Lifecycle Analysis of Climate-Change Mitigation Strategies of the California Air Resources Board

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TABLE OF CONTENTS

ABSTRACT

This report documents the development of a spreadsheet tool designed to help the California Air Resources Board (CARB) estimate total reductions in emissions of greenhouse gases (GHGs) for various climate-change mitigation strategies being considered by CARB. The spreadsheet tool is called the California Air Resources Board Climate Change Mitigation Strategy Impact Calculator, or CARB CCM Calculator for short. The CARB CCM Calculator estimates reductions in CO_2-equivalent (CO2e) emissions of GHGs in a user-specified target year and over a user-specified period of years, for each climate-change mitigation strategy. The CARB CCM Calculator estimates reductions for the following mitigation strategies: Cargo-Handling Equipment Anti-Idling, Low-GWP Refrigerants for Mobile Vehicle Air Conditioning Systems, Cool Automobile Paints, Low-friction Engine Oil, High GWP Reduction from Stationary Sources, Alternative Suppressants in Fire Protection systems, and Foam Recovery and Destruction Program.

EXECUTIVE SUMMARY

This report documents the development of a spreadsheet tool designed to help the California Air Resources Board (CARB) estimate total reductions in emissions of greenhouse gases (GHGs) for various climate-change mitigation strategies being considered by CARB. The spreadsheet tool is called the California Air Resources Board Climate Change Mitigation Strategy Impact Calculator, or CARB CCM Calculator for short. The CARB CCM Calculator estimates reductions in CO_2-equivalent (CO_2e) emissions of GHGs in a user-specified target year and over a user-specified period of years, for each climate-change mitigation strategy. The CARB CCM Calculator estimates reductions for the following mitigation strategies:

Strategy	Description
Cargo-Handling Equipment Anti-idling	Reduce idling (beyond 10 minutes) in cargo-handling equipment at ports and intermodal rail yards.
Low-GWP Refrigerants for Mobile Vehicle Air Conditioning Systems	Low-GWP refrigerants used in mobile air conditioning systems instead of HFC134a
Transportation Refrigeration Unit (TRU) Cold Storage Limits	TRU extended cold storage (beyond 24 hours) is prohibited.
Cool Automobile Paints	Advanced exterior paint and reflective glazing reduces interior temperatures of vehicles, thus reducing air conditioner (AC) use and fuel use.
Low-friction Engine Oil	Low-viscosity oil reduces friction in the engine and thus boosts fuel economy.
High GWP Reduction from Stationary Sources	High GWP Refrigerant Tracking, Reporting, Repair and Deposit for Stationary Refrigeration and Air Conditioning systems and Specifications for New Commercial and Industrial Refrigeration Systems
Alternative Suppressants in Fire Protection systems	Considering GHGs from alternative suppressants in total flooding (fixed) and streaming (portable) fire suppression systems. Most fire suppression systems originally used halons, which are ozone depleting compounds, but new systems have moved to halon alternatives that are high GWP fire suppressants, e.g. HFCs
Foam Recovery and Destruction Program	Reducing the GHG emission from waste insulation foam when it is shredded during appliance recycling or broken during building construction, renovation, and demolition.

The emissions reductions estimated by CARB CCM Calculator are a function of detailed inputs and user-specified scenario variables. The detailed inputs, located in various tabs throughout the spreadsheet, characterize lifecycle emission factors and the phase-in and effectiveness of mitigation measures. The user-specified scenario variables, located on the “Summary” tab, are for the analysis period, the choice of CO_2-equivalency factors, the choice of emissions scenario, and the choice between default or user-specified rates of adoption of mitigation strategies.

The CARB CCM Calculator is designed to perform relatively simple, transparent calculations involving easily identified key parameters. Hence, the Calculator does not perform original detailed lifecycle calculations itself, but rather relies in key places on lifecycle-emission estimates from other LCA models, such as the Lifecycle Emissions Model and SimaPro. The Calculator can be expanded relatively easily by adding new tabs and new results lines in the “Summary” tab.

The CARB CCM Calculator reports emission reductions and key assumptions on a “Summary” page. The following pages provide an example of the output on the “Summary” page, using the IPCC AR4 GWP values, base-case emission reductions, and user-input adoption/implementation percentages. Note that although the CARB CCM Calculator provides point estimates of emission reductions to several decimal places, these should not be interpreted as “significant” digits. The uncertainty in the estimates of the CARB CCM Calculator is difficult to estimate formally, but based on past experience, in our opinion is likely to exceed 20% and probably 30%.

Example of output from the CARB CCM Calculator

Climate Change Reduction Strategy	10^{12} g CO2e Reduced 2020	10^{12} g CO2e Reduced 2010-2020	Key Assumption(s)	Active Value
Cargo Handling Equipment Anti-Idling	0.0001	0.0006	Annual growth rate of cargo equipment	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems	1.0	5.1	CEF of replacement refrigerant	120
			Leakage (grams) per vehicle per year	40
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
Transport Refrigeration Unit Cold Storage Limits	0.00	0.03	Annual growth rate of TRUs	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Cool automobile paints	0.33	1.41	Fuel economy drop with AC: cars	18.2%
			Fuel economy drop with AC: trucks	13.8%
			Percent time AC runs	33%
			Reduction in AC use	26%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%

Low-friction engine oil	8.6	67	**Fuel economy improvement**	**1.5%**
			Initial adoption in year 2010	**50%**
			Annual rate of increase for adoption	**10%**
High GWP Stationary Refri.	10.3	110	**Refrigerant types in blend**	see sheet
			Current and future leakage rates	see sheet
			Refrigerant recycling rates	see sheet
Alternative Suppressants in Fire Protection Systems	12.8	310	**HFC-125**	**25%**
			HFC-134a	**25%**
			HFC-227ea	**25%**
			HFC-236fa	**25%**
Foam Recovery and Destruction Program (Ten Year Model)	146	1,940	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Foam Recovery and Destruction Program (Annual Model)	19,079	220,433	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing Agents Portfolio from 2000 to 2004	
			HCFC-141b	**50%**
			HFC-134a	**50%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

PROJECT BACKGROUND

Introduction

This report describes the development of a spreadsheet tool designed to help the California Air Resources Board (CARB) estimate total reductions in emissions of greenhouse gases (GHGs) for various climate-change mitigation strategies being considered by CARB. The spreadsheet tool is called the California Air Resources Board Climate Change Mitigation Strategy Impact Calculator, or CARB CCM Calculator for short. The CARB CCM Calculator estimates reductions in CO_2-equivalent (CO_2e) emissions of GHGs in a user-specified target year and over a user-specified period of years, for each climate-change mitigation strategy.

Background

The State of California has a stated goal of reducing greenhouse gas (GHG) emissions, which contribute to global climate change. The targets for reductions are to return to 2000 emission levels by 2010, 1990 levels by 2020, and 20% of 1990 levels by 2050 (i.e., an 80% reduction from 1990 levels). The blueprint for meeting the goals for 2010 and 2020 was presented in a 2006 report by the Climate Action Team (CAT) to the Governor.

The 2006 CAT report listed individual strategies and their expected GHG emission reductions. The list included strategies already under way, such as those being established by the Pavley bill (AB1493), and also additional strategies necessary to meet the reduction targets. However, the strategies were not fully developed, and needed to be further evaluated before they could be implemented. In particular, further analysis was needed to determine the life cycle emissions of the proposed strategies.

This original objective of this project was to develop a tool that CARB could use to evaluate the lifecycle CO2e GHG emissions associated with the original CAT emission-reduction measures. However, after the start of the project AB32 was passed by the California Legislature, and as a result the focus was changed to evaluating the lifecycle CO2e GHG emissions associated with a set of high-priority “early action measures.” The early-action measures identified by CARB staff are described below, as “climate-change mitigation strategies.”

General Objectives

The objective of this project is to develop a new calculation tool – the CARB CCM Calculator – for quantifying the life cycle CO2e GHG emission reductions associated with the climate-change mitigation strategies selected for analysis by CARB staff. A new tool must be developed for this project because existing GHG emissions calculators either do not consider all the emission sectors that CARB is interested in, or else do not aggregate emissions in the way that CARB requires. Thus, the main innovations of this project are: 1) to expand to a greater number of emission sectors (e.g., many LCA models look only at transportation fuels or electricity generation); and 2) to provide aggregated results for emissions projects rather than only emissions rates (e.g. total tons of CO_2 vs. tons per mile from driving).

The CARB CCM Calculator is designed to perform relatively simple, transparent calculations involving easily identified key parameters. Hence, the Calculator does not perform original detailed lifecycle calculations itself, but rather relies in key places on lifecycle-emission estimates from other LCA models, such as SimaPro and the Lifecycle Emissions Model (LEM) (see discussion below). The Calculator can be expanded relatively easily by adding new tabs and new results lines in the "Summary" tab.

The CARB CCM Calculator provides order-of-magnitude indications of the climate impacts of various mitigation policies. It should be used for identifying which policies provide the biggest impacts, and for determining which parameters have the biggest impacts on the results. It therefore is most helpful for deciding where policy-making resources should be devoted and where additional research is needed. The calculator should not be used in detailed lifecycle analyses because as noted above it is not itself a detailed LCA model.

DOCUMENTATION OF THE CARB CCM CALCULATOR

This section of the report documents the development of the CARB CCM Calculator.

Climate-Change Mitigation Strategies in the CARB CCM Calculator

The CARB CCM Calculator estimates reductions for the following mitigation strategies:

Strategy	Description
Cargo-Handling Equipment Anti-idling	Reduce idling (beyond 10 minutes) in cargo-handling equipment at ports and intermodal rail yards.
Low-GWP Refrigerants for Mobile Vehicle Air Conditioning Systems	Low-GWP refrigerants used in mobile air conditioning systems instead of HFC134a
Transportation Refrigeration Unit (TRU) Cold Storage Limits	TRU extended cold storage (beyond 24 hours) is prohibited.
Cool Automobile Paints	Advanced exterior paint and reflective glazing reduces interior temperatures of vehicles, thus reducing air conditioner (AC) use and fuel use.
Low-friction Engine Oil	Low-viscosity oil reduces friction in the engine and thus boosts fuel economy.
High GWP Reduction from Stationary Sources	High GWP Refrigerant Tracking, Reporting, Repair and Deposit for Stationary Refrigeration and Air Conditioning systems and Specifications for New Commercial and Industrial Refrigeration Systems
Alternative Suppressants in Fire Protection systems	Considering GHGs from alternative suppressants in total flooding (fixed) and streaming (portable) fire suppression systems. Most fire suppression systems originally used halons, which are ozone depleting compounds, but new systems have moved to halon alternatives that are high GWP fire suppressants, e.g. HFCs
Foam Recovery and Destruction Program	Reducing the GHG emission from waste insulation foam when it is shredded during appliance recycling or broken during building construction, renovation, and demolition.

General guide for using the CARB CCM Calculator

The emissions reductions estimated by CARB CCM Calculator are a function of detailed inputs and user-specified global scenario variables. The detailed inputs, located in various tabs throughout the spreadsheet, characterize lifecycle emission factors and the phase-in and effectiveness of mitigation measures. Users should change these detailed inputs if they understand the nature of the parameters and believe they have more accurate data. User-input areas are indicated by a color code (generally yellow).

The user-specified global scenario variables, located on the "Summary" tab, allow the user to see how the estimated emission-reduction results depend on four key global scenario variables:

1) the period of years and the individual year for which cumulative or single-year emission reductions are estimated (2010 to 2020);

2) the choice of CO_2-equivalency factors ("Global Warming Potentials" from the Intergovernmental Panel on Climate Change [IPCC] Second Assessment Report or Fourth Assessment Report; factors from the Lifecycle Emissions Model [LEM]; user-specified custom factors);

3) the choice of emissions scenario (base case, low emissions reductions, or high emissions reductions); which reflect how optimistic or conservative some assumptions are regarding the effectiveness of the measures;

4) the choice between default or user-specified rates of adoption of mitigation strategies.

These four are discussed in more detail in sections following.

The remainder of the documentation is organized by sheet name in the CARB CCM Calculator. *Note that the spreadsheet has been designed so that the user can change the names of the worksheet tabs in the workbook and all mentions of worksheet names throughout the workbook will change automatically.*

Instructions and notes

As the name implies, this sheet contains instructions and notes for the CARB CCM Calculator. The instructions and notes are reproduced here for convenience:

Sheet Name	Instructions and Notes
Summary	1. ALWAYS START AT THIS SHEET! 2. This table summarizes the results and allows the user to change the key assumptions which drive the results of the model. 3. The 'Global Scenario Variables' section is where the user specifies the year and period of years for which emission reductions are to be estimated, the CO_2-equivalency factors, the scenario (Base-case, Low emissions reductions, High emissions reductions), and whether the user would like to input manual adoption percentages. 4. The user may edit the cells in the 'Active Value' column. 5. On this and other sheets, please see the color legend to understand what the cell color shading means.
Emission Scenarios	1. On this sheet, users may edit the pre-set values for the three scenarios - 'Low emissions reductions', 'Base-case', and 'High emissions reductions.' 2. You cannot change the emission scenario on this sheet. To change which scenario is used, go to the 'Choice of Emission Scenario' menu on the Summary sheet.
Adoption %	1. Users may enter custom adoption percentages for each *active* year in the study period. 2. The controls to activate the percentages on this sheet are in the 'Global Scenario Variables' section of the Summary sheet.
Cargo Anti-Idling	1. This sheet has the calculations for the Cargo Anti-Idling module and supplies the results for the Summary sheet. 2. The choice of analysis period (from the Summary sheet) determines when the anti-idling regulation for cargo equipment is first adopted. 3. The population of different types of cargo-handling equipment are assumed to grow at the same rate, based on the input on the Summary sheet. 4. Diesel fuel use (gals/hr) for each piece of equipment is assumed to be the same for all years.

Low-GWP MACS	1. This sheet has the calculations for the Low-GWP MACS module and supplies the results for the Summary sheet. 2. The choice of analysis period (from the Summary sheet) determines when low-GWP fluids are first adopted for mobile air conditioning systems in new vehicles. 3. Low-GWP working fluids are assumed to be used in NEW passenger vehicles only.
TRU Limits	1. This sheet has the calculations for the TRU Limits module and supplies the results for the Summary sheet. 2. The choice of analysis period (from the Summary sheet) determines when the prohibition on TRU cold storage is first adopted. 3. Diesel fuel use (gals/TRU/yr) is assumed to be the same for all years.
Cool Paints	1. This sheet has the calculations for the Cool Paints module and supplies the results for the Summary sheet. 2. The choice of analysis period (from the Summary sheet) determines when cool paints are first adopted. 3. Cool paint technology is assumed to be used in NEW passenger vehicles only.
Low-friction Oil	1. This sheet has the calculations for the Low-friction Oil module and supplies the results for the Summary sheet. 2. The choice of analysis period (from the Summary sheet) determines when low-friction oils are first adopted. 3. This module takes into account the ENTIRE passenger vehicle fleet (i.e. all vehicles can potentially use these new synthetic engine oils).
High GWP Stationary Refri.	1. This sheet has the calculations for the High GWP Stationary Refri. module and supplies the results for the Summary sheet. 2. Refrigeration Tracking/Reporting and Specifications for Commerical and Industrial Refrigeration Program are included. 3. Stock information for each sub-program needs to be updated when data is available. 4. Refrigerant blends weights and component fractions need to be updated when data is available.

Fire Suppressants	1. This sheet has the calculations for the Fire Suppressants module and supplies the results for the Summary sheet. 2. The module takes into account both fixed and portable fire suppressant systems. 3. The stock information needs to be updated when it is available.
Foam Recovery (10-year) Entry	1. This sheet has the calculations for the Foam Recovery (10-year) Entry module and supplies results for the Summary sheet. 2. If stock survey data is ten-year based, choose "Ten Year Model". (More Instructions in the work sheet) 3. All stock quantity numbers are temporary placeholders; they should be changed when survey data are available.
Foam Recovery (Annual) Entry	1. This sheet has the calculations for the Foam Recovery (Annual) Entry module and supplies results for the Summary sheet. 2. If stock survey data is annual, choose "Year by Year Model". (More Instructions in the work sheet) 3. All stock quantity numbers are temporary placeholders; they should be changed when survey data are available.
CO2 Equiv Factors	1. This sheet contains all of the CO_2 equivalency values that may be used in model. 2. The user's choice of CO_2 equivalency factors on the Summary sheet determines which values are transferred into the 'Active Set' column. 3. The user may enter custom CO_2 equivalency factor values in the 'User-defined' column.
Fuel LCA (from LEM)	1. This sheet calculates upstream (well-to-tank) lifecycle emissions for reformulated gasoline based on results from the Lifecycle Emissions Model (LEM). 2.The raw LEM fuel cycle emissions data and the CO_2 equivalency factors from the 'CO_2 Equiv Factors' sheet are used to estimate the CO_2 -equivalent emissions from upstream fuel processes.

California Vehicle Data	1. This sheet contains VMT, fuel economy, and survival data for passenger cars and trucks (under 10,000 lbs) in California. 2. The data are derived from the EMFAC2007 model and the VISION model.
Acronyms	1. A list of acronyms used throughout the model.
References	1. This sheet has links whenever possible to detailed reports/articles that provide values for the key assumptions on the Summary sheet and elsewhere.
Hidden sheets	*The following three sheets are hidden. They contain lists or intermediate calculations that users do not need to see. The sheet names below are not hyperlinks.*
Foam Annual Calculation	Intermediate calculations used in Foam Recovery (Annual).
Foam 10-Year Calculation	Intermediate calculations used in Foam Recovery (10-year).
Drop-down lists	Contains items in the drop-down menus.

Summary of Inputs and Results

This table summarizes the results and allows the user to change the key assumptions that drive the results of the model. The results are:

- 10^6 tonnes of CO2e GHG emissions reduced in a user-specified target year,

and

- and 10^6 tonnes of CO2e GHG emissions reduced over a user-specified period (e.g., 2010 to 2020),

for each mitigation strategy.

The 'Global Scenario Variables' section of this sheet is where the user specifies the year and period of years for which emission reductions are to be estimated, the CO_2 equivalency factors to be used, the scenario (Base-case, Low emissions reductions, High emissions reductions), and whether the user would like to input manual adoption percentages.

The user may edit the cells in the 'Active Value' column. Note though that many of the values in the "Active Value" column are not pure inputs, but rather refer to inputs in the "Emission Scenario" sheet.

The following pages show sample results from the CARB CCM Calculator. We show five different cases:

Sample results #1, base case.

Sample results #2, low emissions reductions.

Sample results #3, high emissions reductions.

Sample results #4, default adoption percentages.

Sample results #5, LEM CEFs.

After these results tables we have a brief discussion of the results.

Sample results #1, base case. The first series of results assumes:

-- base-case emissions
-- IPCC AR4 GWPs
-- all user input adoption/implementation percentages.

Climate Change Reduction Strategy	10^{12} g CO2e Reduced		Key Assumption(s)	Active Value
	2020	2010-2020		
Cargo Handling Equipment Anti-Idling	0.0001	0.0006	Annual growth rate of cargo equipment	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems	1.0	5.1	CEF of replacement refrigerant	120
			Leakage (grams) per vehicle per year	40
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
Transport Refrigeration Unit Cold Storage Limits	0.00	0.03	Annual growth rate of TRUs	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Cool automobile paints	0.33	1.41	Fuel economy drop with AC: cars	18.2%
			Fuel economy drop with AC: trucks	13.8%
			Percent time AC runs	33%
			Reduction in AC use	26%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%

Low-friction engine oil	8.6	67	**Fuel economy improvement**	**1.5%**
			Initial adoption in year 2010	**50%**
			Annual rate of increase for adoption	**10%**
High GWP Stationary Refri.	10.3	110	**Refrigerant types in blend**	see sheet
			Current and future leakage rates	see sheet
			Refrigerant recycling rates	see sheet
Alternative Suppressants in Fire Protection Systems	12.8	310	**HFC-125**	**25%**
			HFC-134a	**25%**
			HFC-227ea	**25%**
			HFC-236fa	**25%**
Foam Recovery and Destruction Program (Ten Year Model)	146	1,940	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Foam Recovery and Destruction Program (Annual Model)	**19,079**	**220,433**	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing Agents Portfolio from 2000 to 2004	
			HCFC-141b	**50%**
			HFC-134a	**50%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Sample results #2, low emissions reductions. The next series of results uses the low-emissions-reductions scenarios:

-- low emissions reductions
-- IPCC AR4 GWPs
-- all user input adoption/implementation percentages

Climate Change Reduction Strategy	10^{12} g CO2e Reduced		Key Assumption(s)	Active Value
	2020	2010-2020		
Cargo Handling Equipment Anti-Idling	0.0001	0.0006	Annual growth rate of cargo equipment	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems	0.3	1.3	CEF of replacement refrigerant	120
			Leakage (grams) per vehicle per year	40
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
Transport Refrigeration Unit Cold Storage Limits	0.00	0.03	Annual growth rate of TRUs	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Cool automobile paints	0.11	0.48	Fuel economy drop with AC: cars	18.2%
			Fuel economy drop with AC: trucks	13.8%
			Percent time AC runs	33%
			Reduction in AC use	26%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%

Low-friction engine oil	2.9	23	Fuel economy improvement	1.5%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
High GWP Stationary Refri.	10.3	110	Refrigerant types in blend	see sheet
			Current and future leakage rates	see sheet
			Refrigerant recycling rates	see sheet
Alternative Suppressants in Fire Protection Systems	12.8	310	HFC-125	25%
			HFC-134a	25%
			HFC-227ea	25%
			HFC-236fa	25%
Foam Recovery and Destruction Program (Ten Year Model)	120	1,622	Demolition Lost Fraction	15%
			Blowing Agents Portfolio after 2005	
			HCFC-141b	40%
			HFC-134a	40%
			HFC-245fa	20%
			Blowing agents weight fractions	
			Building Insulation	4%
			Appliance (refrigerators, freezers)	4%
			Commerial refrigeration units	4%
			Transport refrigerated units	4%

Foam Recovery and Destruction Program (Annual Model)	17,149	198,085	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing Agents Portfolio from 2000 to 2004	
			HCFC-141b	**50%**
			HFC-134a	**50%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Sample results #3, high emissions reductions. The next series of results uses the high-emissions-reductions scenarios:

-- high emissions reductions
-- IPCC AR4 GWPs
-- all user input adoption/implementation percentages

Climate Change Reduction Strategy	10^{12} g CO2e Reduced		Key Assumption(s)	Active Value
	2020	2010-2020		
Cargo Handling Equipment Anti-Idling	0.0001	0.0006	Annual growth rate of cargo equipment	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems	1.5	7.5	CEF of replacement refrigerant	120
			Leakage (grams) per vehicle per year	40
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
Transport Refrigeration Unit Cold Storage Limits	0.00	0.03	Annual growth rate of TRUs	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Cool automobile paints	0.52	2.22	Fuel economy drop with AC: cars	18.2%
			Fuel economy drop with AC: trucks	13.8%
			Percent time AC runs	33%
			Reduction in AC use	26%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%

Low-friction engine oil	17.0	133	Fuel economy improvement	1.5%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
High GWP Stationary Refri.	10.3	110	Refrigerant types in blend	see sheet
			Current and future leakage rates	see sheet
			Refrigerant recycling rates	see sheet
Alternative Suppressants in Fire Protection Systems	12.8	310	HFC-125	25%
			HFC-134a	25%
			HFC-227ea	25%
			HFC-236fa	25%
Foam Recovery and Destruction Program (Ten Year Model)	171	2,277	Demolition Lost Fraction	15%
			Blowing Agents Portfolio after 2005	
			HCFC-141b	40%
			HFC-134a	40%
			HFC-245fa	20%
			Blowing agents weight fractions	
			Building Insulation	4%
			Appliance (refrigerators, freezers)	4%
			Commerial refrigeration units	4%
			Transport refrigerated units	4%

Foam Recovery and Destruction Program (Annual Model)	**21,083**	**243,577**	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing Agents Portfolio from 2000 to 2004	
			HCFC-141b	**50%**
			HFC-134a	**50%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Sample results #4, default adoption percentages. The next series of results uses the default adoption/implementation percentages:

-- base-case emission reductions
-- IPCC AR4 GWPs
-- default adoption/implementation percentages

Climate Change Reduction Strategy	10^{12} g CO2e Reduced 2020	10^{12} g CO2e Reduced 2010-2020	Key Assumption(s)	Active Value
Cargo Handling Equipment Anti-Idling	0.0001	0.0007	Annual growth rate of cargo equipment	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems	1.0	5.4	CEF of replacement refrigerant	120
			Leakage (grams) per vehicle per year	40
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
Transport Refrigeration Unit Cold Storage Limits	0.00	0.04	Annual growth rate of TRUs	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Cool automobile paints	0.33	1.48	Fuel economy drop with AC: cars	18.2%
			Fuel economy drop with AC: trucks	13.8%
			Percent time AC runs	33%
			Reduction in AC use	26%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%

Low-friction engine oil	8.6	71	**Fuel economy improvement**	**1.5%**
			Initial adoption in year 2010	**50%**
			Annual rate of increase for adoption	**10%**
High GWP Stationary Refri.	10.3	110	**Refrigerant types in blend**	see sheet
			Current and future leakage rates	see sheet
			Refrigerant recycling rates	see sheet
Alternative Suppressants in Fire Protection Systems	12.8	310	**HFC-125**	**25%**
			HFC-134a	**25%**
			HFC-227ea	**25%**
			HFC-236fa	**25%**
Foam Recovery and Destruction Program (Ten Year Model)	146	1,940	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Foam Recovery and Destruction Program (Annual Model)	19,079	220,433	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing Agents Portfolio from 2000 to 2004	
			HCFC-141b	**50%**
			HFC-134a	**50%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Sample results #5, LEM CEFs. In the next series of results, the LEM CO2e factors are used, with the base-case emissions scenarios:

-- base-case emission reductions
-- LEM CEFs
-- all user input adoption/implementation percentages

Climate Change Reduction Strategy	10^{12} g CO2e Reduced		Key Assumption(s)	Active Value
	2020	2010-2020		
Cargo Handling Equipment Anti-Idling	0.0001	0.0006	Annual growth rate of cargo equipment	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems	1.1	5.5	CEF of replacement refrigerant	120
			Leakage (grams) per vehicle per year	40
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%
Transport Refrigeration Unit Cold Storage Limits	0.01	0.04	Annual growth rate of TRUs	2%
			Yr 1 percent of fleet adhering to regulation	75%
			Annual rate of increase for compliance	10%
Cool automobile paints	0.35	1.49	Fuel economy drop with AC: cars	18.2%
			Fuel economy drop with AC: trucks	13.8%
			Percent time AC runs	33%
			Reduction in AC use	26%
			Initial adoption in year 2010	50%
			Annual rate of increase for adoption	10%

Low-friction engine oil	9.1	71	**Fuel economy improvement**	**1.5%**
			Initial adoption in year 2010	**50%**
			Annual rate of increase for adoption	**10%**
High GWP Stationary Refri.	10.3	110	**Refrigerant types in blend**	see sheet
			Current and future leakage rates	see sheet
			Refrigerant recycling rates	see sheet
Alternative Suppressants in Fire Protection Systems	12.8	312	**HFC-125**	**25%**
			HFC-134a	**25%**
			HFC-227ea	**25%**
			HFC-236fa	**25%**
Foam Recovery and Destruction Program (Ten Year Model)	147	1,950	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commerial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Foam Recovery and Destruction Program (Annual Model)	19,122	220,938	**Demolition Lost Fraction**	**15%**
			Blowing Agents Portfolio after 2005	
			HCFC-141b	**40%**
			HFC-134a	**40%**
			HFC-245fa	**20%**
			Blowing Agents Portfolio from 2000 to 2004	
			HCFC-141b	**50%**
			HFC-134a	**50%**
			Blowing agents weight fractions	
			Building Insulation	**4%**
			Appliance (refrigerators, freezers)	**4%**
			Commercial refrigeration units	**4%**
			Transport refrigerated units	**4%**

Discussion of results.

Sample results #1, base case. The *Foam Recovery and Destruction Program* generates the largest GHG reductions of any strategy, by far. The next highest reductions are provided by the two other strategies aimed at "high GWP GHGs, *Alternative Suppressants in Fire Protection Systems* and *High GWP Stationary Refrigeration*. All of the other strategies except *Low-Friction Engine Oil* generate very small reductions. The strategies aimed at reducing "high GWP GHGs" produce large CO2e GHG reductions because they target processes and systems that produce GHGs with relatively high GWPs.

Sample results #2, low emissions reductions. Compared with the base-case (sample-result #1), and ignoring the four strategies that result in small benefits, the low-emissions-reductions scenario results in lower GHG emissions reductions for the *Low-Friction Engine Oil* and *Foam Recovery and Destruction Program* strategies.

Sample results #3, high emissions reductions. Compared with the base-case (sample-result #1), and ignoring the four strategies that result in small benefits, the high-emissions-reductions scenario results in higher GHG emissions reductions for the *Low-Friction Engine Oil* and *Foam Recovery and Destruction Program* strategies.

Sample results #4, default adoption percentages. Switching from the user-input adoption/implementation percentages to the default values does not significantly change the results, compared with the base case (sample result #1).

Sample results #5, LEM CEFs. Switching from the IPCC AR4 GWPs to the LEM's CEFs does not significantly change the results, compared with the base case (sample result #1), because for the high-GWP GHGs, the LEM either does not have values (in which case the CCM Calculator uses the IPCC AR4 GWPs) or else has values close to the IPCC AR4 GWPs.

Note on precision and uncertainty of results. Note that although the CARB CCM Calculator provides point estimates of emission reductions to several decimal places, these should not be interpreted as "significant" digits implying a high degree of accuracy and low uncertainty. The uncertainty in the estimates of the CARB CCM Calculator is unknown. In most cases the uncertainty is due to lack of data, lack of appropriate analysis, or inherent uncertainty about technology and human behavior, rather than to readily quantifiable measurement, statistical or sampling errors. Because of this, the uncertainty in the estimates presented here probably cannot be quantified formally. In our opinion, based on our experience with these sorts of analyses, the uncertainty is likely to exceed 20% and probably 30%.

Emission Scenario

On this sheet, users may edit the pre-set values for three scenarios:

- Low emissions reductions
- Base-case
- High emissions reductions.

The base-case values are based on our judgment or data from the literature. All data based on literature are documented in this report in the “Data Sources” section for each strategy. The low-emissions and high-emissions values are our judgment. All emission scenario values should be changed as information or better data become available.

Note that only some of the strategies have emission scenarios. Note also that you cannot change the choice of scenario on this sheet; that is done via the ‘Choice of Emission Scenario’ menu on the Summary sheet.

Inputs that are not specified on the “Emission Scenario” sheet or the “Summary Sheet” are handled on the sheet pertaining to the specific mitigation strategy.

Adoption percentages

The adoption percentage is the extent to which a particular mitigation measure is adopted in a particular year. Users may enter custom adoption percentages for each *active* year in the study period. Note that only some of the mitigation strategies have variable adoption percentages.

The controls to activate the percentages on this sheet are in the 'Global Scenario Variables' section of the Summary sheet.

Cargo-Handling Equipment Anti-idling

ARB early action item description: Reduce idling (beyond 10 minutes) in cargo-handling equipment at ports and intermodal rail yards.

Method of calculating CO_2-equivalent emission reductions:

The calculation of CO_2-equivalent emission reductions as a result of the use of this measure follows two basic steps:

1. Calculate the reduction in diesel use
   i. Annual fuel from idling = [equip. inventory amount] * [avg. idling per day] * [fuel use while in idle] * [avg. number of days operated per year]
   ii. Fuel savings from rule compliance = [annual fuel use from idling] * [% compliance]
2. Calculate the reduction in lifecycle CO_2-equivalent emissions
   i. [Fuel savings from rule compliance] * ["upstream" + vehicle stage CO2-equiv emissions]*[higher heating value for diesel]
   ii. 10^6 tonnes, CO_2-equiv/year = (10^6 gallons/yr * g/10^6 BTU*10^6 BTU/gal) / 10^6
   iii. Upstream emissions: the CO_2-equivalent emissions resulting from the 'well-to-tank' phase of the fuel's lifecycle.

Key assumptions:

1. Per ARB documentation (see below for source), this measure aims to restrict idling in excess of 10 minutes.
2. This regulation goes into place in 2012.

User inputs from 'Summary' or "Emission Scenario" sheets:

Item	*Base-Case Default Value*
Annual growth rate of cargo equipment	2%
Initial compliance in year 2012	75%
Annual rate of increase for compliance	10%

Data sources:

Item	*Source(s)*
Equipment inventories	California Air Resources Board (2009) "Cargo Handling Equipment Idling Emissions" Public workshop at the Air Resources Board, Sept 16, 2009 (http://www.arb.ca.gov/ports/cargo/idle/presentations/091609present.pdf)
Avg. idling per day	
Fuel use in idle	
Avg. days operated per year	

Low-GWP Refrigerants for Mobile Vehicle Air Conditioning Systems

ARB early action item description: Low-GWP refrigerants used in mobile air conditioning systems instead of HFC134a.

Method of calculating CO_2-equivalent emission reductions:

The calculation of CO_2-equivalent emission reductions as a result of the use of this measure follows two basic steps:

1. Calculate the number of new vehicles that use low-GWP refrigerant
   i. [total cumulative number of new cars in that year] * [% adoption]
2. Using the assumption for refrigerant leakage per year (from the 'Summary' sheet) and the GWP difference between the new refrigerant and HFC134a, calculate the reduction in CO_2-equivalent emissions. 10^6 tonnes, CO_2-equiv/year = [total cumulative new cars] * [refrigerant leakage, g/veh/yr] * [$GWP_{HFC134a}$ – $GWP_{newrefrigerant}$] / (10^6 * 10^6)

Key assumptions:

1. Low-GWP refrigerants are used in new passenger vehicles (cars and light trucks) only.
2. R152a is assumed to be the replacement refrigerant
3. This technology can be phased in starting in 2010.

User inputs from 'Summary' or "Emission Scenario" sheets:

Item	*Base-Case Default Value*
CO_2-equivalency of new refrigerant	120
Leakage (grams) per vehicle per year	40
Initial adoption in year 2010	50%
Annual rate of increase for adoption	10%

Data sources:

Item	*Source(s)*
Vehicle inventories	Argonne National Laboratory (2008) VISION model (http://www.transportation.anl.gov/modeling_simulation/VISION/index.html)
CO_2-equivalency of R152a	Baker (2004) “R-152a Mobile AC System Risk Mitigation Strategy” Mobile Air Conditioning Summit. April 15, 2004.
Refrigerant leakage (g/vehicle/year)	Baker (2004) “R-152a Mobile AC System Risk Mitigation Strategy” Mobile Air Conditioning Summit. April 15, 2004.

Transportation Refrigeration Unit (TRU) Cold Storage Limits

ARB early action item description: TRU extended cold storage (beyond 24 hours) is prohibited.

Method of calculating CO_2-equivalent emission reductions:

The calculation of CO_2-equivalent emission reductions as a result of the use of this measure follows two basic steps:

1. Calculate the reduction in diesel use
    i. Total fuel used for cold storage = [inventory amount] * [gals/TRU/year]
    ii. Fuel savings from rule compliance = [annual fuel use from cold storage] * [% compliance]
2. Calculate the reduction in lifecycle CO_2-equivalent emissions
    i. [Fuel savings from rule compliance] * ["upstream" + vehicle stage CO_2-equiv emissions]*[higher heating value for diesel]
    ii. 10^6 tonnes, CO_2-equiv/year = (10^6 gallons/yr * g/10^6 BTU*10^6 BTU/gal) / 10^6
    iii. Upstream emissions: the CO_2-equivalent emissions resulting from the 'well-to-tank' phase of the fuel's lifecycle.

Are there no key assumptions for this measure?

User inputs from 'Summary' or "Emission Scenario" sheets:

Item	*Base-Case Default Value*
Annual growth rate of TRUs	2%
Initial compliance in year 2012	75%
Annual rate of increase for compliance	10%

Data Sources:

Item	*Source(s)*
TRU inventories	Workshop on Draft Regulatory Concepts for Transport Refrigeration Unit (TRU) Cold Storage Prohibition. Public workshop at the Air Resources Board, March 23, 2009 (www.arb.ca.gov/diesel/tru/documents/tru_cs_slides_3_23_09.pdf)
Fuel used for cold storage	

Cool Automobile Paints

ARB early action item description: Advanced exterior paint and reflective glazing reduces interior temperatures of vehicles, thus reducing air conditioner (AC) use and fuel use.

Method of calculating CO_2-equivalent emission reductions:

The calculation of CO_2-equivalent emission reductions as a result of the use of this measure follows two basic steps:

1. Calculate the reduction in gasoline use
   i. Our assumption is that vehicles have a decrease in fuel economy (FE) due to AC use. $FE_{adjusted}$ = $FE_{original}$ * (1 – [% FE drop when AC is running] * [% time AC runs])
   ii. Our assumption is that cool paints and reflective glazing reduce the AC use by a certain percentage. $FE_{coolpaints}$ = $FE_{original}$ * (1 – [% FE drop when AC is running] * [% time AC runs]*(1 – [% reduction in AC use due to cool paints]))
   iii. Reduction in annual fuel use = ([total VMT]/$FE_{adjusted}$ – [total VMT]/$FE_{coolpaints}$)*[% adoption in that year]
2. Calculate the reduction in lifecycle CO_2-equivalent emissions
   i. [Reduction in fuel use] * ["upstream" + vehicle stage CO2-equiv emissions]*[higher heating value for reformulated gasoline]
   ii. 10^6 tonnes, CO_2-equiv/year = (10^6 gallons/yr * g/10^6 BTU*10^6 BTU/gal) / 10^6
   iii. Upstream emissions: the CO_2-equivalent emissions resulting from the 'well-to-tank' phase of the fuel's lifecycle. Note: the current version of the CARB CCM Calculator only calculates the reduction in LCA emissions associated with fuel use, but future versions should include LCA emission reductions associated with potential downsizing of the AC system, and how that change will result in the reduction of vehicle stage LCA emissions, and CFC emissions.

Key assumptions:

1. Cool paint and reflective glazing technology is used in new passenger vehicles (cars and light trucks) only.
2. Per documentation on the ARB website (http://www.arb.ca.gov/cc/cool-cars/cool-cars.htm), the earliest this technology can be phased in is 2012.

User inputs from 'Summary' or "Emission Scenario" sheets:

Item	*Base-Case Default Value*
Fuel economy drop with AC: cars	18.2%
Fuel economy drop with AC: light-duty trucks	13.8%
Percent time AC runs	33%
Reduction in AC use due to cool paints/reflective glazing	26%
Initial adoption in year 2012	50%
Annual rate of increase for adoption	10%

Data sources:

Item	*Source(s)*
Vehicle inventories	Argonne National Laboratory (2008) VISION model (http://www.transportation.anl.gov/modeling_simulation/VISION/index.html)
Vehicle miles traveled (VMT)	
Fuel economy	
Higher heating value for reformulated gasoline	Delucchi, M (2008) Lifecycle Emissions Model (LEM): scenario results from the U.S. in 2012. www.its.ucdavis.edu/people/faculty/delucchi.
Upstream emissions for reformulated gasoline	
Average percent time AC runs	Rugh, JP, L Chaney, J Lustbader, and J Meyer (2008). Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and a New Solar-Reflective Glazing. Public Workshop at the Air Resources Board. May 20, 2008. Sacramento, CA. (http://www.arb.ca.gov/cc/cool-paints/2007_01_1194_presentation_final.pdf)
Reduction in AC use as a result of cool paints	
Fuel economy drop with AC	Rugh, J, V Hovland and SO Anderesn (2004). Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning. 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit April 15, 2004. www.nrel.gov/vehiclesandfuels/ancillary_loads/pdfs/fuel_savings_ac.pdf.

Low-friction Engine Oil

ARB early action item description: Low-viscosity oil reduces friction in the engine and thus boosts fuel economy.

Method of calculating CO_2-equivalent emission reductions:

The calculation of CO_2-equivalent emission reductions as a result of the use of this measure follows two basic steps:

1. Calculate the reduction in gasoline use
    i. Our assumption is that vehicles have an increase in fuel economy (FE) due to low-friction oil use. $FE_{lowfriction} = FE_{original}$ * [1 + % increase in FE]
    ii. Reduction in annual fuel use = ([total VMT]/$FE_{original}$ – [total VMT]/$FE_{lowfriction}$)*[% adoption in that year]
2. Calculate the reduction in lifecycle CO_2-equivalent emissions
    i. [Reduction in fuel use] * [“upstream” + vehicle stage CO2-equiv emissions]*[higher heating value for reformulated gasoline]
    ii. 10^6 tonnes, CO_2-equiv/year = (10^6 gallons/yr * g/10^6 BTU*10^6 BTU/gal) / 10^6
    iii. Upstream emissions: the CO_2-equivalent emissions resulting from the ‘well-to-tank’ phase of the fuel’s lifecycle.

Key assumptions:

1. Low-friction engine oil can be used in the entire passenger vehicle (cars and light trucks) fleet (new and in-use vehicles).
2. This technology can be phased in starting in 2010.

User inputs from ‘Summary’ or “Emission Scenario” sheets:

Item	*Base-Case Default Value*
Fuel economy improvement with LF oil	1.5%
Initial adoption in year 2010	50%
Annual rate of increase for adoption	10%

Data sources:

Item	*Source(s)*
Vehicle inventories	Argonne National Laboratory (2008) VISION model (http://www.transportation.anl.gov/modeling_simulation/VISION/index.html)
Vehicle miles traveled (VMT)	
Fuel economy	
Higher heating value for reformulated gasoline	Delucchi, M (2008) Lifecycle Emissions Model (LEM): scenario results from the U.S. in 2012. www.its.ucdavis.edu/people/faculty/delucchi.
Upstream emissions for reformulated gasoline	
Fuel economy improvement with LF oil	Tanaka, H., Nagashima, T., Sato, T. and Kawauchi, S. (1999) "The effect of 0W-20 low viscosity engine oil on fuel economy" SAE Paper No. 1999-01-3468.

High GWP Reduction from Stationary Sources

ARB early action item description: High GWP Refrigerant Tracking, Reporting, Repair and Deposit for Stationary Refrigeration and Air Conditioning systems and Specifications for New Commercial and Industrial Refrigeration Systems.

Method of Calculating GHG Emissions Reduction:

GHG reductions are calculated as the sum of savings from leakage repair, refrigerant recycling and energy usage emissions for each of six systems as listed below.

Systems Studied:

Existing systems: Existing AC and refrigeration systems.
Future systems: Future large direct expansion (DX) system, cold storage warehouses, industrial processes and retail food equipment.

Key Assumptions:

1) In the table of Equipment System Characteristics:
   a) For existing systems, equipment is categorized by size. The total number of units is assumed to be 50% AC and 50% refrigeration systems (see Data Sources).
   b) For existing systems, the average weight of refrigerant per equipment is assumed to be 10% of the equipment weight. The average of the lower and upper boundary for this category. (e.g. if the equipment weight is 50-200lb, then the average weight of refrigerant is $\frac{(50+200)lb}{2} \times \frac{0.454lb}{kg} \times 0.1 = 49.94kg$. For unit weight higher than 2000lb (>2000lb), average weight of refrigerant is assumed to be 181.60 kg (20% of 2000lb). For new systems, average weight of refrigerant per equipment data is to be determined.
   c) The average amount of residual refrigerant left in equipment after its useful life is assumed to be 10% of initial amount of refrigerant. However, this number could vary depending on how recently a piece of equipment was recharged prior to be taken out of service.
2) In the table of policy effects, current and future leakage rates and current refrigerant recycling rates are based on CARB workshop information. The energy usage reduction rate resulting from repairing leaks and future refrigerant recycling (reclamation) rates are assumed and could be improved if additional information becomes available.
3) In the table of refrigerant blends: Four common refrigerant blends are currently used in the market. The components that make up each blend are defined based on a report on U.S. phase out of HCFCs (see Data Sources). Based on the components, an average GWP factor is calculated for each blend.
4) In the table of refrigerant blends for each system, U.S. phase out of HCFCs report indicates that industrial process uses R-401A only and cold storage system does not use R-409A. For other systems, each component refrigerant is assigned an equal

percent-contribution in the blends. An average GWP factor is then calculated for each system.

5) In the table of LCA assumptions: Transportation distance from user to disposal site and the leakage rate during the disposal process are simply assumed as there is no data available on the appropriate transport distance.

User inputs from 'Summary' or "Emission Scenario" sheets:

*No user inputs on "Summary" or "Emission Scenario" sheets for this module. See the "**High GWP Stationary Refri.**" sheet for inputs.*

User Inputs in this module:

1) In the table of future stock: The model user needs to fill in the predicted stock information for all four regulated systems. These systems include, large direct expansion (DX) systems, cold storage warehouses, industrial processes and retail food equipment.

Data Sources:

Item	Source(s)
Equipment size and number of units; current, future leakage rate and current refrigerant recycling rate	Stationary Source High-Global Warming Potential (GWP) Refrigerant Management Program (CARB Public Workshops) (Sep 2008)
Refrigerant blend components for each commercial refrigerant name; refrigerant blend portfolio in the industrial process and cold storage systems.	Draft: The U.S. Phaseout of HCFCs: Projected Servicing Needs in the U.S.Air-Conditioning and Refrigeration Sector, prepared for USEPA, ICF Consulting.
GWP factors for transportation of residual refrigerant and average electricity production in the US	Gabi 4 software, PE America
Yearly average electricity usage for AC (200-2000lb and over 2000lb) and Refrigeration systems between 200-2000lb.	http://www.oksolar.com/technical/consumption.html Refrigeration systems electricity usage for 200-2000lb system is the average of all four types of equipment in this source.

Alternative Suppressants in Fire Protection systems

ARB early action item description: Considering GHGs from alternative suppressants in total flooding (fixed) and streaming (portable) fire suppression systems. Most fire suppression systems originally used halons, which are ozone depleting compounds, but new systems have moved to halon alternatives that are high GWP fire suppressants, e.g. HFCs.

Method of Calculating GHG Emissions Reduction:

GWP reductions are calculated as the sum of savings from on site leakage reduction and end of life recycling management program. Considering the lifetime of fixed systems (more than 10 years), GHG reduction from a recycling program is not applicable to future fixed systems. Leakage reduction and recycling are considered in all existing fixed, portable systems and future portable systems.

Systems Studied:

Existing and future systems: Fixed and portable fire suppressant systems.

Key Assumptions:

1) In the table of current stock, average weights of fire suppressant per unit are not based on a reliable data source, they are merely assumed. As this data becomes available to the ARB, they should be updated.
2) In the table of fire suppressants, the fractions of each HFC and Halon are assumed in equal proportion in high GWP systems (HFCs) and halon systems.
3) In the table of policy effects, after implementation, both the on-site leakage rate and end of life recycling are increased by 50%. Current end of life recycling is assumed to be 20% of out-of-duty fire suppressants.
4) In the table of LCA assumptions, the lifetime of portable systems is 5 years, the refill time of fixed systems is 10 years, and the replacement time of existing fixed halon systems is 10 years. Thus, future fixed systems will not have to dispose of (recycle) the fire suppressants until 2020. The leakage rate during the recycling process is assumed to be 0%.

User inputs from 'Summary' or "Emission Scenario" sheets:

Item	*Base-Case Default Value*
Share of HFC-125	25%
Share of HFC-134a	25%
Share of HFC-227ea	25%
Share of HFC-236fa	25%

Note: these base-case assumptions are just place-holders; ARB should input actual values as they become available.

User Inputs in this module:

1) In the table of current stock, the numbers of units for fixed and portable systems are needed.
2) In the table of future stock for both portable and fixed systems, the stock needs to be input for both tables.

Data Sources:

Item	*Source(s)*
Fraction of High GWP suppressants in the table of current stock; current on-site leakage rate.	Climate Change Proposed Scoping Plan Appendices Volume I
High GWP (HFCs) fire suppressants in the table of fire suppressants	http://www.epa.gov/Ozone/geninfo/gwps.html
Halon fire suppressants in the table of fire suppressants	http://www.epa.gov/Ozone/science/ods/classone.html

Foam Recovery and Destruction Program

ARB early action item description: Reducing the GHG emission from waste insulation foam when it is shredded during appliance recycling or broken during building construction, renovation, and demolition.

Method of Calculating GHG Emissions Reduction:

Two models are developed for this measure. Depending on the survey data, the current stocks of foams will be entered as yearly stock (Yearly model) or ten-year stock (Ten-Year Model). The GHG reductions are calculated as the total amount of GHG recovered from foams.

Systems Studied:

Four types of equipment containing foam are included: building insulation, appliances (refrigerators and freezers), commercial refrigeration units and refrigerated transportation units.

Key Assumptions:

For both the Ten-Year and Yearly Model, in the table entitled *Portfolio of blowing agents in foams*, the blowing agent %-weight in foams is assumed at 4%. (This is just an interim assumption. New values can be input on the “Emission Scenario” sheet.)

Based on Scoping Plan Appendices Volume I, we assume the following usage of blowing agents by year:

Period	Ten-year model	Annual model
Up through 1995	CFC-11	CFC-11
1996-1999	HCFC-141b	HCFC-141b
2000-2004	HCFC-141b, HFC-134a, HFC-245fa	HCFC-141b, HFC-134a,
2005 on	HCFC-141b, HFC-134a, HFC-245fa	HCFC-141b, HFC-134a, HFC-245fa

In the Ten-Year model, the blowing agent portfolio used after 2000 and the demolition rates are interim assumptions; as data become available, more accurate values should be input. In the Yearly Model, the blowing agent portfolios between 2000 and 2004 and after 2005, and the demolition rates, also are interim assumptions; again, as data become available, more accurate values should be input.

In the recycling process, the average transportation distance and the GWP factor for recycling GHG in foams are assumed.

User inputs from 'Summary' or "Emission Scenario" sheets:

Ten-Year Model

Item	*Base-Case Default Value*
Demolition Lost Fraction	15%
Blowing agents portolio after 2005	
HCFC-141b	40%
HFC-134a	40%
HFC-245fa	20%
Blowing agents weight fractions	
Building Insulation	4%
Appliance (refrigerators, freezers)	4%
Commerial refrigeration units	4%
Transport refrigerated units	4%

Yearly Model

Item	*Base-Case Default Value*
Demolition Lost Fraction	15%
Blowing agents portolio after 2005	
HCFC-141b	40%
HFC-134a	40%
HFC-245fa	20%
Blowing agents portolio 2000 to 2004	
HCFC-141b	50%
HFC-134a	50%
Blowing agents weight fractions	
Building Insulation	4%
Appliance (refrigerators, freezers)	4%
Commerial refrigeration units	4%
Transport refrigerated units	4%

User Inputs in this module:

1) Based on the survey data, the quantity of foam recovered in each of the four systems in each ten-year period in the Ten-Year model and the quantity each year in Yearly Model are to be filled by the user.

Data Sources:

Item	*Source(s)*
Blowing agents loss rate in each of four systems in the manufacturing phase and use phase (Both models)	US EPA, *U.S. High GWP Gas Emissions 1990–2010: Inventories, Projections, and Opportunities for Reductions*, June 2001. http://www.airimpacts.org/documents/local/highgwp_emit.pdf
Average GWP factor from the transportation of foam in the recycling process	Gabi 4, PE America

CO2 Equivalency Factors

This sheet contains all of the CO2 equivalency factors (CEFs) that may be used in model. The CEF for pollutant *p* is the number by which one gram of *p* must be multiplied in order for it to have the same climatic effect (to be defined in a moment) as an emission of one gram of CO2. Put another way, a CEF converts emissions of *p* into an "equivalent" amount of CO2 emissions, where equivalency is variously defined, as explained below. The product of a CEF for *p* and actual emissions of *p* is the CO2-equivalent (CO2e) amount of *p*. The sum of all CO2 equivalents for all *p,* plus actual CO2 emissions, gives total CO2e GHG emissions. CEFs thus are used to convert all emissions to a common basis so that alternatives can be compared according to a single metric, CO2e GHG emissions.

The most widely used CEF is called a Global Warming Potential, or GWP. GWPs equate emissions on the basis of radiative forcing integrated over a 100-year period. Most lifecycle analyses and policy analyses of GHG emissions use GWPs to estimate CO2e GHG emissions. In its periodic *Assessment Reports* the Intergovernmental Panel on Climate Change (IPCC) estimates GWPs for a wide range of GHGs. We have included IPCC GWPs as options here.

For the development of the Lifecycle Emissions Model (LEM), Delucchi is developing CEFs that equate GHG emissions on the basis of the present value of the damages from climate change. These CEFs go several steps beyond the estimation of GWPs, and better approximate what society cares about, which is the impact of climate change, as opposed to radiative forcing per se (the basis of GWPs).

The CO2 Equiv Factors sheet has four sets of CEFs: GWPs from the IPCC's fourth *Assessment Report* (AR4) GWPs from the IPCCs second *Assessment Report* (AR2), CEFs used in the LEM, and a user-input set, currently blank. The four sets of values, including the space for user inputs, are shown in the **Table of CEFs**, below.

The user may enter custom CO2 equivalency factor values in the "User-input" column of the "CO2 Equiv Factors" sheet. The user then selects among the four CEF sets in a pull-down menu in the "Summary" sheet (*not* the "CO2 Equiv Factors" sheet).

Because the calculation of CO2e emissions from foam recovery, fire suppressants, and high-GWP stationary refrigerants requires CEFs for CFCs and HCFCs, the CARB CCM Calculator is designed to use the IPCC AR4 GWP values for CFCs and HCFCs (see **Table of CEFs**) if the selected set (e.g., LEM CEFs, AR2 GWPs) does not contain values for CFCs and HCFCs.

Table of CEFs

	IPCC AR4	IPCC AR2	LEM CEFs	User Input
CH4	25	21	42	
N2O	298	310	263	
C (in NMOC, CO...)			4	
NMOC-03/CH4, SOA			15	
CO			6	
NO2			-5	
SO2			-91	
NH3			0	
PM (black carbon)			954	
PM (organic matter)			-78	
PM (dust)			-6	
H2			22	
SF6	22,800	23,900	43,700	
CF4	7,390	6,500	14,567	
C2F6	12,200	9,200	23,860	
HF			2,000	
CFC-11	4,750			
CFC-12	10,900		10,715	
CFC-13	14,400			
CFC-113	6,130			
CFC-114	10,000			
CFC-115	7,370			
Halon-1301	7,140			
Halon-1211	1,890			
Halon-2402	1,640			
Carbon tetrachloride	1,400			
Methyl bromide	5			
Methyl chloroform	146			
Propane (R-290)	3			
HCFC-22	1,810			
HCFC-123	77			
HCFC-124	609			
HCFC-141b	725			
HCFC-142b	2,310			
HCFC-225ca	122			
HCFC-225cb	595			
HFC-23	14,800	11,700		
HFC-32	675	650		
HFC-125	3,500	2,800		
HFC-134a	1,430	1,300	1,537	
HFC-143a	4,470	3,800		
HFC-152a	124	140		
HFC-227ea	3,220	2,900		
HFC-236fa	9,810	6,300		
HFC-245fa	1,030	560		
HFC-365mfc	794			
HFC-43-10mee	1,640	1,300		

Fuel LCA (from LEM)

This sheet calculates upstream (well-to-tank) lifecycle CO2e GHG emissions for reformulated gasoline and diesel fuel, using results from the Lifecycle Emissions Model (LEM).

Lifecycle CO2e GHG emissions are calculated here by multiplying "raw" emissions of each pollutant *p*, in grams of *p* per 10^6 BTU of fuel, by the CEF for *p*, and summing over all *p* and all stages of the fuel lifecycle. The CEFs are discussed elsewhere in this documentation. The "raw" emissions, in grams of *p* per 10^6 BTU of fuel, for each stage of the fuel lifecycle and each fuel lifecycle, are in this "Fuel LCA (from LEM)" sheet. (Note that results are included for a number of fuel lifecycles other than reformulated gasoline and diesel fuel, in the event that CARB wishes to analyze alternative fuels.) These results were obtained from the LEM set to simulate the United States and the year 2012.

In the following sections we give a brief overview of the lifecycle stages, emission sources, and pollutants included in the LEM.

Fuel lifecycles in the LEM:

The LEM estimates the use of energy, and emissions of greenhouse gases and urban air pollutants, for the complete lifecycle of fuels, materials, vehicles, and infrastructure for a range of transportation modes. These fuel lifecycles are constructed as follows:

- **end use**: the use of a finished fuel product, such as gasoline, electricity, or heating oil, by consumers.
- **dispensing of fuels**: pumping of liquid fuels, and compression or liquefaction of gaseous transportation fuels.
- **fuel distribution and storage**: the transport of a finished fuel product to end users and the operation of bulk-service facilities. For example, the shipment of gasoline by truck to a service station.
- **fuel production**: the transformation of a primary resource, such as crude oil or coal, to a finished fuel product or energy carrier, such as gasoline or electricity. A detailed model of emissions and energy use at petroleum refineries is included.
- **feedstock transport**: the transport of a primary resource to a fuel production facility. For example, the transport of crude oil from the wellhead to a petroleum refinery. A complete country-by-country accounting of imports of crude oil and petroleum products by country is included in the LEM.
- **feedstock production**: the production of a primary resource, such as crude oil, coal, or biomass. Based on primary survey data at energy-mining and recovery operations, or survey or estimated data for agricultural operations.

Sources of emissions in LEM lifecycles:

The LEM characterizes greenhouse gases and criteria pollutants from a variety of emission sources:

- Combustion of fuels that provide process energy (for example, the burning of bunker fuel in the boiler of a super-tanker, or the combustion of refinery gas in a petroleum refinery).
- Evaporation or leakage of energy feedstocks and finished fuels (for example, from the evaporation of hydrocarbons from gasoline storage terminals).
- Venting, leaking, or flaring of gas mixtures that contain greenhouse gases (for example, the venting of coal bed gas from coal mines).
- Fugitive dust emissions (for example, emissions of re-entrained road dust from vehicles driving on paved roads).
- Chemical transformations that are not associated with burning process fuels (for example, the curing of cement, which produces CO2, or the denitrification of nitrogenous fertilizers, which produces N2O, or the scrubbing of sulfur oxides (SOx) from the flue gas of coal-fired power plants, which can produce CO2).
- Changes in the carbon content of soils or biomass, or emissions of non-CO2 greenhouse from soils, due to changes in land use.

Pollutant tracked in the LEM:

The LEM estimates emissions of the following pollutants:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- carbon monoxide (CO)
- nitrogen oxides (NOx)
- nonmethane organic compounds (NMOCs), weighted by their ozone-forming potential
- sulfur dioxide (SO_2)
- total particulate matter (PM)
- particulate matter less than 10 microns diameter (PM_{10}), from combustion
- particulate matter less than 10 microns diameter (PM_{10}), from dust
- hydrogen (H_2)
- chlorofluorocarbons (CFC-12)
- hydrofluorocarbons (HFC-134a)
- the CO_2-equivalent of all of the pollutants above

Ozone (O_3) is not included in this list because it is not emitted directly from any source in a fuel cycle, but rather is formed as a result of a complex series of chemical reactions involving CO, NOx, and NMOCs. Note that the CCM Calculator does not report non-GHG emissions as such.

California Vehicle Data

This sheet contains VMT, fuel economy, and survival data for passenger cars and trucks (under 10,000 lbs) in California.

The passenger car (PC) and light-duty truck (LT) turnover model uses data from the VISION-CA model, which is a modified version of the Argonne National Laboratory's (ANL) VISION model. VISION provides estimates of energy and petroleum use and the concomitant carbon dioxide emissions resulting from advanced light- and heavy-duty technologies and alternative fuels through the year 2050. The VISION-CA model has the same underlying structure as the Argonne VISION model, but it has been modified to represent the California transportation sector. VISION-CA was originally developed to support the analysis for the Low Carbon Fuel Standard.

Sales and population data by model year (MY) for PCs and LTs are given in rows 35 through 85 (the values are taken directly from VISION-CA). For the calendar years of interest, 2010-2020, we have both new vehicle sales and total population by calendar year.

Total cumulative vehicle miles traveled (VMT) for vehicles newer than MY 2009 are given in the table at cells F90 through Q100 (PCs) and AH90 through AS100 (LTs) using the VMT-by-age (for years 0, 1, 2,…, 20, 20+) estimates in cells I88 through AD88 (PCs) and AK88 through BF88 (LTs). Total cumulative VMT for vehicle newer than MY 2011 are given in the table at cells F102 though S114 (PCs) and AH102 through AU114 (LTs). Total VMT for the entire fleet for 1970 to 2020 are given in rows 119 through 169.

Calendar population and VMT data from the Air Resources Board's EMission FACtor (EMFAC2007) model are shown in columns AH and AI for passenger cars and BJ and BK for light-duty trucks. These grayed-out data are for reference only and are not used in any model calculations.

Acronyms

This sheet contains acronyms used in the CARB CCM Calculator.

Acronym	Full name
AC	Air conditioning
BTU	British thermal unit
CA	California
CEF	Carbon dioxide equivalency factor
CG	Compressed gas
CO2e	Carbon dioxide equivalent
F-T	Fischer Tropsch
FE	Fuel economy
g	Grams
gal	Gallon
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
IPCC AR2	Intergovernmental Panel on Climate Change - Second Assessment Report (1995)
IPCC AR4	Intergovernmental Panel on Climate Change - Fourth Assessment Report (2007)
KJ	Kilajoule - 1,000 joules
LC	Lifecycle
LCA	Lifecycle Analysis
LDV	Light duty vehicle
LEM	Lifecycle Emissions Model
LPG	Liquid petroleum gas
MACS	Mobile (vehicle) air conditioning systems
MDV	Medium duty vehicle
mpg	Miles per gallon
NG	Natural gas
RFG	Reformulated gasoline
RTG	Rubber tired gantry
TRU	Transport refrigeration unit
VMT	Vehicle miles traveled

References

Sheet and Parameter	Source
Cargo Equipment Anti-Idling	
Inventory, idling, and fuel use data	California Air Resources Board (2009) Cargo Handling Equipment Idling Emissions. Public workshop at the Air Resources Board, Sept 16, 2009. http://www.arb.ca.gov/ports/cargo/idle/presentations/091609present.pdf
Transport Refrigeration Unit Cold Storage Prohibition	
Inventory and fuel use data	California Air Resources Board (2009) Workshop on Draft Regulatory Concepts for Transport Refrigeration Unit (TRU) Cold Storage Prohibition. Public workshop at the Air Resources Board, March 23, 2009. www.arb.ca.gov/diesel/tru/documents/tru_cs_slides_3_23_09.pdf
Low-GWP Refrigerants for Vehicle Air-conditioning Systems	
CEF of replacement refrigerant Leakage (grams) per vehicle per year	Baker (2004) "R-152a Mobile AC System Risk Mitigation Strategy" Mobile Air Conditioning Summit. April 15, 2004. http://www.mac-summit.com/mac2004.html

Cool Paints	
Fuel economy drop with AC: cars Fuel economy drop with AC: trucks	Rugh, J, V Hovland and SO Anderesn (2004). Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning. 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit April 15, 2004. http://www.nrel.gov/vehiclesandfuels/ancillary_loads/pdfs/fuel_savings_ac.pdf
Percent time AC runs Reduction in AC use	Rugh, JP, L Chaney, J Lustbader, and J Meyer (2008). Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and a New Solar-Reflective Glazing. Public Workshop at the Air Resources Board. May 20, 2008. Sacramento, CA. http://www.arb.ca.gov/cc/cool-paints/2007_01_1194_presentation_final.pdf
Low-Friction Engine Oil	
Fuel economy improvement	Tanaka, H., Nagashima, T., Sato, T. and Kawauchi, S. (1999) "The effect of 0W-20 low viscosity engine oil on fuel economy" SAE Paper No. 1999-01-3468. http://www.sae.org/technical/papers/1999-01-3468
High GWP Stationary Refrigerants	See section on High GWP Stationary Refrigerants, above.
Fire Suppressants	See section on Fire Suppressants, above.

Foam Recovery -- Ten-Year Model	
Blowing agent loss by stage, fraction, in-use	US EPA, U.S. High GWP Gas Emissions 1990–2010: Inventories, Projections, and Opportunities for Reductions, June 2001. http://www.airimpacts.org/documents/local/highgwp_emit.pdf
Foam Recovery -- Annual Model	
Blowing agent loss by stage, fraction, in-use	US EPA, U.S. High GWP Gas Emissions 1990–2010: Inventories, Projections, and Opportunities for Reductions, June 2001. http://www.airimpacts.org/documents/local/highgwp_emit.pdf
CO2 Equivalency factors	
GWP values - IPCC's 4th AR	IPCC (2007) 4th Assessment Report. http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf
GWP values - IPCC's 2nd AR	IPCC (1995) 2nd Assessment Report. http://unfccc.int/ghg_data/items/3825.php
CO2 equivalency values - LEM	Delucchi, M. (2003) A Lifecycle Emissions Model (LEM): Documentation - APPENDIX D: CO2 EQUIVALENCY FACTORS. http://www.its.ucdavis.edu/publications/2003/UCD-ITS-RR-03-17D.pdf
Fuel LCA (from LEM)	Lifecycle Emissions Model (LEM) run for the year 2012. www.its.ucdavis.edu/people/faculty/delucchi
California Vehicle Data	VISION-CA (California version of Argonne National Lab ViSION model.)