CENTER FOR CLEAN AIR POLICY


# Part Two:
# Vehicle Technology and Fuels

**Written and Developed by:**
**Greg Dierkers, Mark Houdashelt, Erin Silsbe, Shayna Stott,**
**Steve Winkelman & Mac Wubben**

Center for Clean Air Policy
Dialogue. Insight. Solutions.

**www.ccap.org/guidebook**

**guidebook@ccap.org**

**With Support from the:**
**US Department of Transportation's**
**Center for Climate Change and Forecasting**

Center for Clean Air Policy
Dialogue. Insight. Solutions.

**750 First Street, NE**
**Suite 940**
**Washington, DC 20002**
**(202) 408-9260 *Phone***
**(202) 408-8896 *Fax***
**www.ccap.org**



## CCAP'S MISSION

The Center for Clean Air Policy was established in 1985 by a group of state governors to develop and promote innovative policy solutions to energy and environmental problems. From our initial work as a key player in the development of a $SO_2$ trading system to help control acid rain to ongoing projects that focus on market-oriented approaches to ozone, climate change, and air toxics, we have promoted the idea that sound energy and environmental policy solutions serve both environmental and economic interests. The Center has over 20 years of experience addressing climate change, air emissions, and energy policy in ways that are both efficient and effective.

The Center has been actively engaged in analyzing and advancing policies in all sectors of the economy-electricity, transportation and land-use, buildings, commercial, industrial, agriculture, and forestry-as well as cross-cutting experience in emissions trading and emissions registries. The Center uses a number of tools in its efforts to support policy development, including stakeholder dialogues and economic and policy analysis. Through carefully directed stakeholder dialogues, the Center is able to integrate technical analyses with political realities to create recommendations for policy designs that have support from multiple groups and strong prospects for implementation. The Center is also highly experienced in many of the analyses needed to inform the policy development process, including cost-effectiveness analysis, power sector modeling, and economy-wide modeling.

## GUIDEBOOK OVERVIEW

States and localities have influence over a number of decisions that affect transportation emissions such as land use regulation, transportation planning, tax incentives and infrastructure spending. The purpose of this guidebook is to engage state and local officials in understanding the extent to which policy decisions impact air pollution, energy use, and greenhouse gas (GHG) emissions. The Transportation Emissions Guidebook consists of two parts:

- **Part One: Land Use, Transit & Travel Demand Management**
  This first section focuses on policies related to travel demand and examines the impacts of land use and investment decisions on transportation emissions. Policies analyzed in part one include: transit-oriented development, bicycle initiatives, pay-as-you-drive insurance, light rail, comprehensive smart growth policy, etc.

- **Part Two: Vehicle Technology and Fuels**
  The second part of the guidebook focuses on measures that influence vehicle technology, fuel and operational choices that impact transportation emissions. Policies discussed in Part Two include: feebates, hybrid vehicles, biofuels, low-rolling resistance tires, truck stop and vessel electrification, locomotive technologies, driver training, etc.

The purpose of the Transportation Emissions Guidebook is to provide basic 'rules of thumb' to calculate emissions reductions from the implementation of specific transportation and land use policies. The guidebook is a unique tool that consists of a user-friendly spreadsheet tool, or Guidebook Emissions Calculator, which enables users to quantify the emissions benefits from a variety of projects and policies, a series of policy briefs, and a technical appendix. Each of these is discussed in more detail below.

### Guidebook Emissions Calculator

The Guidebook Emissions Calculator consists of individual worksheets for all of the quantified policy briefs, a summary matrix table across measures, and documentation of emission factors used.

For Part One, the Guidebook Emissions Calculator incorporates the rules of thumb into a VMT calculation. For Part Two, the Guidebook Emissions Calculator is based on emissions profiles of drivers and vehicles. The calculation is not meant to give an exact estimate of the reductions from the policy measures; rather it presents an order of magnitude sense of potential emissions reductions. In Part One, the emissions impacts are typically calculated by applying standard emissions factors to the VMT reduction estimates. In Part Two, emissions savings are calculated by estimating the improved driver or vehicle emissions profiles and applying them to a fixed level of VMT.

The policies analyzed within the spreadsheet tool (identifiable with the same numbering as in the report) present impacts based on default or average data on the left (coded in blue), but allow the user to enter regional specific data in the right column (coded in orange). The shaded cells represent the areas typically adjusted by users, but all assumptions can be changed. The default tables from the spreadsheet tool are also incorporated into the policy briefs in the report to give the reader a general idea of the possible reductions from each of the policies quantified.

**Policy Briefs**
Each part of the guidebook contains a series of policy briefs subdivided into key subject areas. An important point to note is that the dividing line between these subject areas is not hard and fast, rather, its purpose is to allow for a more navigable report.

Each of the policy briefs includes:

- A qualitative description including case studies, implementation issues, and references;
- A quantitative analysis including an assessment of potential air quality benefits, energy savings, and GHG reductions (note: the default data tables from the spreadsheet tool are included in the policy briefs); and
- Web-links to relevant models and resources

**Background and Technical Appendix**
The final component of the Transportation Emissions Guidebook is the supplementary information found in the background and in the technical appendix (located together on the website under the *Background* header on the toolbar). In the background section the reader will find relevant introductory text about transportation emissions, and in the technical appendix, the user will find more information on relevant models and quantitative tools that go beyond the scope of the Guidebook Emissions Calculator.

**A Comment on Data and Assumptions**
The authors would like to note that the Transportation Emissions Guidebooks are not designed to model actual reductions in criteria pollutants, greenhouse gases, fuel use, etc., from the Guidebook's transportation policies and programs. Rather, this tool is designed to allow users to obtain an initial order of magnitude estimate of the emissions and fiscal benefits that might occur from implementing the identified policies. Any further certainty will require more thorough analyses. For more information, please contact us at www.ccap.org.

**A LIVING DOCUMENT**
Part Two of the Transportation Emissions Guidebook places an emphasis on current and emerging vehicle technology and fuel measures that help to reduce emissions and energy use in the transportation sector. The guidebook highlights recent case studies and incorporates the latest data sources whenever possible. To keep the Transportation Emissions Guidebook relevant and as useful as possible to the users, we hope to update it at regular intervals with the latest information. To accomplish this however we would greatly appreciate any feedback you, the user, may offer. If you know of a case study or a better “number” for example, please send your feedback to Erin Silsbe, esilsbe@ccap.org

CCAP would like to thank the United States Department of Transportation and the Center for Climate and Environmental Forecasting as well as the United States Environmental Protection Agency and the Surdna Foundation for their support in the development of this guidebook.

# TABLE OF CONTENTS

# CCAP Transportation Emissions Guidebook: Part Two: Vehicle Technologies and Fuels

Part Two of this two-part guidebook focuses on policies related to vehicle technologies, fuels and driving behaviors and examines the impact of these policy decisions on transportation emissions. It consists of 21 policy briefs that include emissions from passenger and freight on-road vehicles, as well as marine and rail sources. The policy briefs are divided into two sections that consist of:

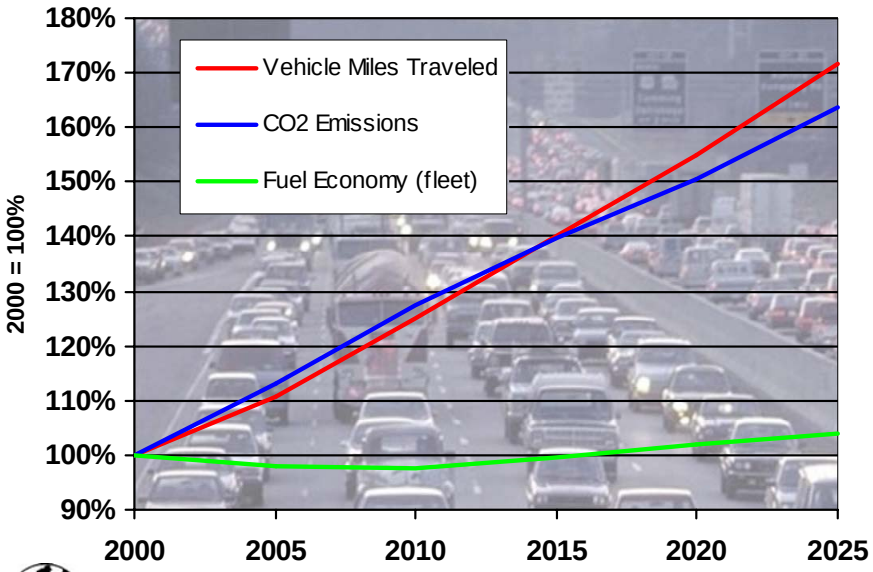
1. Passenger Vehicles
2. Freight and Intercity Travel Vehicles

Current research in the field of transportation typically addresses technology policies and demand side issues separately. Pairing technology-based transportation policies with the demand-side policies contained in Part One of the guidebook provides a unique opportunity to conduct a side-by-side evaluation of a comprehensive set of emissions reductions strategies. The guidebook is an integrated tool that can directly compare both travel demand transportation measures as well as advanced technology and fuels policies.

## BACKGROUND

### Transportation Emissions

Transportation emissions are the result of three main factors; vehicle technology, fuel characteristics and vehicle miles traveled (VMT). Dramatic progress in emissions control technology and fuel quality has reduced emissions over the past 30 years *per mile* for $NO_x$, VOCs and CO (with the exception of $CO_2$); but rapid growth in the amount of driving is offsetting these reductions, especially in some fast-growing regions. In the case of $CO_2$ per vehicle, fleet-wide vehicle emission rates have been essentially stagnant since 1991 while VMT grew 25 percent over the same period. As seen in the figure below, long-term growth in driving is expected to outpace the $CO_2$ emissions benefits of vehicle technology improvements.



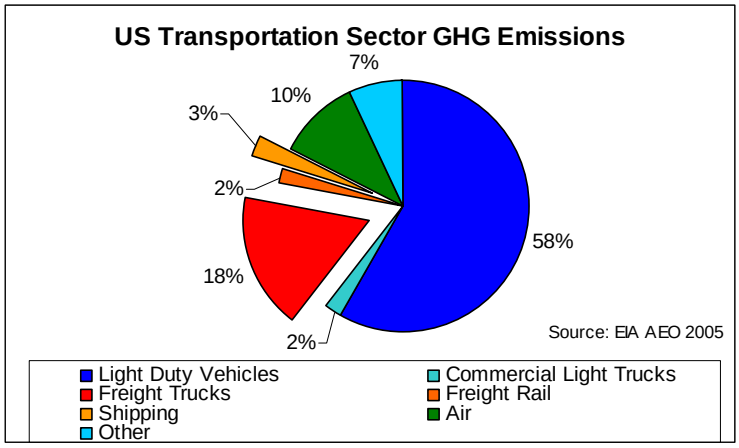

Source: US DOE, EIA "AEO 2004"

The new California $CO_2$ emission standards (if they survive legal challenge), will result in fleet-wide savings of 27 percent in 2030. Thus, we must continue to make progress on all three components of vehicle emissions VMT, vehicle technologies, and fuels – and policies required to implement them.

**Freight Emissions**

Growing worldwide demand for goods requires more trucks (and more truck vehicle miles), larger container ships and more rail infrastructure. Collectively, this means some of freight's external costs - those spillover costs not factored into the full cost of goods - congestion, air pollution and greenhouse gas emissions - are significant and growing.

In the United States, goods movement, primarily truck freight, is responsible for just under half of mobile source nitrous oxide ($NO_x$) emissions and over 35 percent of transportation particulate matter. Recent data conclude that fine particulate matter is a major contributor to long-term health impacts.[1] Further these particulate emissions, both fine ($PM_{2.5}$) and coarse ($PM_{10}$), emitted from trucks, trains and ships in greater concentrations in urban communities with high numbers of low income and minority residents.[2] Likewise, freight activity is responsible approximately 20 percent of transport sector $CO_2$ emissions.[3] Trucks, trains and ocean going vessel that transport goods emit growing levels of greenhouse gas emissions (GHGs) which are linked to changes in earth's climate.[4] *The chart below shows the sources and shares of transportation GHG emissions.*




Criteria pollutants from freight are growing. In 1980, freight was responsible for 20 percent of U.S. $NO_x$ emissions, with the current share estimated at 27 percent.[5] A recent study examined the linkages between freight transportation and air quality at the regional level found freight trucks responsible for 50 to 60 percent of mobile source $NO_x$ emissions and 30

[1] Burnett, T. Richard, et al. "Lung Cancer, Cardiopulmonary Morality, and Long-term Exposure to Fine Particulate Air Pollution". Journal of the American Medical Association Vol. 287 No. 9. March 6, 2002. Available at, http://jama.ama-assn.org/issues/v287n9/abs/joc11435.html

[2] Oak Ridge National Laboratory (2003) "Particulate Matter and Aldehyde Emissions From Idling Heavy-Duty Diesel Trucks": http://www.epa.gov/otaq/smartway/documents/pmteststudy.pdf

[3] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2002.*

[4] Intergovernmnetal Panel on Climate Change (IPCC) (2001), "Third Assessment Report": http://www.ipcc.ch/pub/un/syreng/spm.pdf

[5] More information can be located at: http://www.fhwa.dot.gov/environment/freightaq/index.htm

to 60 percent of mobile source PM emissions.[6] The table below shows the pollutants forecasted from freight (trucks, trains and marine vessels) for 2010 and 2020.[7]

| U.S. Freight Sector Emissions | | | | |
|---|---|---|---|---|
| Year | 2000 | 2010 | 2020 | % of transport emissions (2000) |
| **Criteria Pollutants (tpd)** | | | | |
| NOX | 5,620 | 2,685 | 3,051 | 42% |
| PM | 261 | 321 | 380 | 37% |
| PM2.5 | 232 | 285 | 337 | 38% |
| VOC | 343 | 431 | 520 | 4% |
| Source: US EIA, 2004 and US EPA Trends Report. | | | | |

**Growth in Freight GHG Emissions and Energy Use**

There is a link between energy use, fossil fuels and greenhouse gas emissions. Currently freight represents one quarter of transport sector greenhouse gas (GHG) emissions from burning of diesel and gasoline. US Department of Energy (DOE) projections show that freight GHG emissions will triple by 2025, accounting for almost 1/3 of transportation GHGs.[8] In particular, trucks are the second largest user of oil in the transportation sector at 2.4 million barrels a day in 2002. A number of the policies in contained in the guidebook address issues surrounding freight trucks. Recent investments in truck idling, on-board technologies and hybrids as well as renewable fuels can play a significant role in this growing source of emissions.

Despite increases in freight transportation productivity, growth in demand for goods over the next two decades will result in freight sector fuel use and GHG emissions increases by up to 50 percent. In effect freight growth virtually eliminates any freight's efficiency gains to date.[9] If such trends continue we will also see an increase in pressure on infrastructure, leading not only to higher rates of GHG emissions but also to lost work time, safety and health concerns.

Technologies combined with demand management strategies must be used where effective, but the US still should continue to make modifications to physical capacity with increased emphasis on U.S. border and port facilities. In addition, we must consider the total costs for each mode, the level of service quality, the impacts on regional development, air quality impacts and the way modes are financed. Implementation of solutions will require an intricate web of strategies, including: regulatory actions, incentive programs, lease agreements, land use decisions and voluntary actions. By acting now we can start to reduce freight's reliance on fossil fuels, improve local air quality and lower the rate of GHG growth, while ensuring a productive and secure freight network for future generations.

[6] Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level, ICF Consulting, Inc.: http://ops.fhwa.dot.gov/freight/freight_analysis/air_quality/index.htm

[7] Data from the US Department of Energy's Energy Information Administration's Annual Energy Outlook (AEO) for January 2006.

[8] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2002.*

[9] http://www.bts.gov/programs/freight_transportation/html/freight_and_growth.html

# 1.0 PASSENGER VEHICLES

## 1.1 Low Greenhouse Gas Vehicle Emissions Standards

**OVERVIEW**

In the United States, only the Environmental Protection Agency (EPA) and the State of California are given the authority[10] to set emissions standards for motor vehicles. Other states can choose to adopt either the EPA's or California's standards.[11] To date, the EPA has chosen not to regulate greenhouse (GHG) emissions from vehicles, but California has recently set GHG emissions standards for its new cars and light-duty trucks. This provides policymakers in U.S. states that contain NAAQS non-attainment areas with an option for reducing GHG emissions from their vehicle fleets that would otherwise not be available. Nine states have committed to instituting the California standards within their jurisdictions.[12]

Development of California's GHG emissions standards was directed by state legislation, Assembly Bill 1493 (also known as the Pavley Act) which was signed into law on July 22, 2002.[13] This Act required the California Air Resources Board (CARB) "to develop and adopt regulations that achieve the maximum feasible and cost-effective reduction in greenhouse gases emitted by motor vehicles." The resulting regulations were required to be developed no later than January 1, 2005, could not take effect before January 1, 2006, and could not be applied to vehicles earlier than model year 2009. The legislation was intended to be technology-forcing, as it specifically excluded the use of fiscal measures and most other regulatory options to achieve the greenhouse gas reductions. AB1493 also required that CARB consider the economic impacts of its regulations on the state's economy and on disadvantaged communities in California.

Thus, the California GHG emissions standards are based upon considerations of both feasibility (achievability with technologies that are currently in use in some vehicles or have been demonstrated in prototype form) and cost-effectiveness (providing savings in fuel costs over the life of the vehicle that are greater than the increase in purchase price due to improved technology). The Northeast States Center for a Clean Air Future (NESCCAF) modeled the GHG emissions impacts of the feasible technologies (as packages of complementary options) for five classes of vehicles – small cars, large cars, minivans, small trucks, and large trucks – and calculated the implementation costs of these packages. The resulting standards were derived from the GHG emissions predicted by these models, taking into account the estimated time for widespread deployment across the vehicle fleet of the various technology packages.

In setting the standards, CARB considered the following sources of GHGs:

- tailpipe emissions of $CO_2$, $CH_4$, and $N_2O$ from normal vehicle operation;
- additional tailpipe $CO_2$ emissions from reduced engine efficiency when the air conditioner (A/C) is in operation; and
- leakage and the global warming potential (GWP) of the A/C refrigerant

California designed its system of vehicle GHG emissions standards to be consistent with its existing program for other pollutant emissions from motor vehicles by specifying standards

[10] Sec. 209(b) of the Clean Air Act (CAA) gives California the right to do so after obtaining a waiver from the EPA. The state must also show that its proposed regulations are needed "to meet compelling and extraordinary conditions" and are not "arbitrary and capricious."

[11] Sec. 177 of the CAA allows any State containing an area that is in non-attainment for any of the National Ambient Air Quality Standards (NAAQS) to adopt California's emissions standards, but the State must do so at least two years before the model year in which it intends to enforce the standards, and it must adopt the complete package of California vehicle emissions standards.

[12] Connecticut, Maine, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington.

[13] Text available from CARB at: http://www.arb.ca.gov/cc/ab1493.pdf

for two classes of vehicles – PC/LDT1 (passenger cars and light-duty trucks with test weight less than 3751 lbs.), and LDT2 (light-duty trucks with test weight between 3751 lbs. loaded vehicle weight and 8500 lbs. gross vehicle weight). In addition, these standards were set as conservatively as possible, such that the automobile manufacturer in the most disadvantageous starting position (with respect to vehicle weight) could cost-effectively achieve the standards.

Automakers are allowed to meet the GHG emissions standards on a fleet-average basis and can also trade between the PC/LDT1 and LDT2 classes. In other words, if a manufacturer over complies in one class, it can use these excess reductions to help meet the standard in the other class. Provisions are also built into the regulations to allow automakers to earn credits for early compliance and to achieve credit for adopting alternative compliance mechanisms involving the use of alternative fuels.

The following table shows the GHG vehicle emissions standards adopted by California. Implementation of these standards is expected to reduce emissions of $CO_2$ from passenger cars in California (with respect to predicted levels) by 25 percent in 2012 and by 34 percent in 2016; for light-duty trucks, the estimated reductions are 18 percent and 25 percent in 2012 and 2016, respectively.

| Vehicle Model Year | GHG Emissions Standard ($CO_2$-equivalent g/mi) | |
|---|---|---|
| | PC/LDT1 | LDT2 |
| 2009 | 323 | 439 |
| 2010 | 301 | 420 |
| 2011 | 267 | 390 |
| 2012 | 233 | 361 |
| 2013 | 227 | 355 |
| 2014 | 222 | 350 |
| 2015 | 213 | 341 |
| 2016 | 205 | 332 |

**POLICY QUANTIFICATION**

The greenhouse gas emissions from the average motor vehicle in the fleet progressively decreases with the introduction of vehicle emissions standards, as older vehicles that are not subject to the standards are continually replaced by newer vehicles with lower GHG emissions. For any specific vehicle, CARB expresses the standard with the following equation:

$$\text{GHG emissions} = CO_2(ex) + CH_4(ex) + N_2O\,(ex) - A/C(indir) - A/C(dir)$$

Where all quantities are expressed in $CO_2$-e grams per mile (g/mi) and

- $CO_2(ex)$, $CH_4(ex)$, $N_2O$ (ex) are exhaust emissions of the respective species as measured by the EPA test cycle;
- A/C(indir) is the reduction in $CO_2$ exhaust emissions due to adoption of a more efficient A/C system; and
- A/C(dir) is the reduction in GHG emissions achieved through reduced leakage and/or use of a more climate-friendly refrigerant in the A/C system

The mass of greenhouse gas emissions reductions that can be achieved from adoption of California's standards depends on a number of factors but is primarily a function of new

vehicle sales. In any given year, the mass of GHG emissions is a simple sum of the emissions from each vehicle in the fleet. Thus, the reduction in GHG emissions due to adoption of the California standards is made up of the difference in emissions between the vehicles that meet these standards and the vehicles that would have been present otherwise. In 2009, the GHG emissions reduction is provided entirely by new vehicles. In future years, the reduction is supplied by all new vehicles sold since 2009, including the current year's sales.

To calculate the reduction in GHG emissions that would result in 2020 from adoption of California's program, emissions must be calculated for a baseline case, in which the CARB standards are not in effect, and a policy case, in which the motor vehicle GHG standards apply. To do this, the following data is needed for PC/LDT1 and LDT2 vehicles in both cases:

- the GHG emissions rates (g/mi) of new vehicles;
  - baseline case
  - CARB standards
- the number of new vehicles expected to be sold in 2009;
- the growth rate in new vehicle sales from 2009-2020;
- the annual VMT of new vehicles;
- the rate of annual VMT decrease with vehicle age; and
- the rate of scrappage of vehicles with age

GHG emissions changes can then be calculated by evolving the fleet of new vehicles sold since 2009 forward in time to 2020, taking into account:

- differences between the EPA test cycle and real-world driving conditions;
- CARB's estimate of $CH_4$(ex) + $N_2O$(ex); and
- CARB's estimates of A/C(dir) and A/C(indir)

For any given year, the $CO_2$ emitted by the vehicles sold since 2009 is a simple sum of the emissions from each of these vehicles (PC/LDT1 and LDT2). For each vehicle, the $CO_2$-e mass of GHG emitted is given by:

GHG emissions = (no. of vehicles) x (VMT per vehicle) x (GHG emissions per mile)

The table below shows the parameters used to quantify the GHG emissions reductions that can be achieved through adoption of California's motor vehicle GHG emissions program. Parameter values that the user can adjust are shown in red type.

## 1.1 Low Greenhouse Gas Vehicle Emissions Standards

| Default Data | |
|---|---|
| Tailpipe Stnds | |
| Cars | 150,000 |
| Trucks | 175,000 |
| New Vehicle Annual Sales Growth Rate | |
| Cars | 0% |
| Trucks | 1.6% |
| Average Annual New Vehicle VMT | |
| Cars | 15,000 |
| Trucks | 17,500 |
| Annual Rate of VMT Decrease with Age | 5.40% |
| CO2 Savings (in million metric tons) (1) | |
| In 2020 (2) | 2.55 |
| Cumulative (through 2020) | 10.39 |

Notes: GHG Savings for this measure are reported as $CO_2$-equivalent, and include reductions of HFCs, $N_2O$ and $CH_4$. Criteria pollutant reductions and energy savings will depend on the technology packages adopted by manufacturers.

### CO-BENEFITS

The staff of the California Air Resources Board found that adoption of the proposed GHG emissions standards had a number of ancillary benefits for that State, including:

- reduced upstream emissions of non-methane organic gases, $NO_x$ and CO of 4.6, 1.4, and 0.2 tons per day, respectively, in 2020 (7.9, 2.3, and 0.4 tons per day in 2030);
- a net creation of 53,000 jobs in 2020 (77,000 in 2030);
- an increase in personal income of $4.76 billion in 2020 ($7.32 billion in 2030);
- a net monthly savings of $3.38 (PC/LDT1) or $6.74 (LDT2) for consumers that purchase new vehicles (the monthly savings in operating costs more than offsets the increase in monthly finance costs);[14] and
- typical payback time of two to four years at $1.74 per gallon – even quicker at higher gasoline prices.

These savings were based upon a gasoline price of $1.74 per gallon, so benefits would be even greater at today's higher gasoline prices. Of course, economic and other conditions can differ significantly from State to State, so California's benefits can't be reliably extrapolated to other States. Modeling would be needed to quantify the effects of the motor vehicle GHG emissions standards on any particular state. However, since the GHG standards are simply one piece of California's overall vehicle emissions program, any State adopting these standards could expect to achieve some degree of air quality benefits due to reduced emissions of the other pollutants regulated by the California program. The specific level of emissions reductions would depend upon the characteristics of the vehicle fleet at the time of adoption of California's program and would again require modeling to estimate.

### KEY ISSUES/IMPLEMENTATION

The Alliance of Automobile Manufacturers (AAM) has sued to block California from enforcing its GHG emissions standards for motor vehicles. Their claim is that these regulations are

[14] CARB estimates that the regulations would increase the average retail prices of passenger cars and small trucks in the near-term (2009-2012) by $16 to $308. In the mid term (2013-2016) the price increases would range from $330 to $955.

essentially fuel economy standards because the majority of tailpipe $CO_2$ emissions are directly related to fuel consumption. Because only the U.S. Department of Transportation has the authority to regulate fuel economy, the AAM argues that California is overstepping its authority with the GHG standards. This litigation is scheduled to be heard in court in January of 2007.

Among the other issues that must be considered when deciding whether to implement the California vehicle GHG emissions standards are:

- eligibility – do any CAA non-attainment areas lie within the State?
- State requirements for adopting such standards (rulemaking, legislation, etc.);
- reduced gas tax revenues associated with decreased fuel use;
- how to regulate vehicles purchased out-of-state;
- consumer reaction to increased purchase prices for new vehicles;
- the possibility of harmful impacts on specific businesses and industries;
- a willingness to adopt future California emissions program measures; and
- economic or other impacts of the alternative fuel provisions of the GHG emissions standards

**CASE STUDIES**

As mentioned above, nine additional States have committed to adopt California's emissions program, but the process for doing so varies from State to State. At least one State, Massachusetts, had legislation in place to automatically adopt California's vehicle GHG emissions standards. In some States, new legislation is required, while in others, State agencies have the authority to make such decisions. The details of the adoption process are very State-specific, so policymakers are advised to determine the particular requirements in their own jurisdictions to allow sufficient time for the adoption process to proceed.

**KEY RESOURCES & REFERENCES**

**California Air Resources Board (CARB) –** "Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles" (ISOR) and the associated addendum describe in detail the process of determining the most feasible and cost-effective GHG emissions standards in California:
http://www.arb.ca.gov/regact/grnhsgas/isor.pdf
(Addendum: http://www.arb.ca.gov/regact/grnhsgas/addendum.pdf)

**California Air Resources Board (CARB) -** "Regulations to Control Greenhouse Gases from Motor Vehicles, Final Statement of Reasons" briefly summarizes the ISOR (see above) and addresses public comments to the program:
http://www.arb.ca.gov/regact/grnhsgas/fsor.pdf

**California Air Resources Board (CARB) –** CARB's Climate Change website provides background materials on climate change, California's overall efforts to reduce greenhouse gas emissions, and the establishment of California's motor vehicle GHG emissions standards (including the staff's workshop presentations):
http://www.arb.ca.gov/cc/cc.htm

**Northeast States Center for a Clean Air Future (NESCCAF) –** "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles" presents the modeling used by the California Air Resources Board to develop the greenhouse gas emissions standards for light-duty vehicles:

http://bronze.nescaum.org/committees/mobile/rpt040923ghglightduty.pdf

**Northeast States for Coordinated Air Use Management (NESCAUM) –** "Comparing the Emissions Reductions of the LEV II Program to the Tier 2 Program" describes the additional emissions reductions of $CO_2$ and toxic pollutants that can be achieved by adopting California's LEV II program instead of the federal Tier 2 program: http://www.nescaum.org/committees/mobile/LEV_report_final.pdf

**Pollution Probe –** "Greenhouse Gas Emissions and Vehicle Fuel Efficiency Standards for Canada" provides information about Canada's voluntary agreement with automakers to reduce GHG emissions from motor vehicles: http://www.pollutionprobe.org/Reports/vehiclefuel.pdf

## 1.2 State Feebate Program

### OVERVIEW

A Feebate[15] is a tax on vehicle purchases or a rebate given to buyers of new vehicles based on fuel economy. The feebate acts as both an incentive for efficient vehicle purchases and a disincentive for inefficient vehicle purchases. Under a feebate system, consumers would be charged a *fee* on purchases of relatively high-emitting vehicles and would receive a *rebate* on the purchase of relatively low-emitting vehicles. The program can be designed to be revenue neutral or revenue generating. Feebates can make the lifecycle energy, air pollution, and greenhouse gas costs highly visible to the consumer by altering the purchase price of the vehicle based on its emissions. As opposed to Corporate Average Fuel Economy (CAFE) standards that set fixed fleet targets, feebates put continual pressure on the market to move towards lower emissions. As the average emissions of the fleet decrease, fees and rebates can be recalibrated around a new average to maintain revenue neutrality.[16]

Feebate systems, similar to those being proposed in the state of Connecticut,[17] typically establish a revenue-neutral "pivot point" based on the amount of $CO_2$ emitted per mile driven. Vehicles that emit less than the pivot point would receive a rebate, while those that exceed it would be required to pay a fee. The size of the fee or rebate would be assessed based gallons of fuel used per mile (GPM). If the dollar value is set at $500 per 0.01 GPM, consumers would pay $500 for 0.01 gallons that their vehicle is above the pivot point. A rebate rate of $500 would have the same impact as a tax of $0.43 per gallon of gasoline of consumers value fuel savings over the full life of the vehicle.[18]

In 2002, the California Energy Commission (CEC) conducted an analysis of both national and statewide feebates as a mechanism to reduce petroleum demand in California. The study concluded that a national feebate of $1,825 per 0.01 gallon per mile could reduce fuel consumption in new vehicles by up to 16 percent by 2010 and 40 percent by 2020 leading to total reductions of 6 percent in 2010 and 20 percent in 2020. A California only feebate would result in a response estimated at 30 percent of a national program.[19,20]

### POLICY QUANTIFICATION

The quantification is based on 100,000 vehicles being replaced, a fuel economy improvement elasticity of 0.4 percent for a state-level feebate, given a $500 per 0.01 GPM feebate from the pivot point. Note that the savings here are annual savings for the vehicles

---

[15] Sweden's Nitrogen Tax was one of the first examples of a feebate system. Revenue collected from power generators was refunded to participants based on $NO_x$ emissions per unit of energy. In the first year, $NO_x$ emissions fell by 35 percent, and the adoption of abatement technology was accelerated. See: http://www.iea.org/Textbase/Papers/2004/Transport.pdf

[16] Connecticut Climate Change (2005)"Connecticut Climate Change Action Plan 2005": http://www.ctclimatechange.com/documents/TransportationSector_CCCAP_2005.pdf

[17] Greene et al. "Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy" can be found in *Energy Policy* 33 (2005), 757-775.

[18] *Ibid*. If consumers value only the first 3 years of fuel savings, $500 per 0.01GPM looks like a tax of$1.13 per gallon, because the same up-front charge is distributed over fewer gallons.

[19] California Energy Commission (2002) "Staff Paper on the 3D Option for Feebates"(2003): http://www.energy.ca.gov/fuels/petroleum_dependence/documents/600-03-005A3_ATTACHMENT_B.PDF American Council for an Energy Efficient Economy (ACEEE)(2005) "Vehicle Efficiency Incentives: an Update on Feebates for States": http://www.aceee.org/transportation/feebates.pdf

[20] The impact of national vs. state feebate programs on fuel economy has been highlighted in studies conducted by the CEC, Natural Resources Canada (1999) and Greene et. al (2005). These studies indicate that the impact of state level programs is primarily attributable to changes in consumer demand, while national programs influence the response by manufacturers.

replaced in the first year. The actual savings per year will be increased as multiple years of replacements are incorporated into the fleet, while the individual year savings for a year specific fleet will diminish due to attrition and loss of vehicle efficiency with age.

| Feebates | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 10,441 | 0.82 | 2.47 | $2,352,941 | 1,176,471 |

| Feebates | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 30.85 | 0.17 | 0.16 | 2.49 | 400.30 | 42.70 |
| Tons Per Day | 0.08 | 0.00 | 0.00 | 0.01 | 1.10 | 0.12 |

## CO-BENEFITS

Feebate programs can result in a reduction in the emission of criteria and hazardous air pollutants and greenhouse gases by facilitating fleet wide transition to lower emitting vehicles. Additional benefits may include:

- improved passenger vehicle fuel economy;
- ongoing incentives for manufacturers to invest in the further development of markets for low GHG vehicles;
- minimal program costs to government;
- politically saleable to consumers;
- increased visibility relative to other incentive programs; and
- relatively quick implementation

## CASE STUDIES

**Connecticut-** In February 2005, the Connecticut Climate Change Action Plan 2005 was finalized. When implemented the plan targets a reduction in greenhouse gas emissions to 1990 levels by 2010, and to 10 percent below 1990 levels by 2020. Included within the plan's transportation sector recommendations is a proposal for a state feebate program. An analysis of two feebate levels, $19.25 and $38.50 per pound of $CO_2$ per 100 miles driven, concluded that an increase in fuel economy of 16 percent and 29 percent respectively could be achieved within 10 to 15 years. In June 2005, the Governor signed a bill directing the Commissioner for Environmental Protection to develop an implementation plan for a statewide feebate program.
(http://www.ctclimatechange.com/documents/TransportationSector_CCCAP_2005.pdf)
(http://www.cga.ct.gov/2005/act/sa/2005SA-00006-R00HB-06908-SA.htm)

**Canada-** The 2005 federal budget announcement directed the National Round Table on the Environment and the Economy (NRTEE) to develop recommendations and options for a national feebate program for the 2006 federal budget. Feebates are expected to be one component of Canada's energy and climate change strategy to help the country meet its greenhouse gas reduction targets under the Kyoto Protocol.
(http://www.its.ucdavis.edu/events/outreachevents/asilomar2005/presentations/Dumas2.pdf)

**United States-** While no state has successfully implemented a feebate program, many states, including California, Maryland, Massachusetts, Maine, North Carolina, Vermont, Rhode Island and Arizona have considered feebate legislation. Of these, only Maryland

made it through the legislative process.[21] Other state governments considering feebate programs are Connecticut, Iowa, New York and South Dakota.[22] (http://www.aceee.org/transportation/feebates.pdf)

**KEY ISSUES/IMPLEMENTATION**

The design of a feebate program can vary in several ways. Some of the issues that must be considered in the structure and implementation of a feebate program include:[23]

- less certain environmental impacts than from emissions regulation;
- politically unpalatable fees may be required for feebates to have a significant impact on emissions;
- a one state feebate program will be much less effective than a multi-state or regional effort with large enough market share to influence vehicle manufacturers;[24]
- whether to design the feebate to be revenue neutral or revenue generating;
- classes of vehicles covered and the treatment of vehicles within classes;[25]
- establishment of the midpoint and calculation of the feebate rate;[26]
- movement in the midpoint over time with improving emissions rates;
- mechanisms for the delivery of the feebate program;
- cross-border leakage issues must be addressed to prevent fee avoidance or rebate abuse;[27]
- penalties for extremely inefficient vehicles and rewards for advanced technologies;
- lack of experience with feebates; no successful model/pilot project to look to as an example;
- degree of manufacturer and consumer responsiveness to changes in price;
- impact of feebate rate on vehicle purchases/automotive industry; and
- may require authorizing legislation

**KEY RESOURCES & REFERENCES**

**American Council for an Energy Efficient Economy**- "Vehicle Efficiency Incentives: an update on feebates from states" provides a review of current information and recent state level action on feebates:
http://www.aceee.org/transportation/feebates.pdf

**California Energy Commission**- The 2002 "Staff Paper on the 3D Option for Feebates" can be found in the 2002 CEC study on *Reducing Petroleum Dependency in California,* Appendix C, Attachment B:
http://www.energy.ca.gov/fuels/petroleum_dependence/documents/index.html

---

[21] ACEEE 2005, op cit.

[22] Solstice: http://sol.crest.org/efficiency/energywise_options/ch2-3.html

[23] ACEEE 2005. *op cit*

[24] Even a California program, with 12 percent of US vehicle sales would have limited impact on GHG emissions.

[25] A multi-tiered system (with different fees and rebates for cars than for light trucks) might initially garner more political support, such systems inevitably provide perverse incentives in which a car purchaser could pay a fee, but a consumer who purchases a light truck with a higher emissions rate than the car could receive a rebate. Developing an exemption system for those who need large vehicles for work-related purposes would present significant administrative difficulties. If a particular vehicle was necessary for work purposes, then it might be eligible for favorable federal tax treatment

[26] Feebate design requires strong data on consumer preferences for different classes of vehicles (cross-elasticities). Inaccurate projections could cause the feebate system be revenue negative.

[27] This could be accomplished by administering the feebates at the time of registration, rather than at the time of sale.

## 1.2 State Feebate Program

http://www.energy.ca.gov/fuels/petroleum_dependence/documents/600-03-005A3_ATTACHMENT_B.PDF

**Connecticut Climate Change-** The "Connecticut Climate Change Action Plan 2005" prepared by the Center for Clean Air Policy outlines action items to achieve greenhouse gas reductions including a detailed discussion of a state feebate program: http://www.ctclimatechange.com/documents/TransportationSector_CCCAP_2005.pdf

**European Partners for the Environment**- Feebates- Price Instruments Promoting Efficiency: http://www.epe.be/workbooks/sourcebook/2.11.html

**Greene, D.L, P. Patterson, M. Singh, J. Li** - "Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy" can be found in *Energy Policy* 33 (2005), 757-775.

**Massachusetts Public Interest Research Group (MASSPIRG)-** "Cars and Global Warming: Policy Options to Reduce Greenhouse Gas Emissions from Massachusetts Cars and Light Trucks" includes a detailed discussion of the impact of a feebate program in Massachusetts: http://www.cleanair-coolplanet.org/solutions/trans_solutions/MA_CO2.pdf

**Natural Resources Canada-** "Assessment of a Feebate Scheme for Canada" contains a 1999 analysis of environmental impacts and the cost-effectiveness of feebates based on an economic simulation model of the Canadian market for new automobiles: http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/vehicle_technology/study4/final_report/final_report.htm

**Raab Associates, Ltd.-** Documents and presentations to the Transportation Working Group of the Rhode Island Greenhouse Gas Process discuss feebate programs and implementation issues: http://righg.raabassociates.org/events.asp?type=grp&event=Transportation/Land%20Use

**Regional Economic Models, Inc**- "Economic Impact of Enacting a Feebates Program in Connecticut" a report prepared for U.S. Environmental Protection Agency and the State of Connecticut: www.remi.com

**Transport Canada**- "Feebates in Canada and the U.S." presented by David Greene, André Bourbeau, and Alexandre Dumas at the Conference on Transportation Energy and Environmental Policy, Asilomar California, 2005: http://www.its.ucdavis.edu/events/outreachevents/asilomar2005/presentations/Dumas2.pdf

**Transportation Table on Climate Change-** Results of a report prepared for the federal government of Canada on the "assessment of feebate schemes in Canada": http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/vehicle_technology/study4/Exec_Summary/English/Feebate.htm

## 1.3 Tax Incentives for Efficient Vehicles

### OVERVIEW

Consumers can be influenced to purchase more efficient vehicles through the use of tax incentives (or disincentives), which give consumers a financial reward for buying a more efficient vehicle. In addition to improving the environmental performance of the current fleet, tax incentives can encourage reductions in transportation energy use and emissions by accelerating the development of lower emissions technologies. A variety of tax incentives have been used in the United States and internationally to support the purchase of higher efficiency vehicles by individuals, businesses and governments. Some of the strategies include:

- rebates, tax credits and tax deductions[28] for the purchase of advanced technology vehicles, e.g., hybrids;
- reduced sales and excise taxes; and
- scaled vehicle registration charges based on emissions rates

Tax incentives for advanced vehicle technologies reduce the cost differential between new and conventional technologies. This helps to overcome market barriers faced by technologies that provide environmental benefits but have not achieved the economies of scale needed to reduce costs. As the technology matures, and becomes increasingly affordable, the incentive can be phased out.[29] Tax structures can also be used to encourage consumers to make more fuel-efficient choices among diesel, gasoline and alternative fuel vehicle models.

Similar to, but less popular than, tax incentives, are graduated vehicle taxes. Graduated vehicle taxes are fees based on fuel consumption or $CO_2$ emissions. They impose a penalty on purchasers of higher emitting vehicles thereby discouraging less efficient vehicles.

In 1999, a Center for a Sustainable Economy (CSE) study estimated the energy savings attributable to energy efficiency tax credits proposed in the Climate Change Technology Initiative (CCTI).[30] The study reported the Joint Committee on Taxation's (JCT) estimate that a hybrid vehicle tax credit of $1,000 to $4,000 would yield carbon emissions savings of 13.7 million metric tons (MtC) over the lifetime of the vehicles.[31]

Analysis by the American Council for an Energy Efficient Economy (ACEEE) estimates energy saving of 3.1 quadrillion BTU for a tax credit package that would include up to $4,000 for hybrid electric vehicles (HEVs), $6,000 for battery electric vehicles, and $8,000 for fuel cell vehicles.[32] This is approximately a 55 MtC savings from the incentive package.

### POLICY QUANTIFICATION

Tax incentives effect reductions by lowering the relative cost of lower-emitting vehicles, leading to more efficient vehicle purchases. The sample calculation assumes that 1,000 average vehicles that drive 15,000 miles per year are replaced with emission efficient

---

[28] Tax rebates offer a direct payment to the purchaser after the payment has been made. Tax credits are a direct reduction in taxes owed, independent of tax bracket. The consumer receives 100 percent of the value of the credit. For example a $1,500 tax credit lowers an individual's tax liability by $1,500. A tax deduction lowers your taxable income, therefore $1,500 federal tax deduction for a person in the top (33 percent) tax bracket results in a $500 reduction in tax liability: http://www.aceee.org/energy/taxfaq2.htm

[29] American Council for an Energy-Efficient Economy (ACEEE): http://www.aceee.org/transportation/gvmktg.htm

[30] Center for a Sustainable Economy (CSE) (1999) "Assessing Tax Incentives for Clean Energy Technologies: A Survey of Experts Approach": http://www.redefiningprogress.org/programs/sustainableeconomy/ccti.pdf

[31] *Ibid*.

[32] American Council for an Energy Efficient Economy: http://www.aceee.org/energy/taxfaq2.htm

vehicles, such as hybrids. Emission reductions from this policy are greater if incentives levels are graduated based on the emissions performance of new vehicles. Also, the emissions savings will be greater if the incentives promote early vehicle retirement in addition to efficient vehicle choice.

| Tax Incentives | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 1,321 | 0.10 | 0.31 | $297,744 | 148,872 |

| Tax Incentives | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 3.90 | 0.02 | 0.02 | 0.32 | 50.65 | 5.40 |
| Tons Per Day | 0.01 | 0.00 | 0.00 | 0.00 | 0.14 | 0.01 |

## CO-BENEFITS

Tax incentives for efficient vehicles accelerate the integration technologies into the marketplace, reducing energy consumption and improving air quality. Benefits attributed to clean technology development continue beyond the expiration of the tax incentives. Some of the benefits include:[33, 34]

- lower greenhouse gas emissions from transportation sources;
- reduced fuel costs;
- improved energy security;
- reduced tax bills for consumers;
- incentives for domestic auto manufacturers to increase investments in advanced vehicle technologies;
- increased economic activity and employment in the production of domestic high-efficiency vehicles; and
- long-term efficiency gains that "spill over" to improve the efficiency of related technologies. Spill over benefits accrue to producers or consumers who do not directly receive the credit.[35]

## CASE STUDIES

**Colorado**- The state has an income tax credit available for consumers and businesses for alternative fuel vehicles and HEVs up to $4,713. The credit does not apply to vehicles classified as mild HEVs.[36]
(http://www.revenue.state.co.us/fyi/html/income09.html)

**France-** A new plan was announced September 1, 2005 to help reduce fuel consumption and greenhouse gas emissions from France's transportation sector. The plan includes increased registration fees for higher emitting vehicles to help push consumers towards more fuel- efficient choices. The registration fees will be highest for larger cars and trucks or sport-utility vehicles, which represent about 10 percent of all new car purchases in France. Vehicles that emit 200 grams or more of carbon dioxide per kilometer (km) will see a pollution tax included in the one-time vehicle registration fee. Each gram of $CO_2$ emitted between 200 and 250 grams per km would be taxed an additional 2 €. Above 250 grams per km, emissions are taxed at a rate of 4 Euros with and average tax of 211 € among the highest emitters. It has been estimated that the pollution tax would raise $22.3 million

[33] ACEEE handbook
[34] American Council for an Energy Efficient Economy: http://www.aceee.org/energy/taxfaq2.htm
[35] CSE 1999, *Op Cit.*
[36] *Mild hybrids* utilize start/stop technology but also incorporate downsized engines and regenerative braking capability, achieving up to a 20% improvement in fuel economy. See section 1.13

USD in 2006, which would be dedicated to pollution reduction initiatives run by the Agency for the Environment and Energy Management.
(http://www.greencarcongress.com/2005/09/france_to_tax_h.html)

**New York-** On, January 17, 2006 Governor Pataki announced the creation of a New Hybrid Vehicle Tax Credit to spur the sales of hybrid and alternative fuel vehicles in the state. The tax credit provides a $2,000 personal income tax credit for the purchase of a new hybrid vehicle. The program to support the purchase of fuel efficient vehicles also will include the creation of a "green" E-Z Pass that provides a ten percent reduction in Thruway tolls, and allow access to high occupancy vehicle (HOV) lanes for drivers of fuel-efficient vehicles regardless of the number of passengers in the vehicle.

FedEx has indicated that the expansion of its E700 hybrid delivery truck fleet in 2006 will be concentrated in states that offer the tax credits for advanced vehicle technologies. The majority of the trucks are expected to be used in New York which offers a $2,000 tax credit program. The company plans to add 75 of the hybrid trucks by May 2006. The E700 diesel hybrid-electric delivery trucks were first introduced in 2004, and were developed through a partnership between FedEX, Environmental Defense and the Eaton Corporation.
(http://www.ny.gov/governor/press/06/0116062.html)

**Oregon-** The Residential Tax Credit Program and the Business Energy Tax Credit provide Oregon residents and business owners with tax credits towards the purchase of qualifying HEVs. Eligible hybrids are defined as having a hybrid drive train (gas/electric), regenerative braking, energy storage device (battery), and the capability for significant fuel savings. The Residential Tax Credit allows residents to apply for a total tax credit of $1,500 towards their personal income tax. The Business Energy Tax Credit allows business owners to receive 35 percent of the cost difference between a conventional fuel vehicle and a HEV of the same class and size.
(http://egov.oregon.gov/ENERGY/TRANS/hybridcr.shtml)

**United Kingdom-** To facilitate the use of cleaner, more fuel efficient vehicles, the UK has reformed two of its primary vehicle taxation policies. Both the Vehicle Excise Duty (VED) and the Company Car Tax currently base taxation levels on $CO_2$ emissions.[37] The $CO_2$ based VED levels are applied to vehicles registered after March 2001, with older vehicles continuing to be taxed based on engine size, as was the case under the old system. Vehicle taxation levels are determined by the emission band and by the fuel type. As of April 1, 2005 the tax ranged from £55-75 per year for vehicles emitting less than 100 g/km, to £160-170 for vehicle emitting over 185 g/km.[38] With only a narrow differential between bands, the VED has been criticized for providing only a minor incentive to car buyers to choose more efficient vehicles. In April 2005, the VED rates were maintained for lower emitting vehicle bands and increased those for the two highest bands by £5.
(http://www.vcacarfueldata.org.uk/index.asp)

The $CO_2$ based Company Car Tax was introduced in 2002, and is applied to all company vehicles registered after January 1998. Company cars are a significant component of vehicle purchases, representing about half of the new cars bought each year. Employees are required to pay income tax on company vehicles that are available for private use. Prior

[37] Low Carbon Vehicle Partnership (2005) "UK New Car Registrations by $CO_2$ Performance: Report on the 2004 market": http://www.lowcvp.org.uk/uploaded/documents/SMMT_CO2_Report_-_April_2005.pdf
[38] For a detailed list of VED taxation bands please see: http://www.vcacarfueldata.org.uk/search/vedSearch.asp

to 2002, the taxation level was based on the list price of the vehicle and annual business mileage. Revisions to the tax now mean that income tax will be calculated on a percentage of the list price which ranges from 15 percent for the lowest emitting vehicles to 35 percent for the highest emitters.[39] Between 1994 and 2004, the UK's average fleet emissions for new vehicles decreased by 11 percent. Fleet and business car efficiency has continued to improve in recent years, while purchases of efficient vehicles for private consumers have declined.[40]
(http://www.inlandrevenue.gov.uk/news/budget/p523_2000.pdf)

**United States-** The Energy Policy Act of 2005 includes the replacement of the one time federal tax deduction for hybrid vehicles with a tax credit of $250-$3,400 depending on the vehicle's fuel economy and weight. The tax credits are available from January 2006 through until December 31, 2010, however many will expire before that time. The complete tax credit limited to the first 60,000 hybrid vehicles sold by the each manufacturer. After the sales limit is reached, the credit will be phased out over a period of one year. Diesel vehicles are also eligible for the credit, but there are currently no models that meet federal emissions requirements. The tax credit sales cap has been criticized for being a penalty for companies such as Toyota and Honda which were the first to enter the hybrid market. Toyota estimates that based on current sales, the full credit may only be available to its hybrid vehicles delivered before July 2006. Similar reductions in the tax credit will begin to apply for Honda in late 2006 or early 2007.
(http://www.aceee.org/transportation/hybtaxcred.htm#table)

Heavy-duty hybrid vehicles also qualify for tax credits until 2009. The credit is determined based on the weight class of the vehicle, the incremental cost, and fuel economy relative to a similar conventional vehicle. The credit can range from 20 to 40 percent of the qualified incremental cost.
(http://www.aceee.org/transportation/hdhybtaxcred.htm)

Numerous states provide tax incentives to companies and individual consumers to encourage the purchase advanced technology vehicles such as hybrids. These purchase incentives can include both tax credits and a reduction in sales or excise taxes. States with tax incentives in place to promote HEV purchases include: Colorado, Connecticut, District of Columbia, Louisiana, Maine, Massachusetts, New Mexico, New York, Oregon, Utah, and West Virginia.[41]

**KEY ISSUES/IMPLEMENTATION**

Increasing the use of advanced/efficient vehicle technologies can significantly reduce fuel use and greenhouse gas emissions. However, several issues must be taken into account in the design of an incentive program to ensure its desired effectiveness. Outlined below are some issues pertaining to the use of tax incentives to stimulate growth in clean vehicle technologies:

[39] For a sample calculation of the company car tax please see: http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_506883-04.hcsp

[40] Presentation by Graham Smith, Environmentally Friendly Vehicles Conference (2005): http://www.lewislive.co.uk/efvc/index.php?view=agenda

[41] States that have incentives that are limited to Alternative Fuel Vehicles are not included. For a list of incentives, please see: http://www.eere.energy.gov/cleancities/progs/afdc/search_state.cgi?atv/AA, and http://www.hybridcars.com/incentives.html

- growth in government expenditures;
- structure of $CO_2$ based registration fees require a large enough differential between tax categories or bands to affect consumer choices;
- tax credits are most effective when used in conjunction with a broader set of policies used to stimulated the technology development. A comprehensive policy approach allows manufacturers to account for future regulations and incentives when designing new vehicles. The study of tax incentives by CSE demonstrated that carbon reductions achieved by a package of policies is greater that of a tax credit alone;[42]
- tax credits should target new advanced technologies that currently have low market share in order to support a fledgling technology and to generate real improvements in low-emissions technologies;[43]
- tax incentives that do not impact the sticker price may not be evident to consumers at the time of purchase. Consequently, public education is required to support tax based initiatives in order to ensure consumers are aware of available incentives for more efficient vehicles;[44] and
- tax incentives are designed to induce additional purchases of high efficiency vehicles. If there are no purchases beyond what would have otherwise occurred, the credit becomes a transfer payment to consumers, and generates no emissions reduction benefits.[45, 46]

**KEY RESOURCES & REFERENCES**

**Alliance to Save Energy (ASE)** - ASE's May 2005 report "The Drive to Efficient Transportation: State Policies to Encourage the Purchase and Use of Light-Duty Advanced Technology Vehicles and Alternative Fuels":
http://www.ase.org/images/lib/transportation/Alliance_Transportation_Handbook.pdf

**American Council for an Energy-Efficient Economy (ACEEE)** - ACEEE's estimates of tax credits under the Energy Bill for light-duty hybrid and diesel vehicles on the market today:
http://www.aceee.org/transportation/hybtaxcred.htm#table

**Center for a Sustainable Economy**- "Assessing Tax Incentives for Clean Energy Technologies: A Survey of Experts Approach" estimating the impact of the tax incentive included in the Climate Change Technology Initiative (CCTI) proposed as part of the fiscal 2000 budget:
http://www.redefiningprogress.org/programs/sustainableeconomy/ccti.pdf

**HM Revenue & Customs (UK)-** Provides links to information and guidance for employees and employers about UK taxes and rules on company cars and company car fuel:
http://www.hmrc.gov.uk/cars/

**HybridCars.com**- HybridCars.com includes news and information about hybrid cars, including federal and state tax incentives and their impacts:
http://www.hybridcars.com/incentives.html

[42] CSE 1999, *OP Cit.*
[43] *Ibid.*
[44] *Ibid.*
[45] *Ibid*
[46] Under the fleet average approach of CAFE, energy and emissions savings from advanced vehicles may be offset by increased emissions from other vehicles.

## 1.3 Tax Incentives for Efficient Vehicles

http://www.hybridcars.com/tax-deductions-credits.html

**Low Carbon Vehicle Partnership-** Is a partnership of organizations from the public and private sectors that work to accelerate low carbon transportation options:
http://www.lowcvp.org.uk/

**Union of Concerned Scientists (UCS)** - The UCS hybridcenter.org website provides a detailed discussion of federal, state and local tax and operational incentives for hybrid vehicles:
http://go.ucsusa.org/hybridcenter/incentives.cfm

**U.S. Department of Energy and U.S. Environmental Protection Agency**- The Fueleconomy.gov website provides information on federal 2005 tax incentives for hybrid vehicles and alternative fuel vehicles:
http://www.fueleconomy.gov/feg/tax_hybrid.shtml

**Vehicle Certification Agency (VCA)** - This website provides information on the impacts of vehicle purchasing decisions and details on the UK's $CO_2$ based vehicle excise duties and/or Company Car tax percentage brackets:
http://www.vcacarfueldata.org.uk/index.asp

# 1.4 Fuel Tax

## OVERVIEW

Revenue generated from state and federal gas taxes are an important source of funding for transportation projects across the United States. Gas taxes are considered a form of user fees levied against drivers based on fuel consumption, and can serve as a financial incentive for consumers to reduce the number of vehicle miles traveled (VMT) and/or consider switching to a more fuel- efficient vehicle. Combined, the 18.4 cents per gallon federal excise tax on gasoline and the state tax averaged 20.17 cents in 2002 account for more than one third of spending on highways.[47] Federal gas tax funds are primarily directed towards national highway programs, while state taxes fund spending on a wider range of transportation projects and programs that include public transit investments.[48]

Increasing the per-mile cost of driving with a fuel tax can affect both fuel consumption and efficiency. It is estimated that an increase in the price of fuel of 10 percent over time will reduce VMT by over three percent and improve fuel efficiency by six percent, resulting in an overall reduction in fuel consumption of nine percent.[49]

Further reductions in local and regional VMT can occur through the reallocation of gas tax revenues to fund investments in alternatives to single occupancy vehicle use. Increases in the gas tax can serve as a dedicated revenue stream for local transit systems that can fund service improvements and infrastructure investments. The combination of increasing fuel prices while simultaneously improving alternative transportation modes can result in increased ridership levels for transit and a reduced number of vehicles on the road.[50]

## POLICY QUANTIFICATION

Gas taxes provide incentives to both drive less and choose more fuel efficient cars. The quantification below is an estimate of reductions based on an area with 10 million daily VMT. The savings represent the level achieved once drivers have adjusted their automobile purchases to the new tax level, a marginal increase of $0.20 per gallon.

| Fuel Tax | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 38,860 | 3.07 | 9.20 | $24,000 | 12,000 |

| Fuel Tax | NOx | $PM_{-10}$ | $PM_{-2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 114.87 | 0.62 | 0.58 | 9.29 | 1490.32 | 158.96 |
| Tons Per Day | 0.31 | 0.00 | 0.00 | 0.03 | 4.08 | 0.44 |

## CO-BENEFITS

In addition to the air quality and climate benefits attributable to reducing vehicle emissions, increases in gas taxes or the reallocation of existing gas tax revenues to sustainable transportation modes can result in benefits that include:

[47] The Brookings Institute (2003a) "Fueling Transportation Finance: A Primer on the Gas Tax": http://www.brookings.edu/es/urban/publications/gastax.pdf

[48] *Ibid*.

[49] Victoria Transport Policy Institute (2005) "Efficient Vehicles Versus Efficient Transportation Comparing Transportation Energy Conservation Strategies": http://www.vtpi.org/cafe.pdf

[50] Portland's LUTRAQ project modeled the impact of a charge of 15 cents per mile on travel to and from work, in a transit oriented growth scenario. The result of the congestion pricing alternative was a reduction in daily VMT of 13.2% over the baseline scenario and 6% over the LUTRAQ scenario: http://www.friends.org/goods/pdfs/vol5/chapter2.pdf

- increased transit ridership;[51]
- incentives to seek alternatives to SOVs;
- increased employment in the transportation sector;
- minimal implementation costs;
- can be used as revenue-neutral tax shift away from more economically damaging taxation such as income, investment and payroll taxes;
- reduced mileage related costs (i.e. traffic congestion, road and parking costs and sprawl);[52]
- enhanced mobility options;
- decreased health costs because of air quality improvements; and
- stable source of transportation funding[53]

**CASE STUDIES**

**British Columbia, Canada-** The province of British Columbia has been the first in Canada to enter into an agreement with the federal government that will redistribute an estimated $5 billion to provincial governments from federal gas tax revenues over five years. Under the federal New Deal for Cities program, British Columbia will receive $636 million over five years to address deficits in public transit and infrastructure spending.

The province's largest transit system, Translink, which services the greater Vancouver area, will allocate the new funds to implementing a regional transportation plan including new light rail lines, the expansion and modernization of existing bus and light rail service across the region, highway express coaches, community shuttle mini-buses, transit priority road improvements, and regional cycling network improvements. (http://www.translink.bc.ca/About_TransLink/News_Releases/news04150501.asp)

**Ontario, Canada-** The province of Ontario has begun to reallocate funds from the provincial gas tax up to a level of 2 cents per liter by 2006. This initiative will provide transit systems in 76 municipalities across the province with $1 billion in additional revenue to support investments in transit service and infrastructure improvements. The provision of a stable long-term source of funding is expected to help increase transit ridership by 8 percent by 2007. The allocation of funds across municipalities was determined by a formula based on both ridership and population, to ensure the needs of large urban transit systems and smaller municipalities are balanced. (http://www.mto.gov.on.ca/english/news/provincial/2004/102204b.htm)

**Italy-** The government of Italy has introduced a half- cent per liter tax on gasoline, and one-cent per liter increase on diesel in order to purchase new, lower emissions buses for public transit systems. The increase will provide an additional $456 million (USD) annually into a dedicated fund for transit purchases. Italian cities are struggling to meet EU limits on fine particulate matter (PM), and the reinvestment in public transit is part of a compliance strategy that includes a partial ban on cars in many cities. (http://www.greencarcongress.com/2005/02/italy_hikes_fue.html)

[51] Government of Ontario: http://ogov.newswire.ca/ontario/GPOE/2005/02/16/c4688.html?lmatch=&lang=_e.html
[52] U.S. Congressional Budget Office (2003) "Fuel Economy Standards Versus A Gasoline Tax": http://www.cbo.gov/showdoc.cfm?index=5159&sequence=0
[53] Victoria Transport Policy Institute: http://www.vtpi.org/tdm/tdm17.htm

**Norway-** Norway, the world's third largest oil exporter, has reduced its domestic consumption of oil by increasing the cost of vehicle ownership – a unique strategy among oil producing nations. Prices for gas, now $6.66 per gallon, have increased 30 percent since the late 1990s, with taxes accounting for 67 percent of the cost to consumers. This policy appears to be effective: per capita oil consumption is significantly less (1.9 gallons/day) than in the United States (3.0 gallons/day). Similarly, car ownership rates in Norway (427 cars per 1,000 people) are below that of Germany and the US (500 and 700 cars per 1,000 people, respectively).
(http://www.iht.com/articles/2005/04/29/business/norway.php)

**Washington-** In April 2005, Senate transportation leaders in the State of Washington adopted a 9.5 cent per gallon increase in the gas tax to be phased in over four years. The plan will raise an additional $8 billion over sixteen years to carry out major repairs on the state's aging roadway infrastructure and provide funding for safety and preservation projects, freight mobility improvements, and public transportation rail service.
(http://www.metrokc.gov/kcdot/news/thisweekarch/050503thisweek_tranpkg.htm)

**KEY ISSUES/IMPLEMENTATION**

The inclusion of gas tax increases as an energy conservation or transportation demand management strategy faces several key implementation issues:

- political acceptability - increases in fuel taxes face intense opposition by interests representing automobile and oil industries, as well as motorists. In addition, any measures perceived to increase tax levels are seen as highly politically unpopular in North American jurisdictions.[54] But, it should be noted that despite its unpopularity, a gas tax can achieve the same impact as other emission reducing measures, such as CAFE, at a lower cost;

- equity impacts - gas taxes increase the overall costs of driving and often disproportionately impact rural residents, truck drivers, and low-income drivers. Mechanisms to offset the impact of fuel taxes on vulnerable populations should be considered; [55]

- regional distribution of revenues- in several states, urban regions contribute a significantly larger proportion to gas tax revenues than they receive in state highway spending;[56]

- restrictions on spending- the use of state gas tax revenues is restricted to highway projects in thirty-six states, limiting the ability to finance projects that promote alternative to SOV use;[57]

- declining revenues over time- as fuel efficiency and alternative fuel development progress, the ability of fuel taxes to meet long-term transportation funding needs will diminish. Gas taxes will be an important source of funding in the short-term, however, long-term solutions must take energy efficiency gains into consideration.[58]

[54] The Brookings Institute (2003b) "Improving Efficiency and Equity in Transportation Finance": http://www.brookings.edu/dybdocroot/es/urban/publications/wachstransportation.pdf
[55] Wachs, M (2003) "A Dozen Reasons for Raising Gasoline Taxes": http://www.its.berkeley.edu/publications/UCB/2003/rr/UCB-ITS-RR-2003-1.pdf
[56] The Brookings Institute (2003a), *op cit.*
[57] *Ibid*.
[58] Wachs, M (2003), *op cit.*

## 1.4 Fuel Tax

**KEY RESOURCES & REFERENCES**

**The Brookings Institute-** "Fueling Transportation Finance: A Primer on the Gas Tax" reviews federal and state gas taxes, and assess the impact on transportation systems: http://www.brookings.edu/es/urban/publications/gastax.pdf

**The Brookings Institute Fueling-** "Improving Efficiency and Equity in Transportation Finance": http://www.brookings.edu/dybdocroot/es/urban/publications/wachstransportation.pdf

**Victoria Transport Policy Institute**- "Fuel Taxes: Increasing Fuel Taxes and Fees" discusses implementation, impacts and applications of gas tax initiatives: http://www.vtpi.org/tdm/tdm17.htm

**Victoria Transport Policy Institute-** "Efficient Vehicles Versus Efficient Transportation" compares strategies that have been employed to conserve energy including alternative fuels, fuel efficiency and feebates, fuel tax increases and mobility management: http://www.vtpi.org/cafe.pdf

**Victoria Transport Policy Institute-** Online spreadsheet that provides US fuel trend data from 1960 to 2004: http://www.vtpi.org/tdm/fueltrends.xls

**Wachs, Martin**- "A Dozen Reasons for Raising Gasoline Taxes" http://www.its.berkeley.edu/publications/UCB/2003/rr/UCB-ITS-RR-2003-1.pdf

**World Energy Council**- The "energy efficiency policies and indicators" project evaluates a range of policies that include fiscal measures on vehicles and fuels, energy pricing and auditing and institutions and programs: http://www.worldenergy.org/wec-geis/publications/reports/eepi/policy_evaluation/fiscal.asp

# 1.5 Low Emission Fleet Vehicle

## OVERVIEW

Private companies and government agencies own and operate vehicle fleets that represent a small yet highly visible component of the transportation sector. Policies to promote state purchases of alternatives to gasoline and diesel fueled vehicles have emerged from both federal and state levels of government based on concerns over energy security, air quality and climate change. These alternative fuel vehicles (AFVs) include biodiesel, electric, ethanol, natural gas and propane options.[59] These fuels are eligible for credit under the Energy Policy Act of 1992 (EPAct), which requires certain fleets to purchase vehicles capable of operating on non-petroleum fuels or 'alternative' fuels.[60] AFVs can be used in a variety of passenger, public transit, light-duty and heavy-duty applications. Hybrid electric vehicles are not identified as AFVs under the EPAct, however due to their energy efficiency are being used in a variety of fleet applications to reduce fuel consumption.

Use of AFVs can result in substantial reductions in greenhouse gas and criteria air pollutant emissions compared with their petroleum-fueled counterparts. For example, the use of compressed natural gas (CNG) provides a higher octane rating than gasoline, better air-fuel mixing, and higher combustion efficiency. In addition to improving engine performance, CNG is a cleaner burning fuel and vehicles using it emit fewer hydrocarbon (HC) and nitrogen oxide ($NO_x$) emissions than conventional gasoline vehicles.[61] However fossil fuel sources such as CNG, are not as effective as other alternative fuels in terms of reducing GHG emissions.

Vehicle purchases provide an important opportunity for governments and private sector companies to adopt a leadership role in the development of alternative fuel vehicles. The selection of right-sized vehicles when replacing fleet vehicles will reduce vehicle and fuel costs for the fleet.[62] State fleets can help emergent technologies to receive greater exposure to consumers, and ultimately facilitate the transition towards lower emission levels of the transportation sector.

**Lifecycle GHG and Criteria Pollutant Emissions (Btu/mile or g/mile)**

| | Greenhouse Gas Emissions Components | | | | | Criteria Pollutants | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Vehicle Type** | **Feed-stock** | **Fuel** | **Vehicle Operation** | **Total** | **vs. gasoline** | **VOC** | **CO** | **NOX** | **SOX** | **PM10** |
| Conventional Gasoline | 41 | 100 | 533 | 674 | 100% | 0.257 | 7.297 | 0.41 | 0.044 | 0.034 |
| Diesel | 34 | 60 | 459 | 553 | 82% | 0.138 | 1.109 | 0.674 | 0.057 | 0.122 |
| CNG | 72 | 42 | 458 | 572 | 85% | 0.064 | 5.811 | 0.389 | 0.002 | 0.022 |
| FFV Meth | 43 | 122 | 490 | 655 | 97% | - | - | - | - | - |
| FFV Ethanol (Corn) | -235 | 255 | 507 | 527 | 78% | 0.222 | 4.359 | 0.368 | 0.002 | 0.026 |
| FFV Ethanol (Herb Biomass) | -285 | 28 | 507 | 250 | 37% | - | - | - | - | - |
| FFV Ethanol (Wood Biomass) | -393 | 34 | 507 | 148 | 22% | - | - | - | - | - |
| Electric | 29 | 439 | 0 | 468 | 69% | 0 | 0 | 0 | 0 | 0.021 |

GHG emissions = CO2, N20 & CH4. Fleet assumes a 62% car/32% truck split)

Sources: CCAP analysis using the GREET model, http://www.transportation.anl.gov/greet/

[59] Hybrid electric and hydrogen fuel cell technologies are discussed in sections 1.12 and 1.13

[60] EPACT is a 1992 Congressionally-mandated set of targets for renewable fuel and vehicle use and production, targeted towards federal, state, local and private light-duty fleets as well as fuel producers and manufacturing facilities. The goal of EPACT is to reduce U.S. dependence on imported petroleum. However some have criticized EPACT's fleet-based approach and lack of success in meeting targets. US Department of Energy: http://www.eere.energy.gov/vehiclesandfuels/epact/

[61] Union of Concerned Scientists (2004) "Climate Control Global Warming Solutions for California Cars": http://www.ucsusa.org/global_environment/global_warming/page.cfm?pageID=1394

[62] "Right-sizing" the fleet eliminates underused vehicles and downsizes vehicles to fit the needs of staff based on the minimum size of vehicle required to carry out the duties of the fleet.

## 1.5 Low Emission Fleet Vehicle

US DOT's Center for Climate Change and Environmental Forecasting, Fuel Options for Reducing GHG Emissions *from Motor Vehicles report,* http://climate.volpe.dot.gov

The above chart highlights the difference in lifecycle greenhouse gas (i.e., total fuel energy/total energy used in production, manufacturing, transportation, and distribution) and criteria pollutant emissions for various alternative fuel options. For example, ethanol produced from corn, emits low levels of GHGs as compared to gasoline or diesel fuels. However corn based ethanol is energy intensive to produce, reducing the lifecycle GHG emissions benefits. Fossil fuels are less energy intensive to produce, but have higher GHG emissions, and associated criteria pollutant emissions.

Currently manufacturers of alternative fuel vehicles receive credit towards meeting the federal fleet fuel economy requirements, known as Corporate Average Fuel Economy (CAFE) standards. A 2002 Report to Congress by multiple federal agencies concluded that the credit incentive lead to "an increase in alternative fuel use as well as a 1 percent increase in petroleum consumption and GHG emission increase of less than 1 percent.[63] A related study at Oak Ridge National Laboratory concluded that CAFE credit availability plays a significant role in automakers decision to produce AFVs.[64] The authors concluded that the value of alternative fuel vehicle-generated CAFE credits is responsible for about one-half of all new alternative fuel vehicles that will likely be produced over the next decade. That same study found that if alternative fuel vehicles are produced in large scale production runs and the retail availability of alternative fuel is equivalent to gasoline, there would be a 32 percent penetration of alternative fuel vehicles into the marketplace by the year 2010 and a 7 percent penetration of alternative fuels in the same year.

### POLICY QUANTIFICATION

For calculation purposes we have assumed 10 million gallons of ethanol is used to replace gasoline in E-85 vehicles. This amount represents approximately 3 percent of the estimated 3.7 billion gallon US supply of ethanol in 2004. Further it represents a fraction (10 percent) of the US Renewable Fuels Standard described below. For ethanol we have used a lifecycle benefit or 78 percent of regular gasoline, as described above.

| Low GHG Fleets | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 4,879.72 | na | na | -$4,189,312 | (1,132,246) |

| Low GHG Fleets | NOx | $PM_{-10}$ | $PM_{-2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 42.56 | -1.27 | 0.33 | 4.55 | 578.20 | 76.86 |
| Tons Per Day | 0.12 | 0.00 | 0.00 | 0.01 | 1.58 | 0.21 |

[63] U.S. Department of Transportation, U.S. Department of Energy and the U.S. Environmental Protection Agency Report to Congress (2002) "Effects of the Alternative Motor Fuels Act, CAFE Incentives Policy": http://www.nhtsa.gov/cars/rules/rulings/CAFE/alternativefuels/index.htm#content

[64], Oak Ridge National Laboratory (2000) "An Analysis of Alternative Fuel Credit Provisions of US Automotive Fuel Economy Standards". More detailed information on CAFE can be obtained by reading, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards located at: http://www.nap.edu/execsumm/0309076013.html

## 1.5 Low Emission Fleet Vehicle

### CO-BENEFITS

Increasing the integration of cleaner technologies and practices into fleet vehicles improves air quality and reduces emissions of greenhouse gases. Additional benefits of AFV technologies may include the following:[65]

- increased public awareness of vehicle technologies and alternative fuels;
- enhanced public image;
- public and private sector recognition;
- reduced dependence on foreign oil;
- fuel cost savings due to petroleum displacement;
- lower maintenance costs;
- increased stability in state fuel expenditures;
- greater market share for new technologies; and
- increased availability of new technologies for consumers[66]

### CASE STUDIES

**California**- The vehicle fleet operated by California is one of the largest government fleets in the world operating approximately 73,000 vehicles. California has emerged as a leader in the deployment AFVs. In 2001, the state exceeded its compliance requirements for state purchases of AFVs under the federal Energy Policy Act of 1992 by 9 percent.[67] In addition, state agencies are active in promoting the use of AFVs, high efficiency and hybrid electric vehicles. Caltrans' Greening the Fleet initiative, introduced in 2001 has led to the purchase of nineteen hybrids and 758-gas/propane bi-fuel trucks, and the replacement of fifty-four diesel trucks with low emissions trucks.

In 2001, Assembly Bill 2076 directed the California Energy Commission, California Air Resources Board (CARB), and Department of General Services (DGS) to reduce petroleum consumption by 10 percent by 2005. In compliance with the bill, the DGS has adopted requirements that 25 percent of new state gasoline vehicles must be rated as Ultra-Low Emissions Vehicles (ULEV) or better. By December 2005 state offices, agencies, and departments have been instructed to review their vehicle fleets and dispose of any nonessential SUVs and four-wheel drive trucks. These vehicles are to be replaced with more fuel-efficient vehicles.
(http://www.eere.energy.gov/cleancities/ccn/archive/6_2states.html)

**King County, WA-** Following extensive road testing 2002-2003, King Country Metro Transit purchased 235 General Motors hybrid electric buses that began operations in 2005. The new buses have achieved and improvement in fuel economy of 30 percent compared to the conventional drive buses. By replacing aging vehicles with the hybrid electric bus technology, it is estimated that particulate matter, hydrocarbon and carbon monoxide emissions will be reduced by 90 percent and nitrogen oxides emissions by 60 percent.
(http://www.metrokc.gov/kcdot/whatshap/hybrid/updates.stm)

King County has also sponsored two regional purchasing contracts for all governments in the State of WA and State of OR for the Toyota Prius and the Ford Escape. The County's Fleet Administration Division of the Department of Transportation purchased fifteen Toyota

[65] US Department of Energy: http://www.eere.energy.gov/cleancities/vbg/fleets/about_buying.html
[66] West Coast Governors Global Warming Initiative (2004) "State and Fleet Transportation Issues": http://www.energy.ca.gov/global_climate_change/westcoastgov/documents/2004-04-15_draft_reports/2004-04-19_STATE_FLEETS.PDF
[67] California Energy Commission (2003) "California State Vehicle Fleet Fuel Efficiency Report: Volume I": http://www.energy.ca.gov/reports/2003-05-01_600-03-003-VOL1.PDF

Prius hybrid cars and nine 2005 Ford Escape hybrid SUVs. Recent additions bring the King County hybrid fleet total to 115 Prius' and 25 Escapes for a total of 140, purchased since 2001. (http://www.metrokc.gov/procure/green/hybrids.htm)

**New York-** In 1996, Governor Pataki initiated the Clean Fuel Vehicle Program (CFVP) to promote state acquisition and testing of alternative fuel vehicles. In 2001, Executive Order 111 provided AFV procurement targets by requiring that all state entities acquire 50 percent of all new light duty vehicles as AFVs by 2005 and 100 percent by 2010. The program has succeeded procuring approximately 1,900 AFVs as of 2001, and a fueling infrastructure has been developed to support them. The success of the program has been attributed to a coordinated approach that includes: incentive programs, infrastructure development, communications and program monitoring. The integration of 452 hybrid electric vehicles into New York City's municipal fleet has resulted in the avoided emissions of nearly 1,112 tons of $CO_2$; 1,581 kg $NO_x$; 2,930 kg CO; and 550 kg VOCs.[68] New York City has also been active in procuring hybrid diesel-electric buses, committing to the purchase of 500 new buses for delivery in mid-2006.
(http://www.nrel.gov/docs/fy02osti/31537.pdf)
(http://www.orionbus.com/orion/0,,0-11-9892-1-550233-1-0-0-0-0-0-150-9892-0-0-0-0-0-0,00.html)

As part of a $23 million program to offset emissions in New York City, the New York Power Authority (NYPA), has assisted in the purchase of electric postal trucks to serve New York City. Eight electric trucks were purchased in 2004 to replace the diesel fueled trucks that typically idle on postal routes. These trucks joined the 22 electric postal delivery vans currently used in Manhattan. In 2005, the NYPA purchased two electric delivery trucks for use by the USPS to replace diesel-powered trucks used to transport mail between central distribution facilities and neighborhood post boxes in Queens, NY. NYPA estimates each truck will eliminated 4,833 lbs of $CO_2$, 32 lbs of $NO_x$ and 1 lb of PM annually.
(http://www.nypa.gov/press/2005/051026b.htm)

**FedEx**- In 2004, FedEx introduced the first of its FedEx OptiFleet E700 diesel hybrid electric delivery trucks into service in Sacramento, California. The new trucks were developed in partnership with Environmental Defense and the Eaton Corporation are expected reduce PM emissions by 96 percent, $NO_x$ by 65 percent and increase fuel efficiency by 57 percent compared to the 1999 model FedEx Express standard delivery trucks. Currently the company has 18 hybrid trucks in service in Sacramento, New York, Tampa and Washington, D.C.
(http://www.fedex.com/us/about/responsibility/environment/hybridelectricvehicle.html)

**KEY ISSUES/IMPLEMENTATION**

Successful implementation of clean technology fleets will require a multifaceted approach that can include:[69]

- legislated vehicle emissions specifications;
- procurement policies based on "best in class" emissions ratings;
- inclusion hybrid electric models under the definition of Alternative Fuel Vehicles;
- inter-agency communication;
- financial incentives for state agencies and private fleets for vehicle acquisition;

[68] Massachusetts Climate Action Network: http://www.massclimateaction.org/Green%20Fleets0104.rtf
[69] US Department of Energy (2002) "State and Alternative Fuel Program Success Story": http://www.nrel.gov/docs/fy02osti/31537.pdf

- coordinated planning of vehicle and infrastructure needs;
- communication with vehicle manufacturers and equipment suppliers;
- user training;
- public awareness campaigns; and
- program monitoring

**Alternative Fuel Infrastructure: Technology and Cost Overview**

A key hurdle to alternative fuels is the need to develop and deploy a new refueling infrastructure. Currently, U.S. DOE data show over 1,500 alternative fuel stations in the US this compares to over 30,000 gasoline stations nationwide. According to a recent report, both the technology of the station and the capital cost – the cost of each station – represent the barriers to market entry for alternative fuels.[70]

**Technology -** there are a number of federal programs aimed at developing an alternative fuel infrastructure, including tool kits and funding guides.[71] One example, the NextEnergy Alternative Fuel Infrastructure, has been partially developed for the U.S. DOE to test and demonstrate emerging alternative fuel production and storage systems, including hydrogen, natural gas, bio/synthetic-fuel development platforms for vehicular and on-site power.[72]

**Costs -** There are many notable programs at US DOE's Office of Energy Efficiency and Renewable Energy, which include information on how refinery operations and costs play a role in long-term decisions to develop refueling infrastructure.[73, 74] In addition, a report supported by the US DOT Center for Climate Forecasting quantified the costs of refueling infrastructure in the near term to be approximately $3.5 billion.[75]

**KEY RESOURCES & REFERENCES**

**Alliance to Save Energy**- "The Drive to Efficient Transportation: State Policies to Encourage the Purchase and Use of Light-Duty Advanced Technology Vehicles and Alternative Fuels"
http://www.ase.org/images/lib/transportation/Alliance_Transportation_Handbook.pdf

**BC Climate Exchange**- The Hybrid Experience Report website provides information from a variety of sources on hybrid vehicles, fleet applications, and information for fleet managers:
http://www.hybridexperience.ca/Experiences.htm

**California Energy Commission-** "California State Vehicle Fleet Fuel Efficiency Report: Vol. I Summary of Findings and Recommendations" contains information on California state fleet and regulatory changes influencing purchasing decisions of three state agencies:
www.energy.ca.gov/reports/2003-05-01_600-03-003-VOL1.PDF

[70] Transportation and Infrastructure Requirements for a Renewable Fuels Standard, Downstream Alternatives, Inc. August 20, 2002. Phase III Project Deliverable Report Oak Ridge National Laboratory Ethanol Project: http://www.ethanol-gec.org/information/briefing/18.pdf

[71] US Department of Energy: http://www.eere.energy.gov/afdc/e85toolkit/installing_e85_infrastructure.html

[72] NextEnergy Alternative Fuel Infrastructure: http://www.nextenergy.org/nextenergycenter/hydrogen.asp

[73] US Department of Energy: http://www.eere.energy.gov/hydrogenandfuelcells/

[74] Review of Transportation Issues and Comparison of Infrastructure Costs for a Renewable Fuels Standard (RFS) http://www.eia.doe.gov/oiaf/servicerpt/fuel/rfs.html. While this study was based on a less aggressive RFS, it is worth noting that the average transportation and distribution costs per gallon of gasoline ethanol blend (E10) was estimated to be up to $0.01 per gallon.

[75] US DOT's Center for Climate Change and Environmental Forecasting, *op cit.*.

## 1.5 Low Emission Fleet Vehicle

**Center for the New American Dream-** Assists government agencies and other institutions in purchasing hybrid vehicles for their fleets, including the King County, Washington contract hybrid vehicles:
http://www.newdream.org/hev/

**Colorado Department of Public Health and the Environment**- Reviews the impacts of purchasing hybrid electric vehicles for government fleets in Colorado:
http://www.cdphe.state.co.us/ap/down/Hybridreport.pdf

**Massachusetts Climate Action Network-** "Green Fleets: Fuel-Efficient Vehicle Purchases by City Governments" outlines initiatives taken by municipal governments:
http://www.massclimateaction.org/Green%20Fleets0104.rtf

**National Renewable Energy Laboratory**- Information on advanced vehicle and fuel research initiatives:
http://www.nrel.gov/vehiclesandfuels/

**Sustainable Sarasota**- The green fleet program of the Sarasota County Government includes fleet rightsizing, hybrid and alternative fueled vehicles, driver training and maintenance to reduce greenhouse gas emissions of the County fleet:
http://www.sustainablesarasota.com/Default.aspx?C3D0B6B4=849AA4

**Union of Concerned Scientists-** "Climate Control California: Proving Ground for Global Warming Problems & Clean Car Solutions":
http://www.ucsusa.org/global_environment/global_warming/page.cfm?pageID=1394

**US Department of Energy-** Provides fact sheets, guidance information and compliance tools on the US EPAct:
http://www.eere.energy.gov/vehiclesandfuels/epact/federal/fed_resources.shtml

**US Department of Energy-** The Office of Energy Efficiency and Renewable Energy online vehicle buyers guide for fleets contains information on alternative fuels and vehicles, models, fuelling stations, financial incentives and laws and regulations:
http://www.eere.energy.gov/cleancities/vbg/fleets/

**US Department of Energy-** The Clean Cities Program document database provides information on alternative fuels and vehicles and other petroleum displacement technologies, including links to the Alternative Fuels Data Center:
http://www.eere.energy.gov/cleancities/doc_database.html

**US Environmental Protection Agency-** Provides information on the benefits of AFVs and federal and state AFV programs:
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BMSCX/$File/alternativefueledvehicles.pdf

**WestStart-CALSTART-** The website contains information on a variety of AFV, fuel cell and hybrid electric technology programs:
http://www.calstart.org/

## 1.6 Biofuel Standards

### OVERVIEW

Biofuels are fuels derived from biomass (plants and plant-derived materials). The two primary types of transportation biofuels, ethanol and biodiesel, are used in varying blends to replace gasoline and diesel fuel, respectively. Ethanol is an alcohol made from sugars (corn, sugar cane, beet, potatoes), and very recently from cellulose (e.g., woody crops, wood waste, switchgrass, agricultural residues, municipal solid wastes, as well as corn) and biodiesel is produced from soybean, rapeseed and other vegetable oils and/or animal fats.

Ethanol is blended with gasoline at the refinery in amounts of 10 percent (E10) or less and used in most cars and trucks sold today. It is also used in dedicated E85 vehicles, which have minor fuel system modifications and thus can operate on blends containing gasoline and up to 85 percent ethanol. Biodiesel is typically mixed with diesel fuel in blends of 2 percent (B2), 5 percent (B5) or 20 percent (B20). It can be used in nearly all diesel equipment and, unlike ethanol, can be blended directly with diesel fuel. Both fuels are eligible for credit under the Energy Policy Act of 1992 (EPAct), which requires certain fleets to purchase vehicles capable of operating on non-petroleum fuels or 'alternative' fuels.[76]

Recent studies indicate that corn ethanol and biodiesel reduce life-cycle (i.e., total fuel energy/total energy used in production, manufacturing, transportation, and distribution) greenhouse gas (GHG) emissions by approximately 15 percent compared with gasoline and diesel.[77, 78] Potential life-cycle GHG benefits of cellulosic ethanol are 2-3 times that of corn-based ethanol.[79] The GHG benefits in this section are based on full life-cycle emissions –- often called well- to -wheel -- from using crops such as soybeans and corn to produce biodiesel fuels. Life-cycle emissions calculations take into account emissions from crop production, fuel refinement, transport,[80] and combustion. A primary reason why biofuels offer significant GHG savings is due to carbon sequestration from growing biofuels feedstocks, which offsets in part production and combustion emissions.

### POLICY QUANTIFICATION

Biofuels reduce carbon emissions per gallon of fuel used.[81] There are two primary modeling tools that can be used to estimate lifecycle GHG emissions from transportation biofuels - the GHGenius model and the GREET model.[82]

---

[76] EPACT is a 1992 Congressionally-mandated set of targets for renewable fuel and vehicle use and production, targeted towards federal, state, local and private light-duty fleets as well as fuel producers and manufacturing facilities. The goal of EPACT is to reduce US U.S. dependence on imported petroleum. However some have criticized EPACT's fleet-based approach and the overall lack of success in meeting targets.
US Department of Energy: http://www.eere.energy.gov/vehiclesandfuels/epact/

[77] Argonne National Laboratory's GREET model version 1.6 beta, 2003 indicates ethanol can reduce GHGs by 12 – 19%. This includes GHG emissions from $CO_2$, $N_20$ & $CH_4$. Argonne National Laboratory: http://www.transportation.anl.gov/greet/

[78] US Department of Energy and US Department of Agriculture (1998) "An Overview of Biodiesel and Petroleum Diesel Life Cycles"

[79] Argonne National Laboratory's GREET model shows that cellulosic ethanol (from wood) generates between 63 – 78% fewer GHGs vs. fossil fuels and up to 40% fewer GHGs than ethanol made from corn. For the latter, this is primarily due to cultivation techniques and fertilizer use.

[80] Ethanol cannot be transported through pipelines and must be shipped by truck or rail to its destination, which has a negative impact on net lifecycle energy savings and greenhouse gas emissions

[81] For full information on the potential savings from alternative fuels, see the US DOT's Center for Climate Change and Environmental Forecasting report, " Fuel Options for Reducing GHG Emissions from Motor Vehicles" found at: http://climate.volpe.dot.gov

# 1.6 Biofuel Standards

| Biofuels Rule of Thumb |
|---|
| **Biofuels emit 15% fewer GHGs per equivalent gallon than fossil fuels** |

| Lifecycle GHG and Criteria Pollutant Emissions (Btu/mile or g/mile) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Greenhouse Gas Emissions Components | | | | | Criteria Pollutants | | | | |
| Vehicle Type | Feed-stock | Fuel | Vehicle Operation | Total | vs. gasoline | VOC | CO | NOX | SOX | PM10 |
| Conventional Gasoline | 41 | 100 | 533 | 674 | 100% | 0.257 | 7.297 | 0.41 | 0.044 | 0.034 |
| Diesel | 34 | 60 | 459 | 553 | 82% | 0.138 | 1.109 | 0.674 | 0.057 | 0.122 |
| CNG | 72 | 42 | 458 | 572 | 85% | 0.064 | 5.811 | 0.389 | 0.002 | 0.022 |
| FFV Meth | 43 | 122 | 490 | 655 | 97% | - | - | - | - | - |
| FFV Ethanol (Corn) | -235 | 255 | 507 | 527 | 78% | 0.222 | 4.359 | 0.368 | 0.002 | 0.026 |
| FFV Ethanol (Herb Biomass) | -285 | 28 | 507 | 250 | 37% | - | - | - | - | - |
| FFV Ethanol (Wood Biomass) | -393 | 34 | 507 | 148 | 22% | - | - | - | - | - |
| Electric | 29 | 439 | 0 | 468 | 69% | 0 | 0 | 0 | 0 | 0.021 |
| GHG emissions = CO2, N20 & CH4. Fleet assumes a 62% car/32% truck split) | | | | | | | | | | |

Sources: CCAP analysis using GREET model, http://www.transportation.anl.gov/greet and US DOT's Center for Climate Change and Environmental Forecasting, Fuel Options for Reducing GHG Emissions from Motor Vehicles report, http://climate.volpe.dot.gov

### Sample Calculation

The sample calculations are for biodiesel. We have also provided an example using E85 in light-duty fleets, which is located in the Low Emissions Fleet Vehicles policy brief.

We have assumed a statewide fuel standard requiring the use of B20 in a state in which transportation uses consume 500 million gallons per year. Based on supply constraints we have assumed 5 million gallons of diesel fuel is replaced with biodiesel and that the biodiesel is used in heavy- duty vehicles as B20 (20 percent biodiesel blended with 80% diesel).[83] Studies indicate using B20 provides a net 15.7 percent reduction in $CO_2$ emissions compared to diesel. An EPA assessment of HDV using B20 found the following emissions impacts:

**Emissions Impacts from 20 Percent Biodiesel added to Diesel Fuel (B20)** [84]

| Pollutant | Change in Emissions (%) |
|---|---|
| $NO_x$ (Nitrogen Oxides) | +2.0 |
| Particulates (PM10) | -10.1 |
| Carbon Monoxide (CO) | -11.0 |
| Hydrocarbon (HC) | -21.1 |

[82] Both are spreadsheet models that allow the user to calculate the amount of greenhouse gases generated from the time the fuel is extracted or grown to the time that it is used in a motor vehicle to produce energy. In this case, we applied GREET to estimate the GHG savings from fossil fuels but encourage the user to review the assumptions and methodologies contained in GREET and GHGenius, that later of which is located at: http://www.ghgenius.ca

[83] This amount represents 17% of the U.S. supply of biodiesel in 2004 and can be splash-blended with diesel fuel and used in most diesel-powered vehicles without engine, fuel or fuel line modification. For the purposes of this analysis, we assume a lifecycle energy ratio for biodiesel of 96.7% of conventional #2 diesel.

[84] US EPA (2002) "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions, Draft Technical Report"

## 1.6 Biofuel Standards

On a per-gallon (or mile per BTU) basis, petroleum fuels have greater energy density than biofuels, meaning more than one gallon of biofuel is necessary to travel the same distance as one gallon of petroleum. For example, it takes approximately 1.5 gallons of corn-based ethanol to deliver the same mileage as 1 gallon of gasoline and it takes about 1.1 gallons of biodiesel to replace a gallon of diesel fuel.[85]

| Biofuels | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 41,360 | na | na | -$4,304,550 | -170,631 |

| Biofuels | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | -40.23 | 5.88 | 0.00 | 0.00 | 59.19 | 20.10 |
| Tons Per Day | -0.11 | 0.02 | 0.00 | 0.00 | 0.16 | 0.06 |

### CO-BENEFITS

Biofuel use offers a number of benefits in addition to reducing petroleum consumption and GHG emissions. Below are a few examples of these co-benefits.

- Biodiesel and ethanol can result in fewer particulates relative to blends. One of the most comprehensive studies by the U.S. EPA reviewed a variety of engine models and found that biodiesel reduces PM and CO.[86]

- According the US Department of Energy (US DOE), biodiesel has the most favorable energy balance of any transportation fuel. For every one (1) unit of energy needed to produce a gallon of biodiesel, 3.2 units of energy are gained. In comparison, for every one (1) unit of energy needed to produce a gallon of fossil fuels (i.e., petroleum diesel), only 0.8 units of energy are provided.[87] For ethanol, recent data from the US Department of Agriculture[88] finds a 67 percent net energy benefit of ethanol vs. gasoline.

- Ethanol's high oxygen content (35 percent by weight) allows the fuel to burn cleaner, enhance engine octane and reduce criteria pollutants, including carbon monoxide and other toxics found in gasoline. Ethanol reduces tailpipe carbon monoxide emissions by as much as 30 percent, toxics content by 13 percent and tailpipe fine particulate matter by half.[89] However because ethanol is more volatile than gasoline, production and higher-blend use can create evaporative emissions, ozone precursors $NO_x$ and VOC, which may lead to localized increased ozone formation. However, ethanol production facilities have been required by the US EPA to add pollution controls to limit volatile organic compounds (VOC) production from ethanol manufacturing processes[90]. Further, states using large amounts of ethanol in gasoline require a waiver from EPA due to potential VOC

[85] US EIA: http://www.eia.doe.gov/oiaf/analysispaper/biomass.html
[86] B20 reduces PM by 10%, hydrocarbons (HC) by 21% and carbon monoxide by 11%. US EPA (2002) "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions Draft Technical Report"
[87] US Department of Energy and US Department of Agriculture 1998, *OP Cit.*
[88] Shapouri, H., Duffield, J., Macloon, A.J. (2004) "The 2001 Net Energy Balance of Corn-Ethanol", Proceedings of The Conference on Agriculture as a Producer and Consumer of Energy, Arlington, VA: http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=161244
[89] Based on an analysis conducted by Argonne National Laboratory. For further information on environmental impacts from ethanol, see: http://www.ipd.anl.gov/anlpubs/1999/02/31961.pdf
[90] CBS News:http://www.cbsnews.com/stories/2002/05/03/tech/main508006.shtml

increases from vehicle use in warm months (May to October). Biodiesel use in higher blends tends to increase $NO_x$ emissions (see below for more detail).

- Ethanol offers a favorable energy balance (vs. gasoline) although, when produced from corn, the balance is much less favorable due to the energy inputs used in typical corn farming practices. In 2004, a USDA study estimated that the net energy balance of corn ethanol suggests that corn ethanol is energy efficient as indicated by an energy output / input ratio of 1.67. This analysis used a survey of U.S. corn producers and the 2001 survey of ethanol plants. Further, it is generally assumed that the energy balance will improve as technology advances allowing for more efficient production from a variety of ethanol feedstocks.

**CASE STUDIES**

**Kentucky**- A total of 300 buses in this project are using B20, and 50 buses are using B2. These buses transport 35,500 students in five school systems daily as are part of demonstration program that will displace approximately 60,000 gallons of diesel fuel, resulting in emissions reductions of about 150 pounds of PM, 160 pounds of $SO_2$, 200 pounds of HC, and 1,800 pounds of CO.
(http://www.eere.energy.gov/afdc/apps/toolkit/pdfs/kentucky_success.pdf )

**Minnesota-** After implementing a successful ethanol program in 1997, the State of Minnesota adopted a two percent biodiesel requirement in all Minnesota diesel fuel by September 29, 2005 and state leaders are pushing for a 10 percent requirement. To help increase production capacity, a Biodiesel Task Force was appointed to advise the Minnesota Department of Agriculture to consider methods for greater production and use of biodiesel in the state, and to educate biodiesel marketers, consumers and manufacturers.
(http://www.biodiesel.org/resources/pressreleases/gen/20050929_mn_lubricity.pdf )

**Mississippi**- The National Aeronautics and Space Administration's (NASA) Stennis Space Center in south Mississippi uses ethanol in many of its light-duty vehicles, as required by the Energy Policy Act of 1992. The Stennis fleet has 305 vehicles, of which 75 are E85 flexible fuel vehicles and include minivans, sedan and pickups. Stennis has retrofitted one of its two 10,000-gallon gasoline tanks to hold E85 and plans to open a biodiesel station and use biodiesel to fuel all of its diesel-vehicles.
(http://www.eere.energy.gov/vehiclesandfuels/epact/pdfs/whatsnew_summer_04.pdf)

**KEY ISSUES/IMPLEMENTATION**

Increasing the use of biofuels, either in private or public fleet vehicles, can significantly reduce GHG emissions. However, issues remain pertaining to supply, cost, infrastructure, and air quality benefits. Outlined below are some issues pertaining to biofuels use:

- Supply- According to California Energy Commission and Energy Information Administration data, there are 3.7 billion gallons of ethanol and 30 million gallons of biodiesel produced in the US annually.[91] While these figures represent less than 1

[91] According to California Energy Commission and Energy Information Administration data, there are currently 83 ethanol fuel plants in the U.S. with the capacity to produce more than 3.7 billion gallons of ethanol per year. In addition, 15 ethanol fuel plants now under construction and two major expansions will eventually add nearly 700 million gallons in new ethanol production capacity. By 2004 there were more than 30 million gallons of biodiesel in

percent of U.S. gasoline or diesel use, biofuel use is growing rapidly, thanks in part to federal and state producer tax credits. One such example is the federal Commodity Credit Corporation, which provides a financial support program for farmers who grow soybeans and corn used in the production of renewable fuels;[92]

- On August 8, 2005, President Bush signed the Energy Policy Act of 2005 (H.R. 6) into law. The comprehensive energy legislation includes a nationwide renewable fuels standard (RFS) that will double the use of ethanol and biodiesel by 2012. This law requires renewable fuel use of 4 billion gallons in 2006 increasing to 7.5 billion gallons in 2012. The Act also provides a myriad of tax incentives and potential funding opportunities. Actual funding levels depend on Congressional budget appropriations;

- Infrastructure- As of late 2005, there were over 480 ethanol refueling stations and 330 biodiesel stations, both in over 30 US states.[93] However, the vast majority of ethanol and biodiesel being produced and sold in Midwest;

- Cost- According to most sources, neat (100 percent) biodiesel is $0.75 to $1.00 more expensive per gallon than conventional diesel fuel, making the B20 blend approximately $0.15 to $0.20 per gallon more expensive than diesel ($0.75 times 20 percent or $1 times 20 percent), and the B2 blend about $0.02 per gallon more expensive than diesel ($0.75 times 2 percent or $1 times 2 percent).[94] Feedstock costs alone, therefore, are at least $1.50 per gallon of soy biodiesel. Fats and greases cost less and produce less expensive biodiesel, sometimes as low as $1.00 per gallon.[95] According to the latest price report for alternative fuels, ethanol is selling wholesale for $2.00 gallon (as of December 2005), approximately $0.40 cents a gallon more than gasoline. Further a recent study found that that cost of *producing* ethanol from cellulose is estimated to be between $1.15 and $1.43 per gallon in 1998 dollars. [96] Recent analysis by EIA concludes that the US Department of Energy goals are met, the cost of producing ethanol could be reduced by as much as 60 cents per gallon by 2015 with cellulosic conversion technology;[97]

- $NO_x$ emissions- Biodiesel produced from certain feedstocks causes an increase in nitrogen oxides ($NO_x$), which is of particular concern in urban areas that are subject to strict environmental regulations. Emissions of nitrogen oxides tend to increase relative

---

the US with the number expected to grow to 1 billion gallons in 2010 and 6 billion in 2020. See Ethanol Supply Outlook For California, October 2003, 600-03-017F.

[92] Oak Ridge National Laboratory (2002) "Transportation and Infrastructure Requirements for a Renewable Fuels Standard, Downstream Alternatives Inc, Ethanol Project": http://devafdc.nrel.gov/pdfs/6637.pdf

[93] US Department of Energy: http://www.eere.energy.gov/afdc/infrastructure/station_counts.html

[94] For ethanol and biodiesel, prices will vary depending on taxes, shipping costs, crop prices, and other factors. For detailed information on biodiesel costs for a variety of feedstocks, see Energy Information Administration (EIA): http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/. For detailed information on ethanol supply and prices, see http://www.eia.doe.gov/oiaf/analysispaper/biomass.html

[95] US Department of Energy: http://www.eere.energy.gov/afdc/altfuel/bio_market.html

[96] R. Wooley, M. Ruth, D. Glassner, and J. Sheehan, "Process Design and Costing of Bioethanol Technology: A Tool for Determining the Status and Direction of Research and Development," Biotechnology Progress, Vol. 15, No. 5 (September-October 1999), pp. 794-803.

[97] For both fuels, data show that advances in production technology, especially for ethanol, will lower costs. The Outlook for Biomass Ethanol Production and Demand is forecast for biomass ethanol production under three different technology cases for the period 2000 to 2020, based on projections developed from the Energy Information Administration's National Energy Modeling System.

to the concentration of biodiesel in the fuel but are roughly 2 percent for B20. Certain additives[98] and control technologies have shown promise in reducing the increase.[99] As discussed above, ethanol production and use may cause VOC (and $NO_x$) increases, leading to increased ozone formation;

- Engine warranties- Engine and vehicle manufacturers are generally comfortable with biodiesel blends up to 5 percent (B5). In fact, biodiesel in low blends can increase engine lubricity and also may lead to a reduction in unburned hydrocarbons on engine component. While this is beneficial in the long-term, it initially requires more frequent fuel filter changes as the vehicle's tank and engine is cleaned by the biodiesel. While a number of programs throughout the US are using biodiesel blends of up to 20 percent with no engine or operation difficulties, concerns about fuel quality and stability have caused some manufacturers to issue warranty restrictions for blends above B5;[100]

- Vehicle operations in cold weather conditions- While E10 can be used year-round, biodiesel may require treatment or fuel additives to prevent the fuel from freezing.[101] Biodiesel blends greater than 20 percent may require minor adjustments to fuel line components and/or a fuel additive to prevent gelling in colder temperatures (below 0 degrees F);[102]

- Land requirements and ecological impact- Conversion of food crops to fuel has led to some debate, especially in Brazil, about the impact of energy crops on ecological diversity and food production. While monoculture (single crop) farming can contribute to a loss of biodiversity, erosion, degradation of water quality, etc., the latter issue appears to have been overstated, at least in the case of Brazil. Of the 55 million hectares (ha) of land area devoted to food crops, only 4.1 million ha, or 7.5 percent, was used for sugarcane. This represents only 3 percent of Brazil's total land.[103] Additional studies have found similar results;

- Retrofit devices and Biodiesel- US EPA and CARB require approval of diesel retrofit devices before being used. However, California Senate Bill 975 allows any owner or operator of solid waste collection vehicles to use B20 with retrofit devices through 2008 whether or not the device is verified with its use;[104]

- Public education- many people who have E85 compatible cars are not aware of this fact, and thus do not use E-85;[105] and

- CAFE Credits- Currently manufacturers of flexible fuel vehicles capable of running on ethanol or gasoline receive credit for meeting the federal fleet fuel economy requirements (CAFÉ) standards. A 2002 joint agency report to Congress concluded that

[98] For more information on biodiesel additives, see Hess, M.A., Haas, M.J., Foglia, T.A., Marmer, W.N. (2005) "The Effect of Antioxidant Addition on $NO_x$ Emissions from Biodiesel. Energy and Fuels" 19(4):1749-1754.
[99] US Department of Energy and US Department of Agriculture 1998, *OP Cit.*
[100] The National Biodiesel Board: http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm
[101] Agricultural Research (1998): http://www.ars.usda.gov/is/AR/archive/apr98/cold0498.htm
[102] US Department of Energy (2005) "Biodiesel Blends": http://www.eere.energy.gov/cleancities/blends/pdfs/37136.pdf
[103] For a more complete picture on food vs. fuel, see: http://journeytoforever.org/biofuel_food.html
[104] For additional information, see: http://www.arb.ca.gov/msprog/mailouts/msc0521/msc0521.pdf
[105] US Department of Energy: http://www.eere.energy.gov/cleancities/vbg/ and http://www.fueleconomy.gov/feg/byfueltype.htm

if vehicle manufacturers took advantage of the incentive to "relax the effect of the CAFE standard on the rest of their fleet", then the credit incentive lead to "an increase in alternative fuel use as well as a 1 percent increase in petroleum consumption and GHG emission increase of less than 1 percent. Further, the authors founds that unless the availability and use of alternative fuels is significantly expanded, the CAFE credit incentive program will not result in any further reductions in petroleum consumption or GHG emissions. [106]

**KEY RESOURCES & REFERENCES**

*For more general resources and programs, please see:*

**National Agriculture library**-Has compiled a wide range of information on biofuels including production, economic and market research:
http://www.nal.usda.gov/ttic/biofuels/research.htm#biofuels

**National Biodiesel Board-** Is the national trade association representing the biodiesel industry, serving as a clearinghouse of biodiesel related information:
www.biodiesel.org

**National Renewable Energy Laboratory**- The Non-petroleum Based Fuels website, located at provides links to a variety of biofuels documents:
www.nrel.gov/vehiclesandfuels/npbf/.

**US Department of Energy-** The Alternative Fuels Data Center contains a vast collection of information on alternative fuels and alternative fuel vehicles:
www.eere.energy.gov/afdc/

**US Department of Energy**- The Office of Energy Efficiency and Renewable Energy website contains information on biodiesel and ethanol production and policy:
www.eere.energy.gov/biomass

**US Environmental Protection Agency**- The Biodiesel Emissions Analysis Program website contains emissions and performance data for biodiesel:
www.epa.gov/otaq/models/biodsl.htm

**WestStart-CALSTART-** Works with the public and private sectors to support sustainable transportation options through programs that include biofuels and alternative fuelling infrastructure:
http://www.calstart.org/programs/BioFuels/BioFuels_Index.php

*For more specific technical information, please see:*

**Argonne National Laboratory**- "Effects of Fuel Ethanol Use on Fuel-Cycle Energy and GHG Emissions":
http://greet.anl.gov/publications.html

[106] U.S. Department of Transportation, U.S. Department of Energy, U.S. Environmental Protection Agency (2002) "Report to Congress: Effects of the Alternative Motor Fuels Act, CAFE Incentives Policy":
http://www.nhtsa.gov/cars/rules/rulings/CAFE/alternativefuels/index.htm#content

## 1.6 Biofuel Standards

**Energy Information Administration**: Alternatives to Traditional Transportation Fuels 2003, Estimated Data is available at:
http://www.eia.doe.gov/cneaf/alternate/page/datatables/atf1-13_03.html

**Energy Information Administration**- "Developments in U.S. Alternative Fuel Markets" an analysis by Mary Joyce:
http://www.eia.doe.gov/cneaf/alternate/issues_trends/altfuelmarkets.html#moreinfo

**US Department of Agriculture and U.S. Department of Energy-** An Overview of Biodiesel and Petroleum Diesel Life Cycles:
www.nrel.gov/docs/legosti/fy98/24772.pdf

**US Department of Transportation**- "Fuel Options for Reducing Greenhouse Gas Emissions from Motor Vehicles":
http://climate.volpe.dot.gov/papers.html

**US Environmental Protection Agency**- "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions":
http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf

**US National Renewable Energy Laboratory**-An Overview of Biodiesel and Petroleum Diesel Life Cycles A Joint Study Sponsored by: U.S. Department of Agriculture and U.S. Department of Energy. May 1998:
http://www.nrel.gov/docs/legosti/fy98/24772.pdf

**ITS-Davis-** A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials. December 2003. Publication No. UCD-ITS-RR-03-17-MAIN REPORT:
www.its.ucdavis.edu/pubs/pub2003.

**US Department of Agriculture, Office of Energy Policy and New Uses-** "Contrasting Life Cycle Emissions Studies of Biodiesel" by James Duffield and Hosein Shapouri debates a study by Delcucci that argues biofuels may provide negative energy balance.

# 1.7 Vehicle Scrappage

## OVERVIEW

A small fraction of the car fleet accounts for a large share of the emissions in many countries. Studies indicate that 50 to 60 percent of on-road emissions from light-duty vehicles are generated by the dirtiest 10 percent of vehicles in the light-duty fleet.[107] These higher emitting, older and poorly maintained cars and trucks, may not have been built with the same emissions controls that can be found on newer model vehicles, or may be operating with damaged emissions control equipment. Vehicle scrappage, or accelerated vehicle retirement (AVR) programs, permanently remove these aging, high emissions passenger cars and trucks from operation earlier than otherwise would have occurred. Scrappage programs use economic incentives such as fees, transit passes, or rebates for efficient transportation options[108] to persuade owners to voluntarily retire their vehicles.

By facilitating accelerated adoption of newer, more efficient models, vehicle scrappage programs reduce emissions of ozone precursors--hydrocarbons (HC), and nitrogen oxides ($NO_x$)—carbon monoxide (CO), and other pollutants, thereby improving air quality. In addition, this has the potential to reduce greenhouse gas emissions—primarily $CO_2$, from transportation sources *if* new vehicles are more efficient than older ones.[109] The efficacy of vehicle scrappage programs is dependent on several factors, including:

- the emissions profile of the new vehicle relative to that of retired vehicles, with transit, active transportation, and vanpooling choices providing greater benefits;
- the relative fuel efficiency of newer vehicles; and
- the number of vehicles that are scrapped

## POLICY QUANTIFICATION

Scrappage programs achieve emission reductions by incentivizing replacement of older higher emitting vehicles. The sample calculation assumes that 1,000 older vehicles that drive 10,000 miles per year are replaced with vehicles fitting the current average emissions profile. Emission reductions from this policy are greater if incentives levels are tied to the emissions performance of new vehicles.

| Vehicle Scrappage | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 396 | 0.03 | 0.08 | $78,004 | 39,002 |

| Vehicle Scrappage | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 10.49 | 0.01 | 0.00 | 0.08 | 408.31 | 87.10 |
| Tons Per Day | 0.03 | 0.00 | 0.00 | 0.00 | 1.12 | 0.24 |

## CO-BENEFITS

Vehicle scrappage programs contribute to improved air quality by eliminating the pollutants emitted by the oldest vehicles on the road. In addition, such programs can result in further benefits that include:[110]

- reduced fuel consumption;

[107] Center for Clean Air Policy (2004) "Comparison of EU and US Experiences with respect to Controlling Emissions from High Emitting Vehicles": http://www.ccap.org/pdf/EU%20AQ%20Case%20Study%203.pdf

[108] US EPA: http://yosemite.epa.gov/aa/tcmsitei.nsf/0/c2f7e1d6b69ece73852565d90075b889?OpenDocument

[109] For example, in states adopting the California motor vehicle GHG standards. See policy brief 1.1 Low GHG emissions standards.

[110] Climate change connections (2002) "Feasibility Study on the Implementation of a Vehicle Scrappage Program in Winnipeg, Manitoba": http://www.climatechangeconnection.org/pdfs_ccc/Vehicle_Scrappage.pdf

- decreased ground water pollution due to fluid leakage;
- promotion of sustainable transportation methods;
- improved public health;
- enhanced public safety due to improved safety standards in newer vehicles;
- decreased emissions of air toxics, such as benzene; and
- increased vehicle sales

**CASE STUDIES**

**California-** California implemented the "voluntary accelerated vehicle retirement" (VAVR) program aimed at removing up to 75,000 light-duty vehicles that are 15 years or older from the roads annually. The program, included in the 1994 SIP for the South Coast, is expected to reduce emissions of reactive organic gases (ROG) (similar to hydrocarbons) and $NO_x$ by 25 tons per day in 2010, and has since been expanded to other jurisdictions. The California Air Resources Board administers VAVR, which became California law in 1995. It currently operates in conjunction with the state's Smogcheck program, requiring that for vehicles to be VAVR eligible, they must have failed a smogcheck within the past 90 days. If the requirements are met, the owner receives $1,000 to retire the vehicle. Although this program has yet to be fully implemented, the program is expected to remove 147,000 aging vehicles from the roads by 2010 and to reduce emissions in the South Coast by 13 tons per day (tpd) by 2010—a decrease of about 4 percent.[111]
(http://www.arb.ca.gov/msprog/avrp/avrpeo.htm)
(http://www.breatheeasier.ca.gov/default.htm)

**Texas-** In 2001, the State of Texas created the AirCheck Texas Repair & Replacement Assistance Program to provide financial assistance to low income owners of vehicle that fail emissions tests. The program was established under the Low Income Vehicle Repair Assistance, Retrofit, and Accelerated Vehicle Retirement Program (LIRAP) and is only offered in counties that have implemented a vehicle inspection and maintenance (I/M) program. The program offers owners between $600 and $1,000 towards the purchase of a replacement vehicle. The retired vehicles are then dismantled by LIRAP designated facilities. Through the fourth quarter of fiscal year 2005, 779 vehicles have been replaced through the AirCheck Texas Repair and Replacement Assistance Program.
(http://www.tceq.state.tx.us/implementation/air/mobilesource/vim/lirap.html)

**Vancouver, Canada-** The "Scrap-It" program began in 1996 as a pilot demonstration program aimed at removing 1,100 vehicles from British Columbia's roads with a target of 500 vehicles to be retired annually after the year 2000.[112] The first year of the program resulted in the retirement of 549 vehicles. Requirements for eligibility include: failure to pass the AirCare I/M test, be model year 1993 or older, have been insured within British Columbia for the past two years, and be drivable to the recycling site. Participants can choose to scrap their vehicle and receive one of the following incentives:

- $1,000 towards a natural gas car
- $750 towards a new car
- $500 towards a used car
- $500 towards a new bicycle
- $750 toward van pooling

[111] The study estimated that the "credible" range of emissions reductions for the program was between 8 and 28 tpd.
[112] The program was funded by a variety of organizations including the British Columbia Automobile Dealers Association, Canadian Petroleum Products Institute, BC Hydro, and Vancouver and Victoria Regional Transit Commissions.

- various British Columbia Transit pass options

(http://www.scrapit.ca/)

**KEY ISSUES/IMPLEMENTATION**

Designing and implementing a vehicle scrappage program that effectively achieves emissions reductions requires careful consideration of issues that include:

- levels of incentives required for participation;
- effective public education campaigns;
- clear program requirements;
- retiring of vehicles near the end of their useful life can reduce the emissions impact of the program; and
- older vehicles from outside the program area may migrate to the region as a result of the market demand for vehicles

**KEY RESOURCES & REFERENCES**

**California Air Resources Board-** Website provides access to vehicle scrappage programs and information in California:
http://www.arb.ca.gov/msprog/avrp/avrpeo.htm
http://www.breatheeasier.ca.gov/default.htm

**Car Heaven**- Is a program of the Clean Air Foundation that aims to retire 5,000 vehicles a year in Ontario:
http://www.carheaven.ca/

**Center for Clean Air Policy**- "Comparison of EU and US Experiences with respect to Controlling Emissions from High Emitting Vehicles":
http://www.ccap.org/pdf/EU%20AQ%20Case%20Study%203.pdf

**Dixon and Garber**- "Fighting Air Pollution in Southern California by Scrapping Old Vehicles":
www.rand.org/publications/MR/MR1256/index.html

**Environment Canada-** Provides a review of Canadian vehicle scrappage programs that are administered through local organizations across the country:
http://www.ec.gc.ca/press/2003/030616_b_e.htm

**Environment Canada-** "Canadian In-Use Vehicle Emissions Reduction Programs" reviews provincial and federal in-use vehicle initiatives:
http://www.ccme.ca/assets/pdf/jia_trnsprt_emiss_reduct_e.pdf

**Scrap-it Program-** Website provides a review of the British Columbia based program, incentives and application materials:
http://www.scrapit.ca/

**The World Bank-** "Can Vehicle Scrappage Programs be Successful?" includes a review of program and policy design considerations, incentive structures and examples from European and South American scrappage programs:
http://lnweb18.worldbank.org/sar/sa.nsf/Attachments/Briefing8/$File/Briefing_Note_No_8.pdf

**US Environmental Protection Agency- EPA's** transportation control measures website

contains a brief review of Accelerated Vehicle Retirement Programs, issues and examples from the United States:
http://yosemite.epa.gov/aa/tcmsitei.nsf/0/c2f7e1d6b69ece73852565d90075b889?OpenDocument

**US Environmental Protection Agency-** "Guidance for the Implementation of Accelerated Retirement of Vehicles Programs" is a 1993 technical report aimed at providing guidance to states for program design and implementation:
http://ntl.bts.gov/card_view.cfm?docid=488

## 1.8 Driver Training

**OVERVIEW**

Driving behavior can significantly influence a vehicle's fuel economy performance, and affect the environmental impact of the on-road fleet. As technologies to improve the fuel efficiency of vehicles mature, a driver's skill and habits will become ever more important in reducing emissions of greenhouse gases and criteria pollutants. Driving to maximize fuel efficiency or "eco-driving" is achieved by influencing driving patterns that reduce the energy required, and by operating the vehicle at the engine's optimal efficiency. Habits that reduce fuel use include: trip planning, avoiding aggressive driving behaviors (speeding, rapid acceleration and deceleration), reducing excess weight and aerodynamic drag, maintaining a steady speed, anticipating traffic conditions, smooth acceleration and deceleration and up shifting as soon as possible.[113]

Integrating eco-driving principles into daily driving patterns requires a range of techniques aimed at promoting and developing a market for fuel-efficient driving. Such techniques can include:[114]

- Public education campaigns- focusing on environmental and economic impacts and tips to improve fuel efficiency;
- Driver Training Courses
  - Voluntary courses for interested drivers, supported by ad campaigns
  - Integrated into standard drivers education required before receiving a drivers license
  - Integrated into specialized licensing for heavy duty fleet vehicles i.e. public transit buses
  - Training offered by manufacturers when making a new vehicle purchase; and
- In-car technologies- to improve driver awareness and decision making such as gear shifting indicators (GSI), trip meters and fuel consumption computers;[115]

Driver training programs designed to cultivate eco-driving habits for passenger and fleet vehicles are emerging in Europe as part of national and European environmental policies. Eco-driver training programs have been estimated to reduce fuel consumption by up to 25 percent following training, with an average reduction of 5 to 10 percent that will likely decrease over the long-run.[116] The European Climate Change Programme estimated that Eco-driving could potentially reduce 50 million tons of $CO_2$ in Europe by 2010.[117] Fuel efficiency training is also being increasingly integrated into the business practices of many heavy-duty fleet operators as an environmental and cost saving measure.[118] The EPA

---

[113] For more information on fuel efficient driving tips please visit: http://www.ecodrive.org/newdriving/easytolearn.html or http://oee.nrcan.gc.ca/transportation/personal-vehicles-initiative.cfm

[114] European Climate Change Programme (ECCP) (2005) "Review and analysis of the reduction potential and costs of technological and other measures to reduce $CO_2$-emissions from passenger cars-Draft Interim Report", and Eco-Driving Europe: http://www.ecodrive.org/index.html

[115] A GSI advises the driver on the appropriate time to shift gears using indicator lights on the dash board and can achieve a 4 to 11 percent improvement in fuel economy: http://forum.europa.eu.int/Public/irc/env/eccp_2/library?l=/lightduty_vehicles/meeting_december_2005&vm=detailed&sb=Title

[116] ECCP 2005, *OP Cit.*

[117] ECO-DRIVE Europe: http://www.ecodrive.org/index.html

[118] Natural Resources Canada (NRCAN) (2002): "The Auto$mart Guide: How to buy, drive, maintain your car and save money, energy and the environment": http://oee.nrcan.gc.ca/Publications/infosource/PDFs/Newautosmartguide_E.pdf

## 1.8 Driver Training

Smartway Transport Partnership estimates that improving fuel economy by 5 percent will reduce fuel costs by over $1,200 per truck annually.[119]

### POLICY QUANTIFICATION

Driver training reduces emissions by lowering the per mile emissions rate. For the purposes of the sample calculation, it was assumed that 10,000 drivers received training allowing a 5 percent improvement in emissions per mile rates.

| Driver Training | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 2,218 | 0.18 | 0.53 | $500,000 | 250,000 |

| Driver Training | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 6.56 | 0.04 | 0.03 | 0.53 | 85.06 | 9.07 |
| Tons Per Day | 0.02 | 0.00 | 0.00 | 0.00 | 0.23 | 0.02 |

### CO-BENEFITS

The promotion of fuel efficient driving techniques through driver training programs and educational campaigns has benefits to both the individual motorist and the public. These benefits may include:[120]

- reduced effects of local noise and air pollution;
- improved motorist safety;
- owner costs associated with traffic accidents;
- reduced wear and tear on breaks and engine components;
- lowered fuel costs; and
- improved driver comfort and reduced stress while driving

### CASE STUDIES

**Canada-** Natural Resources Canada (NRCAN) has developed a series of SmartDriver courses under its FleetSmart program to reduce fuel consumption among Canadian heavy duty fleets. The Smart Driver training program offers courses for professional drivers, promoting the economic and environmental benefits of fuel efficient driving. The courses are designed to illustrate the impact of driving habits on fuel consumption. Specific SmartDriver training is available for transit, forestry, highway heavy-duty truck and motorcoach drivers, and is available through many fleet operators and driver training organizations.
(http://oee.nrcan.gc.ca/fleetsmart)

**Edmonton, Canada**- The City's Fuel Sense program was launched as a pilot project in 2000 to cut the city's fuel costs, and has since become integrated as a regular component of the city's energy management strategy. The program consists of a four-hour, on-road and in-class training program that focuses on fuel efficiency, cost savings and environmental impact. The program targets drivers of municipal, transit and emergency services vehicles. As of 2004, the Fuel Sense program has trained 1200 drivers, reduced the fuel consumed per kilometer by 5.5 percent and avoided 350 tonnes of greenhouse gas emissions annually. The program has be adopted as part of regular municipal fleet driver training and transit's driver training programs.
(http://www.tc.gc.ca/programs/environment/UTSP/docs/casestudiesPDF/24E%20-

[119] US Environmental Protection Agency: http://www.epa.gov/smartway/documents/drivertraining.pdf
[120] Eco-Driving Europe: http://www.ecodrive.org/newdriving/benefits.html

%20V%20%20Edmonton,%20Alta.%20%20Fuel%20Sense_Making%20Fleet%20%20and%20Transit%20Operations%20More%20Efficient.pdf)

**Netherlands-** The national Eco-Driving program focuses on five key areas, professional drivers, driving school curriculum, in-car devices, tire pressure and purchasing decisions. The program has trained more than 90 percent of the country's driving instructors and examiners and has been incorporated into testing for instructors, examiners and new drivers.
(http://www.hetnieuwerijden.nl/)

**Winnipeg, Canada-** Winnipeg based Bison Transport has developed a fuel economy program that integrates tractor-trailer upgrades, with a driver training program. Based on the NRCAN SmartDriver training courses, Bison developed Tatonka, a comprehensive program that combines in-class lessons, computer-based modules and a full-motion vehicle simulator. Follow up studies indicated that relative to a control group, the drivers that had completed the course reduced their fuel use by 3 percent. This fuel savings would reduce fuel expenditures by $750,000 annually, and reduce 3.2 million kilograms in greenhouse-gas emissions across the entire fleet.
(http://oee.nrcan.gc.ca/transportation/business/documents/successstories/highway-truck-bison.cfm?attr=16)
(http://oee.nrcan.gc.ca/corporate/awards/energyefficiency/2004/transportation/tatonka.cfm?attr=0)

**KEY ISSUES/IMPLEMENTATION**

Effective promotion of eco-driving focuses on greater integration into driver education and training programs required for licensing. Eco-driving Europe has highlighted strategies that can be applied to the development of national, state and local programs. These strategies may include:[121]

- develop a series of high quality training programs that include in-class lessons, on-road training and simulators designed for different target groups;
- identify partnerships to support and market programs;
- continual re-evaluation of programs;
- develop quality standards for training of instructors and examiners;
- develop high quality teaching materials for driving instructors;
- provide incentives for eco-driver training; and
- where and when possible integrate eco-driving into policies and legal frameworks

**KEY RESOURCES & REFERENCES**

**Ecodrive.org-** The Eco-Driving Europe website provides information on the eco-driving project, profiles national eco-driving programs, and highlights fuel efficient driving tips and technologies:
www.ecodrive.org

**EcoDriving International-** The Ecodriving website provides information on Finland's national driver training program and courses:
http://www.ecodriving.org/

[121] Eco-Driving Europe: http://www.ecodrive.org/index.html

## 1.8 Driver Training

**European Climate Change Programme-** Draft interim report "Review and analysis of the reduction potential and costs of technological and other measures to reduce $CO_2$-emissions from passenger cars": http://europa.eu.int/comm/environment/climat/eccp.htm

**Federal Highway Administration (FHWA)-** FHWA's *It All Adds up to Cleaner Air* website provides the public with information on transportation choices, congestion and air pollution, and emphasizes simple actions that can be taken to improve air quality and reduce congestion:
http://www.italladdsup.gov/index.html

**Ford Motor Company-** The Ford eco-driving program offers information on fuel efficient driving techniques:
http://www.ecodrive.org/pdf/ford_eng.pdf
http://media.ford.com/newsroom/feature_display.cfm?release=17993

**Natural Resources Canada-** The federal government's Personal Vehicles Initiative provides Canadian motorists with tips on buying, driving and maintaining their vehicles to reduce fuel consumption and greenhouse gas emissions:
http://oee.nrcan.gc.ca/transportation/personal-vehicles-initiative.cfm

**Natural Resources Canada-** "The Auto$mart Guide: How to buy, drive, maintain your car and save money, energy and the environment":
http://oee.nrcan.gc.ca/Publications/infosource/PDFs/Newautosmartguide_E.pdf

**Natural Resources Canada** –The FleetSmart program offers information on how energy-efficient practices can reduce fleet operating costs and provides case studies and links to federal driver training programs:
http://oee.nrcan.gc.ca/transportation/fleetsmart.cfm

**Quality Alliance Eco-Drive®-** The Quality Alliance Eco-Drive® is an association for Swiss course providers, transport associations and government agencies that promoting and disseminating the Eco-Drive® standards, licensing and training
http://www.eco-drive.ch/en/01.html

**US Environmental Protection Agency-** The Smartway Transport Partnership includes information on the impact of driver training on emissions and fuel costs for highway trucking:
http://www.epa.gov/smartway/documents/drivertraining.pdf

## 1.9 Anti Idling Campaigns and By-laws

### OVERVIEW

Light-duty vehicle idling wastes fuel, damages engines, and results in excess greenhouse gas and criteria air pollutant emissions. There is a common misconception that leaving an automobile running when waiting for several minutes is better for cars and light-duty vehicles than simply shutting off the engine. However, an idle car gets zero miles to the gallon and with modern engines, idling an automobile for more than 10 seconds wastes more fuel than simply turning it off and then restarting it.[122] Emissions created by idling vehicles contribute toward smog formation, and produces about 19 pounds of carbon dioxide for every gallon of gas consumed.[123]

Natural Resources Canada found that frequent restarting has little impact on engine components such as the battery and starter motor, and the wear caused by restarting is estimated to add $10 per year to the cost of driving, far less than the cost of wasted fuel.[124] In the absence of extreme weather conditions, idling is not an effective way of warming up an automobile engine. Excessive idling results in incomplete combustion, which can damage an automobile by leaving fuel residues that contaminate oil and damage engine components. It can also allow water to condense in the vehicle's exhaust, leading to premature corrosion that can reduce the life of the exhaust system.[125] Because idling cannot always be avoided, many of these laws have exemptions, such as in the case of emergency vehicles, traffic conditions, vehicles being repaired or serviced, or in extreme winter cold (e.g. below 32$^{o}$ F).

The focus of most state idling policies has traditionally been on heavy-duty diesel trucks and buses. However, in recent years, many states have begun to pass measures covering all vehicles, including light-duty cars and trucks. Several U.S. states and cities have adopted regulations that enforce excessive idling when conditions do not necessitate the activity. As of August 2005, 14 states and the District of Columbia have passed anti-idling regulations relating to light-duty vehicles. Eleven states and the District of Columbia apply idling regulations to all motor vehicles in at least one municipality and three states that have regulations preventing idling for all motor vehicles, include anti-idling regulations in their State Implementation Plan (SIP).

### POLICY QUANTIFICATION

The sample quantification demonstrates the emissions savings from avoiding 10,000 hours of idling time based on current fleet emissions per idling hour averages.

---

[122] Natural Resources Canada: http://oee.nrcan.gc.ca/communities-government/transportation/municipal-communities/articles/idling-myths.cfm?attr=8

[123] Hamilton County Ohio Department of Environmental Services: http://www.hcdoes.org/airquality/vehicles/idle.htm

[124] Frequent restarting has little impact on engine components like battery and starter motor. Wear caused by restarting is estimated to add $10 per year to the cost of driving, money likely recovered several times over in fuel savings, Natural Resources Canada: http://www.ecy.wa.gov/programs/air/NO_IDLE/Anti_Idle_FactSheet_long.html

[125] City of Markham, Ontario: http://www.city.markham.on.ca/markham/channels/newscentre/initiatives/idlefree/textonly.asp?ref=http://www.markham.ca/markham/channels/newscentre/initiatives/IdleFree/FAQs.htm

## 1.9 Anti Idling Campaigns and By-laws

| Idling Reduction | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 89 | 0.00 | 0.00 | $20,000 | 10,000 |

| Idling Reduction | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 17.70 | 0.05 | 0.05 | 0.00 | 339.45 | 13.80 |
| Tons Per Day | 0.05 | 0.00 | 0.00 | 0.00 | 0.93 | 0.04 |

### CO-BENEFITS

Anti-idling programs provide a cost-effective way to improve air quality and reduce greenhouse gas emissions. Some of the additional benefits to idle reduction include: [126]

- reduced emissions of pollutants such as CO, $NO_x$, and pollutants contributing to smog formation;
- increased fuel efficiency;
- less wear and tear on engines;
- reduced health risks associated with gasoline exposure; and
- saving money due to a reduction in unnecessary fuel consumption and engine maintenance

### CASE STUDIES

**Connecticut-** The State has two laws relating to anti-idling. One law applied to school bus idling and the other for all motor vehicles. The law relating to motor vehicles has exceptions for vehicle repair or servicing, traffic conditions, mechanical difficulties, heating/cooling when necessary, and if the ambient temperature is below 20° F. All other motor vehicles are in violation of the law if they remain idle for three minutes. This regulation is included in the SIP.
(http://dep.state.ct.us/air2/diesel/antiidle.htm)

**District of Columbia**- In the District of Columbia, it is illegal to leave any diesel or gasoline powered vehicles idle for over 3 minutes. Exemptions exist for installing auxiliary equipment, or if the ambient temperature is below 32° F. In 1999, the DC Council enacted emergency legislation to increase the penalty for excessive idling to $500. The legislation authorizes issuing a civil infraction ticket of $500 to any organization that owns and/or operates a vehicle seen violating the regulation. Once a company is convicted of violating the engine regulation, subsequent fines will be double the amount of the previous fine. The primary offenders of the engine idling regulations in the District are tour buses, construction trucks, taxi cabs, and solid waste transfer trucks.
(http://www.dchealth.dc.gov/doh/cwp/view,A,1374,Q,584041,dohNav_GID,1809.asp)

**Massachusetts**- State idling laws make it illegal to idle any motor vehicle for more than five minutes. The Massachusetts law has exemptions for vehicle repair or service. Massachusetts does have an anti-idling program that is utilized at airports. Massport[127] has posted highly visible signs along the front of the Civil Air Terminal to remind motorists about the state vehicle idling law. The signs read “Massachusetts law prohibits idling vehicles for more than 5 minutes (MGL CH. 90 Sect 16A). Vehicle idling causes pollutants, including: carbon monoxide, oxides of nitrogen, hydrocarbons, and volatile organic compounds, to

[126] Natural Resources Canada: http://oee.nrcan.gc.ca/idling/issues_idling/benefits_action.cfm?PrintView=N&Text=N

[127] Massport is the independent public authority which develops, promotes and manages airports, the seaport and transportation infrastructure in the state.

enter the atmosphere. Please help Massport protect our environment by complying with this Massachusetts law."
(http://www.mass.gov/dep/air/community/schbusir.htm)
(http://www.massport.com/about/pic/c_8796_hansc_s08.pdf)

**New York, NY-** New York City has had a local ordinance on the books since 1971 forbidding the idling of any motor vehicle. The limit is 3 minutes, and the city recently boosted the maximum fine for first offenders to $1000 and multiple offenders to $2000. The new fines, have not led to strong enforcement with only 159 tickets since July 2004. The New York Department of Environmental Protection, as well as the NYC Departments of Transportation, Parks, Sanitation and the Police departments can enforce the city's idling restrictions, however, the agencies themselves do not patrol for violations; issuing most of the citations after someone calls and complains. The city of New York has purchased eight electric postal trucks to replace the diesel fueled trucks that would typically idle on postal routes. These trucks will join the 22 electric postal delivery vans currently used at the Ansonia Station in Manhattan.
(http://www.nypa.gov/ev/ct2.htm)

**Toronto, Canada-** In 2002, 18 municipalities in the Greater Toronto Area (GTA) committed to participate in the GTA Idle-Free Campaign that has become the largest anti-idling initiatives of its kind in Canada. The campaign aimed to create widespread awareness about vehicle idling and to encourage drivers to change their idling behaviors across the region.
(http://www.cleanairpartnership.org/pdf/gta_idlefree_finalreport.pdf)

A City of Toronto study entitled "Turning it Off : Reducing Vehicle Engine Idling" found that signage, combined with personal communication, can be very effective in influencing people's idling behaviors (27 percent of people in the study stopped idling) and reducing idling time (78 percent reduction in idling duration).
(http://oee.nrcan.gc.ca/transportation/idling/material/reports-research/turn-it-off-exec-summary.cfm?attr=16)

**KEY ISSUES/IMPLEMENTATION**
In order to effectively reduce idling, public education and signage are central components of any strategy. If the public is aware of a fine and that idling wastes fuel and can damage their car, they will be more likely to abide by the relevant laws. Options for an anti-idling program for cars and light-duty vehicles may include:

- public education- including signage and literature that informs the public about the law and about the environmental damage, waste and health impact of emissions caused by idling;
- raising fines for idling infractions; and
- targeting enforcement in certain areas or locations (such as rest stops or schools)

Public education campaigns need to be supported by effective enforcement programs. Estimates of levels of enforcement of anti-idling regulations remain low, reasons for this include:

- low prioritization of idling enforcement with enforcement officials;
- enforcement may only take place if police officers witness visual evidence of idling or if they receive a citizen complaint;
- most people are not aware of idling laws;

- regulations contained in SIPs normally refer to buses, locomotives, and heavy-duty vehicles, which typically take priority over passenger cars; and
- SIPs do not appear to have measures dealing with all motor vehicles[128]

**KEY RESOURCES & REFERENCES**

**American Transportation Research Institute-** "Compendium of Idling Regulations" provides a list of state laws on idling, including idling duration and exemptions:
http://atri-online.org/research/results/idling_chart.pdf

**Earth Day Canada**- "A Turnkey Solution to Air Pollution" provides myths and facts about the impacts of vehicle idling:
http://www.earthday.ca/EDy2k/YearRnd/NPNetwork/Turnkey13.html

**California Air Resources Board-**"What is idling?" – A short description of idling and idling policies:
http://www.arb.ca.gov/cap/pamphlets/limitsondieselfueledidling.pdf

**Connecticut Department of Environmental Protection**- Highlights anti-idling efforts in Connecticut:
http://dep.state.ct.us/air2/diesel/antiidle.htm

**Natural Resources Canada –** Office of Energy Efficiency's "Idle-Free Zone Newsletter" is a newsletter dedicated to projects and studies that reduce vehicle idling in Canada and the United States:
http://oee.nrcan.gc.ca/idling/zone_newsletter/winter2005/winter2005.cfm?PrintView=N&Text=N

**Natural Resources Canada-** Office of Energy Efficiency's Idling website includes the tool and resources needed to develop idle free campaigns as well as the "Turn It Off: Reducing Vehicle Engine Idling – Final Report", a study of the usefulness of techniques to encourage motorists to avoid idling their vehicle engines in areas where idling is common:
http://oee.nrcan.gc.ca/transportation/business/idling.cfm?attr=16
http://oee.nrcan.gc.ca/transportation/idling/material/reports-research/turn-it-off-exec-summary.cfm?attr=16

**New York City Council-**"Enforcement of and compliance with idling restrictions in New York City" describes idling restrictions, idling facts, health effects of idling, and provides further resources:
http://webdocs.nyccouncil.info/attachments/59350.htm?CFID=1050950&CFTOKEN=89860126

**US Environmental Protection Agency-** "Drive Wise" provides tips on driving, including recommending no longer than 30 seconds of idling.
http://www.epa.gov/air/actions/drive_wise.html

[128] This is because mobile sources that produce significant emissions (such as locomotives, buses, and heavy-duty trucks) are better candidates to be used as control measures because they are easier to enforce (or easier to be given incentives for enforcement), and are more likely to have a measurable impact on emissions reductions. It does not appear that enforcement of motor vehicle idling, specifically targeting cars and light-duty vehicles are included in any SIP, although an example of such a measure would be a public education program or signage at an area where vehicle idling infractions are commonplace.

## 1.9 Anti Idling Campaigns and By-laws

**US Environmental Protection Agency-** "Summary of State Anti-Idling Regulations" provides a description of state laws, types of vehicles, duration of idling, exemptions, and whether or not the idling regulation is included in the SIP:
http://www.epa.gov/otaq/smartway/documents/statelaws.pdf

**Washington State Department of Ecology**- Provides a fact sheet on idling reduction, concerning issues of air quality, vehicle operation, impacts on health, and impacts on children:
http://www.airwatchnorthwest.org/wa/NO_IDLE/Anti_Idle_FactSheet_long.html

# 1.10 Speed Reduction Programs

## OVERVIEW

Vehicle emissions rates are directly related to vehicle speed and vary by the type of pollutant. For example, VOC emissions rates typically drop as speed increases, $NO_x$ emissions increase at higher speeds, and CO emissions decrease until approximately 55 mph and then rise dramatically.[129] Additionally, emissions rates are highest during the acceleration mode and lowest during the idling mode.[130]

Fuel consumption and greenhouse gas emissions also vary according to travel speeds. Aerodynamic forces result in reduced fuel economy at high speeds, while operating a vehicle at low speed (below 30 mph) requires greater fuel use per mile traveled. Maximum efficiency is achieved at speeds between 30 and 55 mph. Above 55 mph, fuel efficiency can decline approximately one percent for each mile exceeding 55 mph.[131] Consequently, lowering travel speeds from 70 to 55 mph can reduce fuel consumption up to 23 percent, depending on the age of the vehicle.[132] The optimal driving speed within cities is estimated at 35 mph, and 55-60 mph for highway conditions.[133]

Because rates are largely dependent upon acceleration/deceleration behavior, driving patterns can greatly affect emissions levels. The United Kingdom's Department of Transport states, "Emissions can generally be reduced if vehicles are driven in a smooth manner, and drivers observe speed limits."[134] Thus, to minimize emissions, it is important that drivers maintain a steady, moderate speed. There are a variety of ways to reduce both highway and city travel speeds to achieve emissions reductions and increased fuel efficiency, including:

- greater enforcement of existing speed limits;
- reducing speed limits;
- improving signage;
- traffic calming measures;[135] and
- designing narrower roads[136]

## POLICY QUANTIFICATION

Speed reduction programs reduce emissions by lowering the per VMT rate of emissions. The quantification below represents a speed reduction program covering an area of approximately 1 million daily VMT with the average speed reduced from 65 to 55 MPH.

---

[129] Federal Highway Administration (2002) "Transportation Air Quality - Selected Facts and Figures": http://www.fhwa.dot.gov/environment/aqfactbk/factbk13.htm

[130] Rouphail et al. (2000) "Vehicle Emissions and Traffic Measures: Exploratory Analysis of Field Observations at Signalized Arterials": http://www4.ncsu.edu/~frey/emissions/trb2001paper.PDF

[131] Center for Clean Air Policy (2004) "Urban Form and Climate Protection": http://www.ccap.org/Presentations/Winkelman%20TRB%202004%20(1-13-04).pdf

[132] Natural Resources Canada (NRCAN): http://oee.nrcan.gc.ca/transportation/personal/driving/autosmart-maintenance.cfm?attr=8#defensive

[133] *Ibid.* NRCAN

[134] Department for Transport (UK): http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_504787-02.hcsp

[135] Traffic calming refers to a number of techniques used to reduce travel speeds and improve conditions for non-motorized street users. These techniques include a wide range from physical design features such as speed humps and textured pavements, and in some jurisdictions may include education and enforcement strategies: http://www.fhwa.dot.gov/environment/tcalm/

[136] Narrower road design is a technique used to slow travel speeds and create a more pedestrian oriented environment. Narrow streets have been incorporated into "neotraditional" urban design strategies aimed at improving street life and the walkability of communities.

# 1.10 Speed Reduction Programs

Where pollutant-specific data is not available, pollutants are assumed to move in conjunction with $CO_2$ emission rates.

| Speed Reduction Programs | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 10,953 | 308 | 3.37 | $3,212,000 | 1,606,000 |

| Speed Reduction Programs | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 308 | 0.23 | 0.21 | 3.40 | 4,234 | 57.31 |
| Tons Per Day | 0.84 | 0.00 | 0.00 | 0.01 | 11.60 | 0.16 |

## CO-BENEFITS

Comprehensive speed reduction programs that include enforcement, traffic calming, road design, and driver education can be more effective in achieving emissions reductions and increased fuel efficiency than isolated initiatives. Additionally, such programs can result in a greater range of benefits to communities, such as:

- enhanced pedestrian and bicycle safety;[137]
- improved motorist safety;
- reduced vehicle miles traveled;[138]
- increased use of alternate transportation modes;
- reduced congestion;
- mitigated noise pollution from vehicle travel;
- more efficient land use and pedestrian-oriented urban design features; and
- improved community livability

## CASE STUDIES

**Buxtehude, Germany-** German research indicates that traffic calming reduces idle times by 15 percent, gear changes by 12 percent, brake use by 14 percent, and gasoline use by 12 percent. Monitoring vehicle emissions before and after the implementation of traffic calming measures in a 2.5 $km^2$ area of the city of Buxtehude demonstrated emissions benefits from reducing vehicle speeds through traffic calming. Lowering speeds from 50 km/h to 30 km/h resulted in a reduction in fuel consumption by 7 percent, hydrocarbons by 22 percent, and $NO_x$ by 48 percent.
(http://tmip.fhwa.dot.gov/clearinghouse/docs/udes/replogle.stm)

**Tennessee-** In 2005, the Tennessee Department of Transportation (TDOT) agreed to lower the speed limit to 55 mph from 70 mph on highways in Hamilton and Shelby Counties in an effort to reduce emissions from heavy-duty trucks. The counties also agreed to a simultaneous reduction in the speed limit for passenger vehicles to 65 mph. The request was made by the mayors of the cities of Chattanooga and Memphis, along with Hamilton and Shelby counties, in an attempt to bring the region back into federal ozone attainment. TDOT cites a recent study conducted by the Federal Highway Administration that shows reducing truck speed limits by 10 mph can reduce the $NO_x$ emissions factor by 18 percent or more per truck. This policy is expected to have the same effect as reducing industrial $NO_x$ emissions by 11 percent in the county.

[137] Department for Transport (UK): http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_504682-03.hcsp#P105_10751

[138] Reductions in the speed of traffic can reduce total vehicle miles traveled by reducing potential capacity, resulting in a 2-5 percent reduction in vehicle travel in the initial years after implementation of a 10 percent decrease in speeds.

(http://www.state.tn.us/environment/news/release/2005/Mar/speedlimit.php)
(http://www.greencarcongress.com/2005/02/tennessee_reduc.html)

**KEY ISSUES/IMPLEMENTATION**

In order to effectively reduce greenhouse gas and criteria pollutant emissions, a speed reduction plan must consider several issues, including:

- motorist compliance;
- costs of increased enforcement;[139]
- enforcement challenges in high volume traffic;
- impacts on traffic volume and trip duration;
- isolated speed reduction measures may divert traffic to less used roads; and
- politically unpopularity with motorists

**KEY RESOURCES & REFERENCES**

**Climate Change Solutions-** Provides the speed demon calculator to highlight the impact of speed on carbon dioxide emissions and fuel costs:
http://www.climatechangesolutions.com/individuals/transport/tools/demon.html

**Federal Highway Administration-** Outlines the types and composition of vehicle emissions and the effect of speed on the emissions rate for various pollutants:
http://esa21.kennesaw.edu/activities/smog-cars/doe-veh-pollutants.pdf

**Government of Alberta-** Backgrounder on Highway Speeds and Greenhouse Gas Emissions Reductions:
http://www.trans.gov.ab.ca/Content/doctype57/production/SpeedLimitsBrief.pdf

**Iowa Highway Safety Management System**- "Update Report on Speed Limits in Iowa" reviews system-wide safety, economic and social impacts of increased speed limits:
http://www.dot.state.ia.us/pdf_files/speed2002.pdf

**Natural Resources Canada, Office of Energy Efficiency**- Provides guides to reducing transportation energy consumption for individuals, which includes tips on fuel efficient driving and fuel consumption calculator tools:
http://oee.nrcan.gc.ca/transportation/personal/index.cfm?attr=8

**The Slower Speeds Initiative-** Is a UK based research and advocacy organization focused on appropriate speed management policies:
http://slower-speeds.org.uk/

**The Slower Speeds Initiative-** "The Killing Speed: A Good Practice Guide to Speed Management" outlines the benefits of lower speeds, relevant policies and legislation, implementation, design, enforcement, and community consultation strategies for the UK:
http://slower-speeds.org.uk/kscontents.htm

**United Kingdom, Department for Transport-** "New directions in speed management: a review of policy":

[139] Metropolitan Washington Council of Governments (MWCOG) estimated a $4,474 cost per ton of $NO_x$ reduced for 95 miles of increased speed enforcement in Northern Virginia. See Diesel Technology Forum:
http://www.dieselforum.org/retrofit/chart.pdf

http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_504682.hcsp

**US Department of Energy-** This web site provides information on fuel economy for consumers including *the Fuel Economy Guide*, information on current and previous model year vehicle, and educational tools and resources:
http://www.fueleconomy.gov/feg/driveHabits.shtml

**US Environmental Protection Agency-** "A Glance at Clean Freight Strategies: Reducing Highway Speed" highlights emissions reduction potential for trucks from speed management practices:
http://www.epa.gov/smartway/documents/reducedspeed.pdf

**US Environmental Protection Agency**- "The Effects of Raising Speed Limits on Motor Vehicle Emissions":
http://www.epa.gov/otaq/invntory/spd2-rpt.pdf

**Victoria Transport Policy Institute-** "Traffic Calming Benefits, Costs and Equity Impacts" provides a review of traffic calming programs and an evaluation of associated costs and benefits:
http://www.vtpi.org/calming.pdf

# 1.11 Traffic Signalization

## OVERVIEW

Traffic signal optimization reduces fuel consumption and emissions by improving traffic flow, reducing idling, and easing bottlenecks along high traffic roadways in urbanized areas. Options to improve traffic signal management include:

- removing unneeded signals;
- developing and implementing signal timing plans to account for changes in traffic flow;
- adding traffic detectors to side streets, enabling traffic progression through the system;
- installing new signal equipment, such as solid state electronic controllers, that provide the capability to implement more advanced traffic control techniques;
- controlling signals from a central location—enabling remote management;
- coordinating signal operations across jurisdictional boundaries; and
- installing and maintaining equipment properly

The Federal Highway Administration estimates that more than three quarters of the 260,000 traffic signals in the U.S. could be improved by updating traffic signal timing or modernizing equipment.[140] While costs can be significant depending on the technique implemented, the results can be worth the price. According to the Institute of Transportation Engineers (ITE),[141] comprehensive signal retiming programs have created benefits of a 7 to 13 percent reduction in overall travel time, a 15 to 37 percent reduction in delay, and a 6 to 9 percent increase in fuel savings. Other studies have reported a 4 to 13 percent reduction in fuel consumption for travel in affected areas.[142] The effectiveness of this measure in reducing emissions is dependent on existing levels of congestion, the induced demand for VMT (i.e. improved traffic flow leads to more drivers utilizing the roadway), and the level of technology implemented.

## POLICY QUANTIFICATION

Improved traffic signalization reduces emissions by minimizing idling time and increasing the average traffic speed. The existing level of congestion and the geographic range of the program determine the benefits. Studies suggest signalized regions realize a 4 to 13 percent efficiency improvement. This equates to approximately a 1 to 4 percent savings. However, since traffic times are improved, one must also consider the impact of induced demand. For the purposes of this quantification, a 2 percent overall savings is assumed, with a 20 percent rebound effect due to induced demand—for a net savings of 1.6 percent. The savings were estimated for a signalized region with one million VMT per day.

| Improved Traffic Signalization | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 2073 | 0.16 | 0.49 | $467,200 | 233,600 |

| Improved Traffic Signalization | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 6.13 | 0.03 | 0.03 | 0.50 | 79.48 | 8.48 |
| Tons Per Day | 0.02 | 0.00 | 0.00 | 0.00 | 0.22 | 0.02 |

[140] Federal Highway Administration: http://www.ops.fhwa.dot.gov/traffic_sig_timing/index.htm
[141] Institute of Transportation Engineers: http://www.ite.org/signal/index.asp
[142] Government of Canada, Transport Canada (1999) "Strategies to Reduce GHG Emissions from Passenger Transportation in Urban Canada": http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/passenger_urban/study1/FinalAppendices/appendix_g.htm

# 1.11 Traffic Signalization

## CO-BENEFITS

Traffic signalization strategies can result in immediate benefits for local air quality by reducing vehicle emissions and fuel consumption. Additional benefits include:[143]

- potential reduction in travel times;
- improvements in congestion benefit commercial, emergency and public transit vehicles;
- greater reliability in travel times;
- reduction in aggressive driving behavior;
- fewer severe accidents; and
- lower additional capacity requirements

## CASE STUDIES

**California-** California's Fuel Efficient Traffic Signal Management (FETSIM) program optimized 3,172 traffic signals through 1988, and reported an average reduction in vehicle stops of 16 percent and in fuel use of 8.6 percent. "Since one-fifth of total VMT in California is traveled on streets controlled by traffic signals, statewide implementation with comparable success would potentially save 1.7 percent of total highway fuel consumption." (http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/42419C3E5993E9CD852569EA0071D556)

**Los Angeles, CA**- The Automated Traffic Surveillance and Control (ATSAC) system used by the city of Los Angeles to optimize traffic signal control has been estimated to reduce signal delays by 44 percent, vehicle stops by 41 percent, fuel consumption by 13 percent, and travel time by 18 percent. ATSAC is a computer-based system that monitors traffic conditions and selects signal control strategies to effectively manage the flow of traffic. From the initial 120 signals installed prior to the 1984 Olympics, the system has expanded to include 3,100 of the city's 4,300 signalized intersections. (http://www.fordfound.org/elibrary/documents/0289/007.cfm)

**Texas-** Texas' Traffic Light Synchronization (TLS) program involved 171 locations in different sized communities and 2450 signals. In phase one of the program, the annual fuel savings were over 28 million gallons and the financial benefit to motorists was $485 million; in phase two, where 75 locations and 1327 signals were affected, these numbers were ~25 million gallons and $298 million respectively. (http://www.naseo.org/international/china2002-08/06-Managing.pdf)

**Virginia**- Fairfax, Prince William, and Loudon counties undertook improvements to 700 signalized intersections. The improvements resulted in a 6 percent reduction in stops, a 22 percent reduction in system delays, a 9 percent reduction in fuel consumption, and a 134,000 kg reduction in annual emissions for CO, $NO_x$ and VOC. Similar traffic signalization measures in the central business district of Richmond, VA reduced travel times 9 to -14 percent, stops 28 to -39 percent, fuel use 10 to -12 percent, and vehicle emissions by 5 to -22 percent. (http://www.epa.gov/air/caaac/Halkias.pdf)

**Toronto, Canada**- In 1994, the City of Toronto undertook a pilot project to evaluate the SCOOT (Split Cycle Offset Optimization Technique) real-time adaptive signal control system. The system updated signal timing to address changing traffic volumes throughout the day. In addition to a reduction in traffic violations and intersection delays, city officials found that SCOOT decreased travel time by 6 to –11 percent, vehicle stops by 10 to –31 percent, fuel

[143] Federal Highway Administration: http://www.cdtoolbox.org/development_issues/000194.html

consumption by 4 to –7 percent, and pollutant emissions by 3 to –6 percent. The program was expanded in 1996 to include 250 signalized intersections at a cost of C$7.2 million. Today, similar systems are in use across Canada, including Vancouver, Calgary, Edmonton, Saskatoon, Montreal, and Halifax.
(http://www.itsbenefits.its.dot.gov/its/benecost.nsf/5c36f979ce2c926a852569bc006c5713/d18dab8f9e24d44585256a6f0053f14a?OpenDocument)

**KEY ISSUES/IMPLEMENTATION**

Implementation concerns that have surfaced include:

- institutional barriers regarding integrating signal timing plans across jurisdictions;
- technological needs, such as fibre-optic networks to relay real-time traffic information;
- high public costs, including operations and maintenance;
- impacts on pedestrian/bike crossings; and
- signal re-timing should be considered no less than every three years;[144] preferably every year[145]

**KEY RESOURCES & REFERENCES**

**Cornell University-** The Cardi Toolbox on community economic and development tools includes the information on Traffic Signal Management:
http://www.cdtoolbox.org/development_issues/

**Federal Highway Administration-** "Improving Traffic Signal Operations: a Primer" outlines low cost adjustments to traffic signalization systems, maintenance and general operations:
http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13466.pdf

**Federal Highway Administration-** Public Roads magazine highlights traffic signalization issues:
http://www.tfhrc.gov/pubrds/04nov/07.htm

**Federal Highway Administration-** Office of Operations Traffic Signal Timing Program provides access to educational/outreach materials and tools for traffic signal timing:
http://www.ops.fhwa.dot.gov/traffic_sig_timing/index.htm

**Government of Canada, Transport Canada-** "Strategies to Reduce GHG Emissions from Passenger Transportation in Urban Canada" provides estimates the GHG reductions possible from measures traffic signalization improvement:
http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/passenger_urban/study1/FinalAppendices/appendix_g.htm

**North Carolina State University-** "Vehicle Emissions and Traffic Measures: Exploratory Analysis of Field Observations at Signalized Arterials" and "Emissions and Traffic Control: an Empirical Approach" studies the effects of traffic flow on real-world vehicle emissions:
http://www4.ncsu.edu/~frey/emissions/trb2001paper.PDF
http://www4.ncsu.edu/~frey/CRC2000Paper.pdf

[144] Cornell University: http://www.cdtoolbox.org/development_issues/000194.html
[145] Institute of Transportation Engineers: http://www.ite.org/signal/index.asp

## 1.11 Traffic Signalization

**Texas Transportation Institute-** Information on the PASSER© (Progression Analysis and Signal System Evaluation Routine) model software developed by TTI to optimize traffic signal timings on single roadways or entire networks roadways: http://tti.tamu.edu/product/ror/passer.stm

**U.S Department of Transportation-** Intelligent Transportation Systems Technology Overview reviews components of Arterial Management Systems including Advanced Signal Systems and Adaptive Signal Controls: http://itsdeployment2.ed.ornl.gov/technology_overview/AM.asp

**US Environmental Protection Agency-** Transportation Control Measures: Traffic Flow Improvements: http://yosemite.epa.gov/aa/tcmsitei.nsf/0/6e0f189e31055880852565d900721435?OpenDocument

# 1.12 Vehicle Technology & Maintenance

## OVERVIEW

The fuel efficiency of the existing vehicle fleet can be improved by choosing tires and oils that reduce fuel use and ensuring that vehicles are properly maintained in order to achieve an optimum level of efficiency.

Rolling resistance is a measure of how easily a tire will roll down the road. Low rolling resistance tires minimize the energy lost to heat between the tire and the road, within the tire sidewall, and between the tire and the rim.[146] The California Energy Commission (CEC) reported that low rolling resistance tires could improve passenger vehicle fuel economy by three percent, saving up to 300 million gallons of fuel annually in California.[147,148] Car manufacturers commonly install low rolling resistance tires on new vehicles to help meet federal fuel economy (CAFE) standards, however only a limited number of such tires are available to be used as replacement tires. Replacement tires have been found to have rolling resistance values up to 22 percent higher than those originally installed on the vehicle.[149] If all replacement tires in the United States were as efficient as the originals, it is estimated that fuel economy would improve by 3 percent, saving up to eight billion gallons of gasoline annually by 2015.[150]

Low viscosity motor oils and lubricants can provide additional fuel savings for passenger vehicles and heavy-duty trucks by reducing energy loses from internal friction. Testing has revealed a fuel economy benefits ranging from one percent to over five percent in passenger vehicles.[151] The American Trucking Association reports that synthetic transmission and axle lubricants for long-haul freight trucks can result in a gain in fuel economy by 0.5 percent in the summer and 2 percent in the winter. A recent study concluded that a 1.5 percent improvement in fuel economy from low-friction engine oils and 1.5 percent from synthetic drive train lubricants, has would result in a reduction in annual fuel saving of 479 gallons for an average long-haul truck.[152]

Tire and vehicle maintenance practices can significantly impact the performance of any vehicle. Under inflated tires are reported to decrease fuel economy by 0.4 percent for every pound per square inch (psi) of pressure below proper inflation levels. Operating a vehicle with one tire under-inflated by 6 psi can increase a vehicle's fuel consumption by

---

[146] Green Seal (2003) "Choose Green Report: Low Rolling Resistance Tires": http://www.greenseal.org/recommendations/CGR_tire_rollingresistance.pdf

[147] California Energy Comission (2003) "California State Fuel-Efficient Tire Report: Volume I": http://www.energy.ca.gov/reports/2003-01-31_600-03-001F-VOL1.PDF

[148] A study conducted in Germany estimated that a 30 percent reduction of rolling resistance would reduce fuel consumption by 3-6 percent under city conditions and 2-3 percent on the highway: http://www.energy.ca.gov/transportation/tire_efficiency/documents/2002-09-19_workshop/FRIEDRICH_FUEL_SAVINGS.PPT

[149] Natural Resources Defense Council (2004) "Fuel-Efficient Replacement Tires: Guidelines for Transforming the Marketplace": http://www.iea.org/Textbase/work/2005/EnerEffTyre/hwang_Fuelefftire.pdf

[150] Ibid.

[151] Ecos Consulting (2005) "Fuel Savings Possibilities from Low Viscosity Synthetic Motor Oils": http://www.iea.org/Textbase/work/2005/EnerEffTyre/calwell2.pdf

[152] Ang-Olson, J and W. Schroeer (2003) "Energy Efficiency Strategies for Freight Trucking: Potential Impact on Fuel Use and Greenhouse Gas Emissions": http://www.ccap.org/pdf/2003-Aug-13--CT-CCSD--Transp--EE_for_Freight_Trucking.pdf

3 percent.[153] It is estimated that a quarter of all passenger cars, and one-third of all SUVs and light truck are running on under-inflated tires.[154] Similarly, poor maintenance of mechanical systems and filters, or neglecting to change worn out oils can decrease fuel economy. The U.S. Department of Energy estimates that proper maintenance of air filters can improve fuel economy from 1 to 10 percent, while changing oil and oil filters regularly can get an additional 1 to 2 percent.[155]

## POLICY QUANTIFICATION

Through adopting technology and maintenance measures, the per mile emissions rate of the fleet is improved. The sample quantification assumes three measures that improve emission rates by 3 percent each are adopted for 10,000 cars that are driven 12,000 miles per year. Note that the quantification assumes that the technologies will be adopted separately, but it is possible for multiple technologies to be adopted on one vehicle in which case the benefits will be slightly less than adding the measures separately.

| Vehicle Technology | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 3,833 | 0.30 | 0.91 | $864,000 | 432,000 |

| Vehicle Technology | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 11.33 | 0.06 | 0.06 | 0.92 | 146.99 | 15.68 |
| Tons Per Day | 0.03 | 0.00 | 0.00 | 0.00 | 0.40 | 0.04 |

## CO-BENEFITS

Proper vehicle maintenance and tire inflation practices, as well as using tires and oils that improve vehicle fuel efficiency can result in multiple environmental, economic and health benefits. Improving vehicle fuel economy will reduce fuel consumption and emissions. Other benefits can include:

- reduced health costs associated with air pollution;
- lower vehicle operating costs per mile;
- reduced costs for tire disposal and recycling when tires last longer due to improved maintenance;
- improved safety from proper maintenance;
- better engine performance; and
- reduced oil dependency

## CASE STUDIES

**California-** In January 2003, recommendations for the development of a statewide fuel-efficient tire program were submitted to the State Legislature. The report concluded that up to 300 million gallons of fuel per year could be saved in California through the use of low rolling resistance tires. The study resulted in AB 855 being signed into law in October of 2003, requiring manufacturers to develop efficiency labels for tires, and efficiency standards for all replacement tires sold in the state. Subsequently, the California Energy Commission

[153] Natural Resources Canada: http://oee.nrcan.gc.ca/transportation/personal/maintaining/vehicle-maintenance.cfm?attr=8#oil

[154] Center for Energy Efficiency and Renewable Technologies (2004) "Unhooking California: Eleven Things Californians Can Do NOW to Save Gasoline (and Money)": http://www.ceert.org/pubs/crrp/petro/unhookingca.pdf

[155] Ibid.

has undertaken a detailed tire study[156] that is expected in December 2006, and will form the basis for regulation rulemaking. Rulemaking for the development of rolling resistance reporting requirements and a rating system to compare the performance of tires is anticipated to begin in early 2007. Fuel economy standards for tires will be assessed based on feasibility requirements, and are expected in January 2009.

(http://www.energy.ca.gov/2005publications/CEC-999-2005-016/CEC-999-2005-016.PDF)

**Canada-** The Government of Canada and the Rubber Association of Canada have joined to develop the "Be Tire Smart" national public education campaign to encourage proper tire inflation and maintenance. The campaign includes information and education materials, tire inflation and maintenance clinics as well as guidance for developing local clinics. (http://www.betiresmart.ca/)

**New Hampshire**- In July 2005, Governor John Lynch issued an Executive Order directing state agencies to reduce their energy use by 10 percent. This included the implementation of a Clean Fleets Program to reduce fuel use by state fleets. Among the measures included in the Clean Fleets Mission Policy are specifications for preventative maintenance, energy conserving motor oils, and the use of low rolling resistance tires when purchasing replacement tires.
(http://www.sos.nh.gov/EXECUTIVE%20ORDERS/Benson2004-7.pdf)

**United States-** In 2005, several bills introduced into Congress focused on improving vehicle fuel efficiency by establishing a rating system and national standards for new and replacement tires.
(http://www.govtrack.us/congress/subjects.xpd?type=crs&term=Automobile%20tires)

**KEY ISSUES/IMPLEMENTATION**

Low rolling resistance tires display the characteristics of a technology that can overcome barriers, and achieve widespread use in the market place. These characteristics include the ability to improve the energy efficiency of existing vehicle technologies, low incremental costs, short payback periods and the ability to be integrated into new standards and codes. In a study conducted by the Natural Resources Defense Council (NRDC), several market and non-market barriers to the widespread adoption of low rolling resistance tires have been identified, they include:[157]

- consumers often lack adequate information on:
  - full costs of operating a vehicle and the benefits of reduced fuel use;
  - fuel-saving characteristics in tires;
  - other tire characteristics that influence tire quality;
- consumers often fail to integrate energy information it into their decision making process effectively; and
- data on rolling resistance from manufacturers is not readily available to the public

NRDC has also identified nine initiatives that are needed to overcome barriers to the development of a market for fuel efficient replacement tires:

- conduct tire performance testing that can be used to establish fuel savings;

[156] California Energy Commission (2005) "California Energy Commission's Fuel Efficient Tire Program", presented by Arnold Ward Program Manager for Fuel Efficient Tires: http://www.energy.ca.gov/transportation/tire_efficiency/documents/2005-11-15_WARD_TIRE_PROGRAM.PDF

[157] NRDC 2004, *OP Cit.*

- make the results of tire testing publicly available;
- develop effective labeling for the fuel efficiency of tires;
- educate tire dealers;
- conduct consumer education and outreach campaigns;
- integrate fuel efficient replacement tires into state and local fleet requirements;
- provide purchase incentives to accelerate their adoption;
- develop partnerships between governments and industry to further research and development into the efficiency of tires; and
- establish minimum state and federal standards for the efficiency of replacement tires

**KEY RESOURCES & REFERENCES**

**American Council for an Energy-Efficient Economy (ACEEE) -** ACEEE's July 2005 overview of tire performance standards as proposed in the Senate energy bill:
http://www.aceee.org/transportation/tire.pdf

**California Energy Commission (CEC)**- This website provide access to information on California's Fuel-Efficient Tire Program, including the final program recommendations submitted to the state legislature, presentations and workshop materials:
http://www.energy.ca.gov/transportation/tire_efficiency/

**Ecos Consulting**- Presentations by ECOS consulting to the International Energy Agency in November 2005 on "Fuel Savings Possibilities from Low Viscosity Synthetic Motor Oils" and "Empirical Analysis and Program Options for Low Rolling Resistance Tires":
http://www.iea.org/Textbase/work/2005/EnerEffTyre/calwell2.pdf
http://www.iea.org/Textbase/work/2005/EnerEffTyre/calwell1.pdf

**European Association of Rubber Industry**- The European tire industry's response to an integrated strategy for the development of competitiveness and it's impact on road safety and environment:
http://europa.eu.int/comm/enterprise/automotive/pagesbackground/competitiveness/cars21_hearing/blic.pdf

**Federal Highway Administration (FHWA)-** FHWA's *It All Adds up to Cleaner Air* website provides the public with information on transportation choices, congestion and air pollution, and emphasizes simple actions that can be taken to improve air quality and reduce congestion:
http://www.italladdsup.gov/index.html

**Green Seal-** Green Seal's "Choose Green" report featuring Low Rolling Resistance Tires, presents previously unpublished data on leading tires and rolling resistance:
http://www.greenseal.org/recommendations/CGR_tire_rollingresistance.pdf

**National Renewable Energy Laboratory-** A 2002 report "Modeling Tools for Predicting the Impact of Rolling Resistance on Energy Usage and Fuel Efficiency for Realistic Driving Cycles":
http://www.ctts.nrel.gov/analysis/pdfs/itec02_modeling_paper_final.pdf

**Natural Resources Canada**- The Office of Energy Efficiency's AutoSmart vehicle initiative offers tips on vehicle maintenance, oils and tire inflation practices to improve fuel efficiency:

http://oee.nrcan.gc.ca/transportation/personal/maintaining/vehicle-maintenance.cfm?attr=8

**Natural Resources Canada**- "Be Tire Smart- Play Your Part" is a national public education campaign to encourage motorists to adopt good tire maintenance practices including tips on maintenance and inflation and information on starting a campaign: http://www.betiresmart.ca/

**Natural Resources Defense Council (NRDC)**- The 2004 NRDC report "Fuel-Efficient Replacement Tires: Guidelines for Transforming the Marketplace": http://www.iea.org/Textbase/work/2005/EnerEffTyre/hwang_Fuelefftire.pdf

**US Environmental Protection Agency**- The EPA's Smartway Transport Partnership provides a one page analysis of the environmental and cost benefits of tire and lubricant choices for highway trucking:
http://www.epa.gov/smartway/documents/lowviscositylubes.pdf
http://www.epa.gov/smartway/documents/supersingles.pdf

# 1.13 Hybrid Electric Vehicles

**OVERVIEW**

Most motor vehicles in the United States are powered by internal combustion engines (ICEs). However, the ICEs supplied as standard equipment are much more powerful than what is needed for most driving conditions and thus tend to be operated very inefficiently. The only time that the full power of the engine is required is during rapid acceleration – under nearly all other driving conditions, only a fraction of the engine's maximum power is required. Hybrid electric vehicles (HEVs) reduce this inefficiency by downsizing the engine and adding an electric motor to assist the engine when high power is needed by increasing torque at lower rpm. In most HEVs, this improved efficiency is channeled into better fuel economy, and this is the prime attraction of these types of vehicles to most automobile shoppers.

In 1999, the Honda Insight became the first hybrid electric vehicle (HEV) to be sold in the United States. This was followed by the introduction of the Toyota Prius and the Honda Civic Hybrid in 2000. Today, there are nine models of hybrid vehicles available in the U.S. market including compact, sedan, SUV and pick-up truck models.[158] By model year 2007 there are expected to be approximately 20 hybrid models on the market, including an expanded range of SUVs and minivans. The popularity of these vehicles is growing rapidly – the market has expanded from 20,287 HEVs sold here in 2001, while through November 2005, U.S. HEV sales had reached 187,439.[159] With four HEV models expected to be available by 2007, Toyota has set a goal of one million HEVs sold annually by 2010.

[158] Hybrid Cars.com: http://www.hybridcars.com/cars.html
[159] Hybrid Cars.com http://www.hybridcars.com/sales-numbers.html

# 1.13 Hybrid Electric Vehicles

| Vehicle Type | Model Year | EPA Adjusted MPG (city/hwy) |
|---|---|---|
| Compact Car: | | |
| Honda Civic Hybrid (Automatic) | 2005 | 47/48 |
| Honda Civic Hybrid (Manual) | 2005 | 45/51 |
| Toyota Prius Gen. 1 | 2003 | 52/45 |
| Typical Small Car (Non-Hybrid Reference) | N/A | 24/29 |
| Compact SUV: | | |
| Ford Escape Hybrid (2WD) | 2006 | 36/31 |
| Ford Escape Hybrid (4WD) | 2006 | 33/29 |
| Mercury Mariner Hybrid | 2006 | 33/29 |
| Typical Compact SUV (Non-Hybrid Reference) | 2003 | 21/26 |
| Midsize Car: | | |
| Honda Accord Hybrid | 2005 | 30/37 |
| Toyota Prius Gen. 2 | 2005 | 60/51 |
| Typical Midsize (Non-Hybrid Reference) | 2003 | 21/27 |
| Midsize SUV: | | |
| Toyota Hylander (2WD) | 2006 | 33/28 |
| Toyota Hylander (4WD) | 2006 | 31/27 |
| Lexus RX 400h | 2006 | 31/27 |
| Typical Midsize SUV (2WD Non-Hybrid Reference) | 2003 | 17/22 |
| Typical Midsize SUV (4WD Non-Hybrid Reference) | 2003 | 16/21 |
| Two Seater: | | |
| Honda Insight (Automatic) | 2005 | 57/66 |
| Honda Insight (Manual) | 2005 | 61/66 |
| Typical Small Car (Non-Hybrid Reference) | N/A | 24/29 |

Sources: Union of Concerned Scientists: http://go.ucsusa.org/hybridcenter/compare_chart.cfm

## CLASSES OF HYBRID ELECTRIC VEHICLES

Hybrids can also be classified by the degree of hybridization:

- vehicles incorporating *Start/Stop* technology, which shuts down the engine during idling and restarts it on demand - this is required for a vehicle to be called an HEV (in which the electric motor provides this function) but can also be achieved in a conventional vehicle using an integrated starter-generator;
- mild hybrids - utilize start/stop technology but also incorporate downsized engines and regenerative braking capability;
- full hybrids - have all of the attributes of a mild hybrid while additionally allowing the vehicle to be driven using only the electric motor;
- plug-in hybrids – full hybrids that have the ability to recharge the batteries by plugging them into the electrical grid, thus allowing short-distance (20-60 mile) operation as a purely electric vehicle; and

- "Muscle" hybrids - use hybrid technology to improve vehicle performance by adding an electric motor without downsizing the engine, thus boosting power with minimal improvement in fuel economy

Regenerative braking allows the vehicle to retain some of the energy generally lost during braking and use it to charge the batteries. During driving, torque is supplied by the engine or electric motor to drive the wheels. To slow or stop the vehicle, a torque must be applied in the opposite direction. Since an electric motor essentially becomes a generator when operated in reverse, this braking torque can be used by the electric motor to generate electricity to recharge the batteries.

The following table summarizes some of the benefits of hybrid electric vehicles:[160]

| HEV Type | Torque Improvement | Fuel Economy Improvement | Estimated Price Increase |
|---|---|---|---|
| Start/Stop | 0% | 7.5% | $600-$640 |
| Mild Hybrid | 15% | 20% | $1620-$1790 |
| Full Hybrid: | | | |
| Cars/Small Light Trucks | 20% | 40% | $3320-$3920 |
| Large Light Trucks | 15% | 35% | $4100 |

**HYBRID ELECTRIC VEHICLE FUEL ECONOMY AND GREENHOUSE GAS EMISSIONS**

Because the technology used in an HEV is significantly different than that in a conventional vehicle, hybrids have the potential to significantly improve the fuel economy of the motor vehicle fleet and reduce the associated greenhouse gas emissions. Obviously, much of this is due to use of the electric motor rather than the ICE in specific driving conditions. However, the smaller engines in HEVs also produce lighter vehicles and allow body designs that have smaller profiles, thus improving the vehicle's aerodynamics. In addition, HEVs generally incorporate low rolling-resistance tires, lightweight materials and other aerodynamic features to further improve fuel economy.

The Union of Concerned Scientists (UCS) estimates that typical mid-size car with a fuel economy of about 27 mpg could potentially improve its fuel economy in the following manner through hybridization (assuming a parallel drivetrain):[161]

- to ~46 mpg with advanced conventional technologies, including start/stop
- to ~55 mpg for a mild hybrid
- to ~68 mpg for a full hybrid
- to ~80 mpg for a plug-in hybrid

The Institute of Transportation Studies[162] has estimated that, if all vehicles in the fleet were replaced by HEVs, fleet fuel economy would increase from today's value of about 25 mpg to:

[3] Greene, D.L., Duleep, K.G. and McManus, W. (2004) "Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market," Oak Ridge National Laboratory, Aug. 20 (ORNL/TM-2004/181)

[161] Union of Concerned Scientists: http://www.ucsusa.org/clean_vehicles

[162] Burke, A. and Abelas, E. (2004) "Feasible CAFE Standard Increases Using Emerging Diesel and Hybrid-Electric Technologies for Light-Duty Vehicles in the United States," Institute of Transportation Studies, UC Davis, as quoted in Greene, Duleep, and McManus (2004).

- 38 mpg for all mild hybrids, with vehicle costs increasing by 7-9 percent;
- 42 mpg for all full hybrids, with vehicle costs increasing by 16-18 percent;

### HYBRID ELECTRIC VEHICLE CRITERIA POLLUTANT EMISSIONS

In most low-emissions vehicles, the majority of pollutant emissions occur during warm-up of the engine and emissions control system, when partially burned fuel is released from the engine. Since HEVs have smaller engines, they heat more quickly and thus have less toxic emissions than similar vehicles with larger engines. HEVs also achieve a small emissions reduction from the more efficient operation of the gasoline engine. Plug-in hybrids, if recharged regularly by the vehicle owner using "green" electricity, can achieve near-zero emissions levels.

On the other hand, the basic hybrid design and operating characteristics can potentially produce increased emissions. Frequent starting and stopping of the engine can allow it to cool sufficiently to intermittently permit the release of unburned fuel. In addition, most vehicles contain an evaporative canister, which collects the fuel vapors remaining in the engine after it is shut off. Upon restart, this canister purges its contents back into the engine for burning. However, if the engine is starting and stopping often, as can be the case for HEVs, the canister may not have time to fully release its contents before the next engine shutdown, and it can fill up and allow some of the unburned fuel to escape. However, technologies exist that can mitigate each of these potential emissions problems.

### HYBRID ELECTRIC VEHICLE COSTS

HEVs with series drivetrains are generally more expensive than others because they require a generator and tend to have larger packs of batteries, which are expensive. HEVs with parallel drivetrains are less expensive because they have smaller battery packs, although this advantage is partially offset by their slightly larger engines and more complex coupling systems. In either case, HEVs are more expensive than their ICE counterparts.

Calculating the payback period for an HEV purchase is often difficult because most hybrids do not have an ICE counterpart with similar performance characteristics. A good start is to compare to a conventional vehicle with the same total engine horsepower, although that will not capture overall performance and other amenities. The payback calculator shown below (and included in the Guidebook Calculator) provides an example of one such calculation. The calculated payback time for a 2006 Honda Civic Hybrid, using a 2006 Honda Civic EX Sedan with 5-speed automatic transmission as the base vehicle is about 13.6 years when the listed values for the other parameters in the table are assumed.[163]

[163] Price and mpg data from: http://www.hondanews.com/CatID2011?mid=2005090938171&mime=asc. Private communications with Honda officials indicate that, due to differences in the associated vehicle amenities on the Civic Hybrid and Civic EX Sedan, the true marginal cost could be $3000 to $3500.

# 1.13 Hybrid Electric Vehicles

| Hybrid Payback Calculator | |
|---|---|
| Marginal Cost | $2,790 |
| Baseline Efficiency (mpg) | 35 |
| Hybrid Efficiency (mpg) | 50 |
| Miles per year | 15,000 |
| Financing Years | 5.0 |
| Real Rate of Interest | 2.0% |
| Real Rate of Gasoline Inflation | 3.0% |
| Miles per year reducution rate | 5.4% |
| Price of Gasoline | $ 2.00 |
| Payback (years) | 13.6 |

## CO-BENEFITS

HEVs provide a number of benefits other than improved fuel efficiency. These include:

- lower emissions of criteria pollutants;
- reduced emissions of greenhouse gases;
- quieter vehicle operations with lower levels of vibration;
- can provide electricity to more vehicle amenities;
- reduced brake maintenance due to regenerative braking;
- better energy security for the U.S. due to lessened consumption of petroleum; and
- much HEV research and the resulting technological advances, such as improved batteries and electronics, can be applied to hydrogen fuel cell vehicles and thus help to make these vehicles more economically viable

## KEY ISSUES/IMPLEMENTATION

When purchasing HEVs, the primary concerns are:

- fuel economy gain;
- environmental benefits; and
- payback timeframe

Many people automatically associate HEVs with better fuel economy and lower emissions of pollutants and greenhouse gases. However, any efficiency improvement in a vehicle can be used to improve other performance characteristics, such as acceleration or power, rather than fuel consumption. This is the case for "muscle" hybrids (see above). Any individual or entity considering the purchase of an HEV or a fleet of HEVs must be careful to verify that any vehicle that incorporates hybrid electric technologies actually provides a significant improvement in fuel efficiency and emissions performance before making a buying decision.

Due to their advanced technologies, hybrid vehicles are also more expensive than their conventional counterparts. In comparing HEV models, the increase in purchase price must be weighed against future savings in operating costs (fuel, maintenance, etc.). In other words, evaluating the cost-effectiveness of any HEV purchase must take into consideration the entire life-cycle costs of the vehicle.

## HYBRID ELECTRIC VEHICLE TECHNOLOGY

HEV drivetrains consist of a combination of some or all of the following components:

- *Engine* – typically an ICE, downsized from an analogous conventional vehicle;
- *Electric motor* – uses electrical energy to drive the wheels;
- *Battery pack* – stores and supplies electrical energy to power the electric motor;
- *Generator* – generates electricity to power the electric motor or to charge the battery pack; and

- *Transmission* – transmits energy from the engine to drive the wheels

These components can be arranged into a number of drivetrain configurations:

- *Series drivetrain*
  - the engine's power turns the generator
  - the generator supplies electricity to either the electric motor or to the battery pack
  - the electric motor, powered by either the battery pack, the generator, or both, creates the torque to drive the wheels
  - the battery pack is charged by the engine (through the generator) and through regenerative braking
- *Parallel drivetrain* (e.g., Honda Civic, Insight and Accord)
  - either the electric motor or the engine can be used to drive the wheels
  - the battery pack is charged through regenerative braking and by using the motor as a generator during driving
- *Split parallel drivetrain*
  - the engine and the electric motor are not coupled but are instead used to drive the front wheels and back wheels, respectively
- *Series/parallel drivetrain* (e.g., Toyota Prius, Ford Escape)
  - allows the vehicle to operate as either a series or parallel drivetrain

HEVs with series drivetrains have smaller engines than parallel drivetrain vehicles and are optimized for city driving (stop-and-go traffic); however, they are less efficient than parallel drivetrain vehicles on the highway because energy is lost in converting the engine's mechanical energy to electrical energy and then back to mechanical energy to drive the wheels.

**KEY RESOURCES & REFERENCES**

**BC Climate Exchange**- The Hybrid Experience Report website provides information from a variety of sources on hybrid vehicles, fleet applications, and information for fleet managers: http://www.hybridexperience.ca/Experiences.htm

**Center for the New American Dream-** Helps government agencies and other institutions purchase hybrid vehicles for their fleets, including the King County, Washington contract hybrid vehicles:
http://www.newdream.org/hev/

**HybridCars.com-** This website includes information on currently available and future hybrid models, mileage, incentives and technologies:
http://www.hybridcars.com/cars.html

**Massachusetts Institute of Technology Laboratory for Energy and the Environment –** "The Performance of Future ICE and Fuel Cell Powered Vehicles and Their Potential Fleet Impact" compares the potential of various technologies for improving the efficiency of future vehicles:
http://lfee.mit.edu/public/LFEE_2003-004_RP.pdf

**Oak Ridge National Laboratory –** "Future Potential of Hybrid and Diesel Powertrains in the Light-Duty Vehicle Market" provides a technical analysis of hybrid electric vehicle technologies and costs and the potential market penetration of HEVs in the U.S.:
http://www-cta.ornl.gov/cta/Publications/pdf/ORNL_TM_2004_181_HybridDiesel.pdf

## 1.13 Hybrid Electric Vehicles

**Union of Concerned Scientists** – "A New Road: The Technology and Potential of Hybrid Vehicles" describes hybrid electric vehicle characteristics and designs and models the impacts of hybrid technologies on the fuel consumption, emissions, and life-cycle costs for five models of current vehicles:
http://www.hybridcenter.org/hybrid-center-a-new-road-report.html

**Union of Concerned Scientists –** "Hybridcenter.org" contains a wealth of information about hybrid vehicle technologies; informative diagrams illustrating the operations of hybrid vehicles of different types; and an extensive set of resources for consumers, such as a buyer's guide, as well as quantitative comparisons of specific makes and models of today's hybrids and reviews of these vehicles by owners and professional organizations:
http://www.hybridcenter.org/

# 1.14 Hydrogen Fuel Cell Vehicles

## OVERVIEW

In his 2003 State of the Union address,[164] President Bush described his vision for a hydrogen economy, including a future motor vehicle fleet powered by this fuel, "so that the first car driven by a child born today could be powered by hydrogen, and pollution-free." At that time, he also proposed $1.2 billion in funding, spread over five years, toward achievement of this initiative.

The vehicle fleet that the President refers to is made up of hydrogen fuel cell vehicles (HFCVs). Hydrogen fuel cells are electrochemical devices that use hydrogen and oxygen to produce an electric current and water. The electricity is used to power an electric motor that drives the vehicle. The hydrogen used in the fuel cell can either be stored in a tank on the vehicle or produced on-board through reformation of some other hydrocarbon, such as natural gas (see below).

The President's initiative is vital to the deployment of HFCVs because these vehicles are in the early stages of development and must overcome a number of barriers (see below) before they can be expected to significantly penetrate the vehicle market. Without substantial government support, in terms of both financing and policy measures, research and development of HFCVs would probably not progress very quickly, as venture capitalists are reluctant to invest in this field, even given the President's State of the Union message.[165]

The primary benefits of hydrogen fuel cell vehicles are their potential for reducing U.S. dependence on foreign energy sources and eliminating harmful emissions from motor vehicles, particularly $CO_2$. However, the extent to which these benefits are attained is dependent upon the source of the hydrogen used to fuel the vehicles and the hydrogen production method employed.

There are a variety of ways to produce the hydrogen required to power a HFCV, including:

- reformation of natural gas or methanol – conversion of natural gas or methanol into hydrogen and CO through a reaction with steam in the presence of a nickel catalyst;
- oil or coal gasification – allows these hydrocarbons to be converted to hydrogen in a process very similar to natural gas reformation;
- the Kværner process – breaking up hydrocarbons into pure hydrogen and pure carbon using an electric arc;
- gasification or fermentation of biomass;
- electrolysis – splitting of water molecules into hydrogen and oxygen using electricity;

Reformation and electrolysis are the two most commonly used methods for producing hydrogen today.

To evaluate the greenhouse gas (GHG) emissions of HFCVs, one must consider GHGs produced both during vehicle operation, commonly called "tank-to-wheels" emissions, as well as emissions produced during the fuel production process ("well-to-tank" emissions). In HFCVs, use of hydrogen to operate the vehicle will produce only water as a byproduct. However, any hydrogen production process that incorporates fossil fuels or electricity

[164] Text of speech is available at: http://www.whitehouse.gov/news/releases/2003/01/20030128-19.html.
[165] Breakthrough Technologies Institute, Inc. (2003) "Fuel Cells at the Crossroads: Attitudes Regarding the Investment Climate for the US Fuel Cell Industry and a Projection of Industry Job Creation Potential": http://www.fuelcells.org/info/charts/economicstudy.pdf

produced from fossil fuels will emit GHGs during hydrogen production, so the full ("well-to-wheels") climate-friendliness of HFCVs is dependent upon both the fuel input and the specific process used for hydrogen production.

For example, the National Academy of Sciences (NAS) estimates that a HFCV fueled by hydrogen produced through natural gas reformation would have a well-to-wheels emission rate of about 150-190 grams $CO_2$e per mile, which is similar to the emissions levels of today's hybrid-electric vehicles. However, if the hydrogen were instead produced by electrolysis using electricity derived from nuclear power or renewable resources, such as wind or solar power, this well-to-wheels emission rate drops to about 16 grams $CO_2$e per mile.

Currently, the major factor preventing HFCVs from being widely deployed is cost. The NAS predicts that the cost of a fuel cell system, including the on-board storage of hydrogen, needs to drop from its current level (about $1000 per kW) to near $100 per kW before HFCVs can become commercially viable. They anticipate that this will take at lease ten years. This cost must drop even further, to around $50 per kW, for the hydrogen economy to advance, in the absence of any type of government mandate or monetary incentives. In addition, if fuel cell system costs drop to the latter level, the NAS anticipates that electrolyzer costs would fall as well, to the point (~$125 per kW) that hydrogen production would become more dependent on electricity prices then on electrolyzer costs. They anticipate this could be achieved in the next 15-20 years. However, hydrogen distribution costs are currently the most expensive part of the hydrogen fuel system.

Given the current state of HFCVs, the NAS models are based upon a scenario in which HFCVs enter the light-duty vehicle market in about 2015, reach 25 percent of new vehicle sales in 2027, and fully replace the conventional vehicle fleet around 2050. This represents slower development than the U.S. Department of Energy (DOE) is trying to achieve, but the NAS finds that "the near-term DOE milestones for FCVs are unrealistically aggressive." Thus, the NAS doesn't expect these vehicles to have much impact on the $CO_2$ emissions or the energy security of the U.S. over the next 25 years. However, if developments occur as anticipated, they can envision significant improvements in each of these areas thereafter.

**CO-BENEFITS**

As described above, HFCVs provide three major potential benefits:

- almost no emissions of criteria pollutants;
- significantly reduced emissions of greenhouse gases; and
- improved energy security of the U.S. due to lessened consumption of petroleum – this is negated if natural gas or petroleum is used for hydrogen production

**CASE STUDIES**

**United States**- The FreedomCAR and Fuel Partnership[166] is an informal agreement among the U.S. Department of Energy, five major energy companies[167], and the Big Three U.S. automakers.[168] "A major thrust of the Partnership is to examine and advance precompetitive research and development of technologies to enable high volume production

[166] US Department of Energy: http://www.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/index.shtml.
[167] BP America, Chevron Corporation, ConocoPhillips, ExxonMobil Corporation, and Shell Hydrogen (U.S.)
[168] DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation

of affordable hydrogen fuel cell vehicles, and the national hydrogen infrastructure necessary to support them."[169]
(http://www.nap.edu/catalog/11406.html.)

**California**- The California Fuel Cell Partnership was established to promote hydrogen fuel cell commercialization in the transportation sector. The partnership includes 32 member companies that range from automobile manufacturers, energy providers, government agencies to fuel cell technology companies and transit authorities. The partnership aims to facilitate the placement of fuel cell vehicles in fleets, support fuel cell infrastructure development and promote awareness of fuel cell transportation opportunities. (http://www.fuelcellpartnership.org/about_goals.html)

**KEY ISSUES/IMPLEMENTATION**

There are a number of issues that must be addressed before HFCVs can effectively compete with more conventional light-duty vehicles. Replacing the current transportation system with a hydrogen-based system will entail extensive decision-making at the national, regional and local levels, and a high degree of cooperation among the respective authorities, before this transition can begin. Much of the discussion will revolve around costs, and factors that must be considered include:

- logistics – what should be the primary source of hydrogen? What production method is preferred? Where should the hydrogen be produced - at centralized locations (and then piped to filling stations), locally (e.g. at the stations), or on-board the vehicles?;

- technological developments – advances are required in:
  - fuel cell performance, lifetime and durability; and
  - hydrogen storage capacity;[170]

- competition – future improvements and/or cost reductions in other technologies and fuels (such as batteries, hybrid-electric vehicles, synthetic fuels, etc.) could make one of these options more attractive than HFCVs; for example, some argue that it makes more sense to use electricity to power electric vehicles directly, rather than using it to convert water to hydrogen and then using the hydrogen in a HFCV;[171]

- infrastructure development – much of the infrastructure needed to produce, store, transport, and dispense hydrogen needs to be funded and built; this will entail writing or revising government codes, issuing permits, and minimizing vulnerability to terrorist attack;

- advances in carbon sequestration – if carbon capture and sequestration becomes viable, it allows hydrogen to be produced from coal, which is cheap and abundant, in

[169] US Department of Energy (2004) "Partnership Plan: Freedom Car and Fuel Partnership": http://www.eere.energy.gov/vehiclesandfuels/pdfs/program/fc_fuel_partnership_plan.pdf.

[170] Hydrogen has more energy per unit weight than gasoline, but because it is much less dense than gasoline, it contains much less energy per unit volume; current methods of storage (as a compressed gas, a cryogenic liquid, or a metal hydride in batteries) must be improved to allow on-board storage of a sufficient supply of hydrogen to allow HFCVs to achieve the driving range of today's vehicles (about 300 miles) before refueling.

[171] Dr. Joseph Romm, (2005) "2020 Vision: The Future of Oil, Cars, and Our Climate", presentation at *Public Health, Clean Air and Energy: Moving Transportation Towards Cleaner, More Efficient Solutions*, a briefing presented by the Environment and Energy Study Institute: http://www.eesi.org/breifings/2005/Transportation%20&%20Smart%20Growth/7.18.05PublicHealthandTransportation/RommPresentation.pdf

an environmentally-friendly manner; the DOE's FutureGen program[172] is a $1 billion demonstration project dedicated to building a coal-fired power plant that also produces hydrogen and sequesters carbon;

- renewable energy development - displacing electricity produced by coal and natural gas is currently more environmentally beneficial than displacing petroleum in vehicles, so why should "green" electricity be used for hydrogen production rather than fed into the grid?

- safety issues and public perception of the safety of HFCVs and the associated hydrogen infrastructure; and

- government incentives or other policy measures

Most researchers predict that HFCVs will initially be powered by hydrogen produced locally through reformation of natural gas or methanol or through electrolysis using distributed energy sources, such as wind. Development of a more national network would progress on a timescale largely dictated by the difficulties associated with the implementation issues described above.

**KEY RESOURCES & REFERENCES**

**U.S. Department of Energy–** "Hydrogen, Fuel Cells & Infrastructure Technologies Program" provides a wealth of information about hydrogen, its production and storage, hydrogen fuel cells, and U.S. government efforts to develop the hydrogen economy: http://www.eere.energy.gov/hydrogenandfuelcells/

**Congressional Research Service –** "A Hydrogen Economy and Fuel Cells: An Overview" describes some of the basics of hydrogen as a fuel, hydrogen production, fuel cell systems, and other issues related to development of the hydrogen economy: http://www.ncseonline.org/NLE/CRSreports/04Jan/RL32196.pdf

**Rocky Mountain Institute –** "Twenty Hydrogen Myths" presents some general information about using hydrogen as a fuel and describes how many of the perceived obstacles to attainment of a hydrogen economy are less daunting than typically portrayed: http://www.rmi.org/images/other/Energy/E03-05_20HydrogenMyths.pdf

**Santini, D.J., Vyas, A.D., Moore, J., and An, F. –** "Comparing Cost Estimates for U.S. Fuel Economy Improvement by Advanced Electric Drive Vehicles" compares the current and projected performance and cost of conventional and advanced vehicles, including hydrogen fuel cell vehicles.

[172] US Department of Energy: http://www.fossil.energy.gov/programs/powersystems/futuregen/.

# 2.0 FREIGHT & INTERCITY TRAVEL VEHICLES

# 2.1 Truck Stop Electrification (TSE)

## OVERVIEW

Overnight idling associated with long-haul trucking is estimated to consume 838 million to 2 billion gallons of fuel annually or five percent of annual heavy truck fuel consumption.[173] This translates into up to $6 billion in fuel costs lost to drivers each year. Drivers typically let their vehicles idle to heat or cool sleeper cabs, maintain the battery charge while using electrical appliances and to keep engines warm in cooler climates. Recent developments in truck stop electrification (TSE) technology have improved the options for drivers and can result in improved compliance with anti-idling regulations at truck stop facilities.[174]

Truck stop electrification provides an alternative to idling for commercial vehicles. Installed at truck stops or rest areas, TSE technology provides a power source that allows the driver to operate all on-board systems while parked. TSE systems require the use of either stand-alone systems owned and operated by the truck stop (or third party vendor) or shore power systems, which require a modification to the vehicle to be used in conjunction with electric outlets installed at each parking space. Both systems provide heating, ventilation and air conditioning (HVAC) as well as access to AC electrical power outlets. Trucks using shore power systems plug into an external power source provided at each parking space by the truck stop. This requires that the truck be equipped with an inverter, an electrical HVAC system and an extension cord to plug into the power source. Stand-alone systems require the construction of HVAC systems at the truck stop that are accessible to each parking space. The HVAC system is connected to the truck through a hose and a widow panel that includes a touch screen that allows for easy payment and use of services. [175]

Idling generates heavily localized air and noise pollution. Emissions of particular concern include: PM, $NO_x$ and $CO_2$. A study conducted by the Argonne National Laboratory estimated that, compared to current idling practices, TSE could nationally achieve a significant savings in energy, CO and $CO_2$ emissions, while lowering petroleum used in idling by more than 99 percent.[176]

## POLICY QUANTIFICATION

An Argonne National Lab study (2000) compared various anti idling technologies including electrification. Emissions savings are based on the difference in the per-hour emissions factors. This estimate assumes 100 parking spaces utilized approximately 8 hours per day. These variables will change based on the scale and characteristics of the project. Other key assumptions include one gallon of diesel used per hour idling to generate 10 brake horsepower-hours or 7.5 KWh.[177]

[173] Argonne National Laboratory (ANL) (2000) "Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks": http://www.ipd.anl.gov/anlpubs/2000/08/36930.pdf

[174] Antares Group Inc. (2004) "Truck Stop Electrification as a Long-Haul Tractor Idling Alternative": http://www.epa.gov/smartway/documents/dewitt-study.pdf

[175] U.S. Department of Energy, Clean Cities Program: http://www.eere.energy.gov/cleancities/idle/truck_elec.html

[176] ANL 2000, *op cit.* Assumes high market penetration

[177] The 7.5 KWh is based on accessory requirements of 10 brake horsepower-hours which correspond to one gallon of diesel fuel per hour. http://www.transportation.anl.gov/downloads/idling.xls

# 2.1 Truck Stop Electrification (TSE)

| Truck Stop Electrification | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 1542 | 13.59 | -0.02 | $750,000 | 300,000 |

| Truck Stop Electrification | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 13.59 | 0.75 | 0.75 | -3.95 | 28.04 | 3.74 |
| Tons Per Day | 0.04 | 0.00 | 0.00 | -0.01 | 0.08 | 0.01 |

## CO-BENEFITS

Truck stop electrification can result in economic, energy, health and environmental benefits in addition to the reduction of greenhouse gas emissions attributed to long haul trucking. These benefits can include:[178]

- decreased operating expenses through lower fuel and maintenance costs;[179]
- short payback periods;
- reduced noise pollution;
- improved driver health and safety by reducing exposure to vehicle emissions and noise;
- new revenue source for travel centers;
- reduced local impacts of noise and vehicle emissions on communities near truck stops;
- enhanced quality of sleep for drivers, resulting in improved highways safety;
- improved driver retention; and
- greater compliance with anti-idling regulations

## CASE STUDIES

**New York-** New York State has been a national leader in the installation of TSE infrastructure. The state supported the development of the nation's first TSE demonstration project. IdleAire off-board systems were installed at two existing sites on the New York State Thruway that can accommodate forty-five long-haul trucks. The service is provided to trucks for $1.40 an hour.[180]
(http://www.nyserda.org/programs/pdfs/truckstopelec.pdf)
(http://www.nyserda.org/publications/Shorepower.pdf)

A parallel project using shore power technology supplied by Shurepower LLC was initiated on the Adirondack Northway (I-87) in 2002, and began field testing in 2004. The site features 18 Shurepower parking spaces that offer a wide range of amenities including electric power, cable and internet connectivity. Power is provided by a pedestal outside the truck, and makes use of existing shore power connections installed in the truck. If the truck is not equipped for shore power, the company offers "Komfort Kits" that provide electrical distribution for on-board systems. The cost of a kit can range from $200.00 for the most

[178] New York State Energy Research and Development Authority (2004) "Truck Stop Electrification, Advanced Transportation Technologies": http://www.nyserda.org/programs/pdfs/truckstopelec.pdf

[179] Idling typically consumes 1 gallon/hour of diesel fuel, at $2.00 per gallon this saves the driver approximately $1.60 per hour. Other cost savings can occur from requiring less frequent oil changes and more miles before an engine overhaul. Argonne National Laboratory (2001) "Technology Options to Reduce Truck Idling" prepared by the, Transportation Technology R&D Center: http://www.transportation.anl.gov/pdfs/TA/74.pdf

[180] Industry accepted standards estimate an idling truck consumes one gallon/hour at $2.50 per gallon (as of March, 2006), increased maintenance intervals plus additional wear and tear due to idling at $0.92 per hour. For detailed estimates of payback periods for truck drivers at shorepower facilities , please see: http://www.nyserda.org/publications/Shorepower.pdf

basic options, to $2500.00 for a system that includes heating and air conditioning. The estimated the cost of using Shurepower including the $2,500 Komfort Kit and hourly charges at $11,000 over five years, compared to $18,000 for idling with fuel at $2 a gallon. (http://www.shurepower.com/index.htm)

**Oregon and Washington-** the Climate Trust is partnering with the US EPA and the Oregon Department of Energy to develop the I-5 truck idle reduction project. The program will make use of shore power technology provided by Shurepower LLC at 275 spaces in seven truck stops in Oregon and Washington. It is estimated that the project will displace 100,000 tons of $CO_2$, 1,400 tons of $NO_x$ and 40 tons of PM, while saving 10 million gallons of diesel fuel. The Climate Trust will purchase carbon offsets from the project to overcome some of the financial barriers to truck stop electrification implementation. Carbon offsets are equal to the difference in emissions from an idling truck minus the emissions associated with grid supplied electrical power.
(http://www.climatetrust.org/offset_truckstop.php)

**Paulsboro, New Jersey-** The Department of Environmental Protection facilitated the installation of ninety-eight truck electrification bays as part of its diesel emissions reduction program. IdleAire electrification systems were mounted on the passenger window to provide heating, ventilation, air conditioning, power to refrigeration units and appliances. They also provide cable and internet connections. The truck stop electrification project is being conducted in co-ordination with increased efforts to enforce anti-idling laws across the state (http://www.stopthesoot.org/sts-idle.htm)

**KEY ISSUES/IMPLEMENTATION**

Truck stop electrification faces barriers to implementation that differ depending on the technologies that are employed. Stand-alone systems require a high initial investment by truck stop owners, but do not require any modifications to the vehicle. Conversely, shore powered systems require vehicle owners to undertake modifications that allow them to access truck stop facilities. Truck stop owners may be reluctant to install shore power infrastructure, believing that few trucks are equipped to make use of the facilities. Several truck manufacturers offer a small number of models equipped with factory installed shore power connections. This limited availability is due to current low levels of demand associated with the restricted availability of TSE infrastructure.

**KEY RESOURCES & REFERENCES**

**ANTARES Group-** "Truck Stop Electrification and a Long-haul Tractor Idling Alternative" reviews the current state of the TSE industry and the results of the New York State TSE demonstration projects:
http://www.epa.gov/smartway/documents/dewitt-study.pdf

**Argonne National Laboratory**- "Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks" includes an assessment of the energy use, emissions reduction and cost implication of new anti-idling technologies:
http://www.ipd.anl.gov/anlpubs/2000/08/36930.pdf
http://www.transportation.anl.gov/pdfs/TA/74.pdf

**IdleAire Technologies**- provides background information on IdleAire's Advanced Travel Stop Electrification technology:
http://www.idleaire.com/technology

## 2.1 Truck Stop Electrification (TSE)

**New York State Energy Research and Development Authority (NYSERDA)** - a brochure on New York State's Truck Stop Electrification project:
http://www.nyserda.org/programs/pdfs/truckstopelec.pdf

**Northeast States for Coordinated Air Use Management (NESCAUM) -** provides access to NESCAUM's truck stop electrification interactive mapping exercise that maps and evaluates commercial truck stop and rest areas along the I-95 corridor:
http://www.nescaum.org/projects/TSE/

**Shurepower LLC**- provides shore power technologies for heavy-duty trucking applications:
http://www.shurepower.com/

**US Department of Energy**- the Clean Cities Program highlights the benefits of idle reduction strategies and includes information on available idle reduction equipment, research and development and presentations included in the 2004 National Idling Reduction Conference, and a TSE station locator map:
http://www.eere.energy.gov/cleancities/idle/
http://www.eere.energy.gov/vehiclesandfuels/resources/proceedings/2004_national_idling_reduction.shtml#overview

**US Environmental Protection Agency-** the SmartWay Transport Partnership, National Transportation Idle-Free Corridors and Idling Reduction Technologies websites:
http://www.epa.gov/smartway/idling.htm
http://www.epa.gov/otaq/smartway/idlingtechnologies.htm

**US Environmental Protection Agency-** access to the EPA's Diesel Truck Anti-idling campaign documents:
http://www.epa.gov/region08/ej/dieseldocuments.html

**West Coast Diesel Emissions Reduction Collaborative-** includes information on a range of diesel emissions reduction strategies including projects to promote the development of truck stop electrification technologies:
http://www.westcoastdiesel.org/projects.htm

**West Coast Diesel Emissions Reduction Collaborative-** Overview of the "Idle Reduction Projects Plan for Long-Haul Trucks in WA, OR and CA"**:**
http://www.westcoastdiesel.org/files/projects/trucking/WCDERC_Truck%20Idle%20Reduction_The%20Big%20Picture%202.pdf

## 2.2 Vessel Electrification

### OVERVIEW

Ocean going vessels typically run diesel auxiliary engines while at dock to supply power for refrigeration, lighting, pumps and other on-board functions. This practice is commonly known as "hotelling", and accounts for one-third of nitrogen oxides ($NO_x$) and particulate matter (PM) emissions from ocean going vessels.[181] Most ships operate their engines on heavy fuel oil or residual fuel; a relatively inexpensive fuel that is produced using residue from the production of higher-grade fuels. These fuels, which are also called bunker fuels, contain high concentrations of toxic compounds banned from use in most other industrial and consumer applications. A study conducted by the Port of Long Beach evaluated shore power or "cold-ironing" options for the port. Selected vessels included in the study spent on average 50 hours at berth per call.[182] During this period, auxiliary engines contribute significantly to emissions of $NO_x$, sulfur oxides ($SO_x$), carbon monoxide (CO), volatile organic compounds (VOC), and, carbon dioxide ($CO_2$).

Direct emissions from docked vessels can be dramatically reduced by providing access to shore-side electrical power.[183] Shore power allows a ship to reduce its fuel consumption by shutting down its diesel powered auxiliary engines and use power from the electrical grid while in port. Total emissions reduced by cold-ironing, are determined in large part by the fuel mix for electrical generation. States using lower carbon fuels and renewable energy sources can reduce emissions by up to 90 percent or more. By switching from the use of residual fuel to shore power, $NO_x$ emissions can be reduced by up to 99 percent, PM by 83-97 percent and greenhouse gases by 66 percent.[184] In addition to reducing emissions, hotelling allows for displacement of remaining emissions to less environmentally sensitive areas.

### POLICY QUANTIFICATION

The sample calculation below represents the potential emission savings from replacing 100,000 gallons of heavy fuel oil or residual fuels with electricity. Note that actual savings will depend on electricity generation mix along with the efficiency and emission controls of the on board generators.

| Vessel Electrification | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 502 | na | na | $150,000 | 100,000 |

| Vessel Electrification | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 21.87 | 2.60 | na | 18.29 | 1.90 | 21.67 |
| Tons Per Day | 0.06 | 0.01 | na | 0.05 | 0.01 | 0.06 |

[181] A 2005 FHWA study of nine port facilities estimated that hotelling ships accounted for 33% of ocean going vessel $NO_x$. In Southern California, the South Coast Air Quality Management District (SCAQMD) estimated that hotelling vessels accounted for 37% of $NO_x$ and 27% of PM emissions from ships within the district: http://www.fhwa.dot.gov/environment/freightaq/chapter3.htm#s3_4
SCAQMD (2004) "Presentation to the ARB Maritime Air Quality Technical Working Group": http://www.arb.ca.gov/msprog/offroad/marinevess/presentations/040804/carbproposal.pdf

[182] Average time spent at berth per call for vessels included in the Port of Long Beach Study ranged from 12 to 121 hours. Please see: http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2157 for more detailed information

[183] Shore-side electrical power is also known as shore power, vessel electrification or cold ironing. For more information on the technical requirements and cost-effectiveness please see, Port of Long Beach (2004) "Cold Ironing Cost Effectiveness Study": http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2157

[184] *Ibid.*

## 2.2 Vessel Electrification

**CO-BENEFITS**

Cold ironing alleviates the need of ships to use fuel when docked at a port, and can significantly reduce emissions in the localized area. Other benefits include:

- significant reduction of pollutants such as $NO_x$, PM, and $SO_x$;
- reduction of greenhouse gases;
- potential control measure in the SIP;
- improved public health due to reduced diesel emissions; and
- reduced impacts of growing port operations in adjacent communities

**CASE STUDIES**

**Long Beach, CA-** Port of Long Beach (POLB) released its cost-effectiveness study for cold ironing in March of 2004. The study evaluated cost-effectiveness and feasibility for cold ironing of twelve vessels in the POLB that account for significant emissions. The analysis determined that dock electrification could have reduced annual $NO_x$ emissions by 85.5 tons, $SO_x$ emissions by 79.5 tons, and PM emissions by 9.7 tons from the reefer ship Chiquita Joy (calculations for $CO_2$ were not done, but based on the total electrical load emissions factors used for the above calculations, reductions would be at least 1,700 tons). This estimate has been scaled up to account for port growth and for the three large ports in CA, which have the greatest potential in the state for adopting cold ironing.

Following the study, British Petroleum (BP) agreed to undertake a joint cold ironing project with the Port that will include three components: the modification and retrofit of at least two candidate BP affiliate tanker vessels' electrical systems to receive shore-side power supply and distribute it to the onboard electrical equipment; design and construction of the shore-side electrical facilities; and long-term operation and maintenance of all infrastructure both on shore and on the vessels. Planning and construction will take an estimated two years with tentative completion set for late 2006. The Port earmarked $2.5 million for development and construction. BP will retrofit two tankers at an estimated cost of $2 million ($1 million for each tanker).
(https://www.aapa-ports.org/members/advisory/html/2004/advisory39-32.htm)
(http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2157)

**Los Angeles, CA**- In June 2004, the Port of Los Angeles (POLA) opened its shore-side power facilities at Berth 100 of the China Shipping Terminal as part of the Port's Alternative Maritime Power (AMP) program. It is the world's first electrical shore-to-ship power connection facility designed and installed for a container vessel and cargo handling facility. According to the POLA, the use of AMP technology reduces ship emissions by one ton of $NO_x$ and PM for each day the ship is docked. In the first four months of the program, China Shipping vessels made more than 20 calls utilizing AMP power, preventing the discharge of over 100 tons of emissions into the Los Angeles Basin.

In December 2004, the Harbor Commission approved a resolution to promote the Mayor's AMP program by providing $810,000 per container steamship line to help each underwrite the cost of building or retrofitting their first container ship to plug in while at berth. The incentive is provided to signatory companies to the Port's Alternative Maritime Power Program MOU. Eight companies currently qualify for the incentive.
(http://www.portoflosangeles.org/environment_amp.htm)
(http://www.aapaports.org/programs/hne/Case%20Studies/2004_Case_Studies/Environmental%20Enhancement/Los%20Angeles/Submittal%20Documnet.pdf)

## 2.2 Vessel Electrification

**Seattle, WA-** The Princess Shore Power Project at the Port of Seattle is a partnership between the port, Princess Cruises, Seattle City Light and the U.S. EPA to provide shore power to cruise ships homeported in Seattle. Princess Cruises invested $1.8 million in the construction of two new vessels equipped for shore power use. During the 2005 cruise season the Diamond Princess and Sapphire Princess plugged in while at dock resulting in a 30 percent reduction in emissions and saving 1,400 metric tons of fuel. The utility offered a favorable rate for the electricity it provided, making shore power an economically viable option. The US EPA pledged $50,000 in grant money to Seattle City Light to help cover the costs of infrastructure improvements related to providing power to the ships. (https://www.aapa-ports.org/members/advisory/html/2004/advisory39-35.htm) (http://www.cleanfleetsusa.net/cleanports/presentations/seattle.pdf)

**KEY ISSUES/IMPLEMENTATION**

Shore power requires significant capital investment for vessel retrofits and shore-side equipment, including improving local electricity infrastructure, new overhead transmission lines from an existing sub-station, in-terminal facilities (substations, cable and hose handling gear, work-barges, fuel handling facilities, etc) ship-side equipment including new cabling to tie the shore connection into the existing ship power system. There is also the cost of the energy itself.

The Port of Long Beach found that the cost-effectiveness of cold ironing varied from ship to ship depending on three main factors; 1) the electrical "hotel" load of the ship, 2) the number of port visits it has, 3) the duration of the port visits. For other ships, it may be more cost-effective to use retrofit technologies or alternative or higher-grade fuels that lessen emissions from the ship when they are at sea. However, ships may be unlikely to use these technologies without incentives to support their adoption.

In December 2005, the California Air Resources Board (CARB) adopted regulations to control emissions from marine auxiliary engines. Starting in 2007, ocean going vessels traveling in California's waters have the option to reduce emissions by either using cleaner marine fuels or equally effective emission controls. These efforts are expected to reduce diesel PM emissions by 23,000 tons, $NO_x$ by 15,000 tons and $SO_x$ by 200,000 tons by 2020. Making use of shore power facilities while in port, is one method ocean carriers can used to comply with the new regulations. As the cost for marine fuels increases, shore power will become and increasingly cost-effective measure.[185]

**KEY RESOURCES & REFERENCES**

**American Association of Port Authorities (AAPA) -** The 2004 Clean Ports USA workshop hosted by the AAPA provides links to conference materials, presentations and key recommendations on air quality and emissions from ports:
http://www.aapa-ports.org
http://www.cleanfleetsusa.net/cleanports/serlp.html

**California Air Resources Board-** Information on recent CARB efforts to regulate emissions from marine auxiliary diesel engines:
http://www.arb.ca.gov/newsrel/nr120805.htm
ftp://ftp.arb.ca.gov/carbis/board/books/2005/120805/05-12-5pres.pdf

[185] California Air Resources Board: http://www.arb.ca.gov/newsrel/nr120805.htm

## 2.2 Vessel Electrification

**California Air Resources Board-** Presentations to CARB entitled "Statewide Marine Auxiliary Engine Emissions Inventory" and "Shore Power: Emissions Reduction Alternative for Ships Docked in Port":
http://www.arb.ca.gov/msprog/offroad/marinevess/presentations/110904/dockwatts.pdf
http://www.arb.ca.gov/msprog/offroad/marinevess/presentations/082405/082405eiauxpres.pdf

**Natural Resources Defense Council-** "Harboring Pollution: Strategies to Clean up U.S. Ports" provides an assessment of strategies used to reduce the environmental impact of port operations, including shore power:
http://www.nrdc.org/air/pollution/ports/contents.asp

**Port of Long Beach**- The "Cold Ironing Cost-Effectiveness Study" reviews the current state of cold ironing and presents an analysis of the feasibility of emissions control technologies available to the Port, focusing on the provision of shore power and the cost effectiveness for 12 study vessels while at berth:
http://www.polb.com/civica/filebank/blobdload.asp?BlobID=2157

**Port of Los Angeles-** The Port's website provides information on the Port's Alternative Maritime Power (AMP) Program and links to other environmental initiatives:
http://www.portoflosangeles.org/environment_amp.htm

**Port of Seattle**- The Port of Seattle's Air Quality programs webpage:
http://www.portofseattle.org/community/environment/airsea.shtml

**West Coast Collaborative-** The Collaborative's Marine Vessels and Ports work group provides a forum for the exchange of information on marine emissions, emissions control options including shore power and recent legislation and rulemaking:
http://www.westcoastdiesel.org/wkgrp-marine.htm

**Santa Barbara County Air Pollution Control District-** has focused on regional impacts of marine emissions in Santa Barbara County, and provides access to regional, state and national initiatives:
http://www.sbcapcd.org/itg/shipemissions.htm

## 2.3 Heavy-Duty Truck Retrofits

### OVERVIEW

Heavy-duty diesel trucks emit substantially more particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxide ($NO_x$), carbon monoxide (CO) and carbon dioxide ($CO_2$) per mile than light-duty vehicles. The US Environmental Protection Agency estimates that heavy-duty trucks and buses account for one-third of $NO_x$ and one quarter of PM emissions from mobile sources.[186] With the development of cleaner engine technologies, emissions from diesel trucks have improved over time. New EPA regulations governing emissions from on road heavy-duty engines begin in 2007, and are expected to reduce emissions by up to 95 percent for some pollutants. However, due to the durability of large diesel engines and slow fleet turnover, cleaner technologies take longer to work their way into the existing truck fleet.

Heavy-duty diesel retrofit programs have been designed to address emissions from the fleet of more than 3.5 million heavy-duty trucks that are currently on the road.[187] Typically, the term "retrofit" has been used to denote the use of exhaust aftertreatment devices such as catalysts and filters; water emulsified diesel or biodiesel; or fuel borne catalysts (FBCs).[188,189] Diesel retrofit programs have more recently expanded to include five components that can be adapted to meet the needs of targeted fleets or regions:[190]

- repair/rebuild - regular engine maintenance and engine rebuilding;
- refuel – using ultra-low sulfur diesel (ULSD) or biodiesel alternatives;
- retrofit – installing exhaust aftertreatment technologies such as particulate filters, oxidation catalysts, exhaust gas recirculation (EGR), selective catalytic reduction (SCR) devices, and $NO_x$ catalysts;[191]
- repower - replacing an older engine with a new more efficient engine; and
- replace - replacing entire vehicles with the more efficient models

The emissions reductions that will be achieved through retrofit programs depends on the strategies or technologies that are adopted. Repowering or replacing inefficient engines can improve the fuel efficiency of the truck, resulting in fuel savings and greenhouse gas reductions. The use of aftertreatment technologies will reduce $NO_x$ or PM emissions and typically do not result in any fuel efficiency gains. A complete list of EPA verified technologies for heavy duty vehicles is available at: http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm.

### POLICY QUANTIFICATION

The emissions reductions depend entirely upon which of the options or technologies are chosen. Note that there is not necessarily any fuel savings with some of the devices. Also the devices typically are engine specific. For the purposes of the sample calculation, we assume that Clean Diesel Technologies Inc's Platinum Plus Fuel Borne Catalyst/Catalyzed

---

[186] US EPA (2000) "Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements": http://www.epa.gov/otaq/regs/hd2007/frm/f00057.pdf

[187] Heavy- duty trucks are considered by the Bureau of Transportation Statistics to be those with a gross vehicle weight generally in excess of 19,500 pounds (class 6-8): http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_01_21.html

[188] Diesel Technology Forum: http://www.dieselforum.org/retrofit-tool-kit-homepage/why-retrofit/#294

[189] For more detail on heavy-duty diesel aftertreatment devices, and emissions impacts please see the Transit Bus Retrofit Policy Brief.
For more information on the 5Rs of diesel retrofits visit the Diesel Technology Forum website at: http://www.dieselforum.org/retrofit-tool-kit-homepage/what-is-retrofit/

[191] Lists of EPA and CARB verified retrofit technologies are available at: http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm and http://www.arb.ca.gov/diesel/verdev/verdev.htm

## 2.3 Heavy-Duty Truck Retrofits

Wire Mesh Filter System (FBC/CWMF) is being adopted in a fleet that drives 10,000 miles a day.

| Heavy Duty Truck Retrofits | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 0 | na | na | $0 | 0 |

| Heavy Duty Truck Retrofits | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 2.08 | 0.78 | 0.74 | 0.00 | 6.46 | 1.62 |
| Tons Per Day | 0.01 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 |

### CO-BENEFITS

Retrofit programs for heavy-duty trucks can have several advantages relative to other emissions reduction strategies, they include:[192]

- the ability to achieve immediate emissions reductions;
- successful voluntary program options;
- no new infrastructure requirements; and
- cost effectiveness

Reducing emissions can have significant benefits for local air quality and public health that include:

- reduced greenhouse gas and criteria pollutant emissions;
- lower fuel costs for drivers;
- reduced local and regional environmental impacts of diesel air pollution i.e. acid rain and smog;
- lower health costs associated with diesel exhaust exposure in urban areas; and
- reduced emissions from port and terminal operations

### CASE STUDIES

**California**- Created in 1999, the Carl Moyer Program provides incentive grants to private companies and public agencies to reduce heavy-duty diesel pollution beyond what would be required by regulations. Grants are issued by local air pollution control districts, and are assessed based on the "incremental cost" of the proposed project and the emissions benefits that would accrue. In its first four years the program has funded approximately 4,950 cleaner engines, including over 750 alternatively fueled refuse haulers and long-haul trucks and more than 80 cleaner diesel trucks. ARB Staff estimate that the program's heavy-duty engine projects reduce $NO_x$ emissions by about 14 tons per day, and have an average cost of approximately $3,000 per ton. The program also provides grants for replacement, repowering and alternative fuel initiatives that have additional diesel fuel savings and greenhouse gas reduction benefits.
(http://www.arb.ca.gov/msprog/moyer/moyer.htm)

**Los Angeles, CA-** The Gateway Cities Diesel Fleet Modernization Program was established to facilitate the replacement of 3,000 aging heavy-duty trucks in the greater Los Angeles area. The program retires pre-1987 trucks and replaces them with more fuel efficient trucks from 1999 and newer model years. The replacement vehicles are often retrofitted with DOCs, and other PM and $NO_x$ control devices to further reduce emissions. Gateway Cities estimates that each replacement truck will avoid emissions of 0.55 tons per year of $NO_x$ and 0.12 tons per year of PM. This does not include any benefits resulting from the retrofit of

[192] Diesel Technology Forum: http://www.dieselforum.org/retrofit-tool-kit-homepage/why-retrofit/#294

replacement vehicles. The program provides grants that average $25,000 towards the purchase of a replacement truck that must be used primarily within the boundaries of the air basin. The remaining cost of the vehicle must be financed by the owner; however some of the investment can be recouped through lower fuel and maintenance costs of the newer trucks. Since it's inception in 2002, Gateway Cities has replaced 350 heavy duty trucks, with the majority of its funding coming from the Ports of Los Angeles and Long Beach. (http://www.gatewaycog.org/cleanairprogram/overview/overview.html)

The mobile source air pollution reduction review committee (MSRC) was established by the state legislature to provide incentive funding for programs that reduce mobile source emissions, including retrofit programs, in the South Coast Air District. The MSRC receives 30 percent of funds taken in from a vehicle registration surcharge of $4 in the greater Los Angeles region.
(http://www.cleantransportationfunding.org/?fa=faqs#1)

**Oakland, CA**- In September 2005, the Port of Oakland launched its Truck Replacement Project as part of its broader Maritime Air Quality Program. Incentive funding of $2 million has been allocated for the project, and will be used to assist owners of 1986 or older, heavy-duty trucks serving the port in replacing them with newer models vehicles.
(http://www.portofoakland.com/environm/prog_06.asp)

**Sacramento CA,**- The Sacramento Emergency Clean Air Transportation (SECAT) Program was created by legislation which set aside $50 million from the 2000-2001 state budget to help the region heavy-duty truck emissions. An additional $20 million was allocated to the program from federal Congestion Mitigation and Air Quality (CMAQ) funding to the region. The program funds six types of projects including fleet modernization, retrofit, repowering, refueling and the application of any technologies verified by the California Air Resources Board.
(http://www.4secat.com/index1.html)

**Texas**- The Texas Emission Reduction Plan (TERP) is administered by the Texas Commission on Environmental Quality and provides voluntary incentive funding to reduce emissions in non-attainment areas. TERP includes several programs that can be used to target reductions from heavy-duty on road sources, including the New Technology Research and Development Program that can be applied to add-on and advanced technologies; the Small Business Grants Program that supports the repowering and replacement of older on-road heavy-duty diesel engines; and the Heavy-Duty Motor Vehicle Purchase or Lease Incentive Program which assists with the incremental costs of purchasing or leasing of eligible lower emitting on-road heavy-duty vehicles.
(http://www.tceq.state.tx.us/implementation/air/terp/index.html)

**KEY ISSUES/IMPLEMENTATION**

Retrofit programs have to be carefully structured to ensure that the results meet the needs of the communities or regions that they are operating in. When designing a program several issues must be considered, they include:[193,194]

- vehicle repowering or replacement programs designed to improve air quality in a specific area must ensure newer vehicles stay in service in the region;

[193] Natural Resource Defense Council (2004) "Cleaning up Today's Dirty Diesels: Retrofitting and Replacing Heavy-Duty Vehicles in the Coming Decade": http://www.nrdc.org/air/transportation/retrofit/contents.asp
[194] Diesel Technology Forum: http://dieselforum.org/retrofit-tool-kit-homepage/starting-a-program/

- determine which emissions will be targeted;
- prioritize which vehicles or fleets are most suitable for a retrofit program;
- determine the most appropriate strategy (replace, repower or retrofit etc.) or technology for specific vehicles or fleets can maximize the cost effectiveness of the program;
- assess the cost-effectiveness of different options;
- develop criteria to evaluate the program; and
- calculate emissions credits resulting from the retrofits[195]

**KEY RESOURCES & REFERENCES**

**Center for Clean Air Policy (CCAP) -** CCAP's Freight Solutions Dialogue explores emissions reduction opportunities and barriers within the U.S. freight distribution system: http://www.ccap.org/transportation/fsd.htm

**Clean Air Initiative in Latin American Cities**- The website offers detailed information on aftertreatment technologies, emission reduction possibilities and cost-effectiveness considerations: http://www.cleanairnet.org/infopool/1411/propertyvalue-17742.html

**Clean Air Task Force** –"Diesel Engines: Emissions Controls and Retrofits": http://www.catf.us/publications/factsheets/Diesel_Controls_and_Retrofits.pdf

**Diesel Technology Forum-** This website provides a wide range of diesel and retrofit information including case studies, program implementation and funding suggestions and a variety of resources: http://www.dieselforum.org/retrofit-tool-kit-homepage/

**Gateway Cities Clean Air Program-** Provides financial incentives to reduce air pollution in Southern California through fleet modernization: http://www.gatewaycog.org/cleanairprogram/overview/overview.html

**Natural Resource Defense Council**- "Cleaning up Today's Dirty Diesels: Retrofitting and Replacing Heavy-Duty Vehicles in the Coming Decade": http://www.nrdc.org/air/transportation/retrofit/contents.asp

**US Department of Energy**-The 21st Century Truck Partnership promotes research and development in engine systems and heavy-duty hybrids to improve air quality and reduce fuel consumption: http://www.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/index.shtml

**US Department of Energy**- The Alternative Fuels Data Center provides information on alternative fuels for heavy-duty truck applications: http://www.eere.energy.gov/afdc/apps/afvinfo_trucks.html

**US Environmental Protection Agency**- The Voluntary Diesel Retrofit Program is designed to address diesel pollution construction equipment and on-road heavy-duty vehicles and

[195] Diesel Technology Forum: http://www.dieselforum.org/retrofit-tool-kit-homepage/starting-a-program/step-5-emission-credits/

## 2.3 Heavy-Duty Truck Retrofits

provides information on verified diesel retrofit technologies:
http://www.epa.gov/otaq/retrofit/retrofittech.htm
http://www.deq.state.or.us/aq/diesel/EPAVoluntaryRetrofit.pdf

**US Environmental Protection Agency-** The National Clean Diesel Campaign provides information on voluntary and regulatory programs that impact on road heavy-duty trucks:
http://www.epa.gov/cleandiesel/

## 2.4 Transit Bus Retrofits & Replacements

**OVERVIEW**

Heavy-duty diesel engines are commonly used in transit bus applications due to their high efficiency and durability. However, these engines also produce significant levels of pollution that contribute to poor air quality in urban centers. Particulate matter (PM) and nitrogen oxides ($NO_x$) from diesel exhaust are of primary concern due to their impact on human health and their contribution to smog formation. The slow turnover for public transit fleets has resulted in older, higher emitting diesel buses remaining in service.

Retrofit programs[196] reduce emissions from the existing diesel transit bus fleet by installing exhaust after-treatment devices that require little or no modification to the engine. Retrofit technologies are commonly divided into devices for PM and $NO_x$ control. PM control technologies are currently considered more effective and commercially developed than $NO_x$ control devices.[197] These devices result in various levels of emissions reductions for public transit fleets. Some of the most commonly used retrofit devices include:

- **Diesel Oxidation Catalysts** (DOCs) - create a chemical reaction in the exhaust stream, oxidizing pollutants into water vapor and carbon dioxide. DOCs can achieve reductions in PM ranging from 20 to 50 percent in engines using low or ultra-low sulfur diesel fuel, and 50 to 90 percent in hydrocarbon (HC) and carbon monoxide (CO) emissions.[198] DOCs have been in use in on-road heavy duty diesel engines since 1995, and are one of the most widely used and readily available devices on the market.

- **Diesel Particulate Filters** (DPFs) - physically remove particulate matter as the exhaust gases pass through a filter positioned in the exhaust stream. Particulate emissions can be reduced by 80 to 95 percent and HC and CO by up to 90 percent. DPFs are currently the most effective method of removing PM from diesel exhaust emissions. They require the use of ultra-low sulfur diesel fuel (<15ppm) and periodic maintenance to ensure proper functioning, and can be combined with DOCs in one unit to achieve further reductions.

- **Selective catalytic reduction** (SCR) - uses a catalyst and a chemical reagent such as ammonia or urea to convert $NO_x$ into nitrogen and oxygen in the exhaust stream. The EPA estimates potential reductions of $NO_x$ emissions by 60 percent, HC emissions up to 50 percent, and PM emissions up to 30 percent.[199] The use of ultra-low sulfur fuels will enhance the performance of an SCR system.

- **Exhaust Gas Recirculation** (EGR) - reduces $NO_x$ by recirculating a portion of engine exhaust back to the engine air intake, lowering the combustion chamber temperature. The exhaust dilutes the oxygen in the chamber, producing lower combustion temperatures and reducing $NO_x$ emissions by up to 40 percent.

---

[196] Retrofit most commonly refers to the installation of exhaust after treatment control devices, however retrofit programs often include other options such as: repairing/rebuilding, refueling, repowering and replacing diesel engines: http://www.dieselforum.org/retrofit-tool-kit-homepage/what-is-retrofit/

[197] NESCAUM (2003) "Diesel Retrofit Workshop Retrofit Primer –Emission Reduction Technologies and Strategies": http://bronze.nescaum.org/retrofitworkshop/folder/Primer.pdf

[198] Manufacturers of Emission Controls Association (MECA): http://www.meca.org/galleries/default-file/retrofitfact.pdf

[199] US Environmental Protection Agency: http://www.epa.gov/otaq/retrofit/retropotentialtech.htm

Combined EGR and DPF systems have been verified by the California Air Resources Board to achieve 40 percent $NO_x$ and 85 percent PM reductions.[200]

- **Lean $NO_x$ Catalysts**- operate similar to SCR systems, by introducing an external agent that reacts to reduce $NO_x$ into nitrogen, carbon dioxide and water. Lean $NO_x$ catalysts use a small amount of diesel fuel or another hydrocarbon reductant as the agent injected into the exhaust. This technology has been shown to reduce $NO_x$ by up to 30 percent; however a fuel economy penalty of up to 7 percent can result.[201]

Emissions control systems that combine these and other technologies are emerging as some of the most effective mechanisms to achieve emissions reductions. These systems combine catalysts, filters, EGR, engine adjustments and clean fuel options.[202]

The replacement of conventional diesel buses with non-diesel fueled vehicles also provides an opportunity for transit fleets to emissions and diesel fuel consumption. According to the American Public Transit Association the non-diesel bus fleet in the United States has grown significantly over the last decade. The most common diesel alternatives include:

- **Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) Buses-** CNG and LNG vehicles comprise the bulk of the alternative fuel vehicles used in public transit applications.[203] In January 2005, there were 6,600 CNG and 1,000 LNG buses in operation in U.S. public transit fleets.[204] Natural gas is commonly used for fleets in non-attainment areas due to its reduction in $NO_x$ and PM emissions.

- **Diesel-Electric Hybrid Buses**– are a growing segment of new bus orders due to their fuel economy and air quality benefits. Diesel-electric hybrid technology has been most often applied in urban transit buses. [205] Currently there are 700 hybrid buses in service in North American public transit agencies and 400 addition buses are scheduled for delivery in 2006. Testing of the New York City Transit (NYCT) BAE Systems-Orion VII 40-foot hybrids found that the buses achieved a 32 to 48 percent improvement in fuel economy over comparable diesel buses, and significantly lower per mile $NO_x$, PM and CO emissions.[206]

Emissions control technologies such as oxidation catalysts and particulate filters can be used on natural gas and diesel-electric hybrid buses to achieve further reductions in emissions.

---

[200] California Air Resources Board (CARB): http://www.arb.ca.gov/diesel/verdev/currentlyverifiedtech.htm
[201] Manufacturers of Emission Controls Association (MECA): http://www.meca.org/page.ww?section=What+is+Retrofit%3F&name=What+is+Retrofit%3F
[202] NESCAUM 2003, *op. cit*
[203] TIAX LLC (2003) "The Transit Bus Niche Market For Alternative Fuel: Basics of Alternative Fuels in Transit Bus Applications": http://www.eere.energy.gov/afdc/apps/toolkit/pdfs/mod02_af_basics.pdf
[204] APTA January 1, 2005 survey of 300 transit agencies accounting for approximately 70 percent of all public transit buses: http://www.apta.com/research/info/briefings/documents/af_eudy.pdf
[205] For a discussion of hybrid technologies see Policy Brief section 1.13
[206] For a more detailed discussion of diesel-electric hybrid buses please see: Northeast Advanced Consortium (2005) "Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric, and Fuel Cells": http://www.navc.org/ and Heavy Duty Hybrid Transit Vehicles Primer: http://www.navc.org/what_is_hybrid.html

## 2.4 Transit Bus Retrofits & Replacements

### POLICY QUANTIFICATION

Emissions savings from transit bus retrofits and replacement are dependent upon the characteristics of the vehicles being replaced. For the purposes of this sample calculation, the emission savings from purchasing hybrid buses instead of standard diesel buses fitted with modern control technology and that the bus fleet is driven 100,000 miles per day.

| Transit Bus Retrofits & Replacements | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 4,037 | na | na | $794,977 | 397,488 |

| Transit Bus Retrofits & Replacements | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 44.89 | 0.07 | 0.00 | 0.00 | 0.18 | 0.00 |
| Tons Per Day | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

### CO-BENEFITS

The EPA and the California Air Resources Board, among others, have highlighted the harmful impacts of diesel exhaust on human health. Retrofitting public transit buses to reduce $NO_x$ and PM emissions have significant air quality and public health benefits. Additional benefits include:

- reducing local and regional environmental impacts of diesel air pollution i.e. acid rain and smog;
- lowering health risks to diesel exhaust exposure in highly urbanized and pedestrian zones;
- improving the image of public transportation, making it more attractive to riders and thus reduce $CO_2$ emissions;[207]
- improved working conditions at bus depots; and
- lower maintenance costs

In addition to the health and emissions benefits of reduced diesel fuel use, the replacement of diesel buses with hybrid-electric buses can yield benefits that include:[208]

- reduced $NO_x$ and CO emissions relative to conventional diesel and CNG;
- improved acceleration from a stop;
- reduced noise;
- makes use of existing fueling infrastructure;
- increased fuel efficiency and reduced fuel costs; and
- potentially reduced maintenance costs for engine and braking systems

### CASE STUDIES

**California-** In 2005, Long Beach, Orange, Norwalk, Gardena, Montebello and Fresno counties combined their hybrid bus purchases to place an order for 76 New Flyer diesel hybrid buses. The counties found that by aggregating the purchases, the transit agencies could reduce the cost of the buses by up to $50,000 per bus.

Orange County Transportation Authority (OCTA) has invested $20 million in a CNG facility to be ready for the addition of 50 new CNG buses the fleet in 2007. The fuelling center in Santa Ana, will consist of up to four compressor stations connected to an underground natural gas line. The buses will be delivered in 2007, with possible options for 327

[207] For more information see Part I of the Transportation Emissions Guidebook: http://www.ccap.org/guidebook/index.html

[208] Northeast Advanced Consortium (NAVC) (2005) "Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric, and Fuel Cells": http://www.navc.org/

additional buses. The agencies current fleet of 232 LNG buses helps to reduce diesel fuel use by 3.3 million gallons per year.
(http://www.eesi.org/publications/Newsletters/Clean%20Bus%20Update/cleanbusupdate.htm)

The Santa Clara Valley Transit Authority is in the second year of a three year demonstration project pairing an SCR system with DPFs on three of its transit buses. The SCR/DPF combination has achieved emissions reductions for $NO_x$ by over 90 percent and PM by up to 95 percent.
(http://www.ewire.com/display.cfm/Wire_ID/1854)
(http://www.extengine.com/adec.htm)

San Francisco's Metropolitan Transportation Commission (MTC) allocated over $15 million in CMAQ and local matching funds to 12 Bay Area transit operators to purchase 1,700 Longview® emission control systems. The Longview systems combine $NO_x$ Reduction Catalyst technology and DPFs to achieve $NO_x$ and PM reduction from transit buses. The systems were installed on Bay Area buses between 2004 and 2005. The Longview system, manufactured by California based Cleaire Advanced Emissions Controls, has been verified by the California Air Resources Board as effective in achieving a 25 percent reduction in $NO_x$ and an 85 percent reduction in PM, as well as lower CO and HC emissions in on-road 1994-2003 engines.
(http://www.dieselforum.org/retrofit-tool-kit-homepage/success-stories/transit-buses/)
(http://www.cleaire.com/index.html)

**King County, WA-** Following extensive road testing 2002-2003, King Country Metro Transit purchased 235 General Motors hybrid electric buses that began operations in January 2005. Testing of the fleet has shown a 30 percent improvement in fuel economy compared to new conventional drive buses, and a 24 percent reduction in greenhouse gas emissions. The new buses have also allowed King County Metro Transit to reduce mechanical staff by 10 percent due to the improved reliability of the hybrid buses as compared to other buses in the fleet. By replacing aging vehicles with the hybrid electric bus technology, it is estimated that PM, HC and CO emissions will be reduced by 90 percent and $NO_x$ emissions by 60 percent.
(http://www.metrokc.gov/kcdot/whatshap/hybrid/updates.stm)

**Mexico City, Mexico-** The Mexico City Diesel Retrofit Project is a joint US-Mexico demonstration project to reduce pollution from Mexico City's diesel bus fleet using a combination of EPA-verified retrofit technologies and ultra low sulfur diesel fuel (ULSD). The project received funding from the US EPA and the World Resources Institute, which provided grants to the Mexico City-based Center for Sustainable Transport to support implementation of the program.

The project was launched in November 2004, testing twenty retrofitted transit buses under Mexico City's high altitude operating conditions. Twelve of the buses were equipped with DPFs and eight with DOCs. All buses were fueled by imported ULSD. Results from on board monitoring indicated that test fleet PM emissions were reduced by up to 90 percent using DPFs and USLD, and $NO_x$ emissions declined by 10 percent. The deployment of this technology in Mexico is currently limited by the lack of domestic production capabilities for ULSD fuel (but efforts are underway).
(http://embarq.wri.org/documentupload/RetrofitPolicyBriefVersion%20Final.pdf)

## 2.4 Transit Bus Retrofits & Replacements

**New York City, NY**- New York City Transit (NYCT) has undertaken a comprehensive retrofit program as part of a five year plan to reduce emissions from the more than 4,500 diesel buses in its fleet. In 1996, NYCT began equipping all diesel buses with DOCs. In 2000, the entire fleet was converted to the use of ULSD fuel to facilitate further adoption DPF retrofit technologies. By 2004, approximately 3,600 buses had been retrofitted with DPFs. NYCT estimates the PM emissions have been reduced by 85 percent between 2000 and 2005. (http://bronze.nescaum.org/retrofitworkshop/Lowell.pdf)

In October 2005, New York City transit agencies placed an order for 500 diesel-electric hybrid buses with Daimler Chrysler's Orion Industries. The order was the third for the city from Orion industries, and will bring the total number of hybrid units to 825 buses upon their delivery in 2006. The buses which use BAE Systems HybriDrive® series propulsion systems will generate 90 percent less PM, 40 percent less $NO_x$, and 30 percent less $CO_2$. In 2004, NYCT reported emissions results from testing of the Orion VII diesel-hybrids. Emissions of PM were comparable to both diesel buses equipped with DPFs and operating on ULSD fuel and CNG buses. However, $NO_x$ and CO emissions for the hybrids were significantly lower than both the diesel and CNG buses and achieved 32 to 48 percent improvements in fuel economy over the diesel buses.[209]
(http://www.orionbus.com/orion/0,,0-11-9892-1-550233-1-0-0-0-0-0-150-9892-0-0-0-0-0-0-0,00.html)

### KEY ISSUES/IMPLEMENTATION

Options for the design and implementation of diesel retrofit programs vary with the priorities and limitations of the transit systems in which they are being planned for. When planning a diesel retrofit program for transit several issues must be considered including:[210]

- determining which pollutants are most important in the community of interest;
- technology options that best suit the age/size of the fleet;
- fuel requirements for the technology and availability of clean fuels and refueling infrastructure that will be required;
- comparisons to other bus technology options i.e. CNG and hybrid electric buses;
- cost of the retrofit/financing package;
- bulk purchasing options;
- maintenance requirements and costs of additional maintenance; and
- potential partners in a retrofit project

### KEY RESOURCES & REFERENCES

**California Air Resources Board**- CARB's Study of Emissions from in-use CNG and Diesel Transit Buses collects emissions data from late-model heavy-duty transit buses:
http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm

**California Air Resources Board-** The Diesel Emissions Control Strategies webpage lists currently verified technologies and provides access to verification processes, diesel and mobile source programs:
http://www.arb.ca.gov/diesel/verdev/verdev.htm

[209] NAVC 2005, *op cit.*
[210] NESCAUM (2003) "Designing & Implementing Successful Retrofit Programs":
http://bronze.nescaum.org/retrofitworkshop/Park_Designing_Implementing.pdf

## 2.4 Transit Bus Retrofits & Replacements

**Center for Neighborhood Technology –** The Travel Matters Transit Planning Emissions Calculator illustrates $CO_2$ and criteria pollutant emissions generated by your transit fleet and what emissions might be using a variety of fleet alternatives:
http://www.travelmatters.org/

**Clean Air Initiative for Latin American Cities**- Information on diesel emissions reduction technologies for in-use and new buses including retrofit and alternative fuel options, US programs as well as new transit technologies:
http://www.cleanairnet.org/infopool/1411/propertyvalue-17729.html

**Clean Air Task Force-** "Diesel Engines: Emissions Controls and Retrofits" highlights various retrofit technologies and combined systems:
http://www.catf.us/publications/factsheets/Diesel_Controls_and_Retrofits.pdf

**Diesel Technology Forum**- The retrofit tool kit includes introductory information on retrofits, success stories, program implementation and funding:
http://www.dieselforum.org/retrofit-tool-kit-homepage/

**Environmental and Energy Study Institute**- EESI's National Clean Bus Network highlights regulatory, fuel and technology options for clean bus developments on its website and in EESI's Clean Bus Newsletter:
http://www.eesi.org/programs/cleanBus/cleanbus.htm

**Manufacturers of Emission Controls Association (MECA)-** Is a non-profit association comprising manufacturers of emissions control equipment, that provide technical information on emission control technology for motor vehicles:
http://www.meca.org

**National Renewable Energy Laboratory-**
http://www.nrel.gov/vehiclesandfuels/fleettest/avta_king.html
http://www.nrel.gov/vehiclesandfuels/ngvtf/tug.html

**Natural Resources Defense Council**- "Dumping Dirty Diesels: The View from the Bridge" presented at the US DOE Diesel Engine Emissions Reduction (DEER) Conference August 2005:
http://www.eere.energy.gov/vehiclesandfuels/pdfs/deer_2005/plenary/2005_deer_kassel.pdf

**Northeast Advanced Vehicle Consortium-** "Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric, and Fuel Cells" focuses on the hybrid electric buses and the benefits and challenges of increasing their deployment:
http://www.navc.org/Electric_Drive_Bus_Analysis.pdf

**New York City Transit**- "Field Experience with Diesel Retrofits", presented at the 2003 EPA-NESCAUM retrofit workshop:
http://bronze.nescaum.org/retrofitworkshop/Lowell.pdf

**Northeast States for Coordinated Air Use Management (NESCAUM)-**
"Retrofit Primer – Emission Reduction Technologies and Strategies" and links to presentation from the 2003 Diesel Retrofit Workshop:
http://bronze.nescaum.org/retrofitworkshop/folder/Primer.pdf

## 2.4 Transit Bus Retrofits & Replacements

http://www.nescaum.org/retrofitworkshop/agenda.html

**US Environmental Protection Agency**- Website contains general information about heavy-duty highway engines, and emissions and links to EPA's diesel programs, regulations, and retrofit/rebuild programs:
http://www.epa.gov/otaq/hd-hwy.htm

**US Environmental Protection Agency-** EPA's National Clean Diesel Campaign
http://www.epa.gov/cleandiesel/

# 2.6 Freight Mode Shift

**OVERVIEW**

Intermodal freight is the transport of cargo containers via railways, ocean going vessels, inland ship/barge, ferries, and trucks. Intermodal ground freight transportation makes greater use of rail as an alternative to congested roadways and expanding highway systems.[211] Freight trains carry cargo across long distance or high volume corridors, while trucks provide pre-and end-haulage between the rail terminals and the cargo's origin/destination. Intermodal infrastructure facilitates a greater use of railways that can help to maximize transportation efficiencies and offset rapid future growth in truck traffic.[212]

Intermodal rail typically consists of a range of services that include:[213]

- trailer-on-flatcar or piggy back- movement of containers on highway trailers mounted on rail flatcars;
- container-on-flatcar - movement of containers directly on rail flat cars;
- car-less technologies- movement of specialized highway trailers or modified rail trucks that move on rail tracks; and
- doublestack- refers to containers moving on equipment that can be loaded with one container place on top of another and is considered the most efficient means to move containers over long haul distances

Rail offers a greater efficiency on a per ton mile basis than containers moved by truck over long distances, or through high volume corridors. The air quality benefits and energy savings from expanding rail are clear. On average, rail uses 14 percent of truck energy used per ton-mile.[214,215] Recent forecasts show that freight rail is growing at just under 2 percent per year, on a ton mile basis.[216] Class 1 rail accounted for approximately 47 percent of ton miles in 2001, up 7 percent from 1990 (see table below). Much of this share increase was intermodal trailers and containers. This growth rate (while still below truck growth) was aided by federal transportation funding dedicated to the development of intermodal centers.[217]

**Intercity Freight Traffic by Mode[218]**

| Mode | Ton-Miles (%) | Tons (%) | Revenues (%) | CO2 (%) |
|---|---|---|---|---|
| **Class I Rail** | **47** | 30 | 13 | 8% |
| **Truck** | 33 | **57** | **85** | **79%** |
| **Water** | 20 | 13 | 2 | 13% |

[211] ENO Transportation Foundation (2002) "Intermodal Freight Transport in Europe and the United States"
[212] Center for Clean Air Policy (2005) "Reducing Freight GHGs: What are the Possibilities?": http://www.ccap.org/Presentations/Dierkers%20Final%20AM.pdf
[213] Intermodal Association of North America (IANA) (1999) "Intermodal Freight Transportation, 4th Edition"
[214] Based on 2005 Annual Energy Outlook (AEO) data.
[215] ORNL 2004, Transportation Energy Data Book: Edition 24, Table 2.14. For some commodities rail consumes up to 50% of truck energy use per ton-mile: http://www.ccap.org/Presentations/Winkelman%20Freight%20Rail.pdf
[216] ICF, Container Access Study and I-95 Corridor Coalition.
[217] Starting with ISTEA in 1991 (flexible transportation funds) this has been a priority for a number of states, including Maine, New York, California and Connecticut.
[218] $CO_2$ based on EIA *AEO 2004* (includes urban freight) can be found in: Congressional Budget Office (2005) "Freight Rail Transportation: A Review of the 2004 Experience": http://www.cbo.gov/ftpdocs/63xx/doc6350/05-11-FreightRail.pdf

## 2.6 Freight Mode Shift

Increases in freight and passenger movement have resulted in significant congestion problems across passenger and freight transportation networks. Freight and passenger transport compete for the use of shared transportation networks, resulting in capacity challenges at key freight bottlenecks, such as the corridors that serve busy ports. *AASHTO's* Freight Rail Bottom Line Report forecasts that increased rail investment could reduce truck VMT in 2020 by up to 15 percent with national savings of $380 billion to $1 trillion.[219]

### POLICY QUANTIFICATION

The sample calculation is based on removing 1,000 trucks from the road, traveling 100,000 miles per year, and carrying loads averaging 20 tons. The emissions reductions are achieved through the lower per ton-mile emission rates of rail versus truck shipping.

| Intermodal Freight & Infrastructure | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 140,375 | na | na | $27,139,105 | 13,569,553 |

| Intermodal Freight & Infrastructure | NOx | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 528.82 | 17.84 | 17.35 | -29.73 | 244.79 | 31.36 |
| Tons Per Day | 1.45 | 0.05 | 0.05 | -0.08 | 0.67 | 0.09 |

### CO-BENEFITS

The benefits of increasing intermodal freight capacity are felt beyond the freight network and are a key component in reducing air pollution and greenhouse gas emissions by improving freight efficiency. The benefits of intermodal freight can include:[220]

- reduced highway congestion by diverting truck traffic from highways;
- lower economic costs of congestion;
- increased employment and economic activity;
- reduced roadway wear and tear;[221]
- enhanced cargo and container security (trucks harder to secure than trains);
- reduced highway damage and maintenance requirements;
- improved safety by reducing the number of highway accidents; and
- reduced shipping costs over long distances

### CASE STUDIES

**Canada**- Canadian Pacific Railway's "Expressway" network runs daily short-haul service along the high-volume Montreal, Toronto, and Detroit corridor. The Expressway provides shippers with roll-on/roll-off trailer-on-train service to dedicated terminals, allowing standard truck trailers to be loaded onto specially designed rail cars. The service has the capacity to carry 240 trailers per day, and in 2003, removed over 73,000 trucks from Ontario's heavily congested highway 401. The Railway Association of Canada (RAC) estimates that each intermodal carload removes approximately 2.8 trucks from Canadian highways.[222] CPR and the Hudson's Bay Company, one of Canada's largest national retailers, has partnered with CPR to ship 16,000 truck trailers a year (or 60 trucks per day)

[219] AASHTO (2003) "Freight-Rail Bottom Line Report": http://freight.transportation.org/doc/ex_railreport.pdf
[220] I-95 Corridor Coalition (2004) "Mid-Atlantic Rail Operations Study Interim Benefits Assessment": http://144.202.240.28/pman/projectmanagement/Upfiles/reports/summary239.pdf
[221] Each truck causes the equivalent roadway, bridge and other infrastructure damage of 2000 to 3000 cars.
[222] Environment Canada (2004) "Locomotive Emissions Monitoring Program": http://www.railcan.ca/documents/presentations/2003_10_06_RailwaysAndTheEnvironment.pdf

by rail. Daimler Chrysler Canada has also committed to reduce the number of trucks on the 401 by 120 per day through greater use of the Expressway network. The RAC has developed a scenario analysis and model which shows that up to 16.5 MT of GHGs can be saved by increasing intermodal transportation.[223]
(www.railcan.ca/documents/cta_6_intermodal.pdf)

**Chicago, IL**- The Chicago Regional Environmental and Transportation Efficiency (CREATE) project is a joint public-private partnership between the state of Illinois, the City of Chicago, and rail operators to identify needed improvements to the region's rail and highway transportation infrastructure. The project will invest $1.5 billion to reduce train delays and congestion in five key rail corridors. This will include 25 new roadway overpasses or underpasses, replacing grade level crossings for auto and pedestrian traffic; new rail overpasses or underpasses to separate passenger and freight train tracks; viaduct improvements; safety improvements for grade crossings; and upgrades of tracks, switches and signal systems. Improving rail service in the region will allow railroads to improve intermodal interchanges and reduce the number of truck movements across the Chicago region.
(http://www.createprogram.org)

**Los Angeles, CA**- The Alameda Corridor project is a 20-mile, fully grade separated rail link between Ports of Long Beach and Los Angeles, and the transcontinental rail networks that are located near the city's downtown. The $2.4 billion project was completed in 2002. The corridor has eliminated 200 rail-street crossing, reducing emissions from cars and trucks delayed at the crossings and increased rail speeds. Port investments in on-dock rail have facilitated emissions reductions by lowering the number of short-haul truck trips. It is estimated that intermodal investments in the Los Angeles region have eliminated 1.4 million truck trips per year. Funding for the corridor came from numerous state and federal funding sources including $400 million from the USDOT, $394 million from the Ports of Los Angeles and Long Beach and $347 appropriated from the Los Angeles Metropolitan Transportation Authority. Funding from the US DOT was from the Department's TIFIA (Transportation Infrastructure Finance and Innovation Act) program which provides credit assistance in the form of direct loans, loan guarantees, and standby lines of credit to eligible projects.
(http://www.portoflosangeles.org/facilities_Rail.htm)
(http://www.railway-technology.com/projects/alameda/)

**Maine-** The Maine Department of Transportation has produced a statewide Integrated Freight Plan, which emphasizes the use of rail and marine in lieu of trucks. Under the Plan, the state secured a mix of public and private funding in order to build a truck to rail intermodal freight facility in Waterville, ME that offers daily intermodal service to destinations along the east coast.

The Maine Intermodal Terminal located in Auburn has expanded in recent years to accommodate the growth of intermodal shipping in the state. This facility offers double stack service to and from the deep water port in Vancouver B.C., allowing west coast shippers to avoid congestion in the Chicago region, reducing travel times and costs. These facilities have reduced the flow of long-haul trucks into the state generating congestion and

[223] Railway Association of Canada (2004) "Estimating the Opportunity to Reduce Emissions Through Increased Intermodal and Rail Transportation"

air quality benefits. The project received $2.3 million in CMAQ funds and $0.7 million from the City of Auburn and the St. Lawrence and Atlantic Railroad Company. (http://ops.fhwa.dot.gov/freight/freight_analysis/env_factors/env_fact_app_e2.htm) (http://www.fhwa.dot.gov/environment/cmaqpgs/amaq/03cmaq4.htm)

**Netherlands**- The national government has established a goal of reducing the amount of freight moved by truck. The Transactie Modal Shift program provides public funding to shippers to develop long-term plans to improve freight efficiency. Proposed actions have included the development of new logistics strategies, changes in transport technology, consolidation of freight distribution activities at freight centers, and driver training. The Netherland's Betuwe Route corridor connecting the port of Rotterdam to Germany is a project that will provide electrified freight-only twin rail tracks connecting with Germany's rail network. The Betuwe project is one of the priority transport projects of the EU. (http://europa.eu.int/comm/transport/marcopolo/index_en.htm)

**New York City, NY-** The Cross Harbor Freight Movement Major Investment Study completed by the New York City Economic Development Corporation (EDC), in 2000, indicated that a new, direct rail freight link across the harbor would decrease the region's dependence on trucking, improving air quality and would reduce the strain on the region's on highway infrastructure. With the exception of a limited railcar float services, goods moving to destinations east of the Hudson River by rail must take a 280-mile detour to cross the river. The study assessed alternatives that included the construction of a rail tunnel link that would that would displace one million truck trips per year and reduce VMT by 44-93 million VMT per year.
(http://www.crossharborstudy.com/finalrep.pdf)
(http://www.crossharborstudy.com/overview.htm)

**Switzerland**- Switzerland is a mountainous country that is using intermodal transport to reduce the environmental impact of truck traffic. Roll/on roll/off services are available for trucks using the railway to cross the mountains. In 1994, Switzerland banned trucks carrying freight through Switzerland beginning in 2004. In 1998 the decision was altered and required road pricing and quotas for heavy trucks, and improved rail intermodal service. The weight-distance tax on trucks and a value added sales tax are being used to fund the construction of two rail tunnels under the Alps. The Alpine Initiative has been opposed by EU trucking interests, however is consistent with modal shift policies within the EU.[224]
(http://www.enotrans.com/Publications/WhatWeDo_Publications_Freighttransport.htm)

### KEY ISSUES/IMPLEMENTATION

Investment in freight infrastructure will be necessary to accommodate the anticipated growth in the demand for freight rail and to improve freight efficiency. Key investment issues for freight rail include:

- development of a public-policy-driven expansion would require $2.6 to $4.0 billion/yr network-level investment in:[225]
  - nationally significant corridor choke points;
  - intermodal terminals and connectors; and
  - urban rail interchanges

[224] ENO Transportation Foundation (2002) "Intermodal Freight Transport in Europe and the United States"
[225] AASHTO 2003, *OP Cit.*

## 2.6 Freight Mode Shift

- class I railroads are currently investing $2 billion per year for improvements in addition to annual repair and maintenance expenditures. AASHTO estimates that this level of investment would result in freight rail losing market share and increasing required investments in highway and transportation systems[226]

- a clear national freight policy to improve the productivity of the freight system, which must:
  - extend beyond state boundaries;
  - be based on partnership among railroads, States, and the federal government; and
  - integrate a variety of funding tools[227]

- US DOT is in the process of developing a framework for a National Freight Policy. The framework will lay out a vision, objectives, details, strategies and tactics that will be used by the US DOT and public and private sector stakeholders[228]

**KEY RESOURCES & REFERENCES**

**Alameda Corridor Transportation Authority**- updated information on the Alameda Rail Corridor, completed and future projects and financial information:
http://www.acta.org/

**American Association of State Highway and Transportation Officials (AASHTO)**- the Freight Transportation Network provides access to AASHTO's rail, water, aviation, highway and intermodal freight committees as well as access to freight resource material, tools and programs:
http://freight.transportation.org/

**American Association of State Highway and Transportation Officials (AASHTO)**- AASHTO's "Freight Rail Bottom Line Report" describes the issues facing the freight-rail system in the United States and quantifies the potential benefits of increased rail investment:
http://freight.transportation.org/doc/ex_railreport.pdf

**Association of American Railroads (AAR)**- represents U.S. freight and passenger railroads and provides information on the railroad industry including a 2005 review of U.S freight railroads:
http://www.aar.org/
http://www.aar.org/PubCommon/Documents/AboutTheIndustry/Overview.pdf

**Center for Clean Air Policy (CCAP)**- The June 2005 Freight Solutions Dialogue webpage includes presentations exploring emission reduction opportunities, industry trends and barriers to a more efficient freight distribution system:
http://www.ccap.org/transportation/fsd.htm

**Chicago Region Environmental and Transportation Efficiency Program (CREATE)**-

[226] Ibid.
[227] For a review of State and Federal funding sources please see AASHTO 2003
[228] US Department of Transportation: http://ostpxweb.dot.gov/freight_policy_framework.html

## 2.6 Freight Mode Shift

http://www.createprogram.org/

**Congressional Budget Office (CBO)** – "Freight Rail Transportation: Long-Term Issues," January 2006:
http://www.cbo.gov/ftpdocs/70xx/doc7021/01-17-Rail.pdf

**Environment Canada**- In 2004, Environment Canada and the Railway Association of Canada's completed the "Locomotive Emissions Monitoring Program" report, contains emissions data for Canadian railways:
http://www.railcan.ca/documents/presentations/2003_10_06_RailwaysAndTheEnvironment.pdf

**European Commission**- The Marco Polo Programme was designed to reduce road congestion, improve the environmental performance of the freight transport system and to enhance the development of intermodal freight:
http://europa.eu.int/comm/transport/marcopolo/index_en.htm

**Federal Highway Administration (FHWA)** - The FHWA's 2005 report "Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level" discusses freight transportation activity and emissions nationally and in six metropolitan areas and emissions mitigation strategies:
http://www.fhwa.dot.gov/environment/freightaq/

**Federal Highway Administration (FHWA)** - The Office of Freight Management and Operations' Freight Analysis Program provides resources in areas that include congestion, freight planning, financing, intermodal connectors and the environment:
http://ops.fhwa.dot.gov/freight/intermodal/
http://ops.fhwa.dot.gov/freight/freight_analysis/env_factors/index.htm

**General Accounting Office (GAO)**- Report on "Freight Transportation, Strategies Needed to Address Planning and Financing Limitations, Report to the Committee on Environment and Public Works":
http://ntl.bts.gov/lib/24000/24600/24655/d04165.pdf

**I-95 Corridor Coalition**- "Mid-Atlantic Rail Operations Study" examines the performance of the Mid-Atlantic's highway, aviation, and rail systems, focusing on the rail system and identifying opportunities to improve existing rail assets:
http://144.202.240.28/pman/ViewProject.asp?pid=148

**Intermodal Association of North America (IANA)** - Is an industry trade association representing intermodal freight interests provides information on intermodal trends and statistics, legislative updates and industry contacts:
http://www.intermodal.org/index.html

**Railway Association of Canada (RAC)** - Represents some 60 member freight, tourist, commuter, and intercity Canadian railways and provide access to information on Canadian railway emissions, climate change and Canadian legislation:
http://www.railcan.ca/
http://www.railcan.ca/documents/presentations/2003_10_06_RailwaysAndTheEnvironment.pdf

## 2.6 Freight Mode Shift

**Transportation Research Board**- "Freight Capacity for the 21st Century" examines trends in the freight sector that impact efficiency and provides policy options to increase capacity by enhancing the efficiency of the freight network:
http://trb.org/publications/sr/sr271.pdf

**US Environmental Protection Agency**- The Smartway Transport Partnership provides information on the environmental effects of goods movement and emissions reduction options that include intermodal freight:
http://www.epa.gov/smartway/swintro.htm
http://www.epa.gov/smartway/documents/intermodal%20shipping.pdf

## 2.7 Locomotive Technologies

**OVERVIEW**

Locomotives are significant contributors of $NO_x$, HC, and PM emissions. The EPA reports that unregulated locomotives generate almost 5 percent of total nationwide $NO_x$ emissions. In December 1997, the EPA approved standards requiring a two-thirds reduction in $NO_x$ emissions and a 50 percent reduction in particulate emissions from mid-1990s levels.[229,230] Between 2002 and 2020, $NO_x$ emissions are expected to fall by 44 percent and $PM_{10}$ emissions by 28 percent as a result of this rule. However, studies predict that without additional controls, locomotives and marine diesel engines will contribute about 27 percent of mobile source $NO_x$ and 45 percent of mobile source fine diesel PM emissions in 2030.[231] The relative increase in emissions from these large diesel engines is attributable to the anticipated growth in their use, and increasingly stringent controls for on-road emissions sources. Further regulation proposed in 2004 aims to reduce PM and air toxics emissions through use of advanced control technologies.

Techniques to reduce emissions vary according to the nature of the train's use (e.g. passenger train, freight train, etc). Locomotive emissions are measured according to the type of service, either line-haul or switch. The switch operation is characterized by short distance hauls with most time spent in idle and low power notches, whereas the line-haul operation is characterized by a much higher percentage of time spent in the high power notches.[232] Hybrid and fuel cell technologies are two promising technologies that can be readily applied to switch locomotives operating in rail yard and industrial services.

In rail yards, switching locomotives (or switchers) join, separate, and move cars from track to track. In industrial service, these locomotives transfer cars to and from regional railroads. This low speed transport is characterized by high amounts of idling times, wasted fuels, and high emissions.[233] A recently developed hybrid engine utilizes large banks of long-life, recyclable batteries, and dramatically reduces energy use and emissions from yard-switching units. This technology uses a small diesel engine to power an electric generator, which charges a battery bank. The engine only runs when the switcher is in use, thus eliminating idling emissions.[234]

The hybrid locomotive concept is similar to the gasoline-electric hybrid automobile; however, this technology is more effective when applied to locomotives due to the larger vehicle size, which can support a massive, cost-effective lead acid battery. The added weight from the batteries actually improves the vehicle's tractive effort or "pull." This benefit is unique to rail hybrid applications.[235] Demonstrations of RailPower Technologies' newly developed hybrid engine, the Green Goat, achieved a 90 percent reduction in $NO_x$ and

---

[229] Argonne National Laboratory (2002) "Railroad and Locomotive Technology Roadmap": http://www.transportation.anl.gov/pdfs/RR/261.pdf

[230] US EPA: http://www.epa.gov/otaq/locomotv.htm

[231] US EPA: Office of Transportation and Air Quality (2004) "Regulatory Announcement: Clean Diesel Program for Locomotives and Marine Engines": http://www.epa.gov/otaq/regs/nonroad/420f04041.pdf

[232] Diesel Net Online Standards Database: http://www.dieselnet.com/standards/us/loco.html

[233] The 2004 ASME/IEEE Joint Rail Conference cited conventional yard switch engines as the biggest polluters in rail yards when compared with newer locomotives' electronic fuel injection controlled engines Proceedings of the 2004 ASME/IEEE Joint Rail Conference "Hybrid Technology for the Rail Industry": http://ieeexplore.ieee.org/xpl/RecentCon.jsp?puNumber=9111

[234] R. Bradley Queen, "The Green Goat Hybrid Locomotive": http://www.railpower.com/dl/greensavesgreen.pdf

[235] Green Car Congress: Energy, Technologies, Issues and Policies for Sustainable Mobility (2005) "Canadian Pacific Buys 35 Hybrid Locomotives": http://www.greencarcongress.com/2005/03/canadian_pacifi.html

a 77 percent reduction of PM when compared to a typical 2000 horsepower locomotive. Overall, the Green Goat used 59 percent less diesel fuel and is equipped with automatic shut down devices to reduce idling emissions.

Fuel cell technology is an alternative method to reduce locomotive emissions. Based on electrochemistry rather than combustion, fuel cells directly convert the energy of fuel into electric power, thereby eliminating emissions. Fuel cell locomotives generate zero local emissions,[236] low noise, high power density, low temperature and pressure, and have a long lifespan.[237] Recent applications of this technology in the mining sector resulted in a zero emissions car that generated additional ventilation cost savings ranging from 23 percent to 58 percent.[238] Current research is investigating fuel cell applications for light rail and other commercial uses.

## POLICY QUANTIFICATION

The technologies discussed have shown greatest promise in switching operations. The quantification shows the gains from utilizing new technologies in an application previously utilizing 30,000 gallons of diesel fuel per year. The savings result principally from reduced fuel use and pollution controls optimized to the energy demands of a hybrid locomotive.

| Locomotive Technologies | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 107 | na | na | $15,750 | 10,500 |

| Locomotive Technologies | NOx | PM-10 | PM-2.5 | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 9.78 | 0.21 | 0.14 | 0.18 | 1.03 | 0.22 |
| Tons Per Day | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## CO-BENEFITS

Hybrid locomotives reduce emissions, fuel use, and operating costs while improving the overall rail environment. Benefits from the hybrid locomotive include:

- 30-80 percent fuel savings depending on operating environment;
- increased power due to more effective control and motor systems;
- reduced noise as a result of the almost vibration-less switcher; and
- reduced ground contamination from oil spillage.

Fuel cell technologies also offer numerous benefits:

- decreased refueling time for fuel cell powered locomotives when compared to charging time for battery powered locomotives;
- fuel cell power plant is almost twice as efficient as a diesel engine;
- increased productivity due to greater torque characteristics compared to the diesel counterpart; and
- reduced cost of fleet upgrade as fuel cell replaces existing locomotive power structure rather than the whole locomotive

[236] Total upstream emissions will depend on the source of the fuel that is used to provide hydrogen for locomotive fuel cells.
[237] Fuel Cells Canada (2004) "Conceptual Design Of Fuel Cell Locomotive": http://www.fuelcellscanada.ca/Industry%20news/locomotive.html
[238] US Department of Energy (2003) "Fuel Cell-Powered Front-End Loader Mining Vehicle": http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/vib3_slattery.pdf

## 2.7 Locomotive Technologies

Both technologies serve to:

- improve operator health as a result of decreased emissions exposure;
- decrease noise; and
- improve energy efficiency of the transportation sector

**CASE STUDIES**

**Calgary, Alberta-** In March 2005, Canadian Pacific Railway (CPR) purchased 35 Green Goat Series hybrid locomotives. This rail network serves the principal centers of Canada, Northeastern U.S., and Midwestern U.S. Following nearly a year and a half of testing and demonstrations, CPR noted significant fuel, emissions, and operational benefits. The predicted operating cost savings from acquiring all machines is near $4 million annually. A three-year implementation plan is expected.
(www.railpower.com/dl/news/news_2005_03_14a.pdf)

**Denver, CO**- In May 2003, Vehicle Projects LLC of Denver began design of the world's largest fuel cell vehicle. Supported by an international consortium of researchers and sponsors, this five-year project aims to develop the first fuel cell-powered locomotive for military and commercial railway applications. The project will develop the fuel cell locomotive by retrofitting an Army diesel-electric locomotive with a fuel cell power plant. The project will demonstrate the locomotive in a non-tactical application and will facilitate commercialization of fuel cell power for rail transportation. This vehicle is envisioned for use in subway utility locomotives, switchers, commuter rail, subway trains, light rail, heavy freight, and high-speed rail.
(http://www.fuelcellpropulsion.org/army_loco_1aug2003.htm)

**Texas**- The Texas Emissions Reduction Plan (TERP) will fund the purchase of a Green Goat and smaller 1,000-horsepower hybrid locomotives called Green Kids. Railserv, a company providing rail switching services, received this grant in January 2005. In October 2005, Union Pacific Railroad announced it will use the $81 million awarded in TERP grants to purchase 98 low emission road switcher locomotives from RailPower Technologies Corp. RailPower estimates that the new locomotives based on Green Goat hybrid technology will result in a fuel savings of 20-40 percent, and $NO_x$ and PM reductions of up to 80 percent. Since 2000, Union Pacific has purchased over 2,000 new fuel-efficient locomotives, retrofitted more than 1,000 older locomotives, and retired 1,300 of its oldest locomotives.
(http://www.wired.com/news/planet/0,2782,66998,00.html)
(http://www.railpower.com/dl/news/news_2005_10_13.pdf)

**Reno, Nevada**- The first fuel cell-powered mine locomotive was successfully tested in November of 2002. Sponsored by the US Department of Energy, Natural Resources Canada, and others, this machine is designed to pull ore cars in underground mining while yielding zero local emissions. New stringent regulations regarding underground emissions motivated this development. Compared to the battery and diesel version of the vehicle, the fuel cell locomotive provides many benefits, including: equal acceleration, more than twice the power, the ability to pull longer trains, shorter recharge time, and the ability to operate for two labor shifts before refueling. Operating costs are significantly decreased.
(http://www.fuelcellpropulsion.org/loco_20Nov2002.htm)

**KEY ISSUES/IMPLEMENTATION**

Hybrid technology is expensive to implement. Although long-term cost-savings are substantial, initial investment is steep. Alternatives include replacing existing power plants with the hybrid structure or reconditioning existing locomotive units. Also, hybrid

technology is still in the development stage. Although hybrid locomotives have been tested in extreme hot and cold climates, further research will determine their suitability for all climates. Thus far, no hybrid locomotives exist for long-haul use.[11]

Much bigger obstacles remain for fuel cell technologies. It is very costly to initially implement fuel cell locomotives, and advances are needed for this application, as current demonstrations of locomotive fuel cells are limited in field.[12] Further technology development might help this option become more cost effective.

**KEY RESOURCES & REFERENCES**

**2004 ASME/IEEE Joint Rail Conference**- "Hybrid Technology for the Rail Industry" includes a history of electric locomotives, current hybrid initiatives, and an analysis of hybrid technologies:
http://ieeexplore.ieee.org/xpl/RecentCon.jsp?puNumber=9111

**Argonne National Laboratory**- "Reduction of Impacts from Locomotive Idling" presents the varying nature of locomotive emissions and methods to remediate such emissions. It includes a summary of the costs and benefits of each technology:
www.transportation.anl.gov/pdfs/RR/290.pdf

**California Air Resources Board (CARB)-** Information on CARB's locomotive activities including the Rail Yard Emission Reduction Program:
http://www.arb.ca.gov/railyard/railyard.htm
http://www.arb.ca.gov/msprog/offroad/loco/loco.htm

**DieselNet-** Website contains information on diesel emissions standards and technical reports for a wide range of applications in the US and internationally, including diesel locomotive standards:
http://www.dieselnet.com/standards/us/loco.html

**Fuel Cell Today-** Provides information on the latest fuel cell innovations for all applications:
http://www.fuelcelltoday.com/
http://www.fuelcelltoday.com/FuelCellToday/SearchSystem/ResultsDisplay/

**Fritz, S.G. -** A report prepared for the California Air Resources Board on the "Diesel Fuel Effects on Locomotive Exhaust Emissions":
http://www.arb.ca.gov/fuels/diesel/102000swri_dslemssn.pdf

**General Electric Transportation Rail (GE)**- GE is the manufacturer of freight and passenger locomotives including the GE Evolution Series fuel-efficient diesel locomotive. GE is in the process of developing a hybrid diesel electric locomotive as part of its Ecomagination environmental technology program:
https://www.getransportation.com/general/locomotives/hybrid/hybrid_default.asp

---

[11] Linda Gaines "Reduction of Impacts from Locomotive Idling":
http://www.transportation.anl.gov/pdfs/RR/290.pdf

[12] Department of Energy (2003) "Hydrogen, Fuel Cells & Infrastructure Technologies Program" :
http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/merit_review_report03.pdf

## 2.7 Locomotive Technologies

**RAILPOWER Technologies Corporation**- Provides information on RailPower's Green Goat yard switcher and hybrid road switcher technologies. Also includes links to information regarding emissions regulation and other organizations focusing on locomotive technology:
www.railpower.com
http://www.railpower.com/dl/asme.pdf
http://www.railpower.com/dl/greensavesgreen.pdf

**Union Pacific Railroad-** As one of the United State's leading railroad companies, Union Pacific has begun to integrate hybrid electric locomotives into its operations. More information is available at:
http://www.uprr.com/she/emg/index.shtml
http://knowledge.fhwa.dot.gov/cops/italladdsup.nsf/0/51939e33aa00d66f85256fc600782fba?OpenDocument

**US Environmental Protection Agency-** Non-road Engines, Equipment, and Vehicles website describes current locomotive emissions standards and links to detailed text describing projects and law implementation:
http://www.epa.gov/otaq/locomotv.htm

**West Coast Collaborative-** The Collaborative Locomotive and Rail Sector Workgroup holds meetings, exchanges information, and explores funding opportunities for emissions reduction projects. The website also provides access to the Collaborative's information clearinghouse on locomotive initiatives:
http://www.westcoastdiesel.org/wkgrp-loco.htm

## 2.8 Locomotive Idle Reduction

**OVERVIEW**

Locomotive idling has long been a part of standard railroad operations for both line haul and switcher locomotives.[239] Idling is required in temperatures below 40˚F to protect engine components and avoid reduced power output levels. A warm engine is required to properly maintain engine fluids, ensure easy start up, keep the battery charged, avoid freezing toilet water, and to maintain the "hotel" load. Switchyard locomotives have typically been allowed to idle between assignments because the engines can be difficult to restart if they are shut down for lengthy periods of time.

Idling accounts for a large proportion of the locomotive duty cycle. Estimates of time spent idling range from 40 to 60 percent for on-road idling and 60 to 80 percent for yard idling.[240] Locomotive switchers will idle in the "idle" throttle setting or "notch 1", consuming three to four gallons of diesel fuel per hour. When temperatures reach below 10 to 15˚F locomotives are typically idled at "notch 3" setting which will consume eight to eleven gallons per hour.[241] The US EPA estimates that nationwide there are approximately 5,000 switcher locomotives that idle 2,500 to 3,000 hours per year. Idling from switcher locomotives alone consumes up to 65 million gallons of fuel annually, emitting in excess of 800,000 tons per year (tpy) of $CO_2$, 17,000 tpy $NO_x$ and 500 tpy PM.[242] Locomotive idling from all sources is estimated to burn more than 230 million gal/yr, or 6.3 percent of freight rail energy requirements.[243]

There are several options that are currently being employed to reduce locomotive idling by allowing the main engine to be shut down safely while not in use, or automatically shutdown the engine after a period of idling. Anti-idling technologies currently in use include:[244]

- Automatic engine stop-start controls (AESS) - shuts down engines automatically after set period of idling, reducing idling by an estimated 50 percent for line haul and 70 percent for switcher locomotives. Sensors monitor water temperature, brake pressure and battery charge and the engine will restart if any of the parameters are out of an acceptable range. AESS systems do not provide cab comforts while the engine is off. If the ambient temperature is below 40° F, the engine will stay on; thus the greatest benefits from AESS are achieved in warmer climates. Argonne National Laboratory (ANL) estimates a payback of 6 to 12 months;

- Auxiliary power unit (APU) - allows the main engine to be shut down while maintaining all vital engine systems with significantly lower fuel consumption. APUs

[239] In rail yards, switching locomotives (or switchers) join, separate, and move cars from track to track. In industrial service, these locomotives transfer cars to and from regional railroads. This low speed transport is characterized by high amounts of idling times which leads to wasted fuels and high emissions. Line-haul operation is characterized by a much higher percentage of time in the high power notches, and medium to long distance travel.

[240] Range in estimates for idling times from US EPA, American Association of Railroads and the Railway Association of Canada. US EPA "Chicago Locomotive Idle Reduction Project" (2004): http://www.cleancitiescincinnati.org/PDFS/locomotive101804.pdf

[241] *Ibid.*

[242] *Ibid.*

[243] Argonne National Laboratory (2004) "Reduction of Impacts from Locomotive Idling": http://www.transportation.anl.gov/pdfs/RR/290.pdf

[244] All of the options listed, except hybrid switching locomotives, can be retrofitted on to locomotives from any manufacturer. Argonne National Laboratory "Locomotive Idling" (2004): http://www.transportation.anl.gov/pdfs/RR/312.pdf

provide power for on-board electrical and environmental systems such as heat to engine water and oil, lighting, air conditioning and communication equipment. APU devices allow engine shut down in winter at temperatures down to –30º F;

- Diesel-driven heating system (DDHS) - allows a locomotive to be shutdown year round and in cold climates by heating the engine coolant and oil, charging the batteries and powering the cab heaters. DDHS and AESS systems have been combined to achieve an 80 percent reduction in idling (see Chicago case study). ANL estimates a payback of 12-17 months for APU or DDHS units;

- Shore power plug-in units- heat and circulate engine fluids, using an electric powered heating system and battery chargers that connect to the electrical grid. The locomotive must be in a yard equipped with plug-in units, making it a viable option for switcher and commuter engines. Plug-in units are relatively inexpensive with an estimated payback of 3 to 11 months; and

- Hybrid switching locomotive[245] estimated payback of 20 months[246]

## POLICY QUANTIFICATION

Eliminating idling from a fleet of 100 locomotives that idled at notch 1 for 3,000 hours would result in the following savings:

| Locomotive Anti-Idling Measures | $CO_2$ (annual metric tons) | $N_2O$ (annual metric tons) | $CH_4$ (annual metric tons) | Annual Fuel Cost Savings | Annual Fuel Savings (Gallons) |
|---|---|---|---|---|---|
| Total | 10,661 | na | na | $1,575,000 | 1,050,000 |

| Locomotive Anti-Idling Measures | NOx | $PM_{-10}$ | $PM_{-2.5}$ | $SO_2$ | CO | VOC |
|---|---|---|---|---|---|---|
| Annual Emission Reductions (Tons) | 290.85 | 7.35 | 6.37 | 17.78 | 49.35 | 16.80 |
| Tons Per Day | 0.80 | 0.02 | 0.02 | 0.05 | 0.14 | 0.05 |

## CO-BENEFITS

Locomotive idling-reduction programs reduce diesel fuel consumption and provide significant benefits in the reduction of greenhouse gases, $NO_x$ and PM emissions. Some of the additional benefits to locomotive idle reduction include:

- reduced emissions of pollutants contributing to acid rain and smog
- lower fuel, oil and maintenance costs;[247]
- increased engine life;
- reduced health risks associated with diesel exhaust exposure
- decreased noise pollution;[248] and
- reduction in exposure to pollutants in vulnerable communities located within a close proximity to rail yards

## CASE STUDIES

[245] Hybrid Locomotives are discussed in section 2.6 Locomotive Technologies
[246] Cost estimate from ANL based on: GP38-2 with EPA switcher cycle for all technologies, 330 d/y, 50% idle replacement by AESS (will be less in cold climate), 90% by APU, DDHS, or plug-in unit, .05 gal oil used/gal fuel, $0.10/kWh
[247] US EPA (2004) "Case Study: Chicago Locomotive Idle Reduction Project"
[248] *Ibid.* Noise from the idling locomotives was reduced 8-15 decibels or 84 to 97 percent.

## 2.8 Locomotive Idle Reduction

**California**- the State of California, Burlington Northern Santa Fe Railway (BNSF) railway and Union Pacific Railway signed a memorandum of understanding (MOU) in June 2005 to reduce diesel emissions in rail yards across the state. The companies agreed to introduce a statewide idling-reduction program to reduce diesel PM emissions from rail yards by 20 percent through the use of anti-idling devices and operational changes. The plan includes phasing out all non-essential idling within six months and installing idle-reduction devices within three years;
(http://www.arb.ca.gov/railyard/080805moufs.pdf)

**Chicago, IL-** In 2002, the Chicago Locomotive Idle Reduction Project evaluated idle-reduction technologies on seven switch yard locomotives operated by the Burlington Northern and Santa Fe Railway Company (BNSF) and Wisconsin Southern Railroad Company (WS). The Diesel Driven Heating Systems (DDHS) developed by the Kim Hotstart Manufacturing Company was used on all seven locomotives. DDHS allows a locomotive to be shutdown while maintaining the engine temperature at above 100˚F and ensuring batteries are charged. One of the locomotives also received ZTR Control Systems' SmartStart system used to automatically manage the shutdown and restart of locomotive engines during yard idling. The locomotive outfitted with the combined DDHS and SmartStart technology package achieved an 80 percent reduction in time spent idling within the rail yard. The result was a daily reduction in fuel consumption of 42.7 gallons per day or 14,339 gallons per year. At $3.00/gallon, the idle reduction devices would save over $43,000 in fuel costs annually per locomotive. Additionally oil consumption for a standard locomotive would drop from an average of 250 gallons a year (and $1650/year) to 31 gallons ($205) when using the DDHS system. The emissions reduced were estimated at 2.4 tons per year of $NO_x$ and 0.07 tons per year of PM.[249]
(http://www.epa.gov/otaq/smartway/documents/420r04003.pdf)

**CSX-** CSX Transportation is making use of Auxiliary Power Units (APUs) as a central component in the company's Idle-Reduction Strategy. The K9 APUs developed by EcoTrans are stand-alone locomotive idle-reduction systems designed to ensure locomotives maintain engine functions, preventing damage during shutdown times. The K9 APUs are certified by the EPA as an emissions reduction device, and are expected to be installed on 3,600 CSX locomotives by 2006. In 2001, the EPA awarded CSX with the Clean Air Excellence Award for its design, patent, and installation of the APU technologies. Test data from Southwest Research Institute indicated that the APUs can reduce idle fuel consumption by 83 percent, or over 20,000 gallons per year. If half of this reduction is achieved for CSX's 3600 locomotives, the company could save over $100 million in fuel costs annually.[250]
(http://www.eere.energy.gov/vehiclesandfuels/pdfs/idling_2004/stewart.pdf)
(http://www.ecotranstechnologies.com/news-AARaward.asp)

**Vancouver, WA-** the US EPA through its Smartway Transport Partnership has provided a grant of $85,000 to retrofit three BNSF switchyard locomotives in Vancouver, WA. The retrofits consist of the DDHS and SmartStart technologies initially tested two years earlier as part of the Chicago Locomotive Idle Reduction Project.
(http://yosemite.epa.gov/r10/homepage.nsf/0/1134757180bf949588256ec300621441?OpenDocument)

[249] Both fuel consumption and $NO_x$ emissions assume the industry average locomotive availability of 92% or 335 days per year
[250] Assuming $3.00 per gallon

## 2.8 Locomotive Idle Reduction

**KEY ISSUES/IMPLEMENTATION**

Implementation of an idle reduction strategy for locomotive engines requires that several key issues be considered, included among them are:

- capital costs and payback of idle reduction technologies;
- appropriate technology selection for climatic conditions- the technology selected must allow for easy engine restarts in the coldest conditions;
- traditional training to overcome idling behaviors of railway crews to ensure the proper use of new technologies;[251]

**KEY RESOURCES & REFERENCES**

**Association of American Railroads**- "Railroads: Building a Cleaner Environment" outlines the environmental impacts and performance of U.S. freight rail operations:
http://www.aar.org/getFile.asp?File_id=364

**Argonne National Laboratory**- links to ANL documents and presentations and documents on locomotive and heavy-duty diesel idling initiatives by Linda Gaines:
http://www.transportation.anl.gov/pdfs/RR/290.pdf
http://www.transportation.anl.gov/research/technology_analysis/idling.html
http://www.naseo.org/events/annual/2005/presentations/Gaines.pdf

**California Air Resources Board**- this webpage contains information on the CARB's locomotives programs including the Statewide Agreement, South Coast MOU, recent activities and access to the Rail Yard Emissions Reduction Program:
http://www.arb.ca.gov/msprog/offroad/loco/loco.htm

**California Air Resources Board-** the "Roseville Rail Yard Study" conducted by the CARB, is a health risk assessment of particulate matter emissions from diesel locomotives at the Union Pacific J.R. Davis Yard located in Roseville, California:
http://www.arb.ca.gov/diesel/documents/rrstudy.htm

**Ecotrans Technologies**- manufacturer of APU devices for locomotive applications provides information on products, fuel savings and EPA compliance:
http://www.ecotranstechnologies.com

**Kim Hotstart Manufacturing Company**- this website from the maker of the Diesel Driven Heating System (DDHS) includes information several idle reduction technology options:
http://www.kimhotstart.com/railroad.htm

**North Carolina Department Environment and Natural Resources**- information on the state's locomotive idling reduction program including presentations, idling technologies and state grants:
http://daq.state.nc.us/planning/locoindex.shtml

**Southwest Research Institute**- SWRI's locomotive testing page provides information on engine and emissions research and publication listings:
http://www.swri.edu/4org/d08/emmres/hdcont/loctestg/default.htm
http://www.swri.edu/3pubs/ttoday/Spring04/Track.htm

[251] See EPA Chicago Idle Reduction Case study: http://www.epa.gov/otaq/smartway/documents/420r04003.pdf

## 2.8 Locomotive Idle Reduction

**Union Pacific Railroad Company**- safety, health and environmental program website and Union Pacific's presentation on idling reduction technology issues at the 2004 National Idling Reduction Planning Conference:
http://www.uprr.com/she/index.shtml
http://www.eere.energy.gov/vehiclesandfuels/pdfs/idling_2004/iden.pdf

**US Environmental Protection Agency**- report of the results from the Chicago Locomotive Idle Reduction Project:
http://www.epa.gov/otaq/smartway/documents/420r04003.pdf

**US Environmental Protection Agency**- "Guidance for Quantifying and Using Long Duration Switch Yard Locomotive Idling Emission Reductions in State Implementation Plans":
http://www.epa.gov/smartway/documents/420b04002.pdf

**West Coast Diesel Emissions Reduction Collaborative**- links to the Collaborative's "Locomotive Idling Reduction Project" and clearinghouse for locomotive information:
http://www.westcoastcollaborative.org/files/projects/locomotive/Locomotive%20Idling%20Reduction%20Project%20Template.pdf http://www.westcoastdiesel.org/clearinghouse-loco.htm

**ZTR Control Systems**- provides control and monitoring systems for the railroad industry including the SmartStart automatic shut down/restart technology:
http://www.ztr.com/

## TECHNICAL APPENDIX

The Vehicle Technology and Fuels Technical Appendix provides additional information for guidebook users that includes:

A. Comparing On-road LDV Performance vs. EPA-rated MPG
B. Vehicle Technologies
C. Incentive Programs
D. Advanced Modeling and Training Resources

## A. COMPARING ON-ROAD LDV PERFORMANCE vs. EPA –RATED MPG

Part of the difficulty in motivating consumers to purchase more fuel efficient vehicles is the lack of information available. The EPA rated MPG is virtually the only source of efficiency information the average consumer sees. However, the EPA efficiency rating often overestimates the actual fuel economy. This overestimated MPG is a source of consumer dissatisfaction and may lead consumers to purchase less efficient vehicles than they otherwise might.

The EPA has sought to address the issue. The current test, which has been criticized for not accurately reflecting real-world driving conditions, is being replaced with a test that assumes more accurate driving characteristics such as rapid starting and stopping as well as the use of the air conditioner. As a result of the new testing procedures, EPA expects rated highway MPG to drop between 10 and 20 percent and city MPG to drop 5 to 15 percent. These adjustments will not affect Corporate Average Fuel Economy (CAFE) standards which are calculated based on a different methodology.

The American Automobile Association (AAA) has evaluated EPA's new testing procedures. They found that with the new testing procedures, the average deviation of real world MPG from EPA rating will drop from the current 16 percent to 4 percent. The new testing procedures will be in effect for model year 2008 vehicles.

See summary of proposed rulemaking for a complete discussion of the issue:
http://www.epa.gov/fueleconomy/prepublication-preamble.pdfhttp://www.epa.gov/sectors/pdf/emission_20050519.pdf

## B. VEHICLE TECHNOLOGIES

A variety of technologies are available or are under development that can reduce GHG emissions and improve the efficiency of motor vehicles. These can generally be classified into four categories:

1. Valve and cylinder operations;
2. Transmissions;
3. Fuel combustion; and
4. Vehicle accessories and design.

### 1. Valve and Cylinder Operations

In a typical vehicle, all engine cylinders are in use under all driving conditions and the timing and lift of the valves are controlled by cams rotating on a camshaft that is linked, through a series of gears to the crankshaft. The timing and lift of the valves are fixed by the engine manufacturer to maximize engine performance at a specific rpm. However, this produces less-than-optimal performance when the engine is operated at other rpm levels. There are technologies that are now common or under development that can vary some of

these engine parameters to optimize engine performance under most driving conditions. These include:

- variable valve timing (cam phasing) – the timing of the intake and exhaust valve operations can be varied with engine operating conditions;
- variable valve lift – the duration and extent to which the valves open can be varied either continuously or in discreet increments;
- cylinder deactivation – by keeping the associated valves closed, some cylinders can deactivated, permitting more optimal operation of the other cylinders; and
- camless valve actuation – the valves can be operated independently of engine speed, through either electrohydraulic or electromagnetic control

**2. Transmissions**

Three modern types of transmissions can improve vehicle efficiency, primarily by increasing the number of gears available:

- 5-speed or 6-speed automatic transmission (rather than the typical 4-speed);
- automated manual transmission – a manual transmission that automatically shifts at the optimal engine rpm; and
- continuously variable transmission – like having an infinite number of gears, so the vehicle always operates in an optimal manner

**3. Fuel Combustion**

Another way to improve engine performance is to improve the combustion of fuel within the cylinders. This can be done through:

- turbocharging or supercharging – by increasing the pressure of the air-fuel mixture as it enters the cylinder, the power output of the engine is improved;
- variable compression ratio – this technology varies the cylinder geometry with engine operating conditions to allow higher compression ratios at lower engine loads and lower compression ratios at higher loads (where high compression ratios lead to engine "knocking");
- gasoline direct injection and high-speed direct injection diesel – by injecting gasoline directly into the cylinder, instead of the intake manifold, the fuel that typically evaporates from the manifold is now used for combustion; and
- homogeneous charge compression ignition – fuel will homogeneously combust throughout the cylinder under the correct conditions (temperature and pressure), which avoids many of the inefficiencies and pollutants associated with spark plug ignition

**4. Vehicle Accessories and Design**

The efficiency of a vehicle can also be improved by the use of more modern accessories or design features, such as:

- more efficient air conditioning compressor;
- low rolling resistance tires;
- better aerodynamics;
- electrification of accessories, such as power steering and coolant pumps;
- improved alternator;
- upgrading from 12-volt to 42-volt electrical systems;
- integrated starter-generator – allows regenerative braking and engine shut-off during idling (see the associated brief on hybrid vehicles);
- reduced friction lubricants;
- aggressive shift logic – upshifting at lower rpms and reduced downshifting improves engine performance;

- early torque converter lock-up – in automatic transmissions, the torque converter between the engine and transmission can be locked up under a wider degree of driving conditions; and
- reduced weight

## C. INCENTIVE PROGRAMS

Several cost-effective and innovative programs have been developed in jurisdictions across the U.S. that allocate funding to programs to reduce emissions from transportation sources. Grant programs offer direct funding to equipment owners in order to facilitate the purchase of cleaner technologies and fuels or undertake retrofits to improve emissions from existing vehicles. Programs may be administered by federal agencies, states, regional air quality districts, local governments and port facilities. Below, we have highlighted some of the federal, state and local incentive programs that are being used to accelerate the diffusion of emissions reduction alternatives.

### FEDERAL

#### The Energy Policy Act of 2005

The Energy Policy Act (EPAct) of 2005 was signed into law on August 8, 2005 and is considered the first major federal energy legislation enacted since 1992. The EPAct includes several provisions under Title VII that supports the reduction of fuel use and emissions in the transportation sector through vehicle technology and fuel measures.

The Act contains sections pertaining to current programs, federal and state vehicle procurement, automobile efficiency, diesel emissions reduction, railroad efficiency and heavy-duty engine idling. Tax credits for hybrids, alternative fuel and fuel cell vehicles figure prominently in the Act, along side grant and research programs to advance the development and commercialization of clean vehicle and fuel technologies. The Act also provides assistance in reducing emissions from heavy-duty diesel engines through grant programs that include: diesel truck retrofits and fleet modernization, heavy-duty idle reduction, and diesel emissions reductions. The diesel emission reduction program authorizes $200 million per year between 2006-2010 in grants and loans for state and local government agencies and non-profit organizations to replace/retrofit engines in non-attainment areas.

For detailed information on programs, tax incentives and authorized funding contained within the EPAct of 2005, please visit: http://www.eere.energy.gov/afdc/laws/epact_2005.html, or for the complete text of the Act please visit http://thomas.loc.gov/ and search by Bill Number for HR 6.

**US EPA National Clean Diesel Campaign-** provides nationwide funding for the retrofit of diesel engines. Recently the EPA administrator awarded 10 grants totaling $1 million to support clean diesel projects. These grants targeted emissions from non-road sources such as on-dock equipment at ports and construction equipment, and will include the use of cleaner fuels, aftertreatment devices and engine replacement. Recipients of the grants include state and local governments, port authorities and nonprofit organizations. Please see the national clean diesel campaign website for a description of the projects that received grants in 2005.
http://www.epa.gov/cleandiesel/awarded-grants.htm#grants-2005

**US EPA SmartWay Transport Partnership-** is a voluntary partnership between EPA and various freight industry stakeholders that creates incentives for fuel efficiency improvements and greenhouse gas emission reductions. The EPA recently awarded $5 million in grants under the Smartway Transport Partnership to five projects that deploy a variety of idle reduction technologies. For more information on the demonstration projects that received grants visit:
http://www.epa.gov/smartway/index.htm

**US EPA Voluntary Diesel Retrofit Program-** In 2005, EPA awarded 18 grants totaling $1.6 million for diesel emissions reduction projects. The projects target emissions reductions that will impact sensitive populations including children and the elderly. Projects include retrofits of commuter rail locomotives in California, repowering of waste hauling trucks with compressed natural gas in Connecticut, as well as retrofit projects for local governments and port authorities.
http://www.epa.gov/otaq/retrofit/dieselgrants2004.htm

**STATE**

**California**- The Carl Moyer Memorial Program (Carl Moyer) is the largest and arguably the most successful statewide granting program for diesel emissions reductions. The program targets real and quantifiable $NO_x$ and PM emissions reductions, by providing grants to support the adoption of cleaner diesel vehicles and equipment. Carl Moyer funds can be used for replacement, repowering, or retrofits for all types of diesel vehicles and equipment. The vehicles and equipment used for replacement, retrofit or repower projects must meet CARB certification standards. The program has provided grants for projects that include: repower of nonroad equipment/ refuse trucks, compressed natural gas buses, marine and locomotive repowers.

The program began in 1998 and has since provided more than $150 million in awards to private and public sector applicants. Program funding is expected to significantly increase in 2005 by up to $140 annually. Funding is allocated on an annual basis by the California legislature and requires funds to be matched by the local districts. Projects selected for funding are typically assessed based on cost-effectiveness criteria established by California's individual air pollution control and air quality management districts. Emissions reduced by the projects funded through the Carl Moyer Program have been estimated at 18 tons per day (tpd) $NO_x$ and 1 tpd PM through year 6 of the program, at an average cost-effectiveness of $3,000 per ton of $NO_x$ reduced.
http://www.arb.ca.gov/msprog/moyer/moyer.htm

**New York-** The New York State Energy Research and Development Authority's (NYSERDA) Alternative-Fuel Vehicle (AFV) Program provides financial incentives for fleets interested in purchasing light, medium or heavy-duty AFVs or installing alternative fuelling stations. Incentives are also available for bio-fuel and emissions reduction technology projects. State, municipal, school and private fleets all have access to NYSERDA funding through a variety of programs and projects that include:

- The New York State Clean Fuel Bus Program- offers assistance to bus operators for the purchase of new alternative-fuel buses and infrastructure. Funding will cover up to 100 percent of the incremental cost of alternative fuel or hybrid electric buses;

- The New York State Clean Air School Bus Program- funds up to 100 percent of the purchase and installation of emission reduction technologies (DOCs, DPFs) by school districts;

- The New York State Clean Cities Challenge- funds projects to accelerate the purchase of alternative fuel fleet vehicles in New York State. The program provides 75 percent of the incremental costs for the purchase of AFVs, fueling and recharging equipment, and costs for the conversion of medium and heavy-duty engines to alternative fuels. Eligible fleets must be owned or operated by US Department of Energy's Clean Cities member organizations;

- The New York City Private Fleet Program- offers funding to private companies operating fleets in New York City for the incremental costs associated with the purchase of light-duty natural gas or electric vehicles and infrastructure, and new or converted medium and heavy-duty natural gas, electric, dual fuel or hybrid-electric vehicles;

- The New York City Clean Fuel Taxi Program- supports the introduction of compressed natural gas taxi cabs into the New York City taxi fleet;

- The Diesel Idling Reduction Program- is currently underdevelopment, and will fund anti-idling technologies for heavy-duty vehicles.

http://www.nyserda.org/programs/transportation/afv/default.asp

**Texas**- Texas Emission Reduction Plan (TERP) is administered by the Texas Commission on Environmental Quality and provides voluntary incentive funding to reduce emissions in non-attainment areas. Since the plan's beginning in 2001, TERP has provided over $120 million in grants for approximately 280 diesel reduction projects. TERP offers several programs that can be used to target reductions from on-road and off-road sources. These programs include:

- New Technology Research and Development Program- can be applied to add-on and advanced technologies;

- Emissions Reduction Incentive Grants Program- is used to offset the incremental cost associated with the NOx emissions reduction measures in non-attainment areas of the state. Projects eligible for grants under the program include the purchase or lease, replacement, repower, retrofit or add-on of emission-reduction technology projects for on-road heavy-duty vehicles, off-road equipment, marine vessels and locomotives, as well as refueling infrastructure and truckstop and vehicle electrification;

- Small Business Grants Program- supports the repowering and replacement of older on-road heavy-duty diesel engines; and

- Heavy-Duty Motor Vehicle Purchase or Lease Incentive Program and Light-Duty Motor Vehicle Purchase Incentive Program, assists with the incremental costs of purchasing or leasing of eligible lower emitting on-road vehicles;

(http://www.tceq.state.tx.us/implementation/air/terp/index.html)

**LOCAL**

**South Coast Air District-** The Mobile Source Air Pollution Reduction Review Committee (MSRC) was established by the state legislature to provide incentive funding for programs that reduce mobile source emissions, including retrofit programs, in the South Coast Air District. The MSRC receives 30 percent of funds taken in from a vehicle registration surcharge of $4 in the greater Los Angeles region.
http://www.cleantransportationfunding.org/?fa=faqs#1

**Sacramento CA**- the Sacramento Emergency Clean Air Transportation (SECAT) Program was created by legislation which set aside $50 million from the 2000-2001 state budget to help the reduce region's heavy-duty truck emissions. An additional $20 million was allocated to the program from federal Congestion Mitigation and Air Quality (CMAQ) funding to the region. The program funds fleet modernization, retrofit, repowering and refueling projects and the application of any technologies verified by the California Air Resources Board.
http://www.4secat.com/index1.html

**PORTS**The Ports of Oakland, Los Angeles, and Long Beach all administer major grant programs to support diesel emission reductions in California. The programs typically support retrofiting, repowering, and replacing marine terminal equipment. However a growing number of ports are providing grants to scrap and replace older on-road trucks that regularly serve the ports. These port-administered grant programs are funded by the ports themselves, with additional assistance from state or federal agencies. Also see:

**Gateway Cities Diesel Fleet Modernization Program**- was established to replace the oldest and highest emitting heavy-duty trucks serving the ports of Los Angeles and Long Beach. The program is part of the Gateway Cities Council of Governments Clean Air Program, in partnership with the Port of Long Beach, the California Air Resources Board and the US EPA. Initial targets included the replacement of 3,000 existing heavy trucks in the greater Los Angeles area. Some of the replacement trucks are retrofitted with diesel oxidation catalysts and other PM and $NO_x$ control devices to further reduce emissions. Typical replacement trucks emit about 50 percent less $NO_x$ and 85 percent less PM. The Program awards average $25,000 per truck, with owners paying 25 percent to 33 percent of total truck cost. Some of those costs are also recouped with the added fuel-efficiency of replacement trucks. Over 5 years, the 350 trucks replaced to date, can be expected to reduce emissions by approximately 193 tons/year of $NO_x$ and 42 tons/year of PM.
http://www.gatewaycog.org/cleanairprogram/overview/overview.html

**Port of Oakland Air Quality Mitigation Program**- The Port of Oakland has allocated $2 million under its Air Quality Mitigation Program to assist in the replacement of high-emitting heavy-duty trucks serving the port. The Truck Replacement Project will provide incentive funding of up to $25,000 to owners of 1986 or older trucks for the replacement of their vehicle with a model year 1999 or newer truck. The Port also is providing funding for terminal operators to repower and retrofit terminal cargo handling equipment, as well as engine replacements for local transit buses.
http://www.portofoakland.com/environm/prog_06.asp

## D. ADVANCED MODELING TOOLS & TRAINING RESOURCES

We recognize that guidebook users may ultimately require more advanced analyses in order to determine the emissions and other impacts from a chosen policy. Based upon our experience working with states, CCAP has a clear understanding of the types of quantification tools likely to be most valuable to state policy makers. This section will include examples of specific emissions quantification tools, models and information sources. Below we describe several examples of such advanced analytical tools.

**AUTO Feebate Model.** AUTO (Automobile Use, Technologies, and Ownership) is an advanced modeling tool developed by Argonne National Laboratory. The model predicts the effects of feebates and forecasts changes in vehicle production, ownership and use based on implementation of feebate programs (each of which tilt the price that consumers pay for new vehicles in favor of the more fuel-efficient ones shift vehicles). Outputs include fuel consumption, energy and $CO_2$ emission savings.

**Brown University's Feebate Calculators.** In late 2003, the Rhode Island Greenhouse Gas Action Plan established the Vehicle Efficiency Incentive Act which was designed to help quantify emissions savings achieved by increasing the energy efficiency of Rhode Island's light duty vehicle fleet. A series of spreadsheets are available to help the user estimate emissions savings, compare vehicle costs and facilitate analysis of a feebate policy in Rhode Island.
http://envstudies.brown.edu/Classes/ES201/2003/VEIA/index.htm

**CARB Analysis of Mobile Source Emissions** (On-road and off-road)
The Motor Vehicle Emissions Inventory is an accounting of those pollutants attributable to both on-road and off-road mobile sources. The Planning and Technical Support Division has the primary responsibility for developing mobile source emissions inventories in California and for maintaining those mathematical models, EMFAC and OFFROAD, used to project changes in future inventories of mobile source emissions. The EMFAC model includes factors to analyze heavy-duty vehicles, LEVII, Inspection and Maintenance as well as reformulated (cleaner-burning) fuels. The OFF-ROAD model estimates the relative contribution of gasoline, diesel, compressed natural gas, and liquefied petroleum gas powered vehicles to the overall emissions inventory of the state.
http://www.arb.ca.gov/msei/msei.htm

**FHWA, Emissions Analysis Techniques for Transportation Control Measures,**
This report assists the user in understanding a variety of analytical approaches for estimating the emission impacts of transportation control measures. It includes separate sections which 1) review the effects of Congestion Management and Air Quality (CMAQ) strategies on emissions, 2) discusses travel and emissions models commonly used in metropolitan transportation planning that represent the state of practice in travel and emissions forecasting at a regional level and 3) describes alternative analytical approaches to forecasting travel and emissions impacts from transportation policies (technologies and fuel, as well as infrastructure).
http://www.fhwa.dot.gov/environment/cmaqeat/index.htm

**FHWA Analyses.** FHWA has developed two studies on vehicle fuels and technologies: 1) Fuel Options for Reducing Greenhouse Gas Emissions from Motor Vehicles (http://climate.volpe.dot.gov/docs/fuel.pdf) which is an assessment of the potential of gasoline substitutes to reduce emissions of carbon dioxide and other GHGs by automobiles and light-duty trucks and 2) Modeling of Advanced Technology Vehicles (http://climate.volpe.dot.gov/docs/atvm_final.pdf) that reviews some currently-used

methods for representing advanced technology vehicles in engineering and market simulation models, and considers the potential for simple generalized methodologies.

**GHGenius Model.** The GHGenius model is a Lifecycle Emissions Model (LEM) that uses a spreadsheet model to calculate the greenhouse gases generated from the time the fuel is extracted or grown, to the time that it is used in a motor vehicle to produce energy. The model requires extensive information on the energy usage for fuel production; distribution and related fuel cycle sources, as well as factors for emissions of non-greenhouse gases from these sources and motor vehicles. GHGenius can evaluate alternative fuel pathways and has a more detailed output for all contaminants, and an economic assessment of the lifecycle cost of greenhouse gas emission reductions. GHGenius currently has the capacity to predict emissions for past, present and future years through to 2050 for approximately 140 vehicle, fuel and feedstock combinations or pathways.
http://www.ghgenius.ca/

**GREET Model.** Sponsored by the U.S. Department of Energy's Office of Transportation Technologies, Argonne National Laboratory has developed a lifecycle fuel-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers to evaluate various engine and fuel combinations on a consistent fuel-cycle basis. For a given engine and fuel system, GREET separately calculates energy, $CO_2$-equivalent GHGs and criteria pollutants.
www.greet.org

**LEAP Model.** The Long-range Energy Alternatives Planning system (LEAP) is a scenario-based energy-environment modeling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population economic development, technology price and so on. In terms of transportation measures, LEAP can be used to calculate emissions reductions from policies on improved fuel economy, increased market penetration of particular vehicle technologies, and tailpipe emissions standards. Using inputs on fleet stock and sales data, fuel economy and mileage, and emissions factors for relevant fuel, LEAP calculates reductions of GHG emissions.
http://forum.seib.org/leap/

**National Academy of Sciences CAFE Study.** In legislation for fiscal year 2001, Congress requested that the National Academy of Sciences, in consultation with the Department of Transportation, conduct a study to evaluate the effectiveness and impacts of CAFE standards. This report evaluates the implications of these changes as well as changes anticipated in the next few years, the need for CAFE, and the stringency and/or structure of the CAFE program in future years.
http://books.nap.edu/html/cafe/

**Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles.** The March 2004 interim report by Northeast States Center for a Clean Air Future provides an assessment of the GHG emissions reductions that could be achieved in new, light-duty motor vehicles through the application of currently available and advanced motor vehicle technologies in the 2009-2015 timeframe. Results were obtained from original cost and technology analyses conducted for this study, together with information obtained from other available reports.
http://bronze.nescaum.org/committees/mobile/rpt040923ghglightduty.pdf

**TREMOVE Model.** TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates for policies as there are road pricing, public transport pricing, emission standards, subsidies for cleaner cars etc. the transport demand, modal shifts, vehicle stock renewal and scrappage decisions as well as the emissions of air pollutants and the welfare level. The model covers passenger and freight transport in the EU 15 plus the accession countries over the period 1995-2030.
http://www.tremove.org