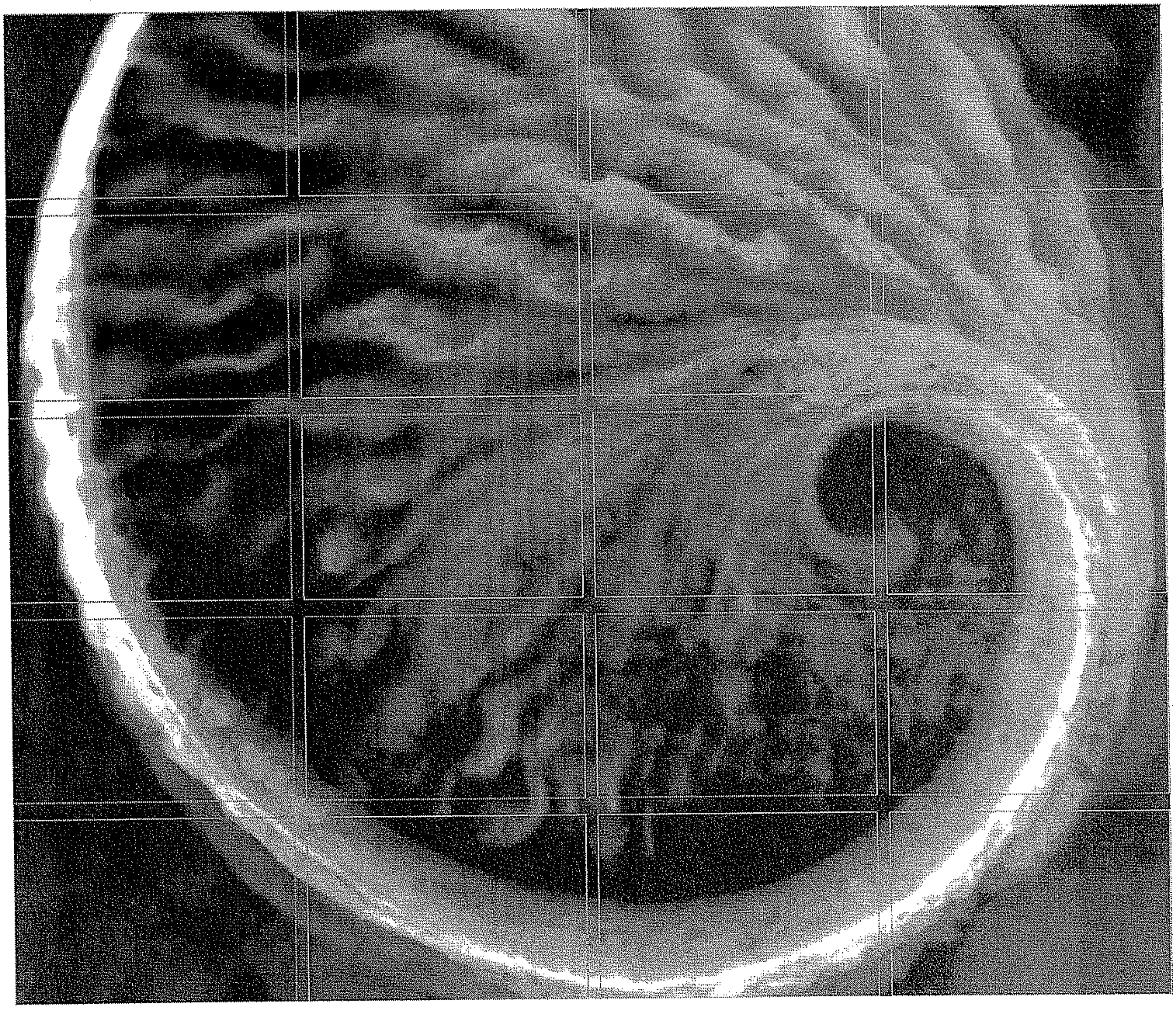


Review of TIAX "Well-to-Wheels" Fuel Cycle Assessment - DRAFT

Prepared for:

Western States Petroleum Association (WSPA)

ERM
March 23, 2007

www.erm.com

Western States Petroleum Association (WSPA)

Review of TIAX "Well-to-Wheels" Fuel Cycle Assessment - DRAFT

March 23, 2007

Project No. 0063379

John M. Beath, P.E.

Partner-in-Charge

Victoria Junquera

Project Manager

Michael Collins

Senior Project Consultant

Environmental Resources Management
15810 Park Ten Place, Suite 300
Houston, Texas 77084-5140
T: 281-600-1000
F: 281-600-1001

TABLE OF CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

Environmental Resources Management (ERM) was commissioned by the Western States Petroleum Association (WSPA) to review the TIAX "Well-to-Wheels" (WTW) fuel cycle assessment methodology, assumptions, and results. The TIAX WTW model is the basis for Assembly Bill (AB) AB-1007 developed by the California Energy Commission (CEC) and the California Air Resources Board (CARB). This bill requires the development of a plan to increase the use of alternative and renewable fuels in California.

ERM has reviewed the full TIAX Wells-to-Wheels (WTW) report, the underlying GREET Model and a number of peer reports to determine the various methodologies and assumptions used in order to inform a critical analysis of the TIAX report.

In order to put this review into perspective, the following reports prepared by others and recommended by WSPA for their relevance, were also reviewed:

- EUCAR, CONCAWE and JRC Well to Wheels Report (version 2c, March 2007),
- GM-Argonne-BP-ExxonMobil-Shell study titled "Well to Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems North American Analysis (June,2001),
- GM Well to Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study (September 2002), and
- Lifecycle Analyses of Biofuels (Draft manuscript, May *2006)* and the lifecycle emissions model (LEM) (Report December 2003), Institute of Transportation Studies, University of California Davis, Mark A. Delucchi.

In all cases ERM has focused more attention on the Wells-to-Tanks (WTT) sections than on the Tanks-to-Wheels (TTW) section which deals with vehicle emissions. This is because ERM feels that TTW assumptions and impacts have been subject to a significant amount of review and criticism by others more qualified to comment on vehicle design and operation. It is well documented that within the boundaries of the TTW portion of the fuel cycle, vehicle technology, combustion and thermal efficiency performance are the main drivers and that these are fundamental in establishing performance and benefits of one system over another.

Based on discussions with WSPA, and in consideration of the limited time available, ERM has limited the scope of this study to the review of the following fuel pathways (considered to be significant and the best benchmarks for analysis of various model impacts): Ethanol (corn feedstock), Ethanol (cellulosic), Biodiesel, Gasoline and Diesel.

Findings

On the basis of the review of the TIAX and peer reports ERM believes that the following areas require further work before the TIAX model can be used for regulatory purposes

1 - Comparison of the Greenhouse Gas Emissions - Results can vary widely based upon input assumptions and calculation techniques. Examined fuel pathways, fuel quality, sensitivity analysis are all masked when examining a final number. For example, the GM (2002) study considers gasoline and diesel in 2010, and this helps impact results showing lower greenhouse gas emissions. Obvious uncertainty in the table below stems from the fact that many numbers are based upon graphs, neglects margins of error and ranges of data, or averages multiple types of a given fuel (example cellulosic feedstock may be from wood or grass).

Because examining only the results masks critical information, a comparison of results highlights the extent to which underlying factors contribute to the message of a study and associated report. Viewed from this high level, it is apparent that:

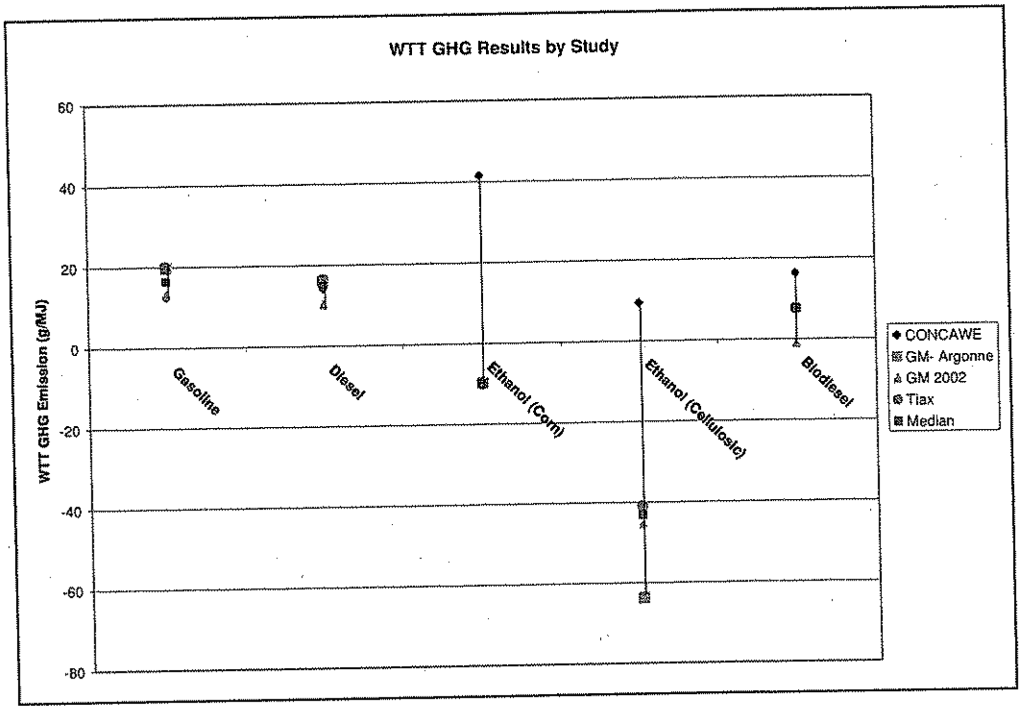
In general, TIAX gasoline and diesel greenhouse gas emissions are greater than other studies for the WTT life cycle portion. Also, in general TIAX ethanol and biodiesel greenhouse gas emissions are lower than other studies for the WTT life cycle portion.

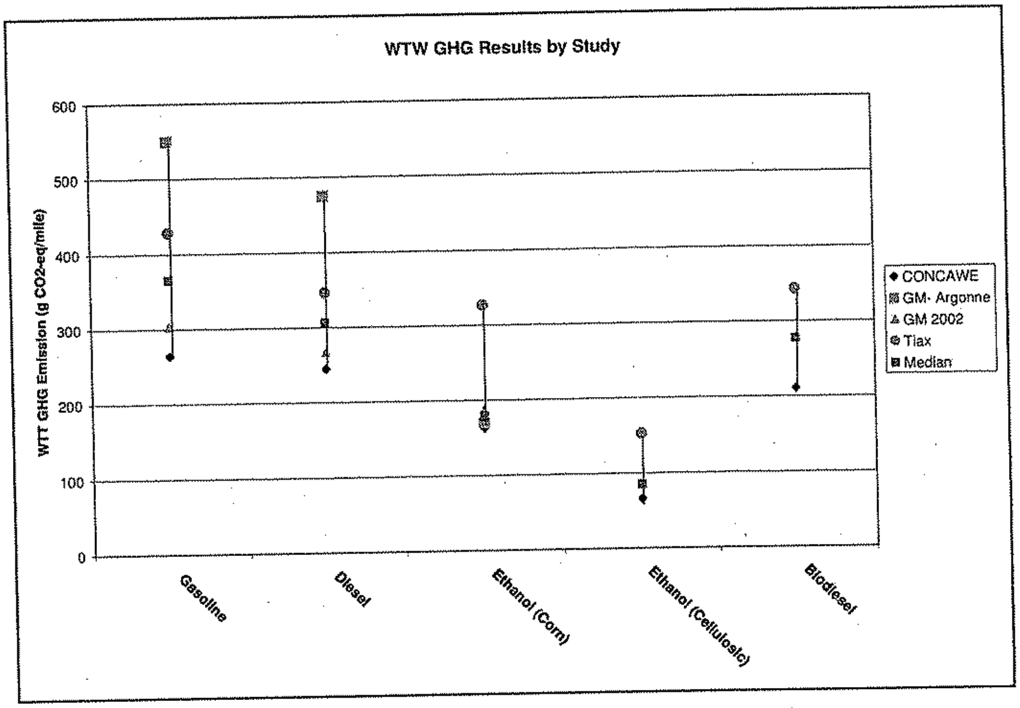
However, GHG emissions reported in TIAX for the full WTW fuel cycle are within the range reported by the other studies reviewed. Moreover, WTW GHG emissions for biofuels (biodiesel and ethanol) are consistently higher in TIAX than in the other studies reviewed.

This is represented graphically below. The range in WTT GHG emission for gasoline and diesel from all of the studies is small, however not insignificant. In contrast the range in WTT GHG emissions for ethanol (corn), ethanol (cellulosic) and biodiesel from the studies examined is very large. This range is likely a reflection of the difference in input assumptions and calculations but nevertheless demonstrates the large uncertainty is estimating WTT GHG emissions from renewable fuels.

The ranges in WTW emissions are very large for all fuel pathways. This reflects a substantial uncertainty in the TTW life cycle portion of the fuel pathways.

More importantly, the range of these values strongly suggests that insufficient evidence exists to mandate a particular fuel policy without further study.





2 - Consequential Impacts - It is clear that the TIAX report does not take into consideration the consequential impacts on the markets for fuels and by-products, or perhaps more importantly, the economic impacts associated with alternative fuel production. ERM understands that economic analysis is subject to separate consideration (presumed to be underway in parallel with this review); however, the importance of combining both environmental and economic impacts to ensure that fully informed decisions can be made should be noted prominently here. Without the economic piece, ERM believes it is quite likely that infeasible, or at least unlikely conclusions could be reached.

3 - Conformance to Standards - A significant criticism that ERM, and others, would level at TIAX is that it does not conform to internationally expected practice with regard to the documentation, reporting and verification of cradle to grave studies. A model that is to be used in such a public and significant manner would be expected to conform to the ISO standards in terms of documentation and peer review (ISO Standards 14040 and 14044). The tool is not transparent, it is not complete (as compared to other models we reviewed) and it is not of appropriate complexity to accurately reflect the emissions implications of California alternative fuel policy, on a Well-to-Wheel basis. With respect to completeness, the following shortcomings were identified:

- *System boundary* - A system boundary was not clearly established, and how and why it was established was not specifically addressed, though key assertions can be inferred from data presented (ISO 14040 4.2.3.3.1);
- *System flow diagram* - A system flow diagram was not included (we developed one) (ISO 14040 4.2.3.3.2);
- *Data attributes* - The data selected was not clearly supported by key characteristics such as precision, completeness, representativeness, consistency, reproducibility, source and uncertainty (ISO 14040 4.2.3.6.2); nor was its selection transparent in terms of why certain values were selected (ISO 14044 5.2 (f)(8));
- *Description of the critical review process* - The standard calls for studies to be released to the public to have been reviewed and the results of the review including a description of the review process to be included with the study report (ISO 14040 5.3.1); and
- *Allocation* - The process of allocating various factors such as energy usage to different elements of the cycle is not discussed, the rationale supporting the decisions is not provided and no sensitivity analysis was used to test the impact of these allocations (ISO 14044 4.3.4.2); and the allocation prioritization was not discussed or utilized (ISO 14044 4.3.4.3.4).

4 - Refinery Efficiency - Refinery efficiency plays a large part in refining-related GHG emissions, and this is not reflected in the TIAX report. ERM performed refining efficiency sensitivity runs to determine how increased gasoline and diesel refining efficiencies affect the WTT GHG emissions reported in the TIAX model for these two fuels. The results clearly show that assumptions regarding refining efficiency can have a very large effect on WTT GHG emissions. Furthermore, TIAX uses lower refinery efficiency values (higher refinery energy intensity values) than other sources. Additional inaccuracies associated with the refinery efficiency values assigned in TIAX result from the fact that the GREET model is not dynamic and does not allow for improvements in gasoline or diesel efficiency over time, and that it allocates refinery energy to various products using a rule of thumb without a strong basis, instead of considering more robust methodologies based on real refinery data

5 – Sensitivity/Uncertainty Analysis - The TIAX model does not incorporate an uncertainty analysis or a sensitivity analysis of the assumptions (most notably, the marginal production approach). ERM performed various modeling runs using GREET 1.7 as modified by TIAX to determine the effect of certain parameters on the TIAX results. One example was to reduce the mass of co-products from corn, ethanol, soybean, and biodiesel production by 20%. The results show general increases in GHG emissions and total energy use, and a dramatic increase (+497%) in GHG emissions for corn-based ethanol. This sensitivity is important since the market for co-products is uncertain, and may be strongly influenced by incentives, supply, operating and transportation cost, capital costs, etc. As noted above refinery efficiency can have a significant impact on WTT GHG emission estimates for gasoline and diesel. TIAX should perform a sensitivity analysis covering, at a minimum, the range of refinery efficiencies quoted on pg 4-1 (84 to 90%) of their Wells to Wheels Report.

The bias that the study has is that TIAX has concluded that gasoline and diesel GHG impacts are unacceptable compared to those for renewables while the data presented, if viewed from a perspective of sensitivity and if the right boundary conditions are selected (as other studies have done) does not support this.

6 - Land Use Assumptions - The TIAX model does not appear to quantify or take into account the land use impacts associated with Biofuel cultivation. Two of the reports reviewed calculated the impacts of land use changes and concluded that the GHG releases associated with the alternate use of land could provide a significant impact over the fuel life cycle. The increase in CO_{2eq} when emissions related to land use are included could range from an increase of 26% for corn/ethanol to 63% for soy/biodiesel. Consideration should also be given to the carbon release resulting from reduced cereal exports. The impacts of fertilizer use should also be considered as N_2O emissions play a major role, and could represent as much as 40% of the agricultural GHG emissions and about 20 to 30% of the total depending on the Model. The results are therefore very sensitive to a change in assumptions regarding these emissions

Before the TIAX report can be used for regulatory purposes, ERM believes that further research and analysis is required in these areas.

7 – Additional Analysis Required

The following list provides a summary of the premises and/or assumptions in the TIAX study that require additional analysis to provide more robust results.

- Biofuel crops will not displace existing grasslands or forest lands;
- The market for biofuel by-products will be large enough to absorb all the by-products generated during crop farming and biofuel manufacture;

- The benefits from biofuel by-products are proportional to their volume (allocation method) rather than to the products they replace (substitution method);
- Agricultural runoff associated with marginal biofuel crop production will not affect California;
- Water use associated with marginal biofuel crop production is zero because the crops will be grown in non-irrigated agricultural land;
- Marginal corn is produced in the Midwest;
- Marginal refinery feedstock and products are produced in the Middle East;
- Refinery efficiency will not increase over time;
- Refinery capacity in California will not increase (expansions are in fact planned as a result of the availability of cap-and-trade programs);
- The model baseline and associated impacts to the environment will not change over time;
- Infrastructure and construction are not taken into account; especially worthy of consideration is the required infrastructure for ethanol distribution in the U.S.;

These observations represent the priority areas and impacts that require further work before the report should be used for regulatory purposes

1.0 *BACKGROUND*

The California Energy Commission (CEC) contracted TIAX to complete a WTW inventory of Greenhouse Gas (GHG) emissions, air toxics emissions, criteria pollutant emissions, and multi-media impacts to water and soil for a number of conventional, alternative and renewable fuels. The TIAX study is a "Well-to-Wheel" (WTW) full fuel cycle assessment, which combines the results from a "Well-to-Tank" (WTT) assessment and a "Tank-to-Wheel" (TTW) assessment of environmental impacts. The TIAX model will be used by CEC and the California Air Resources Board (CARB) in the development of a plan to increase the use of alternative and renewable fuels in California, as mandated by AB-1007.

Additionally, the California Governor signed into law AB-32 in 2006 requiring that California's GHG emissions be reduced to 1990 levels by the year 2020. The program is to include a market-based cap and credit trading program for GHG emissions. An essential element of the resulting AB-32 work is the development of both current and 1990 GHG emission inventories. Part of the well-to-wheels GHG emissions estimated from the TIAX report will be captured in that AB-32 inventory projection.

To support AB-32 emission targets, California's Governor issued an Executive Order in January of 2007 establishing a Low Carbon Fuel Standard (LCFS) by which fuel providers are required to reduce by 10% the carbon intensity of the California transportation fuel by 2020. The Governor also called on the Universities of California (UC) at Berkeley and Davis to conduct studies to provide both policy and technical guidance to aid CARB in this effort. The UC Study is to be incorporated into the AB-1007 report.

The resulting AB-1007 report is to be used to help CARB decide whether to adopt the LCFS as an Earlier Action under California's AB-32 GHG Program by June 2007. The TIAX model will likely impact the resulting LCFS requirements. The AB-1007 report is expected to be approved by both the Commission and Board before ARB adopts the AB-32 Early Action List.

WSPA commissioned ERM to perform a review of the assumptions and calculation procedures associated with the TIAX model. WSPA also asked ERM to develop answers to a number of questions about the TIAX model, and how it compares to existing full fuel life cycle models.

Section 2 addresses the scope of the review performed by ERM.

Section 3 covers the full fuel life cycle models that were reviewed by ERM at the request of WSPA.

Section 4 addresses each question posed by WSPA.

2.0 *SCOPE*

ERM has reviewed the full TIAX Wells-to-Wheels (WTW) report, but has focused more attention on the Wells-to-Tanks (WTT) section than on the Tanks-to- Wheels (TTW) section, which deals with vehicle emissions. This is because ERM feels that TTW assumptions and impacts are relatively well-established and subject to less uncertainty than the WTT considerations.

The TIAX model analyzes over 50 fuel pathways and blends based on feedstock type and origin (e.g., Midwest corn vs. Brazilian sugarcane; use of natural gas vs. coal for energy), fuel production process (e.g., dry mill vs. wet mill), blends (e.g., E85 vs. E10), and other considerations. ERM has limited the scope of this study to the review of the fuel pathways listed below, which are considered to be significant and the best benchmarks for analysis of various model impacts:

- Ethanol, corn feedstock;
- Ethanol, cellulosic feedstock;
- Biodiesel;
- Gasoline; and
- Diesel.

3.0 *FUEL CYCLE ASSESSMENT MODELS REVIEWED*

3.1 *TIAX (2007)*

The TIAX study was prepared by TIAX for the California Energy Commission to "ensure that fair comparisons are made between the various alternative fuels" when setting goals "for increased use of alternative transportation fuels without material increases in air or water pollution" in California (WTT, 2007).

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), sponsored Argonne National Laboratory to develop a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It is intended to be used to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. According to their web site, the first version of GREET was released in 1996. Since then, Argonne has continued to update and expand the model. The most recent GREET version is GREET 1.7 that is intended for fuel-cycle analysis.

The TIAX model consists of two Microsoft Excel spreadsheets with built-in macros. The first spreadsheet is a modified (by TIAX) version of GREET 1.7. The second spreadsheet, called the "wtw processor" uses the WTT input from GREET and TTW assumptions and calculations to arrive at WTW results. ERM reviewed the following spreadsheets:

- greet1.7row_us_ca_v53.xls; and
- wtw_processor 28 feb 07_r.xls .

A diagram of the TIAX model boundaries derived by ERM in its review is included in Attachment XX. Note that the pathways included in the diagram are limited to the fuels listed in the Scope section (gasoline, diesel, biodiesel, corn ethanol, and cellulosic ethanol).

3.2 *CONCAWE-EUCAR-JRC (2007)*

The European Council for Automotive R&D (EUCAR), the oil companies' European association for environment, health and safety in refining and distribution (CONCAWE) and the European Union Commission's Joint Research Centre (JRC) have performed a joint evaluation (referred to hereafter as CONCAWE) of the Well-to-Wheels energy use and GHG emissions for a wide range of potential future fuels and powertrains options. Assistance was provided by personnel from L-B-Systemtechnik GmbH (LBST) and the Institut Français de Pétrole (IFP).

The study is based on collaboration with LBST which enabled access to the comprehensive database compiled by the Transport Energy Strategy Partnership

(TES) consortium and in the course of the study carried out by General Motors et al. in 2001-2002.

The most recent document (dated March 07, ref 2c) reports on the second release of this study, replacing version 2a published in December 2005. The original version 1b was published in December 2003.

The specific objectives of the study were to:

- Establish, in a transparent and objective manner, a consensual well-to-wheels energy use and GHG emissions assessment of a wide range of automotive fuels and powertrains relevant to Europe in 2010 and beyond;
- Consider the viability of each fuel pathway and estimate the associated macro-economic costs; and
- Have the outcome accepted as a reference by all relevant stakeholders.

The CONCAWE Study aims to evaluate the impact of fuel and/or powertrain substitution in Europe on global energy usage and GHG emissions balance, i.e. taking into account induced changes in the rest of the world. In terms of cost, however, the study focused on Europe as a macro-economic entity, taking into account, in particular, the commodity markets that govern the prices of a number of raw materials and products. While economics are not traditionally part of a traditional life cycle analysis, ERM suggests that a view of fuel issues cannot be considered complete without consideration of economics.

The CONCAWE study does not claim to be a comprehensive Life Cycle Analysis. It does not consider the energy or the emissions involved in building the facilities and the vehicles, or the end of life aspects. It concentrates on fuel production and vehicle use, which are the major contributors to lifetime energy use and GHG emissions. No attempt has been made to estimate the overall "cost to society" such as health, social or other speculative cost areas.

The study:

- Only considers sources of biomass which have the potential to substitute a significant amount of transport fuel in the EU and as such does not model ethanol production from corn;
- Uses concept of 'reference crop' - the alternative use of land under set aside. The reference crop used is grass. The baseline agricultural scenario uses an updated version of the DG-AGRI's "Prospects for Agricultural markets and income in the EU" which now projects more set-aside and less cereals export;
- Bases yields on 2012 yields for EU-25 projected by DG-AGRI.B28;
- Accounts for manure use in reference scenario - based on availability rather than which crop is grown;
- Does not attribute farming inputs to the maintenance of the field in set-aside; and
- Accounts for GHG consequences of plowing up grassland.

The study addresses the impacts associated with by-products as follows:
The study endeavors to represent the "incremental" impact of by-products. This implies that the reference scenario must include either an existing process to generate the same quantity of by-product as the alternative-fuel scenario, or another product which the by-product would realistically replace. The implication of this logic is the following methodology:

- All energy and emissions generated by the process are allocated to the main or desired product of that process; and
- The by-product generates an energy and emission credit equal to the energy and emissions saved by not producing the material that the co-product is most likely to displace.

This "substitution" method attempts to model reality by tracking the likely fate of by-products rather than using "allocation" methods whereby energy and emissions from a process are arbitrarily allocated to the various products according to e.g. mass, energy content, "exergy" content or monetary value. Although such allocation methods have the attraction of being simpler to implement, they have no logical or physical basis. It is clear that any benefit from a by-product must *depend on what the by-product substitutes:* all allocation methods take no account of this, and, as such may give misleading results.

The conclusions drawn in the CONCAWE study are as follows:

- A shift to renewable/low fossil carbon routes may offer a significant GHG reduction potential, but generally requires more energy. The specific pathway is critical;
- No single fuel pathway offers a short term route to high volumes of "low carbon" fuel;
    - o Contributions from a number of technologies/routes will be needed;
    - o A wider variety of fuels may be expected in the market;
    - o Blends with conventional fuels and niche applications should be considered if they can produce significant GHG reductions at reasonable cost;
- Transport applications may not maximize the GHG reduction potential of renewable energies; and
- Optimum use of renewable energy sources such as biomass and wind requires consideration of the overall energy demand including stationary applications. More efficient use of renewables may be achieved through direct use as electricity rather than road fuels applications.

In order to combine all uncertainties in a pathway and arrive at a plausible range of variation for the total pathway, the study used the traditional Monte Carlo approach. Subsequent calculations were carried out with the median figure.

3.3 *GM-ARGONNE-BP-EXXONMOBIL-SHELL (2001)*

The Global Alternative Propulsion Center (GAPC) of General Motors Corporation (GM) commissioned the Center for Transportation Research (CTR) of Argonne National Laboratory (ANL) to conduct a study to evaluate energy and emission impacts of producing different transportation fuels from wells to fuels available in vehicle tanks (WTT analysis).

Three energy companies — BP, ExxonMobil, and Shell —participated in the study by providing input and reviewing Argonne's results.

The purpose of GM-Argonne-BP-ExxonMobil and Shell (GM-ANL) Study was to evaluate the energy and GHG emission impacts associated with producing different transportation fuels.

Part 1 of the GM-ANL Study was conducted by ANL and covers the Well-to-Tank (WTT), which includes feedstock and fuel-related stages. GM evaluated the fuel economy and emissions of various vehicle technologies using different fuels (TTW analysis) in Part 2. In a separate effort, ANL's WTT results were combined with GM's TTW results to produce WTW results in Part 3.

To complete Part 1 of the study, the GREET model, which was developed by Argonne, was used to estimate WTT energy and emission impacts of alternative transportation fuels and advanced vehicle technologies.

For energy use modeling, GREET computes total energy use (all energy sources), fossil energy use (petroleum, natural gas, and coal), and petroleum use. For emissions modeling, GREET estimates three major GHGs specified in the Kyoto protocol (carbon dioxide [CO2]), methane [CH4], and nitrogen dioxide [N2O]) and five criteria pollutants (volatile organic compounds [VOCs], carbon monoxide [CO], nitrogen oxides [NOx] particulate matter with diameters of 10 µm or less [PM10], and sulfur oxides [SOx]).

For the GM-ANL study, only total energy, fossil energy, and petroleum use, as well as CO2- equivalent emissions of the three GHGs were estimated. Emissions of criteria pollutants were not included in this study.

With the assistance of the project team, ANL modified the GREET model to make it stochastic in nature, i.e., providing confidence bounds around best estimates to quantify uncertainty. The probabilistic simulations employed in this study, rather than the range-based simulations used in many previous ANL studies, are intended to address uncertainties statistically. For each activity associated with the production process of each fuel, the following parametric values for probability: 20%, 50%, and 80% (P20, P50, and P80) were determined.

The GM-ANL Study analyzed a total of 13 fuels. The fuels listed in the discussion below are limited to the fuels listed in the Scope section (gasoline, diesel, biodiesel, corn ethanol, and cellulosic ethanol). The GM-ANL Study did not address biodiesel fuels.

Petroleum-Based Fuels - The TTW study included two petroleum-based fuels: gasoline and diesel. For gasoline and diesel, cases were established to represent different fuel requirements. For gasoline, federal conventional gasoline (CG), federal Complex Model Phase 2 reformulated gasoline (FRFG2), California Phase 2 reformulated gasoline (CARFG2), California Phase 3 reformulated gasoline (CARFG3), and the gasoline requirements in the U.S. Environmental Protection Agency's (EPA's) Tier 2 vehicle emission standards were considered. These gasoline options contain sulfur at concentrations ranging from 5 parts per million (ppm) to over 300 ppm and may contain methyl tertiary butyl ether (MTBE), ethanol (EtOH), or no oxygenate. For on-road diesel fuels, a current diesel and a future diesel were studied. The current diesel has a sulfur content of 120–350 ppm. The future diesel, which reflects the new diesel requirement adopted recently by EPA, has a sulfur content below 15 ppm.

Ethanol Fuels - Three ethanol production pathways were considered: ethanol from corn, woody biomass (trees), and herbaceous biomass (grasses). Corn-based ethanol can be produced in both wet milling or dry milling plants; and both of these options were studied. Corn-based ethanol plants also produce other products (primarily animal feeds). Energy use and emissions were allocated between ethanol and its co-products by using the market value method.

Results

Total energy use from production – The Study found that petroleum based fuels (gasoline and diesel) offers the lowest total energy use for each unit of energy delivered to vehicle tanks. Corn-based ethanol is subject to moderate WTT energy losses and cellulosic ethanol is subject to large WWT energy losses. (Assumption note: the GREET model measurement of total energy includes both energy loses from WTT *and* energy contained in the fuel delivered. The Argonne study presents total energy use as energy losses only)

Fossil energy use from production - except for cellulosic ethanol, the patterns of fossil energy use are similar for gasoline, diesel, and corn-based ethanol as those for total energy use. For cellulosic ethanol, fossil energy use is much lower than total energy use (a large amount of lignin is burned in ethanol plants, hence less petroleum)

Petroleum use from production - production of all petroleum-based fuels (gasoline, diesel) involves high petroleum use; therefore, the amount of petroleum used in the three ethanols is similar to that used in the gasoline and diesel pathways because a large amount of diesel fuel is consumed during farming and during transportation of corn and cellulosic biomass.

GHG emissions - Gasoline and diesel are associated with lower WTT GHG emissions (relative to other studied fuels) because of their high production efficiency. The three ethanols have negative GHG emissions because of carbon uptake sequestration during growth of corn plants, trees, and grasses. Corn ethanol has smaller negative GHG values because use of fossil fuels during corn farming and in ethanol plants which offsets some of the CO2 sequestered during growth of corn plants. All the carbon sequestered during biomass growth is released back to the air during combustion of ethanol in vehicles, which is accounted for in the integration of the WTT and TTW analyses.

Study Assumptions Discussion

As discussed earlier, with this study ANL began to formally address uncertainties in the GREET model involved in key input parameters with subjective probability distribution functions. Previously, ANL addressed uncertainties with range estimates for key input assumptions. In this study, ANL began to explore probability distribution functions for some of the key input parameters. Instead of point estimates included in previous GREET versions, the new version generates results with probability distributions. The study provides best estimates and associated confidence bounds of the study areas mentioned above to allow the reader to assess differences between fuel/vehicle propulsion systems on a more statistically sound basis. According to the authors, this approach provides not only the best estimate, but also a measure of the uncertainty around the best estimate.

Land use does not seem to be included in the WTT analysis but does get mentioned as the reason corn-based ethanol is excluded from the TTW analysis - it was deemed that the supply of corn-based ethanol will not be adequate for use in high-volume transportation applications (even if the predicted doubling of production to about 3 billion gallons/year in 10 years did occur). The study indicated that, "Although the production of corn ethanol could be doubled in ten years, the amount produced still would be adequate to supply only the ethanol blend market. It does not appear that the supply of corn-based ethanol will be adequate for use in high-volume transportation applications; as a result, we eliminated corn-based ethanol from the analysis. The economics of cellulosic ethanol are not currently competitive with those of gasoline. Further, it has yet to be determined whether cellulosic biomass faces resource availability constraints."

This Study considers fuels and vehicles that might, albeit with technology breakthroughs, be commercialized in large volumes and at reasonable prices. In general, fuels and propulsion systems that appear to be commercially viable only in niche markets are not considered.

Crude oils with different sulfur contents and API gravity values have different impacts on refining energy intensities of US refineries and consequently on petroleum refinery energy use and emissions of the three US Crude Production regions (CA, Alaska and Gulf area). California crude contains more sulfur than does crude from the Gulf area and Alaska; and crude from California and Alaska is heavier than that from the Gulf. This implies that petroleum refineries processing California and Alaska crude feeds need to employ more intensive refining processes than those with Gulf Coast crude. Figure 3.1 below provides the assumed values used for the quality of crude oil; Figure 3.2 below provides the overall refinery energy efficiency ranges assigned for conventional gasoline and the other studied combinations of refined gasoline with different sulfur values; and Figure 3.3 shows the energy efficiency ranges used for production of gasoline and diesel fuels.

FIGURE 3.1: GM-ARGONNE-BP-EXXONMOBIL-SHELL MODEL, ASSUMED VALUES USED FOR THE QUALITY OF CRUDE OIL.

Table 5 Quality of Crude Oil Used in U.S. Refineries

Country	API Gravity[a] Range	API Gravity[a] Median	Sulfur Content (wt. %)[a] Range	Sulfur Content (wt. %)[a] Median	Sources of U.S. Crude (1000 bbl/yr)[b]
United States					2,281,980
Gulf Area	31.0–40.8	35.9	0.34–2.00	1.17	636,880
Alaska	22.4–27.5	25.0	1.11–1.82	1.47	428,851
California	19.4–35.2	27.3	0.21–4.29	2.25	283,628
Saudi Arabia	27.4–38.7	33.1	1.19–2.80	2.00	517,072
Venezuela	10.1–31.8	21.0	1.10–5.50	3.30	499,580
Mexico	22.2–39.8	31.0	0.80–3.30	2.10	477,171
Canada	20.7–40.7	30.7	0.37–3.15	1.76	378,598
Nigeria	25.2–40.9	33.1	0.09–0.29	0.19	258,640
Angola	31.7–33.7	32.7	0.17–0.23	0.20	177,958
Colombia	30.8–36.4	33.6	0.25–0.47	0.36	130,364
Iraq	24.7–35.1	29.9	1.97–3.50	2.74	114,513
Kuwait	18.6–31.4	25.0	2.52–4.55	3.54	109,142
Norway	29.3–43.4	36.4	0.14–0.44	0.29	80,820
Gabon	31.8–39.5	35.7	0.05–0.11	0.08	75,543
The U.K.	33.6–41.7	37.7	0.05–1.01	0.53	66,002

[a] From *Oil and Gas Journal* (1999).
[b] From Energy Information Administration (1999).

FIGURE 3.2: GM-ARGONNE-BP-EXXONMOBIL-SHELL MODEL, OVERALL REFINERY ENERGY EFFICIENCY RANGES

Table 7 Overall Energy Efficiencies of Petroleum Refineries Extracted from MathPro Studies

Refinery	Refinery Overall Energy Efficiency (%) Low	Refinery Overall Energy Efficiency (%) High	Source
Producing federal CG with 340 ppm S	88.4	88.4	MathPro (1999b)
Producing 150 ppm S FRFG2 with MTBE	87.7	87.9	MathPro (1999b)
Producing 5–30 ppm S RFG with MTBE	87.7	89.5	MathPro (1999a, 1999c)
Producing 5–30 ppm S RFG with EtOH	87.4	88.9	MathPro (1999a, 1999c)
Producing 5–30 ppm S RFG without oxygenate	87.6	87.8	MathPro (1999c)

FIGURE 3.3: GM-ARGONNE-BP-EXXONMOBIL-SHELL MODEL, ENERGY EFFICIENCY RANGES USED FOR PRODUCTION OF GASOLINE AND DIESEL FUELS

Table 8 Energy Efficiencies of Producing Gasoline and Diesel Fuels

Fuel	Results from MathPro Simulations (%)		Values Adopted in This Study (%)	
	Low Efficiency[a]	High Efficiency[a]	Low Efficiency[a]	High Efficiency[a]
340 ppm S CG	84.5	85.5	85	86
150 ppm S RFG with MTBE	83.7 (84.7)	84.9 (85.9)	84 (85)	86 (87)
5–30 ppm S RFG with MTBE	83.6 (84.6)	86.9 (87.9)	83 (84)	86 (87)
5–30 ppm S RFG with EtOH	83.3 (84.4)	86.2 (87.2)	83 (84)	86 (87)
5–30 ppm S RFG3 without oxygenate	83.5	84.8	83	86
120–350 ppm S diesel	87.0	89.2	88	90
5–30 ppm S diesel	86.8	89.0	85	89
5–30 ppm S crude naphtha	89.0	93.0	89	93

[a] Numbers in parentheses are efficiencies for production of gasoline blendstocks for RFG. The increased efficiencies for gasoline blendstock production reflect the octane enhancement effect of adding oxygenates into RFG.

In terms of by-products, this study assumes that for cellulosic (woody and herbaceous) ethanol plants, co-generation systems can be employed to generate both steam and electricity. In this case, extra electricity can be generated for export to the electric grid. The GM-ANL Study took the generated electricity credit into account in calculating energy use and GHG emissions for cellulosic ethanol production. In estimating energy and emission credits for cellulosic ethanol electricity, the U.S. average electric generation mix was used and a market value was assigned.

For corn-to-ethanol pathways, key input parameters determining ethanol's energy and GHG emissions impacts include: (1) energy use of corn farming (Btu per bushel of corn harvested), (2) nitrogen fertilizer use of corn farming (grams per bushel of corn harvested), (3) N2O emissions from nitrification and denitrification of nitrogen fertilizer in cornfields (grams of nitrogen in N2O per gram of nitrogen in nitrogen fertilizer applied to cornfields; N2O is 310 times as potent as CO2 in terms of potential global warming effects), (4) energy use in ethanol plants (Btu per gallon of ethanol produced), (5) ethanol yield per bushel of corn, and (6) ways of dealing with ethanol co-products. .

For biomass-to-ethanol pathways, key input parameters include: (1) energy use for farming of trees and grasses, (2) fertilizer use for farming of trees and grasses, (3) N2O emissions from nitrification and denitrification of nitrogen fertilizer in biomass farms, (4) ethanol yield per ton of biomass, and (5) electricity credit from cellulosic ethanol plants. Figure 3.4 below lists the assumption values used for the GM-ANL Study.

FIGURE 3.4: GM-ARGONNE-BP-EXXONMOBIL-SHELL MODEL, ASSUMPTIONS

Table 10 Parametric Assumptions for Ethanol Production Pathways[a]

Item	Pessimistic Assumption	Optimistic Assumption
Corn farming energy use (Btu/bushel of corn harvested)	18,990	17,090
Corn farming N fertilizer use (g/bushel of corn harvested)	440	396
N_2O emissions in cornfields (N in N_2O as % of N in N fertilizer)	1.5	1.5
Soil CO_2 emissions (g/bushel of corn harvested)	390	0
Energy use for tree farming (Btu/dry ton of trees harvested)	234,770	211,290
Energy use for grass farming (Btu/dry ton of grass harvested)	217,230	195,510
N fertilizer use for tree farming (g/dry ton of trees harvested)	709	638
N fertilizer use for grass farming (g/dry ton of grass harvested)	10,633	9,570
N_2O emissions in biomass farms (N in N_2O as % of N in N fertilizer)	1.3	1.3
Soil CO_2 sequestration in tree farms (g/dry ton of trees harvested)	0	-225,000
Soil CO_2 sequestration in grass farms (g/dry ton of grasses harvested)	0	-97,000
EtOH yield of dry milling plants (gal/bushel)	2.6	2.6
EtOH yield of wet milling plants (gal/bushel)	2.5	2.7
Energy use in dry milling plants (Btu/gal)	41,400	36,900
Energy use in wet milling plants (Btu/gal)	40,300	34,000
EtOH yield of woody biomass plants (gal/dry ton)	76	98
EtOH yield of herbaceous biomass plants (gal/dry ton)	80	103
Electricity credit in woody biomass plants (kWh/gal)	-1.730	-1.730
Electricity credit in herbaceous biomass plants (kWh/gal)	-0.865	-0.865

[a] From Wang (1999a).

3.4 *GM EUROPEAN STUDY (2002)*

The GM European Study (2002) study was prepared by GM and L-B-Systemtechnik GmbH, with support from BP, ExxonMobil, Shell, TotalFinaElf, in order for the California Energy Commission to "identify alternative fuels and powertrains for passenger cars which may have a technical and environmental potential to compliment, and eventually substitute, gasoline and diesel conventional fuels and powertrain". The study was initiated in GM in May 2001, completed in September 2002 and serves as a compliment to June 2001 GM-Argonne study. Within the study, a target year of 2010 was used evaluate energy use and greenhouse gas emissions for various fuel pathways. Market saturation factors were not considered. The study did not consider manufacturing or construction of plant, systems, or subsystems equipment.

The paragraphs below discuss some boundary considerations and focus on those areas different than the TIAX model.

Gasoline and Diesel- The GM European Study (2002) uses GEMIS (Global Emission Model of Integration Systems) data as a source for determining the source of crude oil supply in target year 2010. GEMIS notes only 40% from OPEC countries. Within the exploration numbers are expected flare gas emissions for 2010 and 2010 fuel quality which must meet 2005 standards.

The pathway assumes the European crude oil mix is transported via ship 7600 km to a European port, then to a near-port refinery. Although refinery calculations do assume that no additional electricity is needed to run the plant, additional by-product value, such as that from residual oil and coke production, is not included. Refined products are transported via ship, pipeline, or railcar to a terminal, and then transported via truck 150 km to a refueling station.

Lignocellulose Ethanol- The GM European Study (2002) studies two lignocellulose ethanol pathways, one residual straw and the other for poplar crop. The pathway begins by considering planting and cultivation and the study boundary includes direct (formation and decomposition of nitrogen dioxide in the soil) and indirect (fertilizer nitrogen that is not utilized by the crop which is lost in the system, commonly due to leaching and runoff, which produces nitrogen dioxide emissions) nitrogen dioxide emissions, as well as production of synthetic fertilizers. The study uses International Panel on Climate Change (IPCC) guidelines for nitrogen dioxide emission calculations. Notably, as pointed out in the study, carbon dioxide emissions from land use change, while difficult to model with accuracy and therefore not included, may have a significant influence on GHG emissions. By-product GHG credits are not within the study boundary considerations for lignocellulose ethanol.

In the model's fuel pathway, dedicated crop harvest is collected and transported 50 km to an ethanol plant. There the biomass is converted to ethanol by enzymatic hydrolysis and distillation. Then ethanol is trucked 150 km to the terminal and then dispensed.

Biodiesel/FT Diesel- The GM European Study (2002) study includes two biodiesel pathways, namely (1) an evaluation of diesel, blended with 5% rapeseed methyl ester (RME), and (2) an evaluation of wood residues converted to hydrocarbon fuels (including diesel) via either Hydro Thermal upgrading with downstream Hydro-de-Oxygenation or via gasification and downstream Fischer-Tropsch synthesis. Henceforth, pathway one will be referred to as diesel blended with 5% RME and pathway two will be referred to as FT-diesel. Biodiesel pathways begin by considering planting and cultivation with similar boundary inclusions and exclusions as lignocellulose ethanol (example direct and indirect nitrogen dioxide emissions, and exclusion of by-product GHG credits.)

For diesel blended with 5% RME, the seed is collected and transported 50 km to an oil processing plant. There the oil is extracted, refined, and esterified with methanol. Then the oil ester is trucked 150 km for blending with diesel fuel. The fuel pathway does not extend to the fueling station. Significant consideration is given to how the crop is grown, including synthetic fertilizer use and its affects on yield, and whether or not the crop is "plowed in". For "plowed in" crop, overall yield is less but, more importantly, nitrogen dioxide emissions are less due to less synthetic fertilizer use.

For FT-diesel, the pathway begins with woody biomass collection. The biomass is trucked 50 miles for processing. Following processing, FT-diesel is trucked 150 km to the refueling station and then dispensed.

Conclusions from the Study

With respect to energy use, shown in Figure 3.5, crude-oil based fuels such as gasoline and diesel remain the most efficient, followed by FT-diesel from residual wood, and ending with lignocellulose ethanol as the least efficient.

FIGURE 3.5: GM STUDY RESULTS, ENERGY USE

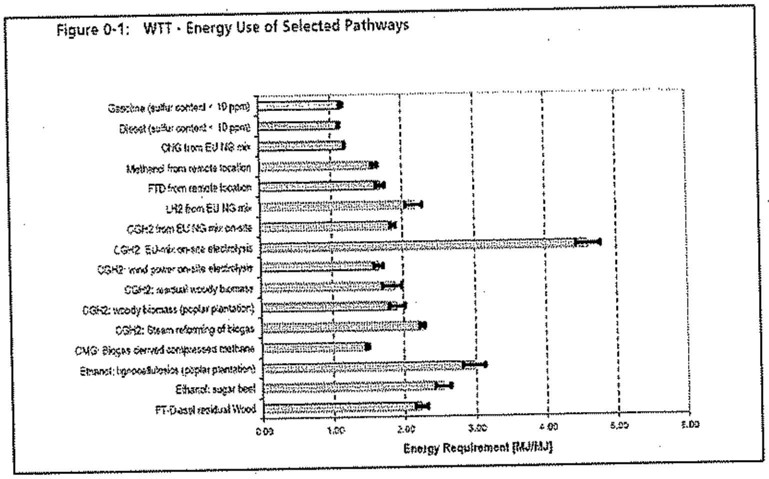
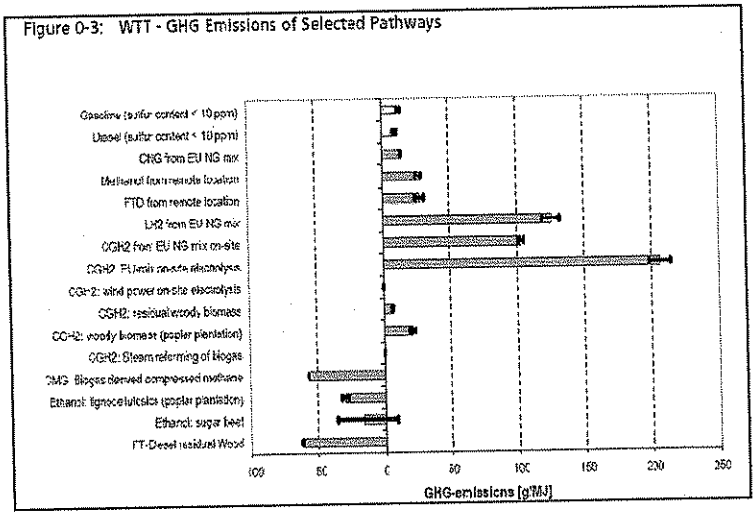


FIGURE 3.6: GM STUDY RESULTS, GHG EMISSIONS



Biomass pathways, including ethanol and biodiesel, have significantly different GHG results based upon the given situation. The differences are largely due to nitrogen dioxide emissions considered in planting and cultivation. These nitrogen dioxide emissions vary based on modifications of microclimate and soil conditions due to crop selection, soil tillage, mulching, fertilization, irrigation, and liming and occurs until a new equilibrium is reached. Land-use causing carbon dioxide emissions, if considered, may also significantly impact results.

3.5 *UC DAVIS (2003)*

The model and its outputs are documented in two main reports:

- LIFECYCLE ANALYSES OF BIOFUELS Draft manuscript, May 2006, Institute of Transportation Studies University of California Davis, Mark A. Delucchi.

- A lifecycle emissions model (LEM): lifecycle emissions from transportation fuels, motor vehicles, transportation modes, electricity, use, heating and cooking fuels, and materials -Documentation of methods and data- UCD-ITS-RR-03-17 MAIN REPORT, December 2003, Institute of Transportation Studies, University of California Davis, Mark A. Delucchi.

The UC Davis model developed by Mark Delucchi is called Lifecycle Emissions Model (LEM). LEM estimates energy use, criteria pollutant emissions, and carbon dioxide-equivalent greenhouse gas (GHG) emissions for conventional and alternative energy sources for different transportation modes. It includes passenger and freight transport. The model was developed to reflect the U.S as a whole, and not just one state (but it does have that capability). The tool was developed to evaluate emissions reduction strategies for urban air pollutants and greenhouse gases.

The LEM addresses the complete life cycle from cradle to grave of fuels, the lifecycle vehicles, materials, and infrastructure. It provides inventories of emissions for different energy policies for regulated air pollutants and greenhouse gases. The UC Davis Study is comprehensive in its coverage of the life cycle of fuels. It can be used to model fuel production and consumption for 20 countries, for the years 1970 to 2050, but it has the greatest specificity and functionality for the U. S. The tool projects energy use, emissions, emission control, and other parameters through the year 2050.

The road transport modes covered are:
- Light Duty Gasoline Vehicle (LDGV);
- Heavy Duty Diesel Vehicle (HDDV);
- Internal Combustion Engine Vehicle (ICEV), diesel (low-sulfur);
- ICEV, natural gas (CNG);
- ICEV, liquefied petroleum gas (LPG) (P95/BU5);
- ICEV, ethanol (corn);
- ICEV, ethanol (grass);
- ICEV, methanol (wood); and
- ICEV, soy diesel (vs.HDDV).

The pollutants covered in the model:
- Carbon dioxide equivalents;

- Carbon dioxide;
- Methane;
- Nitrogen dioxide;
- Carbon monoxide;
- nitrogen oxides;
- NMVOC;
- Sulphur dioxide;
- PM;
- PM10;
- Hydrogen;
- CFC-12; and
- Hydrofluorocarbon(HFC)-134a

The life cycle stages covered are:

- Vehicle use
- Fuel dispensing
- Fuel distribution and storage
- Fuel production
- Feedstock transmission
- Feedstock recovery

Life cycle elements included in the modeling and separately addressed:

- Land-use changes, cultivation
- Fertilizer manufacture
- Gas leaks and flares
- CO2, H2S removed from NG
- Emissions displaced through by-products and energy generation from systems

For crop-based systems the model addresses all of the following issues:

- Nitrogen dioxide (N2O) related to input animal manure N (on-site and off-site);
- N2O related to input of biologically fixed atmospheric N (on-site and off-site);
- N2O related to crop residue N (on-site and off-site);
- Emissions related to incremental use of synthetic N fertilizer induced by incremental use of manure-N fertilizer;
- Credit for emissions foregone from displaced alternative uses of animal manure;
- Credit for synthetic N displaced by leftover N made available to co-rotated crops;

- Emissions from use of synthetic N that substitutes for leftover N "stolen" away by the recipient crop N2O from cultivation, independent of N input (on-site only);
- NOX related to all N inputs (except deposition and leftover) (includes NH3 emissions) (on-site and off-site);
- CH4 soil emissions related to all N inputs (except deposition and leftover) (on-site and off-site) and CH4 emissions independent of fertilizer use;
- CO2 sequestered in soil due to all N inputs (except deposition and leftover) (on-site only). Includes discounted re-emission of CO2 at end of life;
- CO2 sequestered in soil and biomass due to fertilization of offsite ecosystems by all N (except deposition and leftover);
- leached from field of application. Includes discounted reemission of CO2 at end of life;
- CO2 sequestered in soil, due to cultivation (on-site only). Includes discounting of C lifetimes;
- CO2 sequestered in biomass, due to cultivation (on-site only). Includes discounting of C lifetimes; and
- Non- CO2 GHGs from burning of agricultural residues.

Conclusions from the Study

The LEM identifies the largest sources of emissions in the upstream lifecycle of biofuels as: land-use changes and cultivation, fuel production, feedstock recovery, fertilizer manufacture, and displaced emissions. The emissions that result from feedstock transmission and fuel distribution are reported as being relatively small.

The results from LEM (taken from Delucchi 2006) for different years compared with conventional gasoline are presented in Figure 3.8. These show that the benefit of biofuels is dependent on the crop and the crop production method, as well as the performance of the biofuel production process.

The author highlights the lack of data related to critical elements of an analysis of fuel cycles stating that "in many cases there are so few real emissions data that we are happy if we have reason to believe that we know emissions to within a factor of two." The emission the author highlights in his text are N_2O emissions from crop production and vehicles.

The author goes on to highlight the significance and lack of data relating to carbon sequestration in biomass and soils as a result of changes in land use (related to the establishment of biomass for biofuels).

Just reviewing the scale of the numbers for N_2O and carbon sequestration in Figure 3.7, we can see that these numbers are significant in terms of the production of biofuel crops.

The complexity and documentation contrasts sharply to the GREET model and its modification by TIAX. The author of LEM talks of uncertainty of the order of ± 100, such that less detailed studies like TIAX appear to fall short of accurately reflecting the implications of fuel policy. Delucchi, 2006, compares the results from LEM with other WTW studies, and shows the uncertainty associated with each study, see Figure 3.9.

Delucchi describes the current state of analysis as "LCAs of transportation and climate are not built on a carefully derived, broad, theoretically solid foundation; but rather, they are an ad-hoc extension of a method -- net-energy analysis -- that was itself, too incomplete and theoretically ungrounded to be valid on its own terms, and which could not reasonably be extended to the considerably broader and more complex problem of global climate change."

Delucchi goes on to conclude that though the ISO guidelines have only recently properly addressed some of the issues he highlights, they have not yet developed a proper policy/economic based framework for applying LCA.

Delucchi goes to state that "economic systems, whose states are determined partly by prices, are an inextricable part of the real world. As a result, prices are a necessary part of an ideal model of the impact of policy on climate change. Unfortunately, conventional LCAs of transportation and climate change do not consider prices or other aspects of economic systems. This omission introduces an error of unknown but potentially large magnitude, and thereby may render the results of conventional LCAs virtually meaningless."

FIGURE 3.7: CARBON CONTRIBUTIONS FROM CROP PRODUCTION - TAKEN FROM DELUCCHI 2006

TABLE 1. BREAKDOWN OF CO_2-EQUIVALENT EMISSIONS FROM CULTIVATION AND LAND-USE (U. S. YEAR 2010) (G/BU [CORN, SOY] OR G/DRY-TON [WOOD, GRASS])

Cultivation or land use emission category	Corn	Grass crop	Wood SRIC	Soy
N_2O related to input of synthetic fertilizer N (on-site and off-site)	4.262	47,506	9.209	330
N_2O related to input animal manure N (on-site and off-site)	137	0	0	0
N_2O related to input of biologically fixed atmospheric N (on-site and off-site)	0	0	0	11,311
N_2O related to crop residue N (on-site and off-site)	1.250	5.668	1.216	4.452
Emissions related to incremental use of synthetic N fertilizer induced by incremental use of manure-N fertilizer	55	0	0	0
Credit for emissions foregone from displaced alternative uses of animal manure	108	0	0	0
Credit for synthetic N displaced by leftover N made available to co-rotated crops	0	0	0	(2,143)
Emissions from use of synthetic N that substitutes in generic ag. for leftover N "stolen" away by recipient crop E in question	515	0	0	0
N_2O from cultivation, independent of N input (on-site only)	58	1,840	1.704	201
NO_x related to all N inputs (except deposition and leftover) (includes NH3 emissions) (on-site and off-site)	(3.090)	(31,719)	(6,628)	(12,838)
CH_4 soil emissions related to all N inputs (except deposition and leftover) (on-site and off-site) and CH4 emissions independent of fertilizer use	65	2.965	1.030	236
CO_2 sequestered in soil due to all N inputs (except deposition and leftover) (on-site only). Includes discounted re-emission of CO_2 at end of life.	(4)	(360)	(14)	(335)
CO_2 sequestered in soil and biomass due to fertilization of off-site ecosystems by all N (except deposition and leftover) leached from field of application. Includes discounted re-emission of CO_2 at end of life.	(1.589)	(11,646)	(1.974)	(2,853)
CO_2 sequestered in soil, due to cultivation (on-site only). Includes discounting of C lifetimes.	4.595	33,241	116,878	19,447
CO_2 sequestered in biomass, due to cultivation (on-site only). Includes discounting of C lifetimes.	258	14,456	(179,927)	2,922
Non- CO_2 GHGs from burning of agricultural residues	106	443	670	121
TOTAL	6,725	67,393	(57,737)	20,855

Source: LEM calculations (see LEM model documentation for details)

FIGURE 3.8: LEM: WHOLE LIFE FUELS COMPARISON (DELUCCHI, 2006)

TABLE 6. LIFECYCLE EMISSIONS FOR BIOFUEL VEHICLES, U. S., 1980, 2010, AND 2040

	Year 1980		*Year 2010*		*Year 2040*	
LDVs (versus 26 mpg LDGV)	*fuelcycle*	*fuel+veh*	*fuelcycle*	*fuel+veh*	*fuelcycle*	*fuel+veh*
Baseline: Gasoline (CG) (g/mi)	482.7	596.4	461.8	550.7	439.1	504.1
Ethanol (E90 (corn))	-11%	-9%	-2%	-2%	-11%	-9%
Ethanol (E90 (grass))	-23%	-18%	-53%	-44%	-81%	-71%
Methanol (M85 (wood))	-52%	-42%	-58%	-49%	-65%	-57%
Natural gas (CSNG (wood))	-71%	-57%	-82%	-69%	-92%	-79%
HDVs (versus 3 mpg HDDV)	*fuelcycle*	*fuel+veh*	*fuelcycle*	*fuel+veh*	*fuelcycle*	*fuel+veh*
Baseline: Diesel (LSD) (g/mi)	5,594.8	5,985.9	4,158.2	4,405.1	3,671.4	3,869.8
Biodiesel (SD100 (soy))	61%	59%	53%	50%	17%	16%
Ethanol (E100 (corn))	-30%	-28%	6%	6%	-8%	-7%
Ethanol (E100 (grass))	-41%	-39%	-52%	-49%	-92%	-87%
Methanol (M100 (wood))	-76%	-72%	-68%	-64%	-84%	-80%
Natural gas (CSNG (wood))	-80%	-76%	-74%	-70%	-89%	-84%

Notes: LDGV = light-duty gasoline vehicle; HDDV = heavy-duty diesel vehicle; mpg = miles per gallon; CG = conventional gasoline. E90 = 90% ethanol/10% gasoline; M85 = 85% methanol/15% gasoline; CSNG = compressed synthetic natural gas; LSD = low-sulfur diesel; SD100 = 100% soydiesel; fuel+veh = lifecycle of fuels and lifecycle of vehicles. For baseline LDGV and baseline HDDV, total lifecycle CO_2-equivalent emissions are shown; for alternatives, percentage changes relative to basline are shown.

FIGURE 3.9: DELUCCHI COMPARISON WITH OTHER STUDIES

TABLE 14. APPROXIMATE TYPICAL OVERALL RESULTS OF LIFECYCLE GHG-EMISSION ANALYSES OF BIOFUELS

Source	Ethanol from corn	Ethanol from cellulose	biodiesel from soy
GREET (see various papers by Wang and GM et al.; GHGenius (see web site), Kim and Dale, De Oliveira, LBST (GM et al. 2002a), CONCAWE et al., Spatari et al. (2005), and others	50% to 10%	100% to 40%	60% to 10%
LEM estimates	-30% to + 20%	-80% to -40%	0% to +100%

4.0 *WSPA QUESTIONS ADDRESSED*

4.1 *HAS TIAX USED METHODOLOGY, PREMISES, INFORMATION SOURCES, MODELS, AND SENSITIVITY/UNCERTAINTY ANALYSIS THAT ARE GENERALLY ACCEPTED AS APPROPRIATE FOR SUCH EVALUATIONS?*

4.1.1 *Are the above consistent with those used in major Well-to-Wheels studies in other parts of the world, in particular Europe and the CONCAWE-EUCAR-JRC and GM, et al. studies cited in (6) below?*

As a result of ERM's review, the following main differences between the TIAX model and other models or studies evaluated were identified:

- The CONCAWE-EUCAR-JRC study -

  - Uses a "substitution" method in an attempt to <u>model by-products</u> by tracking the likely fate of by-products rather than using "allocation" methods (also called displacement methods) whereby energy and emissions from a process are allocated to the product according to the fraction of, e.g. mass, energy content, "exergy" content or monetary value, of the product vs. that of the by-product. For example, if the production of biodiesel results in 70% biodiesel and 30% by-products, only 70% of the emissions associated with the process would be attributed to the biodiesel. Conversely, using the substitution method, 100% of the emissions would be attributed to the biodiesel, but one would subtract from this number the benefits (negative emissions) of not having to produce the by-product. TIAX uses an allocation method based on by-product mass. A substitution method, whereby the benefit of a by-product is assigned based on its fate, could be a more accurate representation of benefits associated with by-product generation than the allocation method used in the TIAX model. by-product

  - <u>Addresses costs</u> - how much of a certain fuel could conceivably be made from a given feedstock and at what cost is, of course, central to an analysis of competing fuel pathways. The TIAX model does not address costs or market considerations.

  - <u>Addresses how the land would be used otherwise</u> (i.e., if not used for biofuel) in order to determine what possible energy and/or emissions debits or credits are attached to the land. The most common scenario for growing extra biofuel crops is growing on set-aside land. The study estimates nitrogen oxide emissions using the DNDS soil chemistry model which offers a restricted set of options: another arable crop, fallow or grass. The TIAX study only takes into account land changes associated with crop switching in existing agricultural land, but it does not take into account changes from forest land or grassland to agricultural land (i.e., deforestation). The report claims that given a *modest* growth in U.S.-based energy crops, deforestation is unlikely to be of significance, because energy crops are likely to replace other crops rather than expand agricultural areas. These economic impacts are consistent with producing 5 billion gallons of ethanol per year in the U.S. To the extent that this assumption holds true, the impact of agricultural land use change represents a small portion of the WTW impact. However, the TIAX report does not analyze the effect on land use if the U.S. experiences a large increase in energy crop production. The study does not analyze deforestation in other countries either.

- The GM European Study (2002) -

  - Uses GEMIS (Global Emission Model of Integration Systems) data as a source for determining the source of crude oil supply in target year 2010. GEMIS uses only 40% from OPEC countries. The TIAX model assumes that all the oil and refined products come from the Middle East. Among the ways crude oil supply affects GHG emissions are:
    - Flare gas emissions, which are assumed to be higher in the Middle East than in the U.S.;
    - Shipping emissions from burning heavy oil - location of wellhead and refinery sets transportation miles; and
    - Fuel quality, in particular sulfur content and density.

  - Considers state-of-the art refining technology for 2010 with a refinery efficiency of 96%. The TIAX model assumes that the refining efficiency remains constant over time.

  - Considers both direct and indirect emissions of nitrous oxide (N2O) and closely examines the effects of various cultivation factors, including location and cultivation techniques. The study also considers synthetic fertilization production for N2O emissions and how different cultivation scenarios affect synthetic fertilization use. The TIAX model uses a simple assumption on the percent of nitrogen that is emitted in the form of NO and N2O from fertilizer use.

- The UC Davis Study (LEM) -

  - Shows the impact of displaced benefits and land use change. A significant omission of TIAX in comparison with LEM is the failure to display results with and without displaced benefits and land use change impacts. The LEM model provides this level of transparency, see Figure 4.1. Includes a sensitivity analysis - When conducting a cradle to grave analysis it is essential that the sensitivity of the results is conducted and the range of results communicated. It is expected and standard practice that assumptions are tested through sensitivity analysis, especially those relating to:

- o allocation of process burdens in systems with multiple product outputs (e.g., refineries);
  - o choice of average versus marginal production systems;
  - o attribution of benefit through displaced product systems; and
  - o choice of energy mix, both average and marginal; and
  - o land use change.
- It can be reasonably expected that increased demand for conventional fuel will be met by several sources. Market economics would suggest that a number of geographic sources and production sources would in fact be used. The LEM model represents U.S. and international trade in crude oil and petroleum products and assumes a mix of sources and efficiencies. A similar assumption could be true for California. The TIAX study makes simplifying assumptions on the geographical sources of fuels and feedstock.
- It can also be reasonably expected that displaced product systems will change as production volumes increase. Market demand, geographic location and prices will determine the use and value of by-products, including energy. LEM makes some attempt to include market elasticity. TIAX makes no attempt at this.

FIGURE 4.1: WHOLE LIFE WELL TO TANK RESULTS (DELUCCI 2006)

TABLE 2. BREAKDOWN OF "UPSTREAM" FUELCYCLE CO_2-EQUIVALENT EMISSIONS, BY STAGE (U. S. YEAR 2010)

Fuel →	RFG	Methanol	Ethanol	Ethanol	SCG	Biodiesel	CH2
Feedstock →	oil	wood	corn	grass	wood	soy	wood
Fuel dispensing	2%	3%	1%	1%	22%	0%	64%
Fuel distribution and storage	5%	11%	3%	3%	5%	1%	2%
Fuel production	61%	57%	51%	30%	33%	29%	11%
Feedstock transmission	10%	14%	2%	8%	14%	3%	10%
Feedstock recovery	20%	32%	11%	21%	30%	36%	23%
Land-use changes, cultivation	0%	-32%	35%	35%	-33%	81%	-25%
Fertilizer manufacture	0%	14%	13%	20%	16%	34%	11%
Gas leaks and flares	2%	0%	0%	0%	10%	0%	3%
CO_2, H_2S removed from NG	0%	0%	0%	0%	0%	0%	0%
Emissions displaced	0%	0%	-22%	-25%	0%	-64%	0%
Total (g-CO_2-eq/10^6 BTU)	20,172	18,560	89,668	54,494	14,309	132,342	25,174

Notes: RFG = reformulated gasoline; SCG = synthetic compressed gas; CH2 = compressed hydrogen.

4.1.2 *Are there alternatives to the methodology, premises, information sources, models and sensitivity/uncertainty analysis employed by TIAX that could reasonably be expected to produce results more representative of reality?*

Baseline change considerations: TIAX evaluates global GHG emissions and local Criteria Pollutant and Air Toxics emissions from a marginal production perspective, i.e., taking into account only the increase in energy consumption between today and future scenarios, rather than the comparing future energy consumption scenarios with today's baseline. The marginal approach assumes that baseline conditions (energy consumption, fuel mix production, environmental impacts, etc.) remain constant over time, which does not account for potential changes due to changing market conditions and other reasons. Examples of changing baseline conditions include a potential decrease in California refinery output due to an increase in alternative fuel demand, or an increase in diesel production at the expense of gasoline production due to increased diesel demand.

Market size considerations: The TIAX model does not take market size and other economic considerations into account. For example, if 100% of the marginal fuel consumption were to be met by ethanol from Midwest corn feedstock, the model would not take into consideration the Midwest's limited corn supply, and therefore the need for other feedstock and production markets, as well as the possibility that California could be competing with other states for biofuel supply. An additional example is the size of the market for by-products: the model assumes that all the glycerin by-product from biodiesel production is used for soap production; however, at large biodiesel production levels, the glycerin market could become saturated.

Uncertainty/Sensitivity: The TIAX model does not incorporate an uncertainty analysis or a sensitivity analysis of the assumptions (most notably, the marginal production approach).

Marginal Use of Refinery Fuels: The assumption in the TIAX model is that the marginal demand for refinery fuels in California will be met by importing those fuels from overseas, principally from the Middle East. This results in large impacts from transportation, albeit it results in no emissions from stationary combustion sources in California. This assumption in the TIAX model might or might not reflect the future reality of fuel procurement in California.

Refinery Efficiency: TIAX uses lower refinery efficiency values (higher refinery energy intensity values) than other sources. TIAX uses refinery intensity values that are roughly 12% higher than in MathPro (1999), 41% higher than in Delucci (2003), and 41% higher than values calculated from EIA (2002) data (Loreti and Murphy, 2005). In addition, the GREET model is not dynamic in allowing for improvements in gasoline or diesel efficiency over time. In contrast, the TIAX model incorporates increasing efficiency over time for soybean farming, soyoil extraction, and ethanol production, and fertilizer use per acre is assumed to decrease over time.

4.1.3 *Is there any indication that the TIAX study has been conducted in a way that would presuppose the answer? (e.g. ethanol is the fuel of choice)?*

Some assumptions made in the TIAX model benefit the ethanol fuel production pathway, such as:

Land Use Change: The impacts associated with land use change from grassland to agricultural land or from forest land to agricultural land (deforestation) have not been taken into account. This could lead to a large increase in CO_2 emissions associated with ethanol;

Market Size: Market size for biofuel by-products has not been taken into account, i.e., a benefit has been assigned to biofuel by-products without taking into account whether these products will actually be used in the market;

Infrastructure and Construction: Plant infrastructure and construction is not included within the TIAX model boundaries. Thus the construction of ethanol or biodiesel plants in California is not taken into account in the model;

Multi-Media Impacts: The multimedia impacts analyzed by the TIAX study encompass water consumed, wastewater produced, and pollutant discharge to water bodies (WTT 2007, Section 6.1). Water impacts associated with refining operations are thoroughly covered, since there are a lot of data on the issue. Agricultural runoff releases a large amount of toxic chemicals into water bodies. However, the impact of agricultural runoff has not been taken into account in the TIAX study, because (1) few data exist on the subject, and (2) agricultural runoff is assumed to occur outside California (since corn and soybeans are assumed to be produced mainly outside California). Therefore, "fuel spills and treatment of the impacts of agricultural runoff on water quality is considered beyond the scope of this work" (WTT 2007, Section 6.3.1). Additionally, water use for agricultural purposes has not been taken into account either, since corn and soybeans are assumed to be grown on cropland that is not irrigated, and because these crops are assumed to be grown outside of California. The failure to account for the water burden of producing feedstock for biofuels and to account for agricultural runoff could grant biofuels a much better multi-media image than what is reflective of reality. An additional impact to water that has not been taken into account by the TIAX study and is not mentioned in the TIAX report is the use of Methanol in biodiesel production. Methanol is highly toxic (as well as highly flammable and highly volatile) and potential spills should be considered.

Fuel Production Efficiency: The TIAX model incorporates increasing efficiency over time for soybean farming, soyoil extraction, and ethanol production. In addition, fertilizer use per acre is assumed to decrease over time due to increasingly efficient agricultural practices. In contrast, refinery efficiency is assumed to remain constant over time.

4.1.4 *Are there any significant numerical or computational errors?*

The following spreadsheets were reviewed:

- greet1.7row_us_ca_v53.xls: GREET model with updates by TIAX. This is the WTT model; and

- wtw_processor 28 feb 07_r.xls: TIAX WTW model, which uses WTT inputs from GREET.

Both spreadsheets were reviewed by following linkages between worksheets and evaluating representative underlying formulas where possible. The spreadsheets are hard to follow because they contain very little documentation on the sources of emission factors and on the formulas. Moreover, some cells contain very large formulas that have not been broken down into sub-calculation, thus making it very hard to understand how some numbers were derived. Some large elements of the fuel cycle calculation, such as GHG uptake by biomass, were not found in the spreadsheets. Given that the spreadsheets are very hard to understand, they are also hard to check. The biodiesel and ethanol calculations in the WTT spreadsheet were reviewed in detail and no computational errors were found.

4.1.5 *Do the results agree with good engineering judgment?*

Each study has been based on different assumptions and has adopted different methodologies to calculate the results presented – these have been discussed in other sections of this document. It is clear that the TIAX model and the results generated have not conformed to a number of factors that would be expected to have been included for good engineering practices. In particular, the results have not been calibrated against measured or known emissions data; for example, TIAX emission data for California for 2005 could be compared to and calibrated against actual GHG emission data from state emission inventories. In addition, the results are presented without an uncertainty analysis.

A significant criticism that ERM, and others, would level at TIAX is that it does not conform to internationally expected practice with regard to the documentation, reporting and verification of cradle to grave studies. A model that is to be used in such a public and significant manner would be expected to conform to the ISO standards in terms of documentation and peer review (ISO Standards 14040 and 14044). The tool is not transparent, it is not complete (as compared to other models we reviewed) and it is not of appropriate complexity to accurately reflect the emissions implications of California alternative fuel policy, on a Well-to-Wheel basis. With respect to completeness, the following shortcoming were identified:

- *System boundary* - A system boundary was not clearly established, and how and why it was established was not specifically addressed, though key assertions can be inferred from data presented (ISO 14040 4.2.3.3.1);
- *System flow diagram* - A system flow diagram was not included (we developed one) (ISO 14040 4.2.3.3.2);
- *Data attributes* - The data selected was not clearly supported by key characteristics such as precision, completeness, representativeness, consistency, reproducibility, source and uncertainty (ISO 14040 4.2.3.6.2); nor was its selection transparent in terms of why certain values were selected (ISO 14044 5.2 (f)(8));

- *Description of the critical review process* - The standard calls for studies to be released to the public to have been reviewed and the results of the review including a description of the review process to be included with the study report (ISO 14040 5.3.1); and
- *Allocation* - The process of allocating various factors such as energy usage to different elements of the cycle is not discussed, the rationale supporting the decisions is not provided and no sensitivity analysis was used to test the impact of these allocations (ISO 14044 4.3.4.2); and the allocation prioritization was not discussed or utilized (ISO 14044 4.3.4.3.4).

4.1.6 *How do the TIAX results compare to the (1) CONCAWE-EUCAR-JRC study (version 2b, May 2006), (2) GM-Argonne-BP-ExxonMobil-Shell study titled "Well to Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems North American Analysis (June,2001), and (3) GM Well to Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study (September 2002), and (4) Other major well to wheels studies that may be used within California's LCFS regulatory development process (UC Davis)?*

In considering greenhouse gas emission results, it is necessary to view the result in the context of the study and associated report. As shown within this evaluation, results can vary widely based upon input assumptions and calculation techniques. Examined fuel pathways, fuel quality, and sensitivity analysis are all masked when examining a final number. For example, the GM (2002) study considers gasoline and diesel in 2010, and this results in lower greenhouse gas emissions.

The tables below show a summary of the results of the five models reviewed. The results presented are GHG emissions for the WTT portion of the lifecycle (Table 4.1) and the full WTW life cycle (Table 4.2). The results are plotted in Figures 4.2 and 4.3. A source of uncertainty in the tables below stems from the fact that many numbers are based upon graphs; in addition, the numbers neglect margins of error and ranges of data, or represent averages for multiple feedstocks for a given fuel (example cellulosic feedstock may be from wood or grass).

TABLE 4.1: WTT RESULTS COMPARISON BETWEEN STUDIES: GHG EMISSIONS

WTT - GHG Emissions	Gasoline	Diesel	E85 (Corn)	E85 (Cell)	BioDiesel (BD20)	Units	Notes
TIAX	20.0	16.4	-10.0	-41.0	7.5	g CO2-eq/MJ	
CONCAWE-EUCAR-JRC	12.5	14.2	41.5	9.4	16.3	g CO2-eq/MJ	Ethanol Wheat noted under Ethanol (Corn) Ethanol Wheat would be -24.8 g/MJ if considering credit Ethanol Cell would be -62.4 g/MJ if considering credit Biodiesel would be - 50.7 g/MJ if considering credit
UC Davis	23.0	17.1	122.3	58.4	87.7	g CO2-eq/MJ	RFG oil noted under Gasoline
GM-Argonne-BP-ExxonMobil-Shell	19.7	15.9	-9.8	-63.7	??	g CO2-eq/MJ	50% value used.
GM (2002)	13.1	10.2	-9.9	-45.4	-1.2	g CO2-eq/MJ	

TABLE 4.2: WTW RESULTS COMPARISON BETWEEN STUDIES: GHG EMISSIONS

WTW - GHG Emissions	Gasoline	Diesel	E85 (Corn)	E85 (Cell)	Biodiesel BD20	Units	Notes
TIAX	428.0	346.0	327.0	152.0	343.0	gCO2-eq/mi	
CONCAWE-EUCAR-JRC	263.9	244.6	162.7	65.6	210.5	gCO2-eq/mi	
UC Davis	28.0	19.0	182.0	84.0	455.0	%	Upstream fuelcycle emissions as a percentage off end use emissions
GM-Argonne-BP-ExxonMobil-Shell	550.0	475.0	170.0			g CO2-eq/mi	HE 100 value is approx 30 g/mi
GM (2002)	302.5	267.1	186.2	85.1		g CO2-eq/mi	

FIGURE 4.2: WTT RESULTS COMPARISON BETWEEN STUDIES: GHG EMISSIONS

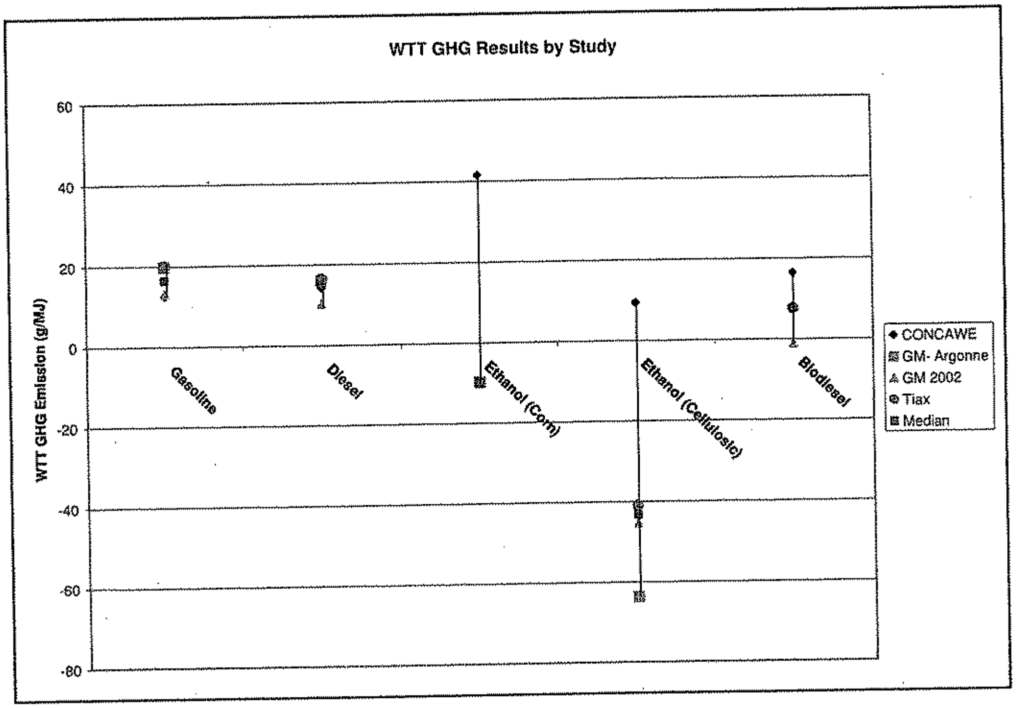
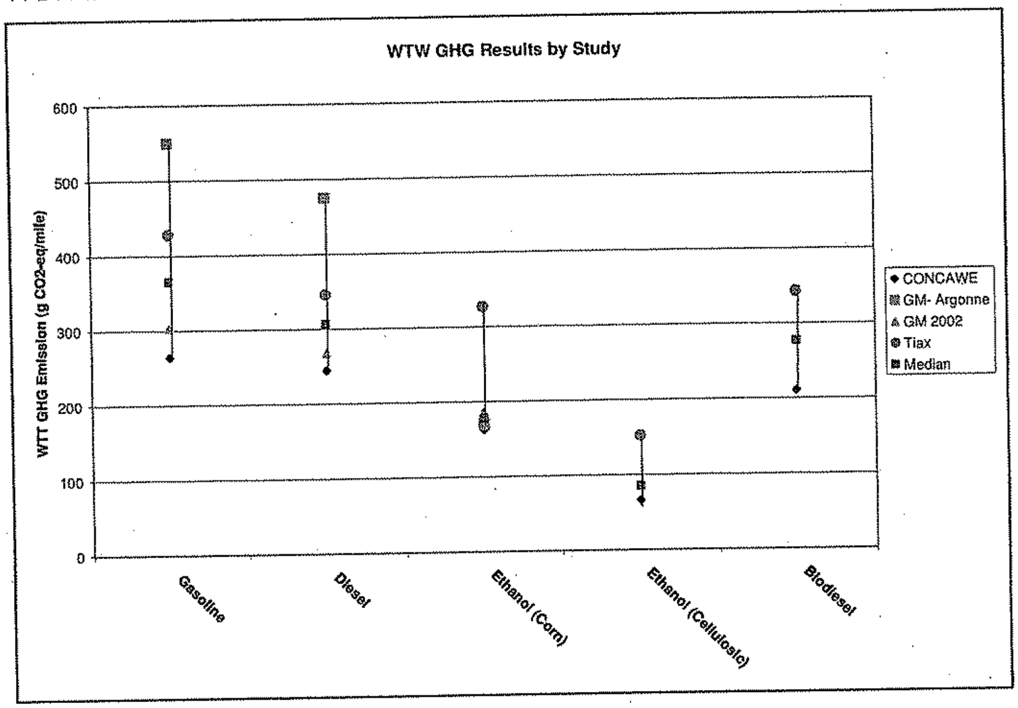


FIGURE 4.3: WTW RESULTS COMPARISON BETWEEN STUDIES: GHG EMISSIONS



The results show that TIAX gasoline and diesel greenhouse gas emissions are greater than other studies for the WTT life cycle portion. Also, in general TIAX ethanol and biodiesel greenhouse gas emissions are lower than other studies for the WTT life cycle portion. However, GHG emissions reported in TIAX for the full WTW fuel cycle are within the range reported by the other studies reviewed. Moreover, WTW GHG emissions for biofuels (biodiesel and ethanol) are consistently higher in TIAX than in the other studies reviewed.

The figures presented above show that there is a high uncertainty associated with these results, especially with the WTW results, and the WTT results associated with biofuels. Key assumptions, such as process efficiency, by-product allocation, origin of feedstock, production technology, and other factors have a large influence on the results. Further study of these results and the underlying assumptions is strongly recommended before a life cycle model can be used for policy-making purposes.

4.1.7 *Which, if any, of the premises or methodologies are incorrect or could justifiably be changed to provide significantly different results?*

Below is an analysis of key items that can have a large effect on the results of a full fuel life cycle assessment. The premises and assumptions made in TIAX regarding these key items have been described below.

1. ***Refinery Efficiency: Sensitivity Analysis***

Figure 4.4 shows the breakdown of gasoline TTW and WTT GHG emissions. The figure shows that TTW emissions are generally much higher than WTT emissions.

Refining is part of the WTT portion of the life cycle. Therefore, a change or in refining efficiency will only impact WTT emissions and thus arguably have a relatively small effect on WTW emissions. However, as shown in Figure 4.5 for gasoline, refining operations comprise the majority of GHG emissions during the WTT life cycle portion of refinery products, and therefore refinery efficiency has a sizeable effect on WTW GHG emissions for refinery fuels.

FIGURE 4.4 WTT BREAKDOWN OF GHG EMISSIONS FOR GASOLINE (WTW 2007)

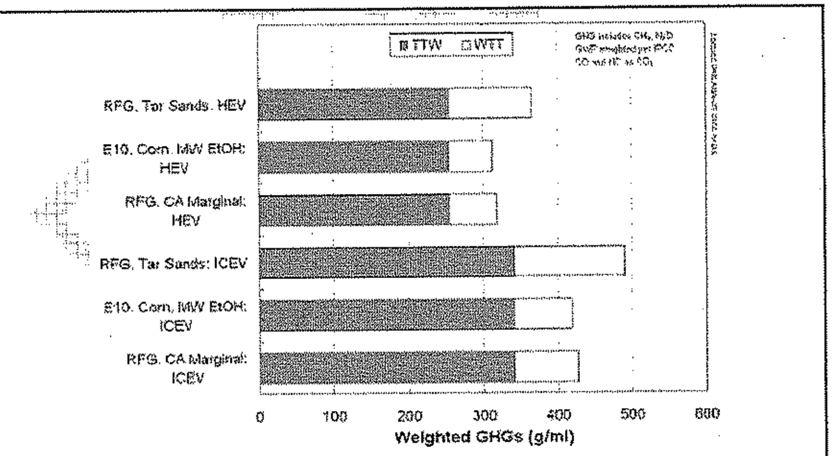
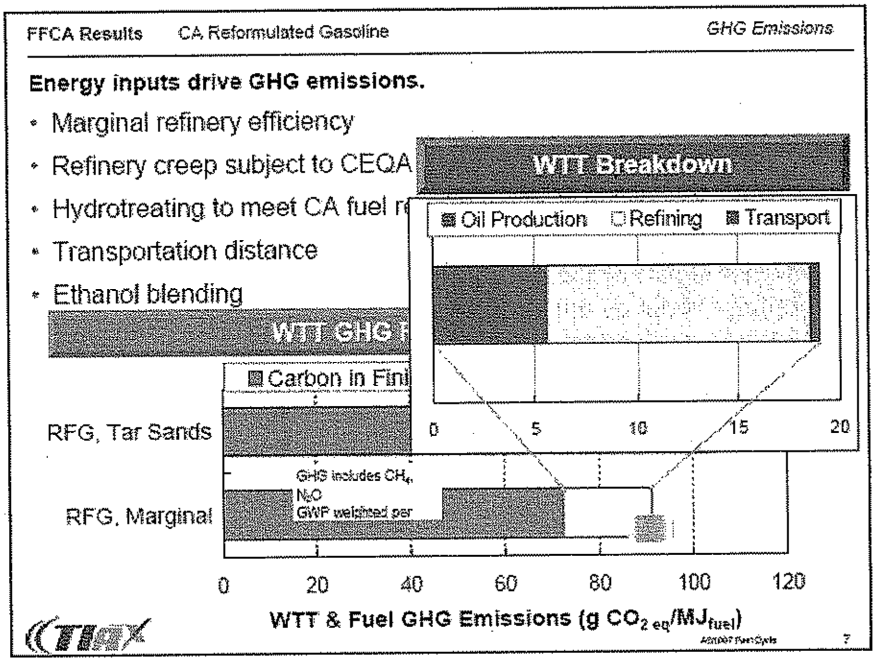


Figure 3-2. WTW GHG Emissions for Gasoline Fuels in Mid-Size Vehicles (2012 New Vehicle Stock)

FIGURE 4.5: WTT BREAKDOWN OF GHG EMISSIONS FOR GASOLINE (TIAX 2007A)



The refining efficiency plays a large part in GHG emissions during the WTT portion of the life cycle for gasoline and diesel. ERM performed refining efficiency sensitivity runs to determine how increased gasoline (California Reformulated Gasoline, CA RFG) and diesel (Ultra Low Sulfur Diesel, ULSD) refining efficiencies affect the WTT GHG emissions reported in the TIAX model for these two fuels. The results are shown in Table 4.1.

Table 4.3 shows WTT GHG emissions for the base case efficiencies assumed in the TIAX model (84.5% for CA RFG and 87% for ULSD). The following cases were modeled:

- Case 1: 5% increase in efficiency for CA RFG and ULSD; and
- Case 2: 10% increase in efficiency for CA RFG and ULSD.

Note that the percentage values of 5% and 10% were not chosen because they are believed to represent reality more accurately, but rather to simply show a two-point relationship between efficiency and GHG emissions.

The table shows that:

- 5% increase in efficiency results in GHG emissions reduction of 25% for CA RFG and 26% for ULSD; and
- 10% increase in efficiency results in GHG emissions reduction of 47% for CA RFG and 50% for ULSD.

These figures clearly show that refining efficiency has a very large effect on WTT GHG emissions.

TABLE 43: SENSITIVITY OF THE TIAX MODEL TO CHANGES IN REFINING EFFICIENCY FOR CA RFG AND ULSD

Refining Efficiency	Fuel Type	Total Energy (J/J-fuel)	WTT CO2 (g/MJ)	WTT CH4 (g/MJ)	WTT N2O (g/MJ)	GHGs (CO2-eq) (g/MJ)	GHGs % Difference from Base Case
Base Case (84.5% CA RFG; 87% ULSD)	CA RFG	0.278	15.9	0.102	0.002	18.8	--
	ULSD	0.218	15.0	0.097	0.000	17.3	--
Case 1 (89.5% CA RFG; 92% ULSD)	CA RFG	0.206	11.4	0.097	0.002	14.2	-25%
	ULSD	0.147	10.5	0.093	0.000	12.7	-26%
Case 2 (94.5% CA RFG; 97% ULSD)	CA RFG	0.142	7.3	0.094	0.002	10.0	-47%
	ULSD	0.084	6.5	0.089	0.000	8.6	-50%

Furthermore, TIAX uses lower refinery efficiency values (higher refinery energy intensity values) than other sources. TIAX uses refinery intensity values that are roughly 12% higher than in MathPro (1999), 41% higher than in Delucci (2003), and 41% higher than values calculated from EIA (2002) data (Loreti and Murphy, 2005).

Refinery energy and GHG values are higher in TIAX and in the GM-ANL study, which is also a U.S. study. Some differences in refinery energy use could be attributed to refinery processing differences between the U.S. and Europe. However, energy use and GHG emissions may be overestimated in the U.S.-based studies (TIAX and GM-ANL) due to reliance on pre-2000 data sources that do not represent current operations. 2005 EIA data indicate PADD V[1] refinery efficiency at >91%[2].

TIAX, like most studies, uses allocation to determine the energy use associated with each refinery product. In TIAX, diesel refining is allocated lower energy use and GHG emissions than gasoline because diesel requires fewer refining steps. The JEC study is the only one that performs a true marginal calculation, using CONCAWE's European refinery model, and found that in the European case, marginal diesel had a higher energy/GHG cost than gasoline. This is attributed to the fact that European refineries already produce maximum diesel, so producing more is difficult. . In contrast the GM (Europe) study used allocation, so estimated lower energy/GHG for diesel than gasoline. While this illustrates the limitations of the allocation approach, it does not provide a better estimate for the US or California, since conditions there are very different

In addition, the GREET model is not dynamic in allowing for improvements in gasoline or diesel efficiency over time. Sunoco 2003 records a reduction in energy consumption of 30% since 1990, and Delucchi 2003 a reduction in energy intensity of 0.25% annually each year after 1990 (these figures are consistent). This improvement would be expected to continue, even at a reduced rate. In contrast, the soybean farming energy use is assumed to decrease by 3.5% between 2005 and 2015 (from 29,500 to 28,500 Btu/bushel), the soyoil extraction energy use is assumed to decrease by 6.8% between 2005 and 2015 (from 6,200 to 5,800 Btu/lb-soyoil), the ethanol yield of corn is assumed to increase 4.4% for the dry mill process between 2005 and 2015 (from 2.66 gal/bushel to 2.78 gal/bushel), and the corn ethanol plant energy use is assumed to decrease by 1.4% for dry mill plants between 2005 and 2010 (from 36,500 to 36,000 btu/gal; no change is assumed between 2010 and 2015).

Refinery efficiency and refinery GHG emissions arguably have very large uncertainty factors, since it is very hard to generate accurate data reflecting refinery energy use and GHG emissions for individual crudes and refineries. This is due, in part, to lack of real data from refineries, refinery complexity, and the wide variety of products produced.

2. *Land Use and Fertilizer Use: Sensitivity Analysis*

The TIAX report states that changes in land use can have a dominant impact on biofuel pathways, while also stating that changes in agricultural land use associated with a modest growth in U.S.-based energy crops are likely to be somewhat insignificant because energy crops are likely to replace other crops rather than expand agricultural areas. The agricultural land use changes in the TIAX study are based on a 5-billion gallon per year ethanol market and need to be reexamined for higher corn prices and other factors.

---

[1] PADD V is the technical term for the U.S. West Coast market, specifically, the States of Alaska, Arizona, California, Hawaii, Nevada, Oregon and Washington (Source: http://www.ftc.gov/os/2000/04/bpamstatepitthomp.htm)

[2] Source: ExxonMobil employee.

Based on the modest growth of energy crops assumption, the study does not take into account changes from forest to agriculture or prairie to agriculture. This was confirmed in conversation between Stefan Unnasch from TIAX and ERM. Mr. Unnasch also stated that the impacts from land use changes from forest to agriculture or prairie to agriculture could be fairly significant.

The TIAX model also takes into account the change in soil uptake of carbon from one crop to another. The biggest impact is for trees, where the roots contribute to carbon storage.

Two of the reports reviewed, namely the Delucci LEM and the CONCAWE-EUCAR-JRC study, calculated the impacts of land use changes and concluded that the GHG releases associated with the alternate use of land could provide a significant impact over the fuel life cycle.

The Delucchi LEM identifies the largest sources of emissions in the upstream lifecycle of biofuels as land-use changes and cultivation, fuel production, feedstock recovery, fertilizer manufacture, and displaced emissions. Delucchi goes on to demonstrate that the change in carbon sequestration due to changes in land use can significantly affect fuel cycle CO_2-equivalent GHG emissions. Data is presented that shows that the increase in CO_2-equivalent g/mi fuel cycle emissions (excluding materials manufacture and vehicle assembly) with and without emissions related to land use ranges from 26% for corn/ethanol to 63% for soy/biodiesel. In all cases, changes in soil carbon due to changes in land use are a significant part of lifecycle GHG emissions for biofuels. Generally, the changes in soil carbon are large because all bio-feedstocks are assumed to displace mainly grasslands, which have higher soil carbon than do managed biocrop lands. In contrast, and as stated above, the TIAX model does not account for changes from grassland or forest land to agricultural land, but merely for alternating crops in agricultural land.

The CONCAWE-EUCAR-JRC study states that there are very serious GHG consequences to plowing up grassland. The change in land-use results in a reduction in the organic carbon stored in the soil and an estimated emission of CO_2 of 73 t/ha (±>50%).

Every year biofuels produced on the land give a GHG saving, gradually compensating the emissions due to the change in land-use. Rough estimates in terms of years for GHG to breakeven are provided for wheat as 111 years, and rapeseed as 49 years, with the caveat that there is also a huge uncertainty in the soil carbon data. The study authors conclude that planting biofuels crops on grazing land would probably not pay off in GHG emissions for decades, and that planting anything on grazing or forest land would be, in the short and medium term, counter-productive with regards to GHG reductions.

Additional consideration is required to account for the carbon release resulting from reduced cereal exports. Making biofuels from cereals that would otherwise be exported from the U.S. would cause an expansion in cereals production outside the U.S., compared to the reference scenario where more biofuels are not produced. This could increase pressure to bring grazing or forest land into cultivation, probably leading to GHG emissions from soil carbon and deforestation.

The impact of soil carbon content on land use-related GHG emissions should not be underestimated. The Delucchi LEM analyzes the contribution to fuel cycle CO_2-equivalent GHG emissions of the various types of land-use, fertilizer, and cultivation-related emissions and finds that the dominant effect, by far, is changes in carbon content of soil due to cultivation. Delucci ranks the following activities related to agricultural activities according to their impact on GHG emissions (in descending order):

1. Changes in carbon content of soil due to cultivation (largest impact by far);
2. N2O emissions due to fertilizer use, manure, crop residue, or biological nitrogen fixation;
3. CO_2 sequestration from nitrogen fertilization of non-agricultural ecosystems (small effect);
4. Effects of burning agricultural residue, assuming that only very small amounts of residue are burned (small effect); and
5. Effects of CH_4 and NOx (small effect).

Changes in the carbon content of soil have the largest effect on GHG emissions due to cultivation because soils store a large amount of carbon and cultivated lands generally have much less carbon than do undisturbed native lands.

N_2O emissions play a major role in the total representing 40% of the agricultural GHG emissions, and about 20 to 30% of the total depending on the model. The results are therefore sensitive to a change in assumptions regarding these emissions.

The International Panel on Climate Change stated in their Third Assessment Report that increasing nitrogen in the soil through fertilizer use increases the emission of N_2O from the soils. The IPCC pointed to evidence of a faster-than-linear feedback in such soil emissions as more fertilizer is applied. N_2O is roughly 300 times as potent a greenhouse gas as CO_2 and remains in the atmosphere for 110-120 years. If those figures are taken into account, greenhouse gas savings for biofuels drop would from 53% to just 7%.

Whereas the Delucci LEM takes into account several nitrogen emission/uptake pathways, such as chemical fertilizer use, use of manure, crop residue, and biological nitrogen fixation, the TIAX model makes a simplistic assumption of N2O and NO emissions as a fixed percentage of the amount of chemical fertilizer use. Other fertilizers, such as natural fertilizers, are not considered.

Sensitivity Analysis: Fertilizer Use

The TIAX model sensitivity to changes in NO and N2O emission from fertilizer use was tested by increasing the emission factors for NO and N2O emissions from fertilizer use for corn and soybean by 10%. This is shown in Tables 4.4 and 4.5. The tables also show that the NO and N2O emissions from fertilizer use for corn growth are much higher than for soybean growth. Note that the value of 10% was not chosen because this is believed to represent reality more accurately, but rather to simply show the effect of a relatively small change in the emission factors.

Figure 4.6 shows that the net increases in N2O emissions for E85 and BD20 were 9.3% and 7.8%, respectively. Such high increases in N2O indicate that most of the N2O emissions associated with E85 and BD20 are from fertilizer use.

Similar to the previous case, the large increase in N2O emissions for E85 result in a dramatic increase in GHG emissions for that fuel.

TABLE 4.4: NO AND N2O EMISSIONS FROM FERTILIZER USE FOR CORN

Ethanol, Corn	Base Case (g/bushel of soybeans)	10% Increase (g/bushel of soybeans)
NO from nitrogen fertilizer	7.110	7.821
N2O from nitrogen fertilizer	13.200	14.520

TABLE 4.5: NO AND N2O EMISSIONS FROM FERTILIZER USE FOR SOYBEANS

Biodiesel	Base Case (g/bushel of soybeans)	10% Increase (g/bushel of soybeans)
NO from nitrogen fertilizer	0.372	0.409
N2O from nitrogen fertilizer	2.188	2.407

FIGURE 4.6: TIAX MODELING RESULTS SHOWING THE EFFECT OF 10% INCREASE IN NO AND N2O EMISSIONS FROM FERTILIZER USE

		BASE CASE		NO, N2O Emissions from Fertilizer +10%		Difference	
		EtOH FFV: E85, Corn, Dry	CIDI Vehicle: BD20	EtOH FFV: E85, Corn, Dry	CIDI Vehicle: BD20	EtOH FFV: E85, Corn, Dry	CIDI Vehicle: BD20
CO2	g/MJ	(13.1564)	3.9921	(13.1564)	3.9921	0%	0%
CH4	g/MJ	0.0905	0.0899	0.0905	0.0899	0%	0%
N2O	g/MJ	0.0353	0.0015	0.0386	0.0016	9.369%	7.812%
GHGs	g/MJ	(0.6392)	6.5104	0.3386	6.5457	152.973%	0.542%
NOx: Total	g/GJ	115.4221	71.5490	117.2274	71.5693	1.564%	0.028%

3. *By-Product Allocation: Sensitivity Analysis*

The TIAX model sensitivity to by-product allocation for ethanol and biodiesel was determined by performing a series of TIAX runs with different by-product assumptions.

The co-products from corn, ethanol, soybean, and biodiesel production were reduced by 20%, as shown in Tables 4.6 and 4.7. The value of 20% was not chosen because this is believed to represent reality more accurately, but rather to simply show the effect of a change in the allocation of by-products.

The results are shown in Figure 4.7. The results show increases in GHG emissions and total energy use, and a dramatic increase (+497%) in GHG emissions for corn. In this case, the increase in each individual GHG is 17% for CO2, 4% for CH4, and 9% for N2O. However, given the high Global Warming Potentials of CH4 and N2O (see Table 4.8), the increase in emissions of these two constituents has a large effect on the total GHG emissions.

TABLE 4.6: CO-PRODUCTS FROM CORN/ETHANOL PRODUCTION, 20% REDUCTION

Ethanol, Corn, Dry Milling	**Base Case**	**20% Co-Product Reduction**
Co-product yield: dry lb. per gallon of ethanol		
DGS (Distillers' Grain with Solids)	5.34	**4.27**
Displacement ratios: lbs. per lb. co-product (DGS)		
Corn	1.08	1.08
SBM (Soybean Meal)	0.82	0.82
Co-products used for new cattle production:		
Total displaced lbs. per gallon of ethanol:		
Corn	-4.88	**-3.90**
SBM	-3.73	**-2.98**

TABLE 4.7: CO-PRODUCTS FROM SOYBEAN/BIODIESEL PRODUCTION, 20% REDUCTION

Biodiesel, Soybean	**Base Case**		**20% Co-Product Reduction**	
	Soydiesel	Co-products	Soydiesel	Co-products
Soybean farming	0.621	0.379	0.6968	0.3032
Soyoil extraction	0.621	0.379	0.6968	0.3032
Soyoil transesterification	0.796	0.204	0.8368	0.1632

TABLE 4.8: GLOBAL WARMING POTENTIAL OF GHGS IN THE TIAX MODEL

CO2	1
CH4	23
N2O	296
VOC	0
CO	0
NO2	0

FIGURE 4.7: TIAX MODELING RESULTS SHOWING THE EFFECT OF 20% REDUCTION IN CO-PRODUCT GENERATION FOR ETHANOL/BIODIESEL

		BASE CASE		E85, BD20 Co-Product 20% Reduction		Difference	
		EtOH FFV: E85, Corn, Dry	CIDI Vehicle: BD20	EtOH FFV: E85, Corn, Dry	CIDI Vehicle: BD20	EtOH FFV: E85, Corn, Dry	CIDI Vehicle: BD20
Total Energy	J/J	0.668	0.288	0.701	0.303	5%	5%
Coal	J/J	0.005	0.000	0.005	0.000	1%	16%
Natural Gas	J/J	0.547	0.161	0.567	0.171	4%	6%
Petroleum	J/J	0.109	0.125	0.121	0.130	11%	4%
CO2	g/MJ	(13.156)	3.992	(10.951)	4.933	17%	24%
CH4	g/MJ	0.091	0.090	0.094	0.091	4%	2%
N2O	g/MJ	0.035	0.002	0.038	0.002	9%	16%
GHGs	g/MJ	(0.639)	6.510	2.537	7.559	497%	16%
VOC: Total	g/GJ	28.528	39.734	36.639	45.182	28%	14%
CO: Total	g/GJ	110.876	98.343	139.292	113.263	26%	15%
NOx: Total	g/GJ	115.422	71.549	124.825	74.749	8%	4%
PM10: Total	g/GJ	13.868	4.918	14.415	5.167	4%	5%
SOx: Total	g/GJ	26.973	27.222	31.682	29.496	17%	8%
VOC: Urban	g/GJ	5.899	3.409	6.068	3.493	3%	2%
CO: Urban	g/GJ	0.443	1.342	0.638	1.498	44%	12%
NOx: Urban	g/GJ	2.355	4.408	2.980	4.904	27%	11%
PM10: Urban	g/GJ	0.065	0.173	0.090	0.193	38%	11%
SOx: Urban	g/GJ	0.017	0.088	0.030	0.098	76%	12%

4. *Uncertainty of Results*

The TIAX model does not incorporate an uncertainty analysis or a sensitivity analysis of the assumptions. The GREET 1.7 model, upon which TIAX is built, has the capability of performing a probability-based uncertainty analysis. However, the TIAX model does not perform any uncertainty analysis.

Without an uncertainty analysis, the error bar associated with the results is not known.

Uncertainty analyses can be done using a range-based approach or a probabilistic approach. In a range-based approach, a model performs a range-based simulation for each input parameter (a simple range defined by upper and lower bounds), which provides only a single point of estimation. It does not give an estimation as to which side of the range, lower or higher, is more likely or less likely to occur. It sets a single point estimate and then carries this assumption throughout the analysis. In addition, under this type of simulation, only one combination of possible inputs can be changed to determine sensitivity to that particular factor. In the case of fuel cycle impact analysis, where there is a multitude of varying inputs and factors, a single point estimate is very limiting.

A commonly used method for dealing with a complex analysis with multiple scenarios is to use a technique called "probabilistic uncertainty analysis" (also known as Monte Carlo uncertainty analysis), where the variability of input parameters is represented by a frequency distribution (e.g., normal, lognormal). This provides more information about input parameters than a simple point estimate, as is used in deterministic analysis. In probabilistic analysis, values are randomly sampled from probability distributions and assigned to input parameters. Sampling parameter values from probability distributions (rather than from a simple range defined by upper and lower bounds) places greater weight on likely combinations of parameter values (and hence you can assign a probability to specific outcomes). The output of probabilistic uncertainty analysis is also a statistical distribution (e.g., mean, median, standard deviation, normal or lognormal), characterizing the uncertainty of the model prediction. This kind of analysis offers the benefit of quantifying the probability associated with the range of possible results.

Probabilistic estimation is used in the GM-ANL Study (2001) in order to address uncertainties statistically. For each activity associated with the production process of each fuel, the following values for probability were determined: 20%, 50%, and 80% (P20, P50, and P80). This approach was carried throughout the study. The values associated with each of these probabilities for each input are transparently part of this Study and they give the reader a clear picture of where uncertainties exist, and where something is more likely to occur.

Each of the CONCAWE-EUCAR-JRC pathways carries a certain variability range representing the combination of the range of performance of the future installations and the uncertainty attached to the expected technical developments. On the basis of the quality of the data available, the degree of development of the process and any other relevant parameter, a judgment has been made as to the level of uncertainty attached to each figure as well as the probability distribution within the range. The study uses a Gaussian distribution as default but also a so-called "double-triangle" for asymmetrical ranges and an equal-probability or "square" distribution when there is reason to believe that all values in the range are equally probable. In order to combine all uncertainties in a pathway and arrive at a plausible range of variation for the total pathway, they have used the traditional Monte Carlo approach. Subsequent calculations have been carried out with the median figure.

A few output values from the CONCAWE-EUCAR-JRC report and the associated uncertainties are listed below:

- Crude oil to Gasoline - Net GHG emitted (gCO_{2eq}/MJ_f) = 12.5 (best est.), range 11.1 to 14.6;

- Crude oil to Diesel - Net GHG emitted (gCO_{2eq}/MJ_f) = 14.2 (best est.), range 12.6 to 16.0;
- Ethanol from Wheat (NG GT+CHP, DDGS as AF) - Net GHG emitted (gCO_{2eq}/MJ_f) = 46.6 (best est.), range 39.2 to 53.2; and
- Sunflower seed to BioDiesel (Glycerine as Chemical) - Net GHG emitted (gCO_{2eq}/MJ_f) = 24.7 (best est.), range 12.2 to 36.1.

The GM European Study (2002) uses the E^2 database to calculate complicated fuel supply pathways based on input and output data (such as data provided by a manufacturing company). The model was chosen to allow for arbitrary fuel chains and also complex recursive chains. A stochastic tool was implemented within the E^2 database allowing for the quantification of uncertainties by providing confidence bounds around best estimates. A parameter with a large range in the GM European Study is the carbon content of crude oil, which can range from 2.5 to 13.9 g/CO2 equivalent.

4.1.8 *Has TIAX done a sensitivity analysis of their premises, and if so, have they done it properly?*

TIAX has not performed a sensitivity analysis or determined the uncertainty associated with the results.

ERM performed sensitivity runs for three parameters, namely refining efficiency for gasoline and diesel, emissions of NO and N2O associated with fertilizer use, and emission benefits associated with by-product allocations. These analyses are presented in the Section 4.1.7.

See Section 4.1.7, Uncertainty Analysis, for a detailed discussion on the subject.

4.1.9 *Which premises should be changed or require additional analysis to provide more robust results?*

Listed below are premises or assumptions in the TIAX study that require additional analysis to provide more robust results. Most of these points have been discussed in previous sections of the report and are only summarized in this section.

- Biofuel crops will not displace existing grasslands or forest lands;
- The market for biofuel by-products will be large enough to absorb all the by-products generated during crop farming and biofuel manufacture;
- The benefits from biofuel by-products are proportional to their volume (allocation method) rather than to the products they replace (substitution method);
- Agricultural runoff associated with marginal biofuel crop production will not affect California;
- Water use associated with marginal biofuel crop production is zero because the crops will be grown in non-irrigated agricultural land;

- Water quality is not affected by methanol spills from biodiesel production operations (methanol spills are not taken into account in the model);
- Marginal corn is produced in the Midwest;
- Marginal refinery feedstock and products are produced in the Middle East;
- Refinery efficiency will not increase over time;
- Refinery capacity in California will not increase (expansions are in fact planned as a result of the availability of cap-and-trade programs);
- The model baseline and associated impacts to the environment will not change over time;
- Infrastructure and construction are not taken into account; especially worthy of consideration is the required infrastructure for ethanol distribution in the U.S.; and

Flexible fuel vehicles (FFV), which can operate on E85 or gasoline, are operated on alternative fuels 50% of the time (in reality, they are fueled with regular gasoline more than 99% of the time).

4.2 *ARE THE EMISSION INVENTORIES CREATED BY THE TIAX REPORT CONSISTENT WITH THOSE INVENTORIES BEING CREATED FOR THE AB 32 EFFORT? IF NOT, WHY NOT?*

TIAX is a Life Cycle Assessment model that reports GHG emissions from transportation vehicles in grams of CO2-equivalent per mile. The AB-32 emissions inventory (EI) presents a detailed account of GHG emissions broken down by year. Comparison of the two would involve checking the underlying assumptions behind the AB-32 GHG EI, such as the emission factors and the equations used.

An initial review of the AB-32 GHG EI has revealed that the Global Warming Potential factors assigned to each GHG are different than those GWP factors used in TIAX. The differences, however, are not very large.

Additional analysis could be performed to investigate this issue if desired.

4.3 *WHAT CHARACTERISTICS OF THE TIAX REPORT MAY LIMIT ITS USEFULNESS IN PROVIDING EMISSIONS ESTIMATES TO GUIDE DEVELOPMENT OF THE LCFS RULES AND REGULATIONS?*

4.3.1 *What types of changes would be required to make the TIAX results more useful in the LCFS regulatory process?*

Before the TIAX report can be used for regulatory purposes, a sensitivity analysis must be conducted. The sensitivity analysis would show the impact of certain assumptions on the results. Similar to the sensitivity analysis, an uncertainty calculation should be carried out. The results in the TIAX report should be reported with an associated ± uncertainty number.

ERM has performed a number of sensitivity runs for the aspects listed below:

- Refining efficiency for gasoline and diesel;
- Emissions of NO and N2O associated with fertilizer use; and
- Benefits associated with biofuel production by-products.

The results are listed in Section 3.1.7. These data suggest that further study is going to be necessary to quantify definitively the GHG benefits of an alternative fuel policy mandate.

4.3.2 *Does the TIAX report contain all the analysis needed to support developing regulations allowing substantial flexibility for fuel providers complying with a LCFS?*

The TIAX study has an important limitation, which reduces its usefulness to lawmakers designing a LCFS compliance strategy. The model does not factor in market and economic considerations. The results generated by the TIAX model do not take into account the feasibility of duplicating in reality what the model is assuming. For example, one could model the impacts associated with having a fleet of cars that is 100% E85 from corn, and the model would not factor in the feasibility of growing all the required corn and manufacturing ethanol in the Midwest. Under such a scenario, some of the corn/ethanol would have to be imported, at an increased impact to the environment. Similarly, the by-products from corn farming and ethanol production would likely outgrow the size of the market for those by-products, thus resulting in no net benefit. An analysis of some aspects associated with this argument is presented below.

- Future markets for biofuel by-products might get saturated, in particular for DDGS, as there is already concern regarding potential saturation of US market. CONCAWE-EUCAR-JRC study "warns that the glut of protein-animal feed from biofuels by-products is likely to severely impact protein-feed prices, which will increase the costs of biofuels production";
- Additional land being brought into agricultural production driven by the incentive for corn production provided by the increased value of corn (driven by demand for ethanol use), lowered enrollments in the Conservation Reserve Program, an increase in acreage dedicated to intensively managed, and environmentally damaging, continuous corn rotations, and a decline in acreage managed using conservation tillage techniques;
- Incentives for renewable fuels, such as credits for energy generation from renewable sources (e.g. using DDGS to fuel ethanol plant boilers), tax credits and incentives for growing biofuel crops and the role of current ethanol tax credits along with the new biodiesel tax incentives.

4.3.3 *Does the TIAX report contain the analysis needed to support development of a simple LCFS compliance and enforcement scheme?*

As stated in Section 4.3.2, the TIAX model does take market size and economic considerations into account, which limits its usefulness as a policy-making tool. Additionally, the model does not incorporate an uncertainty or sensitivity analysis. These limitations undermine the usefulness of the TIAX model as a regulatory support tool.

5.0 *REFERENCES*

TTW, 2007: "Full Fuel Cycle Assessment: Tank to Wheel Energy Inputs, Emissions, and Water Impacts", TIAX, February 2007. http://www.energy.ca.gov/ab1007/documents/index.html

WTT, 2007: "Full Fuel Cycle Assessment: Well to Tank Energy Inputs, Emissions, and Water Impacts", TIAX, February 2007. http://www.energy.ca.gov/ab1007/documents/index.html

WTW, 2007: "Full Fuel Cycle Assessment: Well to Wheel Energy Inputs, Emissions, and Water Impacts", TIAX, February 2007. http://www.energy.ca.gov/ab1007/documents/index.html

TIAX, 2007a: "Full Fuel Cycle Analysis for AB-1007, by Fuel: Assumptions, Results, Sensitivities," Presented at CEC-ARB Workshop on Developing a State Plan to Increase the Use of Alternative Transportation Fuels. Stefan Unnasch, Jennifer Pont, Matthew Hooks, Larry Waterland, Dan Rutherford, Michael Chan, and Mike Jackson, TIAX LLC, March 2, 2007. http://www.energy.ca.gov/ab1007/documents/2007-03-02_joint_workshop/presentations/TIAX-1_2007-03-02.PDF

Loreti and Murphy, 2005: "Review of the Well-to-Pump Pathways for Petroleum Fuels and Alternative Fuels in the GREET Model," Prepared for American Petroleum Institute, Christopher P. Loreti and Michael J. Murphy, Batelle, December 2005.

TIAX Boundary

Appendix A

March 23, 2007
Project No. 0063379

Environmental Resources Management
15810 Park Ten Place, Suite 300
Houston, Texas 77084-5140
(281) 600-1000

TIAX Boundary
(EtOH, BD, Gasoline, Diesel)