant contribution to the reduction of greenhouse gas (GHG) emissions in Brazil, substituting fossil fuels, gasoline and fuel oil, respectively.

However, fossil fuels are used in the operations of planting, harvesting, transportation and processing of the sugar cane, resulting in GHG emissions. Energy and GHG balances are required to evaluate the net effects during the complete well-to-wheel cycle of ethanol, i.e. ethanol production from sugar cane and its use as fuel in the transport sector. To facilitate the comparison with other studies, the GHG data are presented as CO_2 equivalent emissions (CO_2eq.).

In the energy balance three levels of energy flows are considered, making it easier to compare with other energy balances.

Level 1 – Only the direct consumption of external fuels and electricity (direct energy inputs) is considered.

Level 2 – This is the additional energy required for the production of chemicals and materials used in the agricultural and industrial processes (fertilizers, lime, seeds, herbicides, sulfuric acid, lubricants, etc.).

Level 3 – This is the additional energy necessary for the manufacture, construction and maintenance of equipment and buildings.

Due to the diversity of the database for the technical parameters related to the sugar cane and ethanol production in Brazil, a limited but reliable database was prepared using the information available at Copersucar. This database has the advantage of traceability and consistent references.

Two cases have been considered in the evaluation of energy flows: Scenario 1 based on the average values of energy and material consumption and Scenario 2 based on the best values being practiced in the sugar cane sector (minimum consumption with the use of the best technology in use in the sector). In both Scenarios the balance is referred to one metric ton of cane (TC).

Under these conditions, the results obtained for energy consumption were: 48,208 kcal/TC and 45,861 kcal/TC in the agricultural sector for Scenarios 1 and 2, respectively, and 11,800 kcal/TC and 9,510 kcal/TC in the industrial sector for Scenarios 1 and 2, respectively. The total energy consumptions for Scenario 1, 60,008 kcal/TC, and Scenario 2, 55,371 kcal/TC, compare very favorably with the total energy production (ethanol and surplus bagasse) of 499,400 kcal/TC and 565,700 kcal/TC, for Scenarios 1 and 2, respectively. The ratios of output energy (renewable) to input energy (fossil) are 8.3 and 10.2, for Scenarios 1 and 2, respectively.

In the GHG balance the emissions have been divided into two groups: emissions derived from the use of non renewable energy (diesel and fuel oil) and emissions from other sources (cane trash burning, fertilizer decomposition).

For the first group the calculated values were 19.2 kg CO_2eq./TC and 17.7 kg CO_2eq./TC for Scenarios 1 and 2, respectively, while the values determined for the second group were 12.2 kg CO_2eq./TC for both Scenarios.

The emissions avoided due to the substitution of ethanol for gasoline and surplus bagasse for fuel oil, deducting the above values, gives a net result of 2.6 and 2.7 t CO_2eq./m^3 anhydrous ethanol and 1.7 and 1.9 t CO_2eq./m^3 of hydrous ethanol, for Scenarios 1 and 2, respectively.

The Brazilian sugar cane agribusiness is an economic activity responsible for 2.2% of GDP, generating an income of over US$ 8 billion and creating approximately one million direct jobs: more than 400,000 in the State of São Paulo alone – the country's largest producer State – as well as fostering the economic development of a large number of municipalities and contributing to the employment of a large number of workers in the rural areas.

The activity has a positive environmental differential that is the efficient production of fuel grade ethanol from sugar cane. The extensive use of fuel ethanol in Brazil, whether as a 25% blend with gasoline (gasohol), or used as a neat fuel in vehicles equipped with dedicated alcohol engines or used in the newly produced flex fuel vehicles, which can operate on neat ethanol, gasohol or any intermediate blend, places Brazil as a leader in carbon emission reduction and Greenhouse Effect mitigation.

The production of ethanol in the 2003/2004 crop season will reach the significant volume of 14.4 billion liters and the Center-South region, which includes São Paulo State, will respond for 89.6% of the total.

In addition to the production of ethanol, the industrial processing of sugar cane generates bagasse, another valuable product. This residue also adds to the industry's positive environmental differential because it has been widely used to replace fossil fuels in the production of industrial heat and electricity in the sugar mills and distilleries thereby boosting the abatement potential of greenhouse gases emission.

The present work is a contribution to a better understanding of the renewable energy value and energy efficiency of this important industrial sector.

Objective

This work presents the life cycle analysis of the GHG emissions in the production and use of ethanol, under the typical conditions found in Brazilian sugar and ethanol mills. It also presents the emissions derived from fossil fuel consumption and those not related to the use of energy.

Data collected in 2002 have been used for the latest update of the analysis of energy consumption in the sugar cane ethanol production at Copersucar mills undertaken in 1985[1], then updated in 1998[2].

The observations made in the first report, especially those concerning the correct definition of the boundaries of the process analysed, remain valid. Some of the parameters defined at that time have been maintained in this report, due to the difficulties found in their updating. However this fact can be considered of little importance since it would have only a very small impact on the energy consumption figures.

The evaluation of the GHG emissions in the production and use of ethanol is also an update and a revision of previous work performed at the Copersucar Technology Center (CTC), whose studies were published in 1992[3] and revised in 1998, with 1996 data[4].

Methodology

The energy flows have been considered in two situations: one (Scenario 1), based on the average values of energy and chemicals' utilizations, and the other (Scenario 2), based on the best existing values (minimum consumption values resulting from the application of the best technology in use by the sector). The use of these scenarios allows not only the characterization of the present situation (Scenario 1) but also the estimation of a situation that may become reality in the medium term (Scenario 2) by the widespread use of good practices already being used in some mills. Technologies that are already developed, or in the process of being developed, but are not used in a significant degree today, have not been considered in this work.

Technologies in the process of gradual introduction, that may have significant impact on the GHG emissions, have been considered at the present degree of utilization. This is the case of mechanically harvested unburned cane, without trash recovery for power generation.

The energy flows have been considered in three levels, to facilitate the comparison with other studies:

Level 1 – Only the direct consumptions of external fuels and electricity (direct energy inputs) are considered.
Level 2 – The energy required for the production of chemicals and materials used in the agricultural and industrial processes (fertilizers, lime, seeds, herbicides, sulfuric acid, lubricants etc.) is added.
Level 3 – The energy necessary for the fabrication, construction and maintenance of equipment and buildings is added.

The parameter values recommended by the Intergovernmental Panel on Climate Change (IPCC)[7] have been used in the GHG emission calculations whenever available.

Database

A complete countrywide database for the sugar cane sector has not yet been fully established, thus the use of a database covering part of the sector but based on reliable and traceable information has been preferred. It is important to point out that this database is representative of the agricultural and industrial practices, especially of the Center-South region, accounting for approximately 85% of the sugar cane production in Brazil.

Under these considerations the following documents have been selected as references for the energy balance of ethanol production in Brazil.

– Copersucar: Agricultural Benchmark Program (26 to 31 mills in the State of São Paulo) – These reports present dozens of performance parameters in the agricultural sector of a group of Copersucar associated mills. They have been prepared for many years, bring monthly and annual averages, and have been fully discussed among the participating mills.
– Copersucar: Industrial Benchmark Program (17 to 22 mills in the State of São Paulo) – These reports present the industrial sector performance parameters (efficiencies, consumption of chemicals etc.) of a selected part of Copersucar member mills. They have been also extensively discussed among the participants, and show the monthly and annual averages.
– Copersucar: Agricultural Monthly Performance Follow up Program (98 mills in the Center-South region) – These reports present the agricultural sector parameters for a larger number of participating mills in the Center-South region. However the traceability of the information and the uniformity of procedures have not the same level of accuracy as in the cases of the two previous sets of documents.

In the cases where weather conditions can have significant impacts on the results (such as the case of sugar cane productivity) the averages for five seasons in sequence (1998/99 to 2002/2003 seasons) have been used. In other cases, the 2001/2002 harvesting season has been used as reference for both agricultural and industrial performance data.

Systems and emission flows definition

To evaluate the GHG emission mitigation in the life cycle of ethanol produced from sugar cane, the concept of "autonomous distillery" has been adopted, meaning that the mill will process the sugar cane to produce ethanol only. In this way the effects of sugar production can be ignored.

The mitigation corresponds to the reduction of GHG emissions obtained by the production and use of ethanol (substituting for gasoline as a fuel). It is, therefore, the difference between the emissions in a situation where no ethanol is produced nor used and a situation with the actual emissions with ethanol: both of which situations reflect Brazilian conditions.

For the life cycle analysis the control volume used included the cane production area, the distillery and the final use of fuel ethanol.

To facilitate the calculations the GHG emissions have been divided into four groups.

Group 1:
Carbon flows associated with the uptake of atmospheric carbon by photosynthesis and its gradual release by oxidation.
1.a Uptake of atmospheric carbon (photosynthesis);
1.b Carbon release during cane field burning, before harvesting (around 80% of tops and leaves are burned with an efficiency of 90%);
1.c Oxidation of unburned residues, in the field;
1.d CO_2 release in the fermentation of sucrose to ethanol;
1.e CO_2 release by the combustion of all bagasse, for power and heat generation, in the boilers of the mills or in other industries boilers (surplus bagasse);
1.f CO_2 release by the combustion of ethanol in automobile engines.

These emission flows can be considered to be nearly neutral, for it is assumed that all fixed carbon is released again within the cycle of sugar cane production and the final use of ethanol and bagasse. An exception is the uptake of part of the carbon in the soil (in past decades the cane fields showed a positive average carbon uptake because land was generally poor in organic matter before being used to grow cane). In this study, due to the difficulties in estimating with a minimum accuracy the level of carbon fixed in the soil, this fraction has been ignored, which results in a conservative assumption.

Thus, the net contribution of the Group 1 carbon flows has been considered as zero which is a common assumption for cycles of biomass production and use.

Group 2:
Carbon flows associated with the use of fossil fuels in the production of all chemicals and inputs used in the agricultural and industrial sectors for the production of sugar cane and ethanol, as well as in the manufacture of equipment, construction of buildings and their maintenance:
2.a CO_2 release due to the use of fossil fuels in the cane fields: tillage, irrigation, harvesting, transportation etc.;
2.b CO_2 release due to the use of fossil fuels in the production of agricultural inputs (seeds, herbicides, pesticides, fertilizers, lime etc.);
2.c CO_2 release due to the use of fossil fuels in the production of agricultural equipment, spare parts and their maintenance;
2.d CO_2 release due to the use of fossil fuel for industrial inputs (lime, sulfuric acid, biocides, lubricants etc.);
2.e CO_2 release due to the use of fossil fuels in the manufacture of equipment, construction of buildings, and their maintenance in the industrial area.

These are negative flows since they contribute to emission increase.

Group 3:
The GHG flows not associated with the use of fossil fuels are mainly N_2O and methane; consideration was given to:
3.a Release of other GHG (non CO_2) in the process of cane field burning;
3.b Release of N_2O from the soil, due to fertilizer decomposition;
3.c Release of other GHG (non CO_2) in the combustion of bagasse in steam boilers;
3.d Release of other GHG (non CO_2) in the combustion of ethanol in engines.

These flows are also negative, that is, they contribute to the increase of GHG emissions.

Group 4:
This group includes what can be called “virtual” flows of GHG emissions; they would take place if, in the absence of ethanol, the fuel demand was met by gasoline and if in the absence of surplus bagasse, fuel oil was used.
These emissions can be characterized as:
4.a GHG avoided emission by substituting ethanol for gasoline;
4.b GHG avoided emission by substituting bagasse for fuel oil in other industrial sectors.

In the analysis that follows, the flows of Groups 2 to 4 will be evaluated; the flows of Group 1 will not be calculated since the net balance is zero. To facilitate the understanding of some simplifying assumptions, it is important to bear in mind that the emissions of Groups 2 and 3 are nearly ten times smaller than those of Group 4. This is normally true for fossil fuels or biomass systems where the energy embodied in equipment and buildings is small when the whole useful life is considered. The same applies to the energy inputs for the manufacture of chemicals and other materials used in the production process. There are some exceptions such as the case of ethanol from corn in the USA.

Use of fossil fuel in sugar cane production

The detailed analysis is presented in Annex 1. The three energy levels considered in sugar cane production are:

Level 1 – Diesel oil used in agricultural operations and sugar cane transportation.

Level 2 – Other inputs: fertilizers, lime, herbicides, pesticides, seeds.

Level 3 – Energy for production and maintenance of equipment and labor.

In Level 1, the energy consumption associated to fuel (diesel) can be calculated using the energy value of diesel (lower heating value, LHV = 9,235 kcal/l plus 2,179 kcal/l for production, transportation and processing) of 11,414 kcal/l. It should be pointed out that if the objective of the analysis was just to verify the fraction of self consumption of the same type of energy in the ethanol production, without regard to the life cycle, the diesel use should be considered as its LHV value. For fuel oil the energy values are equivalent to diesel[5]. Some additional comments on these values can be found in Annex 3, Note 1.

The summary of the results is presented in Table 1. In this summary, no distinction is made between the different forms of energy (usually electric energy is considered at its thermodynamic value, that is, the thermal energy used in its generation) but a complete discussion is presented in Annex 3, Note 2.

Use of fossil fuel in the industrial production of ethanol

The detailed analysis is shown in Annex 2.

In the industrial processing of sugar cane to produce ethanol there are three items that should be considered in the final energy balance:

Level 1 – Purchased electric energy, if any.

Level 2 – Energy required for the production of inputs to the industrial process (chemicals, lubricants).

Level 3 – Energy for the manufacture of equipment, construction of buildings and their maintenance.

Table 2 summarizes the results for the three levels and two Scenarios without distinction between the forms of energy (*see Annex 3, Note 2*).

It can be seen from the energy balance (Annex 2) that there is a surplus of energy being produced, in the form of surplus bagasse that will be considered in the overall analysis, amounting to 40,300 kcal/TC (Scenario 1) or 75,600 kcal/TC (Scenario 2).

A comparison between the energy produced in the process in the form of ethanol and surplus bagasse and the fossil energy consumed is shown in Table 3. It can be seen that the output energy to input

Table 1 – Energy consumption in sugar cane production

Level		Energy consumption	
		Scenario 1 (kcal/TC)	Scenario 2 (kcal/TC)
1	Fuel		
	Agricultural operations/harvesting (A2)	9,097	9,097
	Transportation (A3)	10,261	8,720
	Level total	**19,358**	**17,817**
2	Fertilizers (A4)	15,890	15,152
	Lime (A5)	1,706	1,706
	Herbicide	2,690	2,690
	Pesticides	190	190
	Seeds (A6)	1,404	1,336
	Level total	**21,880**	**21,074**
3	Equipment (A7)	6,970	6,970
	Level total	**6,970**	**6,970**
	Total	**48,208**	**45,861**

energy ratio is 8 to 10, considerably larger than in the case of ethanol from corn in the USA. The energy flows in and out of the control volume of the agricultural and industrial sectors are shown in Figure 1, for Scenario 1.

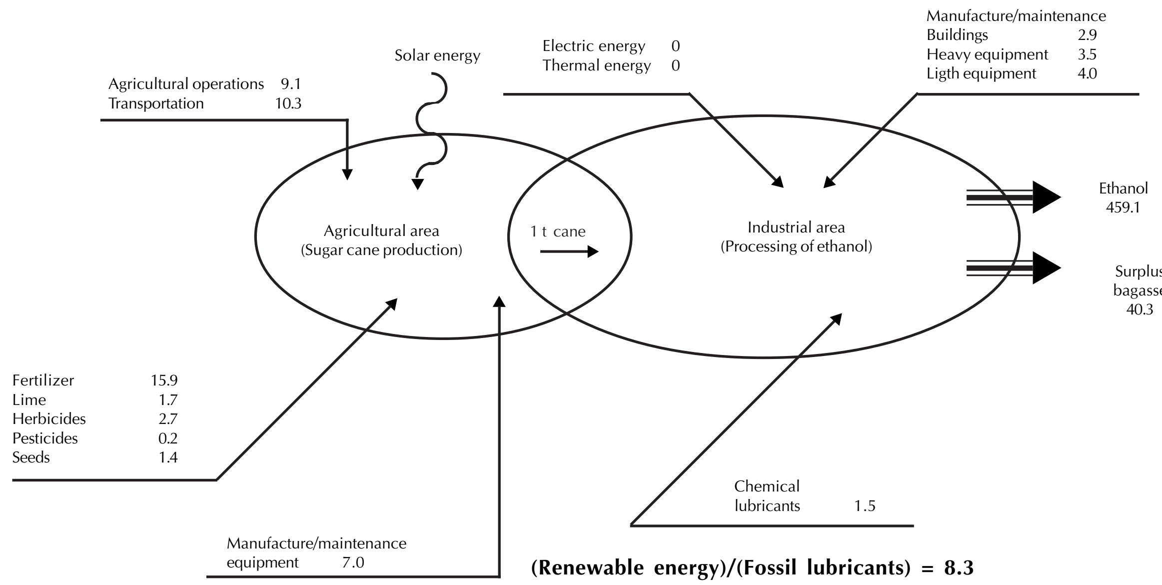
Table 2 – Energy consumption in the production of ethanol

	Level	Energy consumption	
		Scenario 1 (kcal/TC)	Scenario 2 (kcal/TC)
1	Electric energy	0	0
2	Chemicals and lubricants (A9)	1,520	1,520
3	Buildings (A10) Heavy equipment Light equipment	2,860 3,470 3,950	2,220 2,700 3,070
	Total	**11,800**	**9,510**

Table 3 – Energy generation and consumption in the production of sugar cane and ethanol

Activity	Energy consumption			
	Scenario 1 (kcal/TC)		Scenario 2 (kcal/TC)	
Sugar cane production (total)	**48,208**		**45,861**	
Agricultural operations	9,097		9,097	
Transportation	10,261		8,720	
Fertilizers	15,890		15,152	
Lime, herbicides, pesticides etc.	4,586		4,586	
Seeds	1,404		1,336	
Equipment	6,970		6,970	
Ethanol production (total)	**11,800**		**9,510**	
Electricity	0		0	
Chemicals, lubricants	1,520		1,520	
Buildings	2,860		2,220	
Equipment	7,420		5,770	
External energy flows	**Input**	**Output**	**Input**	**Output**
Agriculture	48,208	-	45,861	-
Factory	11,800	-	9,510	-
Ethanol produced	-	459,100	-	490,100
Surplus bagasse	-	40,300	-	75,600
Total	**60,008**	**499,400**	**55,371**	**565,700**
Output/input	**8.3**		**10.2**	

Figure 1 – Energy balance – Scenario 1 (Mcal/TC)



GHG emissions due to the use of fossil fuels

All fossil fuel use listed in Tables 1 and 2 has been considered here, including direct and indirect uses. The values of indirect uses of energy for fuels, as well as the carbon emission coefficients for their combustion, can be found in Annex 3, Note 2.

Diesel has been considered in the agricultural operations, cane harvesting and transportation and fuel oil for the production of chemicals and the energy embodied in equipment, buildings and their maintenance. This simplification is acceptable considering the structure of the energy use in such applications and the small magnitudes involved.

Total diesel oil consumption: 19,358 kcal/TC and 17,817 kcal/TC, for Scenarios 1 and 2, respectively.

Total fuel oil consumption: 40,650 kcal/TC and 370,554 kcal/TC, for Scenarios 1 and 2, respectively.

The corresponding GHG emissions, as CO_2 equivalent (CO_2eq.), are: 19.2 and 17.7 kg CO_2eq./TC, for Scenarios 1 and 2, respectively.

Other GHG emissions in the production and use of ethanol

In this category are included the emissions associated with sugar cane production, cane processing for ethanol and final use of ethanol (as fuel) that are not derived from use of fossil fuels. The most important are:
– Methane and N_2O emissions from the burning of sugar cane trash before harvesting;
– N_2O soil emissions;
– Methane emissions from bagasse burning in boilers;
– Methane emissions from ethanol combustion in vehicle engines, compared with those from gasoline combustion.

Emissions from sugar cane trash burning in the field.

The calculation have been done considering emission coefficients measured in a wind tunnel simulating the cane field burning[6] and alternatively the average values for agricultural residues recommended by IPCC[7] (*see Annex 3, Note 4*).

The IPCC values led to higher emissions values and, being on the conservative side, have been adopted; the results for methane and N_2O, shown in detail in Annex 3, Note 4, are: 9.0 kg CO_2eq./TC

N_2O soil emissions

Evaluations based on the use of nitrogen fertilizers (Annex 3, Note 5) considered that for the Center-South region conditions around 28 kg N/ha are used in cane planting and 87 kg N/ha for each ratoon, which gives an average value of 75 kg N/(ha.year) for the whole cane cycle. Most of the fertilizer used is of the NH_4 type.

The resulting emissions are 1.76 kg N_2O/(ha.year). Since N_2O has a global warming potential 296 larger than CO_2, this results in 521 kg CO_2eq./(ha.year) or 6.3 kg CO_2eq./TC

Methane emissions from bagasse burning in boilers.

Significant unburned organic compound emissions, including methane, in bagasse fired boilers take place only during operational transients or uncontrolled disturbances in the combustion process. Because of almost continuous operation during the crop season, which is the ethanol production period, such transients and disturbances are relatively small in the ethanol distilleries and sugar mills, and this substantially reduces methane emissions. Therefore, this type of emissions will be ignored in this study.

Methane emissions from automotive engines fueled with ethanol or gasoline/ethanol blends, compared with those from pure gasoline engines.

It is shown in Annex 3, Note 6, that although it is difficult to measure differences between emissions from ethanol and gasoline engines (since there are no engines in use in Brazil that operate on ethanol-free gasoline), the technological evolution of the engines fueled with ethanol and gasoline/ethanol blends has made it possible for these engines to meet current tight legal emission limits. It has also brought the methane emissions to very low levels.

These values are very small when compared with other items considered in this study. In Annex 3 the beneficial aspects of the use of ethanol in automobile engines are also discussed.

Avoided emissions

GHG emissions are avoided by the use of surplus bagasse as fuel in other industrial sectors, substituting for fuel oil, as well as by the use of ethanol as an automotive fuel, substituting for gasoline. In a near future, a fraction of the bagasse produced (and the trash) could be used to generate considerable amounts of surplus electric energy or more ethanol, via hydrolysis, contributing even more to reducing the GHG emissions.

Surplus bagasse

An analysis of the surplus bagasse situation is presented in Annex 3, Note 7.

On average, 280 kg of bagasse/TC are produced with a moisture content of around 50%. The surplus is estimated as 8% in Scenario 1 and 15% in Scenario 2; therefore, the energy corresponding to these amounts of bagasse are 40,300 and 75,600 kcal/TC, for Scenarios 1 and 2, respectively (*see Annex 2*).

To estimate the avoided emissions when this bagasse is substituting for fuel oil, operating conditions have been established for both bagasse and fuel oil fired boilers. Under these conditions (*see Annex 3, Note 7*), the 8% and 15% of surplus bagasse correspond, in terms of end energy use, to 3.2 and 6.1 kg fuel oil/TC being displaced.

The total avoided emissions (including indirect emissions) related to the fuel oil displaced are 12.5 and 23.3 kg CO_2eq./TC, for Scenarios 1 and 2, respectively.

Ethanol

Considering the average productivity and efficiencies of the mills and distilleries, the total emissions (direct and indirect) of the displaced gasoline (Annex 3, Note 8) and the fuel equivalence of Brazilian automobile engines, the avoided emissions due to the use of ethanol were calculated for hydrous and anhydrous ethanol. The details are presented in Annex 3, Note 8.

The resulting avoided emissions are:
2.82 kg CO_2/l anhydrous ethanol
1.97 kg CO_2/l hydrous ethanol
Referring to metric ton of cane, the figures are:
Anhydrous ethanol: 242.5 or 259 kg CO_2eq./TC, for Scenarios 1 and 2, respectively
Hydrous ethanol: 169.4 or 180.8 kg CO_2eq./TC, for Scenarios 1 and 2, respectively.

Balance of emissions and conclusions

The results presented above are summarized in Table 4.

The values are alternative, which means that 242.5 kg CO_2eq./TC is avoided if anhydrous ethanol is produced or 169.4 kg CO_2eq./TC with the production of hydrous ethanol.

For many applications it is more convenient to have the emission data referred to as cubic meters of ethanol (net value), whether it is anhydrous or hydrous. The conversion can be done using the sugar cane productivity of the two scenarios, leading to:
Anhydrous ethanol: 2.6 and 2.7 t CO_2eq./m^3 ethanol, for Scenarios 1 and 2 respectively
Hydrous ethanol: 1.7 and 1.9 t CO_2eq./m^3 ethanol, for Scenarios 1 and 2, respectively.

The values for Scenario 1 (current average), should be preferred for GHG emissions evaluations because they reflect realistic conditions.

Figure 2 shows the emission flows related to the Agricultural Production, Industrial Processing and Ethanol Bagasse Utilization control volumes (Scenario 1).

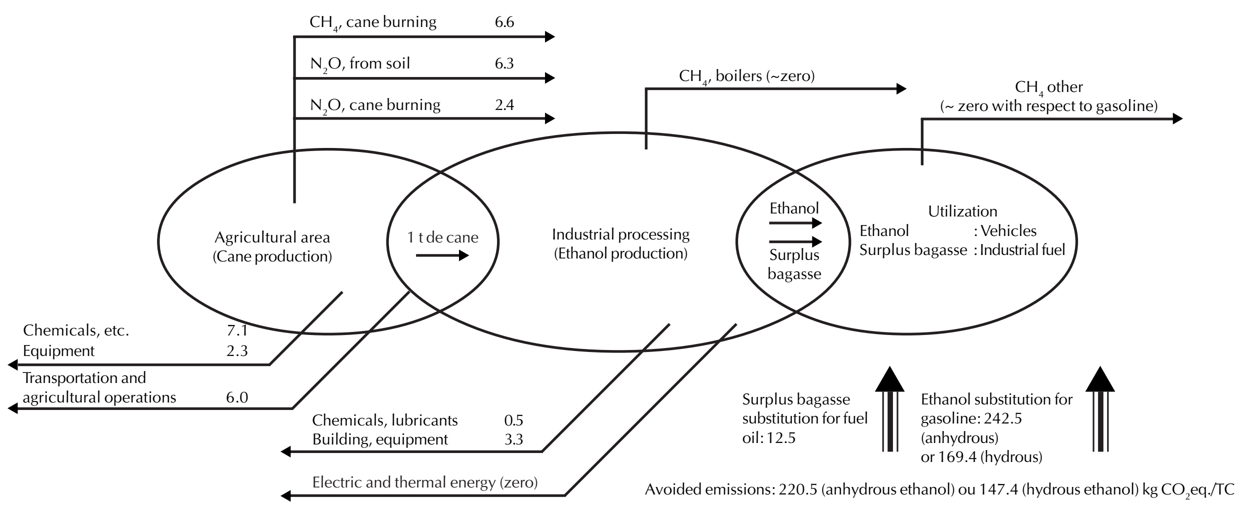
Taking as a base case that Brazilian fuel ethanol consumption is around 12 million m^3 per year, in approximately equal shares of anhydrous and hydrous ethanol, it can be estimated that the use of ethanol as a fuel in Brazil reduces the GHG emissions by 25.8 million t CO_2eq./year or 7.0 million t Carbon eq./year.

Table 4 – Ethanol life cycle emissions

	(kg CO_2eq./TC) Scenario 1 (average)	Scenario 2 (best values)
Type		
Fossil fuels	19.2	17.7
Methane and N_2O from trash burning	9.0	9.0
Soil N_2O	6.3	6.3
Total emissions	34.5	33.0
Avoided emissions		
Surplus bagasse use	12.5	23.3
Ethanol use	242.5 (A); 169.4 (H)	259.0 (A); 180.8 (H)
Total avoided emissions	255.0 (A); 181.9 (H)	282.3 (A); 204.2 (H)
Net avoided emissions	220.5 (A); 147.4 (H)	249.3 (A); 171.1 (H)

(A): Anhydrous ethanol
(H): Hydrous ethanol

Figure 2 – GHG (*) Emissions – Scenario 1 (kg CO_2eq./TC)



(*) Photosynthesis cycle is not included since all carbon fixed by the cane is released as CO_2 (bagasse burning, burning/oxidation of trash, ethanol burning, fermentation; except for a small fraction that is fixed into the soil).

Introduction

The data used in this analysis refers to the year 2002 for the Copersucar associated mills. In the present situation some of the basic parameters for harvest and sugarcane quality used were:

1. Sugar cane harvest – present situation[8]

Type of harvest	São Paulo (%)	Center-South (%)
Manual	63.8	65.2
Mechanical	36.2	34.8
Burned sugar cane	75.0	79.1
Unburned sugar cane	25.0	20.9

Considering that approximately 85% of the Brazilian ethanol production occurs in the Center-South, the following situation was assumed for Brazil:

Mechanical harvest	35%
Manual harvest	65%
Burned sugar cane harvest	80%
Unburned cane harvest	20%

For simplicity all the unburned cane harvested was considered to be mechanized harvest. It is important to mention that this simplification results in a more conservative analysis.

These data were used to determine the necessary equipment for the agricultural operations.

2. Pol and Fiber

Considering the average of five consecutive harvest seasons (1998/99 to 2002/03) the following data were obtained[9]:

Average Pol % cane	14.53%
Average Fiber % cane	13.46%

A1: Agricultural yield

The averages for various regions and sugar cane varieties (Copersucar Technology Center – CTC) are:

Table 5 – Sugar cane yield (averages for harvest seasons 1998/99 to 2002/03)

Harvest		Yield (t/ha)
1st – Plant cane (18 months)	113 (80%)	$\bar{X}$weighed = 106
Plant cane (12 months)	77 (20%)	
2nd – (1st ratoon)		90
3rd – (2nd ratoon)		78
4th – (3rd ratoon)		71
5th – (4th ratoon)		67
Average of 5 harvests		82.4 t/ha (68.7 t/ha.year)

Average age of plow out[9]:

99/00 harvest season	5.13 harvests
00/01 harvest season	5.18 harvests
01/02 harvest season	5.33 harvests

Normally 5 harvests are carried out (average of 82.4 t/ha). The ratoons are cut after one year and the plant cane two years after harvesting the previous ratoon for "18 month cane". Therefore the average for a full cycle of 5 harvests is 68.7 t/ha.year.

A2: Agricultural operations and harvest

a) Agricultural operations
The agricultural operations, the equipment used and their capacities are listed in Table 6.

Table 6 – Agricultural operations: equipment

Nº	Equipment	Power (cv)	Implements	Capacity (ha/h)	Consumption (l diesel/h)
1	MF 290	78	Lime distributing wagon	1.61	6.0
2	CAT D-6	165	Heavy harrow, 18 discs x 34"	1.30	27.6
3	CAT D-6	165	5 shanks subsoiler	1.00	26.0
4	CAT D-6	165	Heavy harrow, 18 discs x 34"	1.35	27.6
5	Valmet 1780	165	Light harrow, 48 discs x 20"	1.60	15.0
6	MF 680	170	2 row furrower – fertilizer	1.10	15.0
7	MF 275	69	Planting wagon	0.60	4.0
8	MF 275	69	2 row furrow coverer	1.80	4.8
9	MF 275	69	Herbicide pump	2.50	4.0
10	MF 292	104	Cultivator	1.30	8.0
11	MF 275	69	Trash rake	1.50	4.0
12	Valmet 1580	143	Triple cultivator	1.30	9.2
13	Valmet 1580	143	Mechanical ratoon eliminator	1.10	12.2
14	Case A7700	330	Combine sugar cane harvester	45.0 t/h	40.4
15	MF 290 RA	78	Sugar cane grab loader	46.0 t/h	7.1
16	MB 2318	180	Sugar cane transport (8%)	2.2 km/l	-
17	MB 2325	250	Sugar cane transport (25%)	1.6 km/l	-
18	Volvo	360	Sugar cane transport (67%)	1.2 km/l	
19	MB 2318	180	Dumpster (skip tipper) truck	2.0 km/l	-
20	MB 2213	130	Flat bed fertilizer transport	2.0 km/l	-
21	MB 2318	180	Vinasse transport	2.2 km/l	-
22	MB 2220	200	Vinasse transport	2.0 km/l	-
23	Volvo	360	Vinasse transport	1.3 km/l	-
24	Diesel pump	120	Vinasse application	120 m^3/h	14.0
25	Valtra BH 180	180	Tractor hauler/transloader	35.0 t/h	9.0

The data for Table 6 were obtained from the research and development database[10]. The normal sequence for agricultural operations is given in Table 7.

Observations:

- *The previous analysis of soil compaction permits the reduction of 30% in subsoiling area.*
- *The mechanical cultivation (ridge removal) is approximately 70% of the planted area and is done after the chemical cultivation.*

The total consumption of energy in agricultural operations can be estimated based on Table 7.

Table 7 – Consumption of diesel oil in agricultural operations

Nº	Agricultural operations	Equip.	Capacity (ha/h)	Specific consumption (l/ha)	Fraction of area worked
	Land preparation and planting operations (20% of total area)				
1	Lime application	1	1.61	3.73	1.00
2	Mechanical elimination of ratoons	13	1.10	11.09	0.30
3	Chemical elimination of ratoons	9	2.50	1.60	0.30
4	Heavy harrowing I	2	1.30	21.23	0.90
5	Subsoiling	3	1.00	26.00	0.70
6	Heavy harrowing II	4	1.35	20.44	0.70
7	Heavy harrowing III	4	1.35	20.44	0.30
8	Light harrowing	5	1.60	9.38	0.90
9	Furrowing and fertilizing	6	1.10	13.64	1.00
10	Seed cane distribution	7	0.60	6.67	1.00
11	Closing furrows and insecticide application	8	1.80	2.67	1.00
12	Chemical tillage (herbicide application)	9	2.50	1.60	1.00
13	Mechanical tillage	10	1.30	6.15	0.70
	Ratoon tillage operations (80% of total area)				
1	Trash raking	11	1.50	2.67	0.25
2	Triple operation tillage	12	1.30	7.08	1.00
3	Chemical tillage (herbicide application)	9	2.50	1.60	0.85

The values for consumption in agricultural operations are equivalent for Scenarios 1 and 2:
Plant cane: C_p = 102.6 l/ha
Ratoon cane: C_r = 9.1 l/ha

b) Harvest
For the equipment 14, 15 and 25 (Table 6) and an average yield of 82.4 t/ha the results are shown in Table 8.

Table 8 – Harvest equipment

Equipment	Operational capacity (ha/h)	Specific consumption (l/ha)
Case harvester	0.5461	74.0
Santal cane loader	0.5583	12.7
Tractor hauler/transloader	0.4248	21.2

Calculations:

Case Harvester

$$\text{Operational capacity} = 45\ \frac{t}{h} \times \frac{1}{82.4}\ \frac{ha}{t} = 0.5461\ ha/h$$

$$\text{Specific consumption} = 40.4\ \frac{l}{h} \times \frac{1}{0.5461}\ \frac{h}{ha} = 74.0\ l/ha$$

Santal Loader:

$$\text{Operational capacity} = 46.0\ \frac{t}{h} \times \frac{1}{82.4}\ \frac{ha}{t} = 0.5583\ ha/h$$

$$\text{Specific consumption} = 7.10\ \frac{l}{h} \times \frac{1}{0.5582}\ \frac{h}{ha} = 12.7\ l/ha$$

Tractor hauler/transloader:

$$\text{Operational capacity} = 35.0\ \frac{t}{h} \times \frac{1}{82.4}\ \frac{ha}{t} = 0.4248\ ha/h$$

$$\text{Specific consumption} = 9.0\ \frac{l}{h} \times \frac{1}{0.4248}\ \frac{h}{ha} = 21.2\ l/ha$$

The present situation can be described as:

In a 6 year cycle: one cane elimination, four ratoon crops and five harvests, 35% of which mechanically (15% unburned and 20% burned) and 65% manually with mechanical grab loading are effected[8]. The annual diesel oil consumption in agricultural operations and in harvesting is given by:

$$C_{AC}(l/TC) = \frac{1}{P_A}\ \{0.17C_P+0.67C_S+0.83[0.35(C_{CC}+C_{TR})+0.65(C_{CM}+\tfrac{2}{3}C_{TR})]\}$$

Here, C_{CC} and C_{CM} (l/ha) are the consumption in mechanical and manual harvesting respectively. C_{TR} is the consumption of the hauler tractors or transloaders and P_A is the annual cane yield, TC/(ha.year).

Observation: For manual harvesting, the transport of cane was considered to be made by triple trailer trucks, which implies a participation of haulers in 2/3 of the total cane.

The results obtained are:

Scenarios 1 and 2: C_{AC} = 0.797 l/TC

A3: Transportation

All the values for capacity and consumption are given in reference 9.

Sugar cane transportation from the field to the mill

The specific consumption values vary according to the type of truck and distance. The mean harvested area distance is 20 km. Based on Table 6 and in the proportion of each type of truck used in cane transport: Single truck (15 t) = 8%, Double wagon (28 t) = 25%, Triple wagon (45t) = 67% it is estimated, for Scenario 1 the value of 20.4 l/t.km.

Calculations:

$$\textbf{Single Truck} = \frac{1}{2.2}\ \frac{l}{km} \times \frac{1}{15t} \times 1{,}000\ \frac{ml}{l} = 30.3\ \frac{ml}{t.km}$$

$$\textbf{Double Wagon} = \frac{1}{1.6}\ \frac{l}{km} \times \frac{1}{28t} \times 1{,}000\ \frac{ml}{l} = 22.3\ \frac{ml}{t.km}$$

$$\textbf{Triple Wagon} = \frac{1}{1.2}\ \frac{l}{km} \times \frac{1}{45t} \times 1{,}000\ \frac{ml}{l} = 18.5\ \frac{ml}{t.km}$$

$$\bar{X}\text{weighed} = 20.4\ \frac{ml}{t.km}$$

$$\text{Four Wagon/58 t} = \frac{1}{1.1}\ \frac{l}{km} \times \frac{1}{58\ t} \times 1{,}000\ \frac{ml}{l} = 15.7\ \frac{ml}{t.km}$$

The use of trucks with a larger transport capacity decreases the values, as is the case with the four Wagon Volvo FH (specific consumption= 15.7 ml/t.km) used as a reference in Scenario 2.

Results:

Scenario 1: C_{TC} = 0.816 l/TC **Scenario 2:** C_{TC} = 0.628 l/TC

Seed cane transportation

For the use of 12 t of seed cane/ha, at an average distance of 20 km, the MB2318 consumes C_{TM} = 17.4 l/ha

$$\text{Truck with 12 t of load: 2.3 km/l} \longrightarrow \frac{1}{2.3} \times 40 = 17.4\ \text{l/ha}$$

Filter mud cake

Where filter mud cake is used, it is applied in 30% of the planted area. In the present situation, only Scenario 2 considers the application of filter mud cake.

A dumpster truck (MB2213) with an average load of 8 t and a consumption of 2.5 km/l is used for the application of filter mud cake in the fields; the average distance is 8km and the application rate is 12 t (wet)/ha (5 t dry/ha).

Results: C_{TT} = 9.6 l/ha

Vinasse

To be conservative, only Scenario 2 considers vinasse application in 30 % of the ratoon area. The types of applications are:

Direct application with tanker trucks – 6% of the area – rate 100m^3/ha (MMB2318 truck with 15 m^3 tank), average distance is 7 km;

Sprinkler (water cannons) system – 63% of the area – rate 150 m^3/ha (diesel pumps with channel);

Trucks combined with cannons – 31 % of the area – rate 100 m^3/ha with Volvo Tanker (two 30 m^3 tanks, distance up to 12 km.

Calculations:

$$\textbf{Direct application with tanker trucks} = \frac{1}{2.2}\ \frac{l}{km} \times \frac{14\ km}{15\ m^3} \times 100\ \frac{m^3}{ha} = 42.4\ \frac{l}{ha} \times 0.06 = 2.54\ \frac{l}{ha}$$

$$\textbf{Sprinkler system (channels + water cannons)} = 16\ \frac{l}{h} \times \frac{h}{120\ m^3} \times 150\ \frac{m^3}{ha} = 20\ \frac{l}{ha} \times 0.63 = 12.6\ \frac{l}{ha}$$

$$\textbf{Tanker truck + water cannons} = \frac{1}{1.3}\ \frac{l}{km} \times \frac{24\ km}{60\ m^3} \times 100\ \frac{m^3}{ha} = 30.8\ \frac{l}{ha} \times 0.31 = 9.55\ \frac{l}{ha}$$

$$\bar{X}\text{weighed} = 24.7\ \frac{l}{ha}$$

Results: C_{TV} = 24.7 l/ha

Fertilizers

For Scenario 2 it was considered a 30% reduction in area of fertilizer application due to the use of vinasse and filter mud cake. Values used for calculations are found in Table 9.

Typically a MB2213 (cargo weight of 12 t, 2.5 km/l) is used. For an average distance of 20 km and a cycle of 6 years, we have:

Scenario 1: 2,500 kg fertilizer/ha, C_{TA} = 3.33 l/ha
Scenario 2: 1,200 kg fertilizer/ha, C_{TA} = 1.60 l/ha

Table 9 – Fertilizer applicaton

	Plant cane	Ratoon	Total
Scenario 1	500 kg/ha (6-24-24)	500 kg/ha (16-5-24)	2,500 kg/ha (in 6 years)
Scenario 2*	400 kg/ha (0-125-200)	200 kg urea	1,200 kg/ha (in 6 years)

*areas with filter mud cake and vinasse application (30%).

The amount of fertilizers is calculated considering that, at present, only 30% of the area can be treated with vinasse and filter mud cake.

The different consumptions can be associated with agricultural yields, leading the total consumption in transport to:

Scenario 1: $C_T = C_{TC} + \frac{1}{P_A}\{0.17C_{TM}+0.83C_{TA}\} = 0.899$ l/TC

Scenario 2: $C_T = C_{TC} + \frac{1}{P_A}\{0.17C_{TM}+0.7(0.83C_{TA}) + 0.3\,(0.17C_{TT} + 0.67C_{TV})\} = 0.764$ l/TC

A4: Fertilizers

There is a large variation in application rate due to different soil types. Average values are listed in Table 10.

Scenario 1 represents the conventional fertilization, while Scenario 2 considers the use of filter mud cake in plant cane and vinasse in ratoons.

Considering that only 30% of these areas can be treated, the final figures for the 2 scenarios are presented in Table 11 *(page 26)*.

The specific energy costs are known[5].

Table 10 – Rate of fertilizer application

Macronutrient	Rate (kg/ha)			
	Plant cane		Ratoon	
	Scenario 1	Scenario 2*	Scenario 1	Scenario 2*
Nitrogen – N	30	–	80	90
Phosphorus – P_2O_5	120	50	25	–
Potassium – K_2O	120	80	120	–

*areas with the application of filter mud cake and vinasse (30%).

Table 11 – Enery in fertilizers

	Nutrient	Annual rate of application (kg/ha.year)	Energy (kcal/kg)	Energy/ha (Mcal/ha.year)	Energy/TC (Mcal/TC)	Total (Mcal/TC)
Conventional	N	58.3	14,700	857.50	12.48	15.9
	P_2O_5	36.7	2,300	84.33	1.23	
	K_2O	100.0	1,600	150.00	2.18	
With vinasse and mud cake (30%, Scenario 2)	N	60.0	14,700	882.00	12.84	13.4
	P_2O_5	8.3	2,300	19.17	0.28	
	K_2O	13.3	1,600	21.33	0.31	

Final results:

Present situation

Scenario 1: E_f = 15,890 kcal/TC

Scenario 2: E_f = 15,890 x 0.7 + 13,430 x 0.3 = 15,152 kcal/TC

A5: Lime, herbicides and insecticides

Lime

Application rate of 2,200 kg/ha in 6 year cycles; energy cost of lime in the field is 313.4 kcal/kg[5].

Results:

E_c = 1,706 kcal/TC

Herbicides

As a reference the values for the 1996 study were maintained due to the lack of information regarding the energy cost (kcal/kg) of specific herbicides (*see Annex 3, Note 3*).

Results:

Eh = 2,690 kcal/TC

Insecticides

In sugar cane, insecticides are used in the control of soil pests and leaf cutting ants. The energy cost of previous studies was maintained for these controls (190 kcal/TC).

A6: Seed cane

The average consumption is of 12 t of seed cane per hectare for each cycle of 6 years, that is: 0.0299 TC/TC. Admitting that the procedures for the production of seed cane are essentially equivalent to those for commercial cane, 3% global energy cost represents the equivalent for seed cane.

Scenario 1: 1,404 kcal/TC (= 3% X 46,804 kcal/TC)
Scenario 2: 1,336 kcal/TC (= 3% X 44,525 kcal/TC)

A7: Agricultural machines and equipment

The present situation is based on a survey of a typical Copersucar mill with the results presented in Table 12[10].

Table 12 – Use of agricultural equipment

Equipment	Mean density of use (kg/ha)
Tractors and harvesters	41.8
Implements	12.4
Trucks	82.4
Total	136.6

The method suggested by Pimentel[5] is used to calculate the energy cost associated with equipment. Basically the hypotheses are:

1) Considering the energy incorporated in the materials (steel, tires) and the production and maintenance. The incorporated energy is essentially in the steel (15,000 kcal/kg) and tires (20,500 kcal/kg). The energy consumed for the production of the various equipments is evaluated by weight (excluding tires).
2) The energy for maintenance corresponds to 1/3 of the cumulative total repairs (ASAE[5] estimates the values for each class of equipment).
3) The useful life of the equipment corresponds to 82% of the total life (due to interruptions) and the energy cost is calculated, per year, using these values. These hypotheses lead to the results in Table 13.

With the data for density of use, estimated useful life and the yield of sugar cane the results presented in Table 14 are obtained.

Table 13 – Energy for the production and maintenance of equipment

Equipment	Energy of the material (kcal/kg)	Weight of tires (fraction of total weight)	Energy of production (kcal/kg)	Total accumulated repairs (%)	Energy of repairs (fraction of material energy + production energy)
Tractors	11,814	0.179	3,294	89.1	0.297
Implements	15,000	-	2,061	92.6	0.309
Trucks	15,000 steel 20,500 tires	0.06	3,494	60.7	0.202

Table 14 – Energy cost of equipment

Equipment	Energy of material (kcal/ha)	Production energy (kcal/ha)	Energy for repairs (kcal/ha)	Energy mat. + production corrected for useful life (kcal/ha)	Total energy (kcal/ha)	Useful life (years)	Energy cost (kcal/TC)
Tractors	493,825	113,043	180,240	497,632	677,872	5	1,973
Implements	185,550	25,495	65,213	173,057	238,269	8	434
Trucks	1,263,170	270,631	309,828	1,257,717	1,567,545	5	4,563

Results for the present situation:

E_e = 6,970 kcal/TC

A8: Labor

For this study, the energy in labor is not considered as an energy cost and it is therefore not included in the calculations. In the 1984 balance, the estimated value was 1,880 kcal/TC. Currently it is certainly less than that due to the increase in mechanical harvesting.

Introduction

This work is an updating of the industrial area parameters used in a 1995 study for Copersucar member mills. Reference 11 provided the values used to assess the industry performance data; the values related to the 2001/29002 crushing season were selected as reference. It is important to point out that these values compare very closely with the five year average of the crushing seasons 1998/1999 through 2002/2003.

RS (reducing sugars)	0.545%
Mill extraction efficiency	96.2%
Juice treatment efficiency	99.2%
Sugar loss in cane washing	0.61%
Fermentation efficiency	91.1%
Distillation efficiency	99.6%

Industrial sector energy balance

The present situation of the ethanol production has been analyzed using efficiency and energy consumption average values for Copersucar member mills. These values are important to determine the operating equilibrium condition for the co-generation system used, and to verify the surplus and deficits of energy.

Specific consumptions per ton of processed sugar cane have not changed much in the conventional areas of the mills. A few major changes due to new processes (such as the substitution of cyclohexane for benzene as dehydration agent) have been considered. The effects of the more efficient technologies such as bagasse gasification/gas turbine have not been evaluated, simply because they are not in use.

Industrial conversion efficiency

Based on a pol % cane = 14.53[8] and the RS and efficiencies listed above, the following conversion rates have been determined:

Scenario 1: 88.7 l/TC (anhydrous ethanol)
Scenario 2: 91.8 l/TC (anhydrous ethanol)

Although these values have been calculated based on performance data shown in Copersucar Benchmark Program[11], it would be reasonable to apply them to the sugar cane industry in the State of São Paulo or even to the whole Center-South region. However, to be on the safe side in the energy and CO_2 balances the conversion rate value of 86 l anhydrous ethanol/TC has been used for Scenario 1 as representative of Brazilian sugar cane sector. This value is a weighed estimate of various specialists of the sector who suggested 88 l anhydrous ethanol/TC for the Center-South region and 75 l anhydrous ethanol/TC for the Northeast region (ethanol production can be divided as 85% in Center-South and 15% in the Northeast. For Scenario 2, the value of 91.8 l anhydrous ethanol/TC was maintained.
Accordingly, the values used in the energy/CO_2 balance are:

Scenario 1: 86.0 l/TC (anhydrous alcohol)
Scenario 2: 91.8 l/TC (anhydrous alcohol)

Utilisation of electricity

The mills increased the internal production of electrical energy during the 2001/02 harvest[11] (average generation: 16.83 kWh/TC; maximum: 29.13 kWh/TC). Consequently, bagasse excess was reduced (average: 5.8%; maximum: 17%). Mills exist with large excesses and complete electricity self-sufficiency.

The average electricity consumption was 12.90 kWh/TC and the minimum, 9.64 kWh/TC.

Electricity bought (average) was 0.26 kWh/TC, which indicates 98% self-sufficiency. On the other hand, the average sale of electric power was 5.86 kWh/TC (maximum: 16.98 kWh/TC). These statistics refer to 2001/2002[11] crop season.

It follows that the hypothesis of the totality of the mills on average neither acquiring nor exporting electricity is no longer absolutely valid: there is in fact an increase in energy export (though relatively unimportant in the context of its potential).

There are two methods of evaluating (to evaluate emissions) the mills' exports of electricity (still incipient): we either consider the export to be small, and compute its value as mitigation of emission and consider the resulting real bagasse excess, or we consider only the excess bagasse (conservatively). As the excess statistics refer to the joint production of sugar and ethanol (it being currently unrealistic to separate them), the securest option is the conservative one, though adopting a slightly higher average figure (in the production of ethanol, the bagasse excesses are larger than for sugar).

Thus, the values used for excess electricity are zero and from 8% (average) to 15% (maximum) for surplus bagasse (see commentaries in the following section).

Energy used in milling sugar cane

An estimate of consumption can be made from the installed capacity together with some observations of milling conditions, in some mills. The bigger mills have on the average a lower installed specific power capacity (22.1 cv/TC for mills with milling capacity of over 300 tons of sugar cane per hour - TCH). As in general they also have better cane preparation it is to be expected that the actual power used would be very close to that installed. Although minimum values of 17 cv/TCH (installed power) were identified, analysis of the whole sector shows that an average value of 20 cv/TCH is a good estimate of the power actually used in the mills with good cane preparation and milling. The relationship between power used in milling and in preparation is approximately 1.5.

Energy consumption in the processes: sugar and ethanol

The conditions found in the Brazilian mills make it difficult to analyze "average" values due to the variations in the sugar/ethanol production ratios and the diversity of operating procedures in ethanol production, as well as the differences in levels of energy conservation. Techniques to reduce energy consumption in sugar production have been established and used for many years. In Brazil today the simultaneous production of sugar and alcohol makes the sugar production easier, since it is not necessary to exhaust the molasses.

The potential to increase the production of surplus bagasse (or electric energy) has been analyzed and the results are impressive. However, for the objective of this work only two Scenarios have been considered, the first with the present average values and the second with the best values achieved today.

For the sugar/ethanol mills, the values considered today are still:

– Average surplus bagasse of 5%, reaching 15% in the best cases;

– No outside electric power needed, for an average power consumption of 12.9 kWh/TC. (Most mills are self sufficient in energy).

It is quite reasonable to assume that for the production of ethanol only (autonomous distillery) a higher percentage of surplus bagasse can be obtained; therefore 8% is assumed as average value and 15% as best value.

With an average fiber content of 13.5% and a bagasse with 50% moisture content, 280 kg of bagasse with a LHV = 1800 kcal/kg is obtained. A summary of the bagasse and electric power situation is shown in Table 15.

Table 15 – Surplus bagasse energy

Scenario 1:		
Surplus bagasse	8%	40,300 kcal/TC
External electric energy	0	0
Scenario 2:		
Surplus bagasse	15%	75,600 kcal/TC
External electric energy	0	0

A9: Chemicals and materials for industrial sector

The main chemicals and lubricants used in the ethanol industrial production process are listed in Table 16, with the corresponding average utilization and associated energy consumption. These averages refer to the 2002/2003 crushing season but they reflect well the averages for the last five years[11].

Table 16 – Energy in the chemicals and lubricants used in the industrial sector

Item	Consumption	Energy (kcal/TC)
Sulfuric acid	9.05 g/l	740
Cyclohexane	0.60 kg/m^3 anhydrous	130
Sodium hydroxide	–	180
Lubricants	13.37 g/TC	170
Lime	930 g/TC	300
Total	–	1,520

A10: Buildings, equipment and installations of the industrial sector

The evaluation of the energy used in the construction and erection of an ethanol distillery can be done in a simplified way for the objective of this study, because it does not represent a significant fraction of the energy flows involved in the ethanol production. This energy is used in the construction of buildings, working areas and in the fabrication and erection of industrial equipment.For this evaluation, an ethanol distillery with a nominal capacity of 120,000 l/day, operating 180 days per year was used as reference.The energy embodied in the building and working areas is detailed in Table 17[5].

Table 17 – Energy in the buildings and working areas

	Area (m^2)	Energy used (10^6 kcal/m^2) (a)	Total energy (10^9 kcal)
Industrial buildings	5,000	2.7	13.50
Offices	300	4.5	1.35
Repair shops, laboratories	1,500	1.7	2.55
Storage	4,000	0.5	2.00
Total			19.40

There are large variations in the industrial equipment installed in the various mills; a typical case has been used as reference. The results are shown in Table 18.

Table 18 – Energy in equipment fabrication

	Weight (t)	Total energy (10^9 kcal)	Notes
Cane belt conveyor (30 m)	45	0.75	(c)
Bagasse belt conveyor (200 m)	180	3.9	(c)
Cane feed table and acessories	42	0.70	(c)
30″x54″ mills tandem, 5 mills	220	6.16	(d)
Turbine, turbine generator, speed reducing train	50	0.9	
Boilers	310	4.34	(e)
Distillery			
– Stainless steel	76	1.67	(f)
– Carbon steel	400	6.64	(g)
Total		24.16	

It must be pointed out that for each piece of equipment there are two components in the energy cost: the energy required for the production of the raw material (steel, iron) and the energy required to manufacture the equipment (b). From Tables 17 and 18, the total energy necessary for the installation of the industrial sector can be estimated as $43x10^9$ kcal. An analysis of this set of equipment has shown that some of the main equipment (mill tandem and distillery) have a processing capacity adequate for 180,000 l ethanol/day.

The useful lives of the items in Table 17 and 18 have been assumed as:

Buildings: 50 years
Heavy equipment (mills, boilers): 25 years
Light equipment: 10 years

For maintenance, the energy cost has been considered as 4%/year of the total cost. With these assumptions the specific energy costs per ton of cane (TC) can be estimated. Table 19 presents the results.

Table 19 – Energy use related to equipment and buildings in the industrial area

	Total energy (10^9 kcal)	Useful life (years)	Energy/ year (10^9 kcal)	Energy/year (maintain) (10^9 kcal)	Total energy (10^9 kcal/year)	kcal/(TC/year) Scenario 1	Scenario 2
Buildings	19.40	50	0.348	0.696	1,044	2,860	2,221
Heavy equipment	15.85	25	0.634	0.634	1,268	3,474	2,698
Light equipment	10.31	10	1,031	0.412	1,443	3,953	3,070
Total					3,755	10,290	7,989

For the best case condition (Scenario 2) the operating conditions of several good distilleries have been evaluated. The most energy efficient have indicated that the same equipment considered in the tables above for the typical mill, with minor modifications, could produce 240,000 l anhydrous ethanol/day. Adopting these values leads to the following results:

Scenario 1: 180,000 l/day and 377,000 TC/year
Equipment energy use: 10,290 kcal/TC

Scenario 2: 240,000 l/day and 470,000 TC/year
Equipment energy use: 7,989 kcal/TC

Notes:
a) Data from Hannon[12].
b) The energy necessary to produce raw steel varies according to the process used. A summary of data collected from many sources[13] (P.F. Chapman, *The energy cost of materials*, Energy Policy, March, 1975) shows a variation from 9,000 kcal/kg to 14,300 kcal/kg for six independent studies in the 70's. In this work the value of 9,030 kcal/kg has been used (Statistical Year Book, 1972[14]). Values for the finished product (including the energy for equipment fabrication) can be estimated based on the available data[15].
c) Essentially structural steel.
d) In this case, the mill capacity is larger than required by the factory. It has been considered as forged steel to estimate the energy cost.
e) Values estimated for "tractors and combines". It could be one 65 t steam/h boiler or two 45 t steam/h boilers.
f) A,B,C,P columns; condensers; k heat exchanger.
g) Conventional distillery with wine and water tanks, condensers at 25 m height; fermentation vats, tanks, piping, cooling coils (carbon steel) structures.This distillery had a nominal capacity of 120,000 l/day but could reach, with minor improvements, 240,000 l/day of anhydrous ethanol.

Table 20 – Energy cost for different equipment and materials

	Energy cost (kcal/kg)	Note
Forged steel	28,000	Finished product
Structural steel	16,600	Finished product
Turbine generator	9,500	Fabrication only
Tractor	14,350	Finished product
Combine	13,160	Finished product
Stainless steel (pipes, vessels)	16,200 to 22,000	Finished product

Note 1: Life cycle CO_2 emissions of fossil fuels used (or replaced) by sugar cane products (ethanol and bagasse).

The analysis includes not only the direct emissions (such as CO_2 emissions per liter of diesel used in the agricultural operations) but also the indirect emissions (emissions in oil extraction, its transportation to the refinery, refining, transportation to the consumers, evaporation). For petroleum derived fuels the indirect emissions represent between 10 to 20% of the total emissions.

There are variations in the values of indirect emissions due to several factors: differences in transportation distances and means (ships, pipeline, trucks), refining process and refining profile.

However, it is reasonable to use the simplifying assumption that the total emission of the petroleum cycle is equally divided among the products, with respect to the corresponding LHV.

An example is shown in[16] for diesel:

Indirect emissions	(kg CO_2/kg diesel)
Extraction and transportation of oil	0.06
Refining	0.16 – 0.26
Transportation to consumers	0.02
Evaporation	0.25 – 0.35
Direct emissions	3.15
Total emissions	3.40 – 3.49

Therefore in this case, the indirect emissions are 9% of the direct emissions.

In a classic reference in the 80's, Pimentel[5] indicated that the direct fuel energy is 81% of the total energy; the same value applying for gasoline, diesel and fuel oil.

	Direct (kcal/l)		Indirect (kcal/l)		Total(kcal/l)
Gasoline:	8,179	+	1,930	=	10,109
Diesel, fuel oil:	9,235	+	2,179	=	11,414

For Brazil, some important points should be considered such as oil extraction technology (most of the oil comes from deep water), oil type (mostly heavy oil) which may result in a higher energy consumption for extraction and refining.

In this study, the 81% value for the direct energy has been used in conjunction with the heating values and densities presented in BEN 2002[17]. For the carbon content the IPCC[7] values have been used. Table 21 presents the main results.

Table 21 – Fossil fuel emissions

	Density (kg/l)	LHV (MJ/kg)	Direct carbon IPCC – 2001 (kg C/GJ)	Direct emissions (kg C/t)	Total emissions (kg C/m^3)
Gasoline	0.742	44.8	18.9	846	776
Diesel	0.852	42.7	20.2	862	908
Fuel oil	1.013	40.19	21.1	848	1,061

Note 2: Forms of energy used in the production of agricultural and industrial chemicals and materials, and embodied in equipment, buildings and structures

Energies embodied in the manufacture of equipment (field and industry) and construction of buildings/structures are, as expected, small compared to the energy flows in the systems dedicated to energy generation. They can, therefore, be estimated in a simplified way based on the weight and type of material used in the equipment (steel, iron, aluminum) and in some cases, such as tractors and trucks, with some specific considerations. For buildings and others facilities the estimate is made based on the covered area and type of construction (warehouse, office).

The tables used show the total energy value (kcal/kg of material, for example); in these values are included the direct use of thermal energy (heat, transportation fuel) and the thermodynamic equivalent of electric energy (in general, converted using the thermal efficiency of the local thermal power plants). Thus, the CO_2 equivalent emissions are estimated based on the fuels used (fuel oil, natural gas, mineral coal), including electric energy. To identify the fraction corresponding to electric energy it is necessary to investigate to what extent electric energy is used in all involved sectors in Brazil.

To estimate the emissions, it would be adequate in the case of Brazil to separate electric energy from others types of energy since today more than 90% of the country's electric power comes from hydro power plants (with nearly zero GHG emissions). It is important to notice that many sectors involved (steel, iron) generate most of the electric energy they need, partly in a renewable way.

In any case, the values are small. BEN-2002[17] provides data to establish the following: (electric power has a thermal energy equivalent of 1 kWh = 3,132 kcal for fuel oil fired thermal power plants):

– Mining/pelletizing sector
Electric energy: 60%; thermal energy: 40% (fuel oil, coal, NG, diesel)

– Iron/steel sector:
Electric energy: 25%; thermal energy: 75% (charcoal, coke, mineral coal, others).
Renewable energy: around 25%

– Steel alloy sector:
Electric energy: 75%; thermal energy: 25% (charcoal, wood, others)
Renewable thermal energy: around 85%

– Cement sector
Electric energy: 31%; thermal energy: 69% (fuel oil, coal, diesel, others)
Renewable thermal energy: around 5%

– Ceramics sector
Electric energy: 23%; thermal energy: 67% (wood, LPG, fuel oil)
Renewable thermal energy: around 60%

Considering the relative participation of each sector above, the participation of each type of energy in the manufacture of equipment and construction of buildings can be estimated as:

Buildings/constructions
Electric energy: 30%; thermal energy: 70%

Equipment
Electric energy: 30%; thermal energy: 70%.

It must be understood that electric energy has been converted in equivalent thermal energy (1 kWh = 3,142 kcal) and that in the mining, iron and steel sectors there is a lot of co-generation involved. This separation of types of energy is considered for information only and is roughly estimated. For the emissions balance all the energy involved in this section has been assumed as thermal energy derived from fossil fuels (an important fraction of renewable energy has been ignored).

In the production of chemicals, for agriculture and industry, thermal energy is the major part of the total energy. For instance, for ammonia, electric energy participation is only 1%.

In the Brazilian case, where more than 90% of electricity comes from hydro power plants, to consider the total energy cost of chemicals as being from thermal origin is the conservative assumption used is this study.

Note 3: Energy in the production of herbicides and pesticides

It is difficult to define values for this item since the products are frequently changing and there is little information about energy use in the production process. This area in Brazil has inclined to develop biological controls (as in the cases of cane borer and froghopper) with a significant reduction in the use of pesticides.

Data from the 80's for the herbicides and pesticides used in cane fields indicate that (6): herbicides averaged 99,910 kcal/kg and insecticides averaged 86,000 kcal/kg.

Based on these energy values and product consumption of the mid 90's, the emission values have been estimated and considered to be very small.

Note 4: Methane emissions from trash burning, before harvest

There is only one complete study covering methane emissions from the trash (cane leaves) burning before the cane harvest. This study developed an adequate methodology and simulated trash burning conditions in a wind tunnel in 1994[6]. IPCC[7] recommends the use of generic values for the emissions from the burning of agricultural residues when specific data are not available; because these values are substantially higher than those presented in reference[6], the IPCC[7] values for GWP-100 are used to convert in CO_2 equivalent emissions.

Table 22 presents the results for both reference[6] and IPCC[7].

Table 22 – Methane emissions from cane field burning

	Emission coefficient (kg CH_4/t trash)	Trash burned (t trash/TC) (*)	Emissions (kg CH_4/TC)	GWP–100	Emission (kg CO_2 eq./TC)
IPCC[7]	2.83	0.101	0.286	23	6.6
Jenkins[6]	0.41	0.101	0.041	23	0.94

(*) 140 kg (DM) of trash/TC, with 82.4 TC/ha; 80% of cane burned with an efficiency of 90% (incomplete burning)

To maintain a conservative position, the IPCC values have been used, leading to 6.6 kg CO_2eq./TC. The N_2O emissions from trash burning can be estimated using IPCC (7) values for agricultural residues burning in general, as follows:

Residue carbon content:
0.50 kg C/kg residue (DM)

Residue nitrogen content:
N/C = 0.010 – 0.020

N_2O emission coefficient:
0.007 kg N/kg N in the residue

Considering 0.101 t trash/TC and assuming N/C = 0.15, results:

Carbon in the trash = 0.50 kg C/kg trash x 0.101 kg trash/TC = 50 kg C/TC

Nitrogen content in the trash = 0.015 x 50 = 0.75 kg N/TC

N_2O emissions = 0.75 kg N (trash)/TC x 0.007 kg N/kg N (trash) = 0.00525 kg N/TC = 0.00825 kg N_2O/TC

Using IPCC value for GWP – 100 = 296, the CO_2 equivalent is N_2O emissions = 2.4 kg CO_2eq./TC

Therefore, the total GHG emissions due to trash burning before harvest is 9.0 kg CO_2eq./TC.

Note 5: N_2O soil emissions (nitrogen fertilizer)

Although there are not many studies available on N_2O soil emissions, the value for sugar cane culture can be estimated using some assumptions[18]:

1. N_2O emissions depend on the quantity of nitrogen fertilizer used, the application technology (NO_3 or NH_4) and soil conditions.
2. The emissions amount to 0.5% to 1.5% (in weight N/N) of the fertilizer used; the higher values refer to NH_4 type.

For the Center-South region in Brazil, around 28 kg N/ha is used during cane planting and 87kgN/ha for each ratoon, resulting in 75 kg N/ha year for the whole cycle. Most of the fertilizers used is of the NH_4 type.

The resulting N_2O emissions are therefore 1.76 kg N_2O/ha year which is equivalent to 521 kg CO_2eq./ha.year or 6.3 kg CO_2eq./TC.

Note 6: Methane emissions from automotive engines fueled with ethanol, in comparison with gasoline fueled engines.

From 1980 to 1996 the regulated emission limits for automotive engines were changed considerably, in two phases (1986 and 1992)[19]. The analysis of the average emissions from 1986 and 1992 shows that carbon monoxide (CO) emissions have always been lower in ethanol engines compared with gasohol engines (gasoline/ethanol blends). In this same period, NO_x emissions were similar in both cases and the organic compound emissions, expressed as hydrocarbons (HC), were similar or lower. Based on the lower CO emissions it can be said that the use of ethanol in automotive engines is beneficial in terms of reducing GHG emissions since CO is a gas with indirect effect in the formation of GHG (can be oxidized to CO_2 or participate in the generation of ozone, which is also GHG). With respect to HC and NO_x, the combination of these gases results in the formation of ozone. However, there are no consistent studies in Brazil that would allow the conclusion that the use of ethanol has had the beneficial effect of reducing ozone in the lower atmosphere, although there are indications in the literature[20] that this may be true. One fact that favors this line of reasoning is that in USA, ethanol is one of the oxygenates used in the production of Reformulated Gasoline, that has as the main objectives the reduction of toxic emissions and the reduction of ozone formation. In spite of the referred indication of positive impacts it has been decided not to claim any benefit in this area from the use of ethanol in cars.

One point that deserves attention is the characterization of the HC's formed in the combustion process, especially with respect to the presence of CH_4. It is known that the mass ratio CO_2/CH_4 for internal combustion engines is, typically, around 4,700 for gasoline and diesel and around 3,900 for methanol and ethanol[21,23] which permits the statement that the relative importance of methane emission is very small, even considering its GWP = 23.

Data from Cetesb[22] show that with the different technologies existing in 1993, the ratio ethanol/HC in ethanol engines was in the range of 0.70 to 0.85, and the non ethanol HC's emissions were around 0.6 g/km. Assuming that 30% of HC is methane, the result would be 15 kg CO_2eq./m^3 ethanol. Using a similar reasoning for the gasohol engine emissions, the result would be no higher than 3.75 kg CO_2eq./m^3 ethanol (for 25% ethanol in the gasohol). These figures represent less than 1% of the avoided emissions which can be considered to be negligible.

It is very difficult to compare methane emissions from ethanol and gasoline engines in Brazil since there are no engines in the country that operate on pure gasoline.

For today's technology (electronic engine management, multipoint fuel injection, 3-way catalysts) in use since 1997 due to the introduction of tighter emission limits, methane emission level is 0.05 g/km [23]. If this level is reached, the emission would be no higher than 0.9 kg CO_2eq./TC, thus, still negligible.

Due to the above reasons automotive methane emissions are not included in the CO_2 balance.

Note 7: Use of surplus bagasse substituting for fuel oil in other industries (orange juice, pulp and paper)

It has been shown that an average of 280 kg bagasse/TC, with 50% moisture content is produced in cane milling. The LHV is 1,800 kcal/kg and the HHV is 2,260 kcal/kg.

The estimated surpluses are 8% and 15% for Scenarios 1 and 2, respectively; accordingly, the energy of this surplus bagasse is 40,300 and 75,600 kcal/TC for Scenarios 1 and 2, respectively (*see Annex 2*).

To estimate the avoided emissions when this surplus bagasse displaces fuel oil, the following operating conditions are assumed for the two systems:

Bagasse: boiler average efficiency of 78.7% (LHV) and 10% losses to account for fuel conditioning, start ups and shut downs.

Fuel oil: boiler efficiency of 92% (LHV); LHV = 49.19 MJ/kg under these conditions the 8% and 15% surplus bagasse would correspond, in terms of final energy use, to 3.2 and 6.1 kg of fuel oil/TC, displaced.

The total emissions, including the indirect ones, related to these amounts of fuel oil are 12.5 and 23.3 kg CO_2eq./TC, for Scenarios 1 and 2, respectively.

Note 8: Use of ethanol, substituting for gasoline, in E-100 engines (hydrous ethanol) and gasoline/ ethanol blend engines (anhydrous ethanol).

Scenario 1: 86.0 l anhydrous ethanol/TC
Scenario 2: 91.8 l anhydrous ethanol/TC

With the same amount of cane, the production of hydrous ethanol is approximately 3% larger.

The gasoline direct CO_2 emissions, calculated from the Brazilian data (density = 0.742 kg/l; LHV = 44.8 MJ/kg and IPCC emission data (Annex 3, Note 1: 18.9 kg CO_2/GJ, LHV), are 628 g carbon/m^3. Adding the indirect emissions[5] (Annex 3, Note 1), the total value to be considered is 0.77 kg C/l or 2.82 kg CO_2/l gasoline.

Although a direct comparison between ethanol, gasohol and gasoline engines in Brazil is not possible, the equivalence that is widely accepted today, as a function of the relative performance of new vehicles, is as follows:

1 l of hydrous ethanol (E-100 engine) = 0.7 l of gasoline
1 l of anhydrous ethanol (E-25 engine) = 1 l of gasoline

Under these conditions, the avoided emissions are:

2.82 kg CO_2/l anhydrous ethanol
1.97 kg CO_2/l hydrous ethanol

or referring to sugar cane production:

Anhydrous ethanol: 242.5 or 259 kg CO_2/TC, for Scenarios 1 and 2, respectively.
Hydrous ethanol: 169 or 181 kg CO_2/TC, for Scenarios 1 and 2, respectively.

References

1. Macedo, I. C. e Nogueira, L. A. H. *Balanço de energia na produção de cana-de-açúcar e álcool nas usinas cooperadas*. Boletim Técnico Copersucar – BTC nº 31/85, Julho 1985, 22-33.
2. Centro de Tecnologia Copersucar (CTC), RLT-018 – Atividade 5.51 – Energy Balance/CO_2 Emission, Março 1998.
3. Macedo, I. C. *The sugar cane agro-industry – its contribution to reducing CO_2 emissions in Brazil, Biomass and Bioenergy*. 1992, (3), 77-80.
4. Macedo, I. C. *Greenhouse gas emissons and energy balances in bio-ethanol production and use in Brazil (1996)*. 1998, 14 (1), 77-81.
5. Pimentel, D. *Handbook of energy utilization in agriculture*. CRC Press, 1980.
6. Jenkins, B *Atmospheric pollutant emission factor from open burning of sugar cane by wind tunnel simulation – Final Report*. University of California, Davis, 1994.
7. IPCC: Climate Change 2001: The Scientific Basis.
8. Centro de Tecnologia Copersucar (CTC), *Programa de Acompanhamento Mensal de Performance Agrícola (PAMPA) – Safra 2003/2004*.
9. Centro de Tecnologia Copersucar (CTC), *Controle Mútuo Agrícola Anual – Safras 1998/1999, 1999/2000, 2000/2001, 2001/2002, 2002/2003*.
10. Centro de Tecnologia Copersucar (CTC), *Relatório C.428.00266 – Capacidade operacional e eficiência de equipamentos*, 2002.
11. Centro de Tecnologia Copersucar (CTC), *Controle Mútuo Industrial – Safras 1998/1999, 1999/2000, 2000/2001, 2001/2002, 2002/2003*.
12. Hannon, B. *Energy and labor in construction sector*. CAC Doc. 228, Center for Advanced Computation, University of Illinois, Urbana, 1977.
13. Chapman, P. F *The energy cost of materials*. Energy Policy, Março 1975.
14. ONU. *Anuário Estatístico da ONU*, 1972.
15. Galliland, A. *Science*. Setembro 1975.
16. Rheinhard, G. A. *Energie und CO_2 Bilanzierung Nachwachsender Rohstoffe*. Vieweg, 1992.
17. *Balanço Energético Nacional* – BEN 2002 – Ministério de Minas e Energia (MME), 2002.
18. Lewandowski, I *CO_2 balance for the cultivation of miscanthus*, Biomass and Bionergy, 1995. 8 (2), 81-90.
19. Companhia de Tecnologia de Saneamento Ambiental – São Paulo (Cetesb), *Relatório da Qualidade do Ar – 2002*. São Paulo, Agosto de 2003.
20. Brandberg, A. Unregulated Emissions from Engines Fueled with Alcohols and Other Fuels, Proceedings of the IX International Symposium on Alcohol Fuels Florence, Italy, November 12 - 15, 1991.
21. Hirai, E. Y. *Determinação de concentração de álcool nos gases de escapamentos de veículos leves*, Relatório Interno, Cetesb, São Paulo, Março 1993.
22. Branco, G.M. *Controle de poluição veicular no Brasil*, Relatório Interno, Cetesb, São Paulo, Março 1992.
23. Unpublished information from automotive manufactures in Brazil.

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E85 Fueling Stations in California

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Details	Shell - Bressi Ranch	2741 Gateway Road	Carlsbad	Public - see hours	Map
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Details	Propel Fuels	7741 Auburn Blvd	Citrus Heights	Public - credit card at all times	Map
Details	Black Diamond Chevron - Pearson Fuels	1001 Willow Pass Ct	Concord	Public - see hours	Map
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Details	Sacramento Municipal Utility District	6201 S St	Sacramento	Private access only	Map
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Details	Shell - Green Wave Fuel	730 29th St	Sacramento	Public - see hours	Map
Details	Truxel Road Shell	3721 Truxel Rd	Sacramento	Public - see hours	Map
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Details	Pearson Fuels	4067 El Cajon Boulevard	San Diego	Public - see hours	Map
Details	Department of Veterans Affairs	4150 Clement St	San Francisco	Private - government only	Map
Details	Stanley's Food Mart #1	North M Street & W Cartmill Avenue	Tulare	Public - credit card after hours	Map
Details	Pacific Pride - Interstate Oil Company	917 Cotting Ln	Vacaville	Public - credit card at all times	Map
Details	Reed Avenue Shell	800 Ikea Ct	West Sacramento	Public - see hours	Map
Details	Pacific Pride - Interstate Oil Company	3879 Chanel Dr	West Sacramento	Public - credit card at all times	Map
Details	Pacific Pride - Interstate Oil Company	3022 Evergreen St	West Sacramento	Public - credit card at all times	Map
Details	76 - DMC Green Incorporated	705 Harbor Pointe Pl	West Sacramento	Public - credit card after hours	Map
Details	Arco AM/PM - DMC Green Incorporated	450 County Road 102	Woodland	Public - see hours	Map
Details	Texaco	1660 Oceanside Boulevard	Oceanside	PLANNED - not yet accessible	Map

DOE Biomass R&D TAC Meeting – September 10, 2007

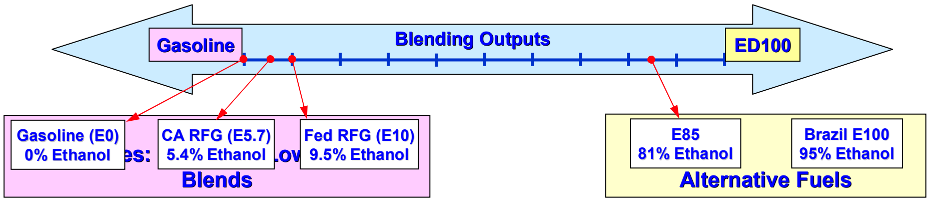
Fuel Economy & Emissions: Ethanol Blends vs Gasoline

Kevin Cullen GMPT Engineering - Compliance & Cert 248-685-6339

Outline

- General Trends as Ethanol is added to Gasoline
- E85 vs Gasoline Detailed Emissions/Fuel Economy Comparison
  - Test vehicle & program
  - Comparative Data – E85 vs Gasoline
    - Regulated exhaust and evaporative emissions
    - Carbon dioxide, fuel economy & thermal efficiency
  - Test fuel properties
  - Carbon balance measurement methodology
  - Emissions and fuel economy in perspective
- The Next Challenge – E85 FFV PZEV

General Trends as Ethanol is added to Gasoline



Fuel characteristics, emissions & fuel economy impacts:

- Volatility – gasoline middle, low blends higher, E85 much lower
  - High volatility increases evaporative emissions on low blends
  - Low volatility requires more cold-start fuel & increases exhaust HC and reduces evap on E85
- Permeation – gasoline middle, low blends much higher, E85 much lower
  - Evap emissions much higher with low blends & much lower on E85
- Energy density – decreases in direct proportion to ethanol concentration
  - Slight fuel economy loss at low blends & significant fuel economy loss on E85

Test Vehicle & Test Program

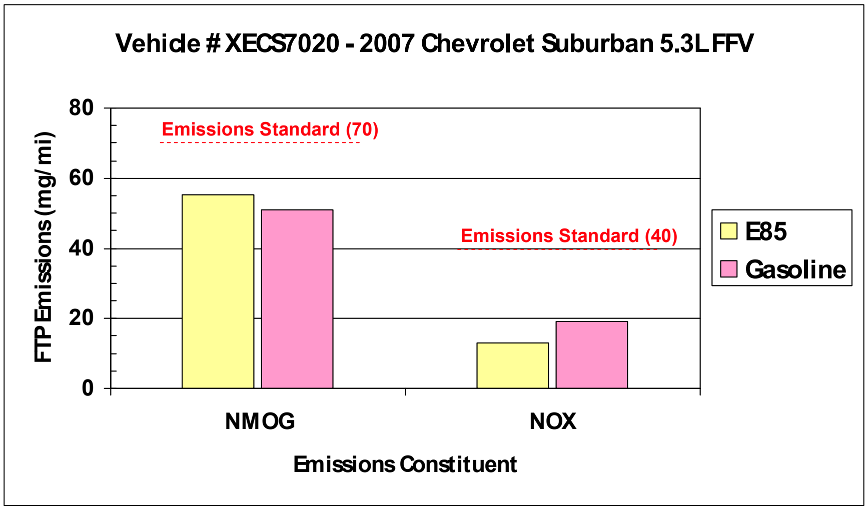
2007 Chevrolet Suburban

- 5.3L LC9 Flex fuel engine
- California emissions
  - EPA Bin 4 certified
  - Qualifies as CA $ULEV_2$
  - CA Near-zero evap
- 6000 pounds test weight class
- 31.8 gallon fuel capacity
- Equipped with catalyst & O_2 sensors aged to full useful life (120,000 miles)

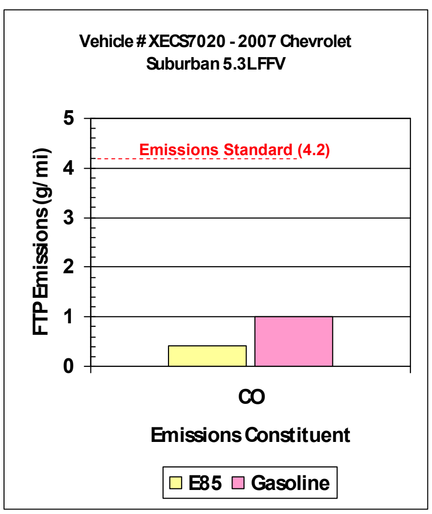
Comprehensive comparison of emissions on various blends

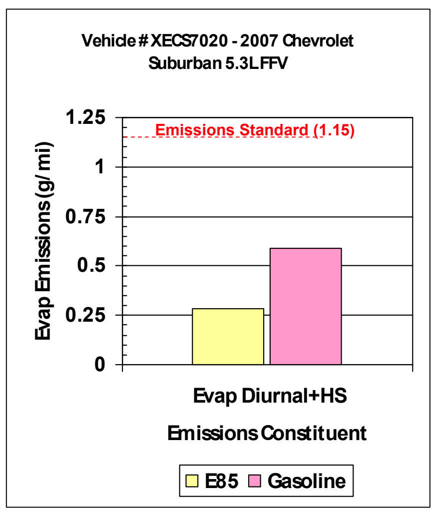
- Exhaust and evaporative emissions
- Fuel blends including gasoline, E85, E20 & E10
- Regulated emissions constituents (NMOG, CO, NOx, Evap HC)
- Toxics (benzene, acetaldehyde, 1,3 butadiene)
- HC speciation to allow ozone reactivity analysis
- Testing nearing completion

E85 vs Gasoline Emissions – Regulated Exhaust Constituents

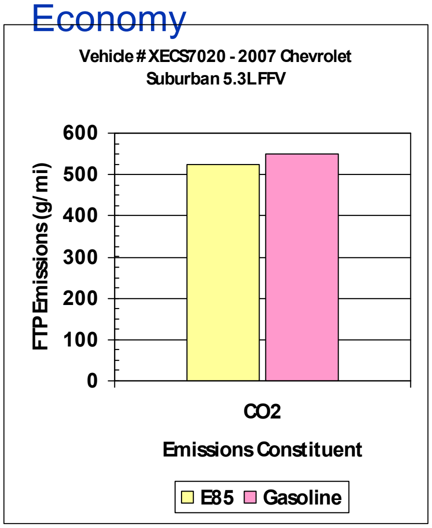


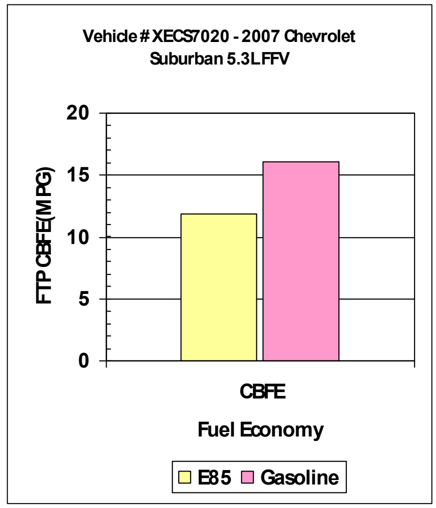
E85 vs Gasoline Emissions – Exhaust CO and Evap HC





E85 vs Gasoline Emissions – CO_2 & Fuel Economy





Key test fuel properties

EPA Tier 2 certification gasoline

- Non-oxygenated straight gasoline
- 28 ppm Sulfur
- 94 octane (R+M)/2
- LHV 114,365 BTU/gallon
- 0.744 specific gravity
  - 2816 grams/gallon total
  - 2439 grams/gallon Carbon
  - 378 grams/gallon Hydrogen

ED85 Tier 2 certification blend

- 85% denatured ethanol & 15% Tier 2 certification gasoline
- 5 ppm Sulfur
- 98 octane (R+M)/2
- LHV 82,332 BTU/gallon
- 0.783 specific gravity
  - 2964 grams/gallon total
  - 1713 grams/gallon Carbon
  - 384 grams/gallon Hydrogen
  - 867 grams/gallon Oxygen

Carbon balance fuel economy measurements

For regulatory fuel economy we do not measure the volume of fuel used

- The technique is the carbon balance method
- Exhaust emissions of hydrocarbons, carbon monoxide & carbon dioxide are measured over the test in grams/mile
- The total carbon exhaust emissions in grams/mile are calculated based on the carbon weight fraction of each measured constituent
- The carbon content of the fuel in grams/gallon is measured
- Fuel economy is calculated as the ratio of fuel grams C/gallon to exhaust grams C/mile

E85 vs Gasoline Fuel Economy & Efficiency

Parameter	Gasoline		E85	
	Emissions x CWF	Carbon	Emissions x CWF	Carbon
Carbon from HC	0.0509 g/mi x 0.866	0.04 g/mi	0.0554 g/mi x 0.817	0.05 g/mi
Carbon from CO	1.007 g/mi x 0.429	0.43 g/mi	0.413 g/mi x 0.429	0.02 g/mi
Carbon from CO_2	551.1 g/mi x 0.273	150.55 g/mi	525.1 g/mi x 0.273	143.36 g/mi
Total Exhaust Carbon Emissions		150.92 g/mi		143.43 g/mi
Fuel Carbon Content		2439 g/gal		1713 g/gal
Fuel Economy	(2439/150.92)	**16.16 MPG**	(1713/143.43)	**11.94 MPG (-26%)**
Fuel Lower Heating Value		114,365 BTU/gal		82,332 BTU/gal
Energy Efficiency	(114,365/16.16)	**7,077 BTU/mi**	(82,332/11.94)	**6895 BTU/mi (+3%)**

E85 emissions and fuel economy perspective

- Higher exhaust NMOG results from low volatility of E85
  - More E85 needed at cold start to offset low volatility
  - Results in moderately more NMOG before catalyst is active
  - E85 NMOG has a large fraction that is ethanol, which is much less prone to smog formation than gasoline HCs
  - These results are typical of E85
- Significantly lower NOx results from low sulfur level of E85
  - Sulfur acts to slightly impair catalyst reduction of NOx
  - These results are typical of E85

E85 emissions and fuel economy perspective

- Lower evaporative HC results from both lower permeability and low volatility of E85
  - Aromatic HCs in gasoline are primary permeation driver
  - Small gasoline fraction in E85 limits permeation
  - Lower volatility of E85 results in less vapor emissions
  - These results are typical of E85
- Lower CO_2 emissions result from lower E85 carbon content
  - E85 has 30% less carbon per gallon and E85 fuel consumption is 26% higher than gasoline
  - These results are typical of E85

Future challenge – E85 FFV PZEV

GM currently offers a range of E85 FFVs in Cars & Light Trucks

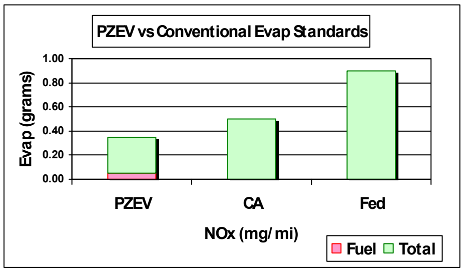
- Committed to grow FFV offerings to 50% of our 2012 MY fleet
  - Contingent on continued progress on fueling infrastructure
- Today's FFVs meet all but the most stringent California emission requirements
  - CARB PZEV emissions standards
  - Progress needed on both FFV exhaust & evaporative emissions to meet PZEV
  - GM working to solve these technical issues so that the PZEV requirements do not preclude providing a full range of E85 FFV offerings in the CA emissions states

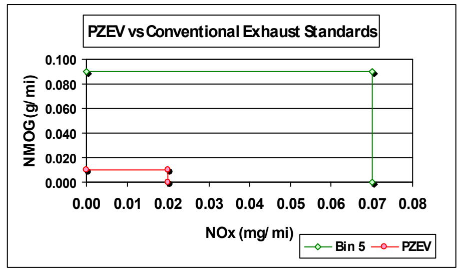
E85 FFVs and CARB's PZEV requirement

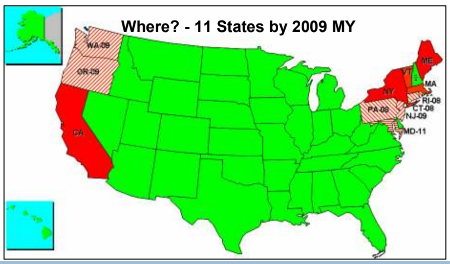
Under the CARB ZEV Mandate a growing fraction of GMs sales each model year through 2018 must be PZEV compliant:

- PZEVs are required to meet the most stringent exhaust & evaporative emissions standards
  - SULEV exhaust emissions:
    - 0.010 g/mi NMOG, 1.0 g/mi CO, 0.020 g/mi NOx
  - Zero evaporative emissions
    - Vehicle fuel evaporative emissions limited to 0.054 g
  - For E85 flex-fuel vehicles the standards apply on worst-case blends of gasoline & ethanol
    - Exhaust emissions on both gasoline and E85
    - Evaporative emissions on E10

ZEV Mandate – PZEV & AT-PZEV overview







Fleet Penetration of PZEV + AT-PZEV	2012-14	2015-17	2018-On
Max PZEV Credit Vehicle Credit ZEV States Penetration	6% 0.2 30%	6% 0.2 30%	6% 0.2 30%
Max AT-PZEV Credit Vehicle Credit ZEV States Penetration	3% 0.60 5%	4% 0.50 8%	5% 0.5 10%
Total ZEV States	35%	38%	40%
U.S. Penetration	**11%**	**11%**	**12%**

E85 FFV challenge meeting SULEV exhaust emissions

SULEV compliant vehicles need the catalyst warmed-up & near-perfect air:fuel ratio control within ~10 seconds of cold start

- E85 fuel has low volatility due to the high fraction of ethanol
  - Requires more excess fuel for cold-start than gasoline
  - Ethanol fraction of excess fuel disturbs air:fuel ratio control as it vaporizes at ethanol boiling point
  - Much more challenging than gasoline in this regard
- Significant improvements required to meet SULEV emissions on E85
  - SIDI (direct injection) fueling systems expected to help
  - More complex exhaust after-treatment anticipated
  - Improved control algorithms & calibrations also needed

E85 FFV challenge meeting Zero evap emissions

Zero evap emissions compliance requires extremely low permeation of fuel through non-metallic fuel system components

- HDPE fuel tank and elastomeric fuel lines & seals
  - Fuel evap loss standard of 0.054 grams
  - Very challenging compliance requirement on gasoline
  - E85 FFVs are certified on E10 blend to represent worst case
  - E10 permeates at roughly double the level seen on gasoline
- E85 FFVs will require metal fuel tank to comply – issues:
  - Platform redesign for crashworthiness with metal tank
  - Corrosion concerns with metal tank
  - Lack of metal fuel tank supply base
- CARB expected to change cert fuel to E10 – this will be a gasoline PZEV issue also

E85 FFV PZEV Summary

GM is aggressively expanding its FFV offerings

- We will provide a full lineup of E85 FFVs to CA states
  - In the near term we are restricting FFV volume where there is an identical PZEV model
  - In the longer term we are working on technical solutions to allow E85 FFVs to meet the PZEV requirements

Opportunities for E85 in California

California Air Resources Board

Meeting on Vapor Recovery for E85 Facilities

February 2, 2006

Gary Herwick

Transportation Fuels Consulting

On behalf of

National Ethanol Vehicle Coalition

National Ethanol Vehicle Coalition

- **Primary national advocate for E85 and flexible fuel vehicles.**
- **The NEVC Board of Directors includes the National Corn Growers Association, state corn grower groups, the Governors' Ethanol Coalition, Verasun Energy, Clean Fuel USA, ethanol producer groups, General Motors and Ford.**
- **To date, the NEVC has 364 members including corporate, individual and associate.**
- **Policy accomplishments include new federal infrastructure tax credit, fuel purchase for federal alternative fuel fleets and flexible fuel vehicle labeling.**
- **There are currently 585 public E85 fueling facilities across the Unites States. In 2005, the NEVC assisted in establishing 323 of these sites.**

California Objectives

- **Non-petroleum fuel use: 20/30% in 2020/2030**
  - **Energy Commission 2005 Integrated Energy Policy Report to the Governor**
  - **Calls for simultaneous emission and GHG reduction**
  - **Long term transport plan to Governor by March 31, 2006 including alternative fuel use**
  - **AB 1007 “Pavley” requires plan by June 2007**
  - **Ethanol and E85 are likely to be a major part of that plan**
- **GHG reductions: 17/27% in 2020/2030 in the vehicle fleet, 22/27% in 2012/2016 in new vehicles**
  - **AB 1493**
  - **Auto industry lawsuit**
  - **Currently not clear how much of a role E85 could play**

Integrated Energy Policy Report Recommended Strategies

- "…move toward more sustainable technologies and fuel types, and build the necessary infrastructure to protect California from future supply disruptions and high prices."
- Increase the use of non-petroleum fuels to 20% by 2020, 30% by 2030
- "The state should simultaneously reduce petroleum fuel use, increase fuel diversity and security, and reduce emissions of air pollution and greenhouse gases."
- "The state should establish a state renewable gasoline fuel standard so that the pool of all gasoline sold in California contains, on average, a minimum of 10 percent renewable content."
- "The state should, for its fleet of vehicles, establish …a procurement requirement for alternative fuels and vehicles......"
- "The Energy Commission should develop petroleum infrastructure permitting guidelines based upon a "best practices" approach following this inter-agency evaluation."
- Greenhouse gas emission reduction strategies are a priority.

E85 and Flex Fuel Vehicles

- **Ethanol has the potential to address reductions in petroleum fuel use and GHG's proposed in California in the near term. E85 and FFVs maximize the use of ethanol.**
- **Based on technical assessment, permeation evaporative emissions may not be an issue with E85**
  - **CRC "E-65" research due to provide data by December 2005**
- **20% GHG reduction with E85 from corn, 60-65% GHG reduction with cellulose E85***
- **Research suggests that 25-30% of the US fuel pool could be replaced by ethanol****
- **Currently about 300,000 FFVs estimated in the California in-use fleet, growing at the rate of 50,000 per year.**
- **E85 can be cost competitive to gasoline at $2.20 per gallon on an energy equivalent basis without subsidies for ethanol.**
- **Alternative Fuel Infrastructure Tax Credit expected to allow credit for 30% of new I/S investment up to $30,000.**

* "An Update of Energy and Greenhouse Gas Emission Impacts of Fuel Ethanol", Michael Wang, Argonne National Laboratory, February 2005.

** GM/University of Toronto research on cellulose ethanol supply

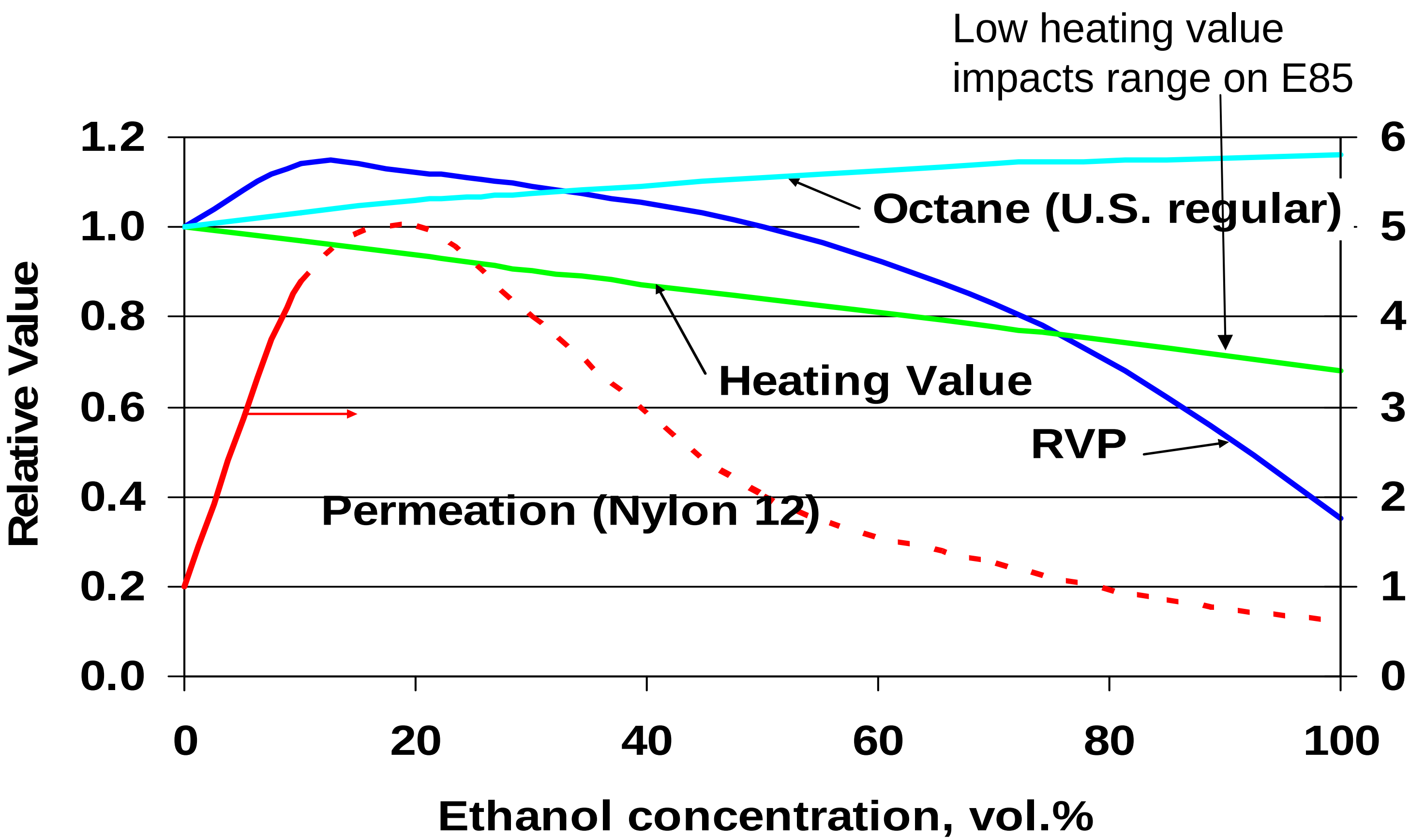
Expansion of E85 and FFVs in California

- **Investment in E85 infrastructure has been discouraged by regulatory requirements**
  - **New processes are likely to encourage development of “novel” facilities**
  - **A long term plan is needed to support widespread infrastructure**
  - **New federal infrastructure tax credit will encourage investment in new stations**
- **Supply/availability of ethanol**
  - **4.7B gal of ethanol would be needed annually to supply 20% of California’s transportation fuel consumption**
  - **Production of ethanol from cellulose would be needed to address GHG reduction targets**
- **Current wholesale fuel prices will require incentives to permit attractive retail pricing approaching energy equivalence**
- **Continued incentives are needed to insure availability of FFVs**
- **Future California emission requirements are likely to limit the availability of E85 FFVs beyond 2007 as PZEVs are sold to meet the ZEV mandate**

Ethanol Issues

- **Evap emission impact of E5.7 & E10 requires mitigating strategies**
- **Tailpipe NOx emissions impact of E5.7 & E10 requires mitigating strategies**
- **Oil industry concerns – API/AIR report on inventory impact**
- **Opposition to ethanol by select environmental groups – national ALA, Sierra Club**
- **Energy Balance - Prof. Patzek at UC Berkley, Pimentel formerly of Cornell Univ.**
- **Sen. Feinstein opposition to RFS – June 15, 2005 letter to Congressional colleagues - high cost, energy balance, ozone impact of E10**
- **Sulfates and peroxides formation**
  - **Fuel pump wear, fuel injector sticking**

Typical Ethanol Impacts on Fuel Properties



Permeation results are illustrative, depend on polymeric material

Summary

- **E85 represents perhaps the best opportunity to address California goals of reducing petroleum fuel use and greenhouse gas emissions.**
- **Several barriers must be addressed including infrastructure development, increased ethanol supply, FFV availability and pricing.**
- **More streamlined certification of a limited number of new "novel" E85 dispensing facilities should help to encourage equipment manufacturers, and identify issues to further infrastructure expansion.**
- **The National Ethanol Vehicle Coalition has played a key role in obtaining incentives and establishing new E85 infrastructure.**
- **NEVC is prepared to participate in the California process and offer assistance and resources**