Modal Primer on Greenhouse Gas and Energy Issues for the Transportation Industry

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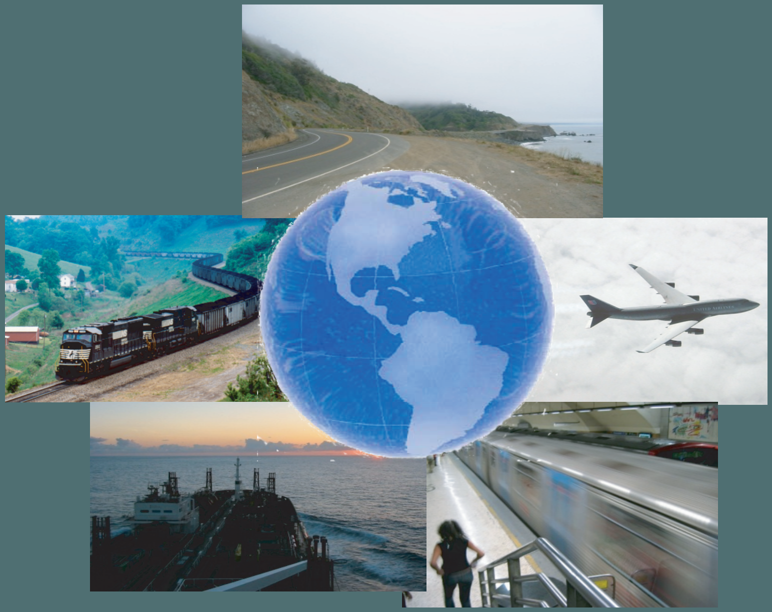

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Modal Primer on Greenhouse Gas and Energy Issues for Transportation

Prepared for the
Transportation Research Board
Special Task Force on Climate Change and Energy

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TRB expresses appreciation to the volunteers who wrote and reviewed sections of this circular, with special thanks to Peter Bryn, who led this effort from initiation through delivery of the final report.

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Contents

Introduction

PETER BRYN
SeaRiver Maritime, Inc.

This circular presents the collective results of an effort by volunteer members throughout the transportation industry to develop brief but informative overviews of the primary transportation modes focused on climate change and energy issues. The teams were varied in background, though each worked hard to provide a comprehensive discussion of the current status and potential future of its respective transportation mode. This has been particularly challenging given the ever-changing nature of this subject, most notably in the evolving regulatory arena. All of the teams and their readers are to be commended for producing and reviewing these high-quality discussions under several very tight deadlines.

The goal of this effort has been to provide transportation decision makers with an inclusive, educated, and objective overview of the current state of the transportation industry from a greenhouse gas and energy standpoint. These are neither position nor advocacy papers, and best efforts were made to include a broad spectrum of viewpoints, from academics and researchers to practitioners and policy makers alike. While each paper had readers, they have not been formally peer-reviewed and therefore should not be used as a sole or primary reference for academic research.

One important area not discussed in this primer is climate change adaptation. The reason for this was both to limit the paper’s scope and to avoid redundancy with the adaptation-focused TRB policy study, *Special Report 290: The Potential Impacts of Climate Change on U.S. Transportation*.

Please also note that while this effort was intended to be conducted in parallel with existing TRB efforts and was coordinated by the TRB Special Task Force for Climate Change and Energy, these discussions were written as white papers by contributing authors. Therefore, they neither necessarily reflect the opinions of TRB nor the respective organizations with which the authors are associated.

Read this primer and become engaged in the already active discussions on greenhouse gas and energy issues, which are sure to become even more fundamental to the future of the transportation industry and society at large.

1

Road Transportation

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The U.S. transportation system is the largest in the world, and road transportation, by most measures, is its largest mode (especially for passenger travel). In 2006, Americans traveled nearly 5 trillion miles, of which 87% was carried out on road, specifically in personal vehicles (cars, light trucks and motorcycles). Road transportation alone is responsible for 72% of all transportation-related greenhouse gas (GHG) emissions in the United States. The number of personal vehicles currently registered is 229 million, which means every thousand Americans own 766 cars, light trucks, or motorcycles: the highest in the world. Each of these vehicles travels, on average, over 11,300 miles a year.[1] The high level of ownership and travel activity is driven by high income, large geographic area, a suburban lifestyle, and lack of alternate transportation modes. Total travel activity has been increasing (except during the 2008–2009 recession period), caused predominantly by growth in per capita income, economic output and population (Greene 2007). Table 1 and Figure 1 present the summary of U.S. road travel and corresponding energy use, for both passengers[2] and freight.

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[1] Numbers are slightly different from those in the *Transportation Energy Data Book* (Davis and Diegel 2008) because we considered personal vehicles *only*.
[2] Exclusive of passenger travel on road public transit modes.

TABLE 1 Summary of U.S. Road Activity in 2006

Item	Vehicle Count	Vehicle-Miles	Pass-Miles, Ton-Miles	Load Factor	Energy Intensity		Energy Use
Units	10^3	10^6	10^6	Pers/veh, tons/veh	Btu/veh-mile	Btu/pas-mile, Btu/ton-mile	10^{12} Btu
Cars	135,400	1,682,671	2,641,793	1.57	5,514	3,512	9,277.7
Light trucks	87,223	910,229	1,565,595	1.72	6,785	3,944	6,175.5
Motor cycles	6,686	12,401	14,881	1.2	2,226	1,855	27.6
Heavy Single unit trucks	6,649	80,331	320,000	4	15,900	3,975	1,278
Combination trucks	2,170	142,706	710,000	12	25,600	2,133	3,652

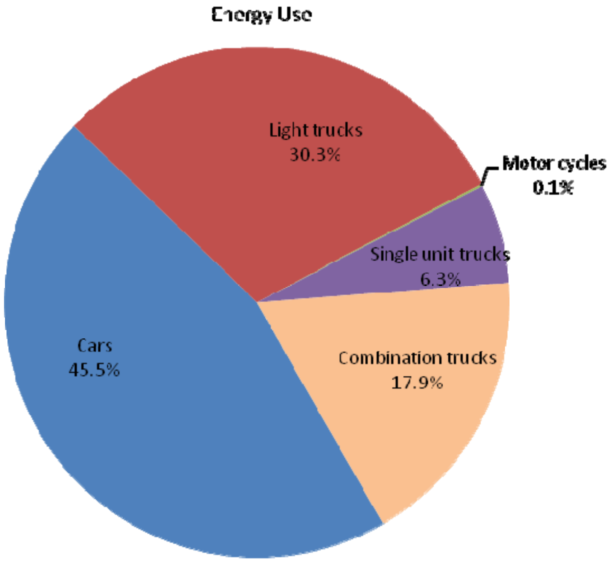

FIGURE 1 Share of energy use by different vehicles in U.S. road sector (except for road transit). (Davies and Diegel 2008, 2007).

Highway vehicles were responsible for more than 84% of all civilian transportation petroleum use by volume.[3] Within the road transportation sector, 75.5% of this petroleum is used by personal light vehicles (automobiles and motorcycles), 21.6% by medium or heavy trucks, and 0.8% by different bus types. U.S. fuel consumption for personal vehicles alone was 135.6 million gallons of gasoline, diesel, or gasohol in 2006 (Davies and Diegel 2008).

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[3] Carbon emissions are directly proportional to fuel consumption.

TECHNOLOGY LANDSCAPE

The personal vehicle segment is dominated by gasoline powered vehicles, as only 0.5% of the cars and 4% of the personal light trucks use diesel. Diesel, however, dominates the heavy vehicle segment. Both gasoline and diesel vehicles use internal combustion engines (ICE), the difference being that diesel engines use a compression ignition (CI), as opposed to spark ignition (SI) in gasoline engines. Diesel engines are significantly more efficient primarily because some of the flow losses are avoided and compression ignition allows for a much higher compression ratio. Petroleum diesel fuel also contains more energy per unit volume than gasoline, further enhancing diesel engine fuel efficiency (on a per gallon basis) over gasoline. In 2006, 97.8% of new light-duty vehicle sales in the United States. were SI engines (89.5% conventional, 5.1% flex-fuel, 1.9% gasoline hybrid, 1.1% compressed natural gas or liquid petroleum gas), and the remaining 2.2% were diesel CI (Yang et al. 2008a).

The United States also has significant ethanol production facilities from renewable feedstock, almost all of which is blended with gasoline for use in vehicles. Vehicles that can run on either gasoline or E85 (15% gasoline, 85% ethanol) are known as flex-fuel vehicles. In addition, a small number of light trucks, buses, and heavy trucks run on liquid petroleum gas (LPG) or compressed natural gas (methane, CH_4).

The current car and light-truck fleets in the U.S. have fuel economies of 22.4 and 18 mpg, respectively, though the average of the current fleet entering the market is higher, with the best conventional midsize gasoline automobiles rating over 30 mpg when new (U.S. EPA 2008a).[4] The most fuel-efficient compact diesel vehicle is rated at 41 mpg. In the past few years, hybrid vehicles, which innovatively use a gasoline combustion engine coupled with an electric motor and regenerative braking technology, have also been introduced. These vehicles typically rate above 40 mpg. Although the sale of hybrid vehicles have been impressive (currently 700,000 on road), they represent only 0.3% of the total light-duty vehicle fleet.

The heavy-vehicle fleet, due to its larger range of vehicle sizes and duty cycles, has a broad range of fuel economy. A typical long-haul tractor trailer rig, weighing 30 to 40 tons when loaded, will average around 6 mpg. Heavy urban vehicles, such as buses or garbage trucks, may average as low as 2 mpg due to frequent stops and idle time. Hybridization is helping to facilitate significant improvements in fuel economy in these types of urban vehicles.

EMISSIONS INVENTORY

The dominant GHG emission for the road sector is CO_2 resulting from the combustion of petroleum fuels. Unlike “criteria” emissions (e.g., nitrogen oxides (NOx), unburned hydrocarbons, particulates), which are undesirable products of internal combustion that can be reduced by engine technology and catalytic systems, CO_2 is a direct output of hydrocarbon fuel combustion and is directly proportional to the amount of fuel burned, for any given fuel type. In other words, the only way to reduce CO_2 from gasoline consumption is to reduce the amount of gasoline consumed. Every gallon of gasoline consumed results in 19.4 lbs. of CO_2 emissions.

Carbon emissions from different types of on-road vehicles can be expressed by the following relationship:

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[4] On-road fuel economy is around 20% smaller than the EPA-reported drive cycle–based fuel economy.

$$\textit{Emissions} = \textit{vehicle travel activity} \times \textit{vehicle fuel intensity} \times \textit{fuel carbon intensity} \qquad (1)$$

where

vehicle travel activity = total freight ton-miles or passenger-miles carried by that mode or vehicle class (it is impacted by a large number of economic and societal factors);
vehicle fuel intensity = measure of fuel consumption per passenger-mile or ton-mile of travel and is a function of vehicle loading logistics (people or tons carried per vehicle trip), vehicle technology, transportation infrastructure, and travel conditions; and
fuel carbon intensity = ratio of carbon dioxide generated per unit of fuel, which is a function of fuel type (accounting for only tailpipe emissions, not life cycle).

Table 2 presents the tailpipe GHG emissions from personal vehicles and freight trucks. It is important to recognize that road transportation's carbon emissions are generally calculated only for tailpipe emissions. Upstream emissions in the fuel cycle can be different for different fuel types, and may account for 20% or more of total life cycle (or "well-to-wheel") carbon emissions from the fuel (Weiss et al. 2000).

In addition to CO_2, small amounts of nitrous oxides (N_2O) and methane (CH_4) are emitted by internal combustion engines. Although N_2O and CH_4 are 310 and 21 times more effective as GHG than CO_2,[5] their small generation rates make them negligible fractions of road transport's overall GHG emissions (Weiss et al. 2000).

REGULATORY LANDSCAPE

The U.S. federal government plays a regulatory role in motor vehicle safety, fuel efficiency, and operations. Most of these regulatory responsibilities fall under the jurisdiction of agencies housed within the U.S. Department of Transportation.

The Federal Highway Administration administers the federal-aid highway program, influencing the design, construction, and operating performance of the nation's highway system. The highways themselves are owned and operated by state and local governments, which establish most operating parameters such as speed limits and truck size and weight limits.

The Federal Motor Carrier Safety Administration is concerned with commercial truck and bus safety, strengthening commercial vehicle equipment and operating standards.

The National Highway Traffic Safety Administration (NHTSA) sets and enforces safety performance standards for motor vehicles. NHTSA also has responsibility for setting and enforcing vehicle fuel economy standards (see next section).

The U.S. Environmental Protection Agency (EPA) regulates the criteria pollutants and air toxic pollutants emitted from motor vehicles under the Clean Air Act, and thus regulates the composition of motor fuels (e.g., sulfur content in fuel).

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[5] 100-year global warming potential (radiative forcing change when the time period is considered).

TABLE 2 Tailpipe GHG Emissions (Tg) from Road Transportation (EPA, 2008b)

	Fuel	**CO_2**	**CH_4 (CO_2 equivalent)**	**N_2O (CO_2 equivalent)**
Passenger car	Gasoline + gasohol	630.4	1.0	15.6
	Diesel	4.1	<0.05	<0.05
Light-duty trucks	Gasoline + gasohol	488.0	0.7	12.6
	Diesel	26.4	<0.05	<0.05
	Others (LPG)	0.4	<0.05	0.1
Medium or heavy trucks	Gasoline + gasohol	35.2	0.1	0.7
	Diesel	365.4	<0.05	0.3
	Others (LPG)	0.6	0.05	0.1
Motorcycles	Gasoline	1.9	<0.05	<0.05

California and many other state and regional jurisdictions nationwide also regulate emissions standards or fuel composition within state borders. Local governments have jurisdiction over the planning of local roads and parking requirements, which can also impact carbon emissions.

At times, the automobile industry, particularly in the United States, has demonstrated resistance to mandates on the types of vehicles that it produces, and standards on emissions or fuel economy. However, fluctuating fuel prices; the expectation of a climate policy; regional emissions and fuel economy regulations (particularly those in California); and the success of hybrid vehicles have all provided impetus to the entire auto industry to improve the fuel economy of their vehicles. The “big three” U.S. manufacturers (General Motors, Ford, Chrysler), along with several other relevant industry consortia, actively participate in the FreedomCAR initiative and other fuels programs to conduct research on advanced vehicle and fuel technologies.

Within the commercial truck market, there is a strong demand for fuel efficiency since it enhances the slim profit margins for commercial carriers. The 21st Century Truck Program coordinates government–industry cooperative efforts to improve heavy truck fuel efficiency and reduce emissions. However, the economic viability of fuel efficiency technology is directly impacted by the cost of fuel. Fluctuation in fuel prices drives a conservative planning basis for investment in such technologies, making it more difficult for them to compete. Further, full implementation and production would take many years.

EMISSIONS MITIGATION

There are three basic ways to reduce GHG emissions from the road transport sector:

1. Increase energy efficiency (measured either as vehicle-miles per gallon, passenger-miles per gallon, or freight-miles per gallon) through technological innovation and improved operational efficiency of vehicles, transport logistics, and transportation infrastructure,
2. Decrease GHG intensity of the fuel, and
3. Reduce transportation activity.

It is important to note that any one of these strategies alone cannot guarantee an absolute reduction in emissions, since exogenous factors, particularly economic and population growth, often counter such progress. Despite significant improvement in the fuel economy of light-duty vehicles, for instance, total fuel consumption has increased because population, vehicle ownership, and travel activity have all increased.[6] Similarly, heavy-truck freight and VMT have increased with the economy. Further, there has been a strong shift in consumer preference toward light trucks, which are far less fuel efficient. An effective mitigation strategy may need to address all three of the above elements, though any policy decision should engage the markets to find the most efficient solution.

Initiatives on Fuel Economy

Historically, the single most important federal regulation to curb U.S. carbon emissions from the road sector was the Corporate Average Fuel Economy (CAFE) standard. CAFE was enacted during the 1970s oil crisis to reduce petroleum dependency and improve U.S. energy security. The policy mandated that every light-duty vehicle manufacturer (or importer) in the U.S. meet a target, sales-weighted fuel economy for all of its new vehicles. Two different standards were developed: one for cars and one for light trucks. Current car fuel economy standard is 27.5 mpg, which has been stagnant since 1990 model cars. For light trucks, the standard is 22.2 mpg for model year 2007, which was slightly tightened in 2004 and then again in 2006 after a stagnant period from the mid 1990s.

The Energy Independence and Security Act of 2007 (EISA, Congressional Research Service 2007) expanded the existing CAFE rules. The new standard mandates a fuel economy of 35 mpg by model year 2020 for the combined fleet of cars and light trucks, while interim standards will be enacted starting in model year 2011. The Act also allows trading fuel economy credits among the manufacturers. In addition, the Act calls for developing fuel economy standards for medium and heavy duty trucks. By 2015, federal agencies are required to reduce their fuel consumption by 20% and increase the alternative fuel consumption by 10% over a 2005 baseline. The EISA also enhances the existing Renewable Fuels Portfolio Standard to mandate a minimum of 9 billion gallons/year of renewable fuel in the transportation fuel mix in 2008, increasing to 36 billion gallons/year by 2022. An increased share of appropriate renewable fuels in the fuel mix could reduce the life cycle carbon intensity of the fuel, thus reducing the overall carbon emissions from fuel combustion. EPA also has set emissions standards for both light-duty vehicles and heavy vehicle engines for criteria air pollutants, including NO_X emissions standards that can indirectly affect N_2O emissions, a GHG. However, most options to control diesel NO_X may reduce cycle efficiency, resulting in increased fuel consumption.

There are many federal and state programs that fund vehicle R&D to improve efficiency and promote purchase of the most efficient vehicles. One example is EPA's SmartWay program, which certifies light duty vehicles and heavy duty tractors and trailers, based on fuel efficiency features and capability to use alternate fuels. This has been quite successful in heavy duty where trucking fleets welcome advice on saving fuel in their operation and can become SmartWay partners.

In addition to the federal mandates, some states and cities can have imposed their own GHG mitigation plans. The state of California's comprehensive climate plan includes light-duty

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[6] Travel activity decreased recently, primarily because of higher fuel prices during 2008 and the slowing of the economy.

vehicle GHG standards, low carbon fuel standards, and other vehicle efficiency measures for light, medium and heavy vehicles. California has also proposed a mandate that certain heavy trucks be equipped with the EPA's SmartWay features to improve fuel efficiency. Many states also have anti-idling rules for trucks. Washington also has a policy to reduce total VMT within the state. Finally, in May 2009, the federal government announced a historic agreement for joint regulation of GHG emissions and fuel economy involving EPA, NHTSA, and the state of California.

Other Initiatives

The regulatory initiatives mentioned above primarily focus on increasing fuel economy and decreasing the carbon intensity of fuel by mandating specific standards, targets or technologies. The EISA 2007 does not address managing vehicle activity as an option to reduce carbon and GHG emissions. While the EISA aims for a reduction in carbon emissions from the vehicles by 2030, U.S. Department of Energy forecasts an increase of 50% in the total vehicle travel activity between 2005 and 2030. These competing factors are likely to yield an absolute increase of carbon emissions in 2030 (Winkleman 2008), which emphasize the importance of managing vehicle activity and/or more aggressively pursuing the technological options in curtailing carbon emissions from road transport.

There are numerous other initiatives that can directly or indirectly help reduce carbon emissions from the road transport. These can include

- Pricing mechanisms to reduce driving, encourage fuel efficient vehicles and driving habits, and enhance the value of both renewable fuels and fuel-saving technologies; e.g., implement fuel taxes (fixed or variable), carbon cap and trade, road pricing, pay-as-you-drive insurance, parking pricing, etc.;
- Promotion of less-GHG intense alternatives to road travel; e.g., improve transit systems, invest in walking and biking facilities, coordinate land use and transportation planning (which reduces travel), increase telecommuting, etc.; and
- Improvement of operational efficiency; e.g., carsharing and carpooling, reduce speed limits, mandate tire pressure warning or maintenance systems, implement congestion mitigation and traffic calming measures, traffic systems management, improve freight logistics, promote infrastructure to maximize the effective use of intermodal freight (truck, rail, and water), reduce packaging volume and waste, reduce truck idling, increase truck size and weight limits to increase payload capacity, increase flexibility in truck hours of service rules, etc.

Many of these initiatives (congestion reduction, land use planning, transit improvement, walking and biking facility investment, and parking charges) are local or regional in nature and have been implemented by various local councils within the United States, though the primary focus has often been to relieve traffic congestion.

Besides CAFE standards, consumer incentives to buy more fuel efficient vehicles currently include a tax rebate program for buying hybrid, flex-fuel, and some fuel efficient vehicles. The "gas guzzler" tax discourages poor fuel economy cars, although there is no such tax for light trucks that have even worse fuel economy. Feebates and accelerated scrapping of old vehicles can also remove less efficient vehicles from the road, though it shortens vehicle turnover time, and in turn requires production of more vehicles.

Mitigation Potential

The principal approach to mitigate carbon emissions in the United States has been to rely on technological innovation to reduce carbon emissions through increased fuel efficiency and reduced carbon intensity of fuel. Opportunities exist to enhance the fuel efficiency of the vehicles through incremental improvements, since there are significant inefficiencies inherent to the internal combustion engines and various other components in an automobile. For example, in a typical SI port injection gasoline vehicle under urban conditions, 87% of the input fuel energy is essentially unproductive (Yang et al. 2008a). A recent study at MIT (Bandivadekar et al. 2008) outlines the potential gains possible in vehicle fuel efficiency through improvements in current internal combustion engines, advanced internal combustion engines and other advanced propulsion technologies. Table 3 presents the summary of fuel economies for a future passenger vehicle using different propulsion technologies. It appears that the passenger car segment of the industry is well within the reach of 35 mpg limit set by the Energy Security Act 2007, although the light truck segment may struggle.[7]

Economic models (Creyts et al. 2007) predict that gains associated with conventional IC engines (rows 5–7 in Table 3) may be achieved at a negative cost, i.e., cost savings due to higher fuel economy can compensate for increased purchase cost of the vehicles.[8] National Commission on Energy Policy (2004) also concluded that future increases of fuel economy ranging 40% to 80% are possible without additional costs (considering fuel saving costs) to the users. This represents a potential reduction of 250 to 400 million tons of carbon per year by 2030.

TABLE 3 Projected Fuel Economy (in gasoline equivalent mpg) of Future Light Vehicle Propulsion Technologies

	Technology	Fuel	Cars	Light Trucks
1	Current SI	Gasoline	26.7	17.3
2	Current CI	Diesel	31.8	23.3
3	Current turbo SI	Gasoline	29.8	20.8
4	Current hybrid	Gasoline	37.9	24.8
5	2035 SI[a]	Gasoline	42.8	27.4
6	2035 CI[a]	Diesel	50.0	34.6
7	2035 Turbo SI[a]	Gasoline	48.0	32.2
8	2035 Hybrid[a]	Gasoline	75.9	49.0
9	2035 Plug-in hybrid	Gasoline + electricity	109.4	69.0
10	Fuel cell	Hydrogen	102.3	
11	Battery electric	Electricity	138.4	

Source: Bandivadekar et al. 2008.

[a] Represents incremental changes in current technology.

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[7] However, the standard is set for combined cars and light trucks.

[8] For petroleum price of US$59 per barrel.

Diesel engines have superior fuel economy to gasoline, though, until recently they emitted more black carbon particulate matter that is both a criteria pollutant and a potential greenhouse contributor. Therefore, without particulate emission control, diesel engines may have the potential of a net warming effect over gasoline engines (Yang et al. 2008b). However, since the introduction of wall-flow particulate traps in 2007, over 99% of black carbon emissions can be eliminated.

Although new vehicle fuel economy can be improved, fleet turnover will drive the rate at which these improvements are realized. The average fuel economy (mpg) of the 2035 on-road vehicle fleet, therefore, could possibly be half that of a contemporary new vehicle (Greene and Schafer 2003). It is also important to note that commercial and cost effective deployment of fuel cell (FCV) and battery electric vehicles (BEV) still require significant breakthroughs in research, as well as deployment of a new fueling infrastructure. The carbon reduction potential of plug-in hybrids, FCVs, and BEVs also all critically depend on the carbon intensity of the energy sources for electricity or hydrogen.

The other primary technology-based alternative is reducing the carbon content of fuel on a life cycle basis. The currently dominant renewable fuel in the United States is corn-based ethanol (4 billion gallons produced in 2005). Although corn ethanol is a renewable fuel, the net GHG improvement over gasoline is estimated at only 0% to 14%, depending on the emissions intensity of the production processes and land use impact.[9] Biodiesel fuel, typically made from soy oil in the United States, has been estimated to reduce life cycle CO_2 emissions by approximately 40% versus petroleum diesel. However, emissions from land use changes due to increased biofuel production remain an area of significant uncertainty, and some recent studies suggest that there could be a net increase in emissions once considered.

Cellulosic biofuels, where feedstock can be sourced from crop residue, wood waste, or energy crops (like switch grass), has the potential for a reduction of 70% to 88% of carbon emissions compared to gasoline (Yang et al. 2008b). It is estimated that a biomass feedstock for up to 86 billion gallons of cellulosic biofuels is available without adversely affecting current land use patterns (Creyts et al. 2007). Cellulosic ethanol, however, may require a parallel delivery infrastructure for large scale penetration since it cannot utilize existing pipelines. Cellulosic synthetic diesel or gasoline, on the other hand, can avoid these additional delivery capital costs since it does not face the same incompatibility issues, but will still require significant investments in processing plants and feedstock delivery. At present, however, producing cellulosic biofuels is more expensive than producing corn-based ethanol. Significant technological breakthroughs in the conversion process and sustained increases in the cost of petroleum will be required to bring costs to a competitive level.

Among the alternative fuels, hydrogen has received perhaps the greatest attention because of its carbon-free combustion characteristics. Although hydrogen produced from biomass or renewable electricity can have near-zero GHG emissions on a life cycle basis, current methods of hydrogen production from natural gas, coal, or grid electricity, create significant upstream emissions. Some frontier technologies may allow hydrogen production with lower life cycle emissions (from coal with carbon capture and storage, biomass gasification, etc.).

The success of low-carbon electricity generation will be crucial in guiding the future of road transportation. If carbon capture and storage, nuclear, solar, wind, biomass, or other

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[9] There is a possibility that the renewable fuel mandate by the EISA-2007 may lead to no carbon savings if corn-based ethanol is used to fulfill the target volume.

technologies can be successfully deployed, electricity may be produced with very low associated carbon emissions. Under such a scenario, hydrogen FCV, BEV, or plug-in hybrid vehicles could be operated with little associated carbon emissions.

Fuelling infrastructure will be an important component in all of these future strategies. Fuels that can be used at some blend level in the current fleet and with similar storage requirement as gasoline or diesel, like ethanol or biodiesel, can be introduced without major new infrastructure. Use of frontier fuels like hydrogen, however, would require new infrastructure, making it more of a long-run option, perhaps beyond 2030 (Greene 2007). Fortunately, new technology will be introduced at the gradual rate of fleet turnover, which will help this process.

Similarly, some fuels, like hydrogen and electricity, present challenging energy storage hurdles, which are significant barriers to economic implementation. The primary challenges are energy capacity, safety, and, for gaseous fuels, compression requirements. Energy capacity is particularly challenging for heavy trucks where the average energy demand is 10 to15 times greater than for light duty vehicles. There are no current viable technologies for replacement of IC engines in heavy vehicles except for very short distances.

Although technological innovation (through improving fuel economy and reducing carbon content of fuel) has been the primary policy approach in the United States, this only reflects the policy priorities of the United States and some state governments. Widespread improvements in operational efficiency and reduction in travel activities through other means can contribute significantly in slowing the emissions growth in the long run.

CONCLUSION

For the first time since the dawn of the automobile age, it now seems possible that the conventional gasoline SI engine could actually lose its dominance in U.S. light-duty vehicles due to major technological breakthroughs, continued volatility in petroleum prices, stringent regulation of fuel economy or GHG emissions, and recent government influence on bankrupt auto manufacturers. Though some economic analyses show that road transportation may not be the most cost-effective sector of the economy for emissions reduction, economically sound progress is still likely to be made. Substantial cobenefits may also exist, including reduced criteria emissions with associated health benefits, reduced use of petroleum, greater energy security, and reduced traffic congestion.

The principal challenges will be to find the right cost–benefit balance amongst the full array of policy options, costs, and outcomes, which will be needed to develop and implement an appropriate portfolio of mitigation strategies.

ACKNOWLEDGMENT

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2

Rail Transportation

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Association of American Railroads

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America's freight and passenger railroads are the most energy efficient mode for moving cargo and passengers among other land-based alternatives. This section will deal primarily with rail freight operations and the use of railroads for freight transportation to reduce GHG emissions. While Amtrak is discussed briefly in this section and many technologies used in freight operations can be used in heavy rail passenger operations, passenger rail is discussed in the Transit section.

As shown in Figure 2, Class I railroads account for most of the transportation of freight by rail. Class I railroads, and indeed most small railroads, are privately held, for-profit companies. The railroads utilize approximately 28,000 locomotives to move approximately 1.6 million rail cars.[1]

Since passage of the Staggers Rail Act in 1980, which reduced economic regulation of the railroad industry, America's freight railroads have undergone a renaissance. Freight railroads are competing effectively with highway trucks as shown in Figure 3. Freight railroads account for approximately 43 percent of intercity freight ton-miles.

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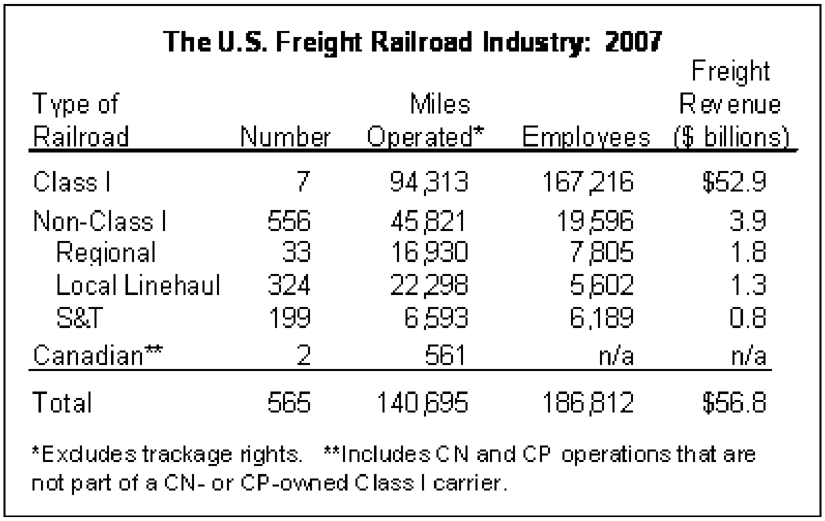
[1] Data from the Bureau of Transportation Statistics, *National Transportation Statistics*, http://www.bts.gov/publications/national_transportation_statistics/, Table 1-46b.

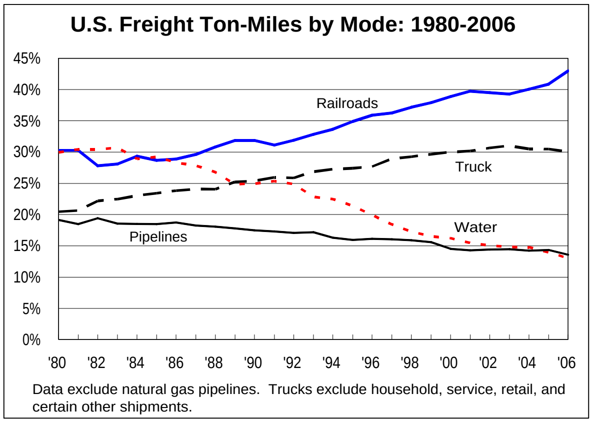


The U.S. Freight Railroad Industry: 2007

Type of Railroad	Number	Miles Operated*	Employees	Freight Revenue ($ billions)
Class I	7	94,313	167,216	$52.9
Non-Class I	556	45,821	19,596	3.9
Regional	33	16,930	7,805	1.8
Local Linehaul	324	22,298	5,602	1.3
S&T	199	6,593	6,189	0.8
Canadian**	2	561	n/a	n/a
Total	565	140,695	186,812	$56.8

*Excludes trackage rights. **Includes CN and CP operations that are not part of a CN- or CP-owned Class I carrier.

FIGURE 2 Freight rail industry profile. (Association of American Railroads, *Railroad Facts: 2008 Edition*, October 2008, p. 3)



Data exclude natural gas pipelines. Trucks exclude household, service, retail, and certain other shipments.

FIGURE 3 Freight rail industry. (Association of American Railroads, *Profiles of U.S. Railroads*, 2007 (an AAR database); Association of American Railroads, *Railroad Equipment Report*, 2008, p. 63)

TECHNOLOGY LANDSCAPE

Virtually all freight locomotives are diesel–electric locomotives. Passenger locomotives are either diesel–electric or electric. Amtrak uses electric locomotives on its Northeast Corridor and electric locomotives are also used by some commuter railroads.

There has been some experimentation with alternative technologies. A small number of hybrid switch locomotives have been built. There also are a few LNG-powered locomotives and a demonstration low-powered fuel cell locomotive is being built. However, diesel–electric technology has been, and for the foreseeable future will be, the means by which virtually all freight locomotives are powered.

Diesel–electric locomotives vary widely in terms of horsepower. Line-haul locomotives range up to 6,000 horsepower. Switch engines, used in rail yards, typically have engines in the 1,500 to 2,000 horsepower range. One recent innovation has been genset switch locomotives using two or three 700 diesel horsepower engines based on low-emissions highway technology.

Locomotive engines differ from engines used in most other mobile sources in that the engines are connected to an electric alternator or generator to convert mechanical energy to electricity. The electricity powers axle-mounted traction motors that turn the wheels. In most other cases, mobile source engines utilize a mechanical transmission to transfer energy from the engine to the wheels. Thus, as compared to highway engines, locomotive engines operate in an essentially stead-state mode, typically using eight discrete engine speeds or “throttle notches.”

Another difference between locomotive engines and diesel engines used in most other mobile sources is that, with the exception of the genset engines, locomotive engines generally use water as a cooling medium, not antifreeze. If antifreeze were used, larger radiators, which might not fit on the locomotive, would be necessary. In addition, ethylene glycol-based antifreeze reacts unfavorably with the lubricating oils used in railroad diesel engines when coolant leaks occur.

Still another unique feature of locomotives is dynamic braking. In dynamic braking, the traction motors act as generators. The generated power is dissipated as heat through an electric resistance grid. One locomotive manufacturer has a prototype locomotive that captures the power generated during braking and stores it in batteries.

Finally, locomotive engines typically last much longer than engines used in most other applications. Locomotives can last over 40 years. Of the approximately 24,000 locomotives owned or leased by the seven largest railroads, approximately one-third were built before 1985.[2] Most locomotives used by small railroads are decades old.

EMISSIONS INVENTORY

Rail accounts for 2.9 percent of GHG emissions attributable to transportation.[3] Of course, almost all of the GHG attributable to the railroad industry are from locomotives. CO_2 accounts for almost all of the GHG emitted by locomotives.

Most, but not all, of the railroad industry’s CO_2 emissions are attributable to diesel emissions. EPA estimates diesel locomotives annually emit 46.0 Tg of CO_2.[4] Electric locomotives also account for some CO_2 emissions, estimated by EPA to be 4.8 Tg CO_2e.[5]

EPA also estimates annual emissions of CH_4, N_2O, and HFCs. Only 0.1 and 0.4 Tg CO_2e

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[2] *Railroad Facts*, supra n., p. 50.

[3] Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*, http://www.epa.gov/climatechange/emissions/usinventoryreport.html, p. 2–21.

[4] Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*, http://www.epa.gov/climatechange/emissions/usinventoryreport.html, pp. 3–13.

[5] Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*, http://www.epa.gov/climatechange/e.missions/usinventoryreport.html, pp. 3–13

of CH_4 and N_2O, respectively, are attributed to the railroad industry.[6] HFCs are also emitted in small amounts, attributed to the refrigeration equipment used to transport agricultural goods.[7]

REGULATORY LANDSCAPE

Overview

EPA regulates both criteria pollutants emitted from locomotives and the fuel used in locomotives. As with other mobile sources, EPA's regulations are not directly aimed at GHG. However, at least one of EPA's regulations does affect both fuel consumption and the emission of GHG. EPA requires that when locomotive engines are manufactured or remanufactured, the locomotives must be equipped with idling reduction technology.[8] The most widely used technology is a stop-start system, which will shut down a locomotive automatically assuming certain parameters are met, e.g., ambient temperature. Some locomotives are also equipped with auxiliary power units, which will keep an engine warm in freezing temperatures, thus enabling the shutting down of locomotives in cold weather.

The regulation of the remanufacturing of locomotives is an important feature of EPA's regulatory scheme for the railroad industry. Locomotives are regulated both when initially manufactured or when remanufacturing, which takes place a number of times over a locomotive's life. Although EPA first issued its locomotive emissions standards in 1998, the agency applied its remanufacturing standards to locomotives built as far back as 1973. Thus, even though turnover of the locomotive fleet occurs very slowly (in most years, less than a thousand locomotives are built),[9] EPA's emissions standards have reduced emissions significantly more than if the standards had just been applied to the initial manufacturing process.

Railroads' Role in Greenhouse Gas Emissions

While the railroads account for 2.9 percent of the GHG emissions attributable to transportation, they play a positive role in reducing the emissions of GHG. According to a DOT study, railroads are approximately three times more fuel efficient than motor carriers for truck-competitive traffic. [10] Consequently, GHG are reduced by approximately two-thirds for each ton-mile of freight that moves by rail instead of truck. To put it another way, GHG would be reduced by approximately 1.2 million tons for every 1 percent of long-haul freight that moved by rail instead of by truck (see Figure 4).

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[6] Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*, http://www.epa.gov/climatechange/e.missions/usinventoryreport.html, pp. 3–14, 3–15.

[7] pp. 4–60. EPA might have overstated the amount of HFC emissions from railroad transportation of refrigerated goods. The Association of American Railroads submitted comments to EPA stating that EPA had vastly overstated HFC emissions from refrigerated equipment used in the railroad industry.

[8] 40 C.F.R. § 1033.115(g).

[9] *Railroad Facts,* supra n., p. 55.

[10] Abacus Technology Corporation, *Rail vs. Truck Fuel Efficiency,"* at S-6 (April 1991) (written for the Federal Railroad Administration) (railroad double-stack transportation is "2.51 to 3.43 times more energy-efficient than comparable truck moves").

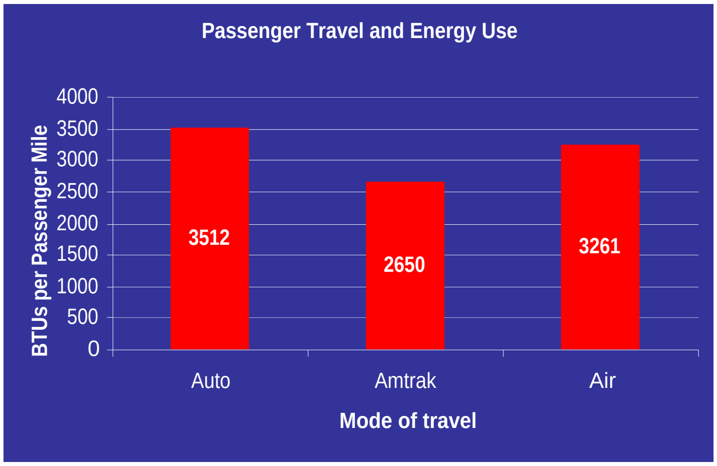

FIGURE 4 Passenger travel and energy use.[11]

Another advantage of railroad transportation is that moving more freight by rail reduces highway congestion by taking trucks off the highway. A single train can take hundreds of trucks off the highways.

Passenger rail service is also advantageous. Virtually all intercity passenger service is provided by Amtrak. According to Oak Ridge National Laboratory, on a systemwide basis (i.e., taking into account disutilization losses), it takes fewer BTUs per passenger mile to transport a passenger on Amtrak, as opposed to car or air.

EMISSIONS MITIGATION

The industry has a strong incentive to reduce fuel consumption, and hence GHG emissions, because fuel represents such a significant expense for railroads. The industry as a whole consumes over 4 billion gallons of diesel fuel annually.[12] The largest railroads consume hundreds of millions of gallons annually.

Thus, from a fuel and GHG efficiency perspective, the railroad industry has a good story to tell. In 1980, the industry transported one ton of freight an average of 235 miles on one gallon of diesel fuel. In 2008, the industry transported one ton of freight an average of 457 miles on one gallon of fuel (see Figure 5).[13]

Industry initiatives that contribute to reduced GHG emissions include the following:

- **New locomotives.** Newer locomotives are more efficient than the locomotives they replace;

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[11] Davis, Diegel, and Boundy, *Transportation Energy Data Book: Edition 27*, http://www-cta.ornl.gov/data/tedb27/Edition27_Chapter02.pdf, p. 2-14 (Oak Ridge National Laboratory 2008).

[12] *Railroad Facts*, *supra* n., p. 40.

[13] *Railroad Facts*, *supra* n., p. 40 (The 2008 edition of *Railroad Facts* does not contain data for 2008. The 2008 data will be included in the 2009 edition.).

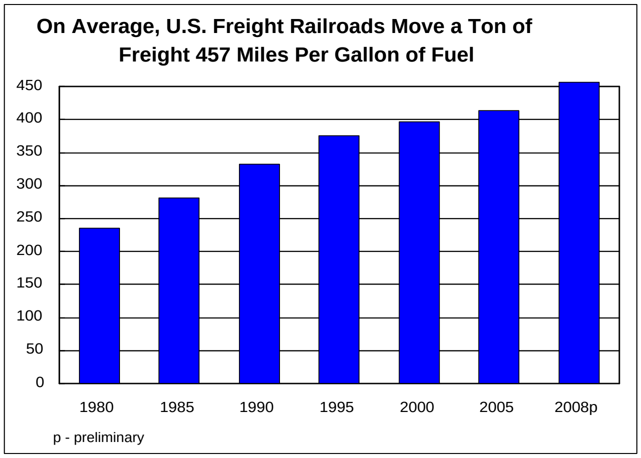

FIGURE 5 Ton-miles per gallon of fuel.

- **Genset (generator set) technology.** While there have been some hybrid switch locomotives placed in service, the most promising innovation in switch locomotive technology is the genset locomotive, mentioned earlier. Genset engines cycle on or off, depending on the amount of horsepower needed at the moment. The emissions reductions from using less horsepower than would be used by a typical switch locomotive are substantial;
- **Regenerative braking.** On the Northeast Corridor, most of Amtrak's electric locomotives utilize regenerative braking. Power is cut off to the traction motors, at which point the train's momentum turns the motors, which then become generators. The resistance helps to slow the train, and it also generates electricity, which can be returned to the power system through the overhead wire. Locomotives return up to 8 percent of the power they use to the grid as electricity. Similarly, as mentioned previously, one locomotive manufacturer is conducting research on a system for diesel–electric locomotives which will capture energy generated during braking in batteries;
- **Reduced idling.** Railroads have been equipping locomotives with idling-reduction technology. One such technology is "stop-start," which will shut down a locomotive when idling if certain parameters, such as ambient temperature, are met. Another such technology is the auxiliary power unit, which will keep an engine warm and thus enable a locomotive to shut down even in cold weather. While the railroads have been voluntarily installing these systems for years, in its 2008 regulations the EPA mandates the installation of idling-reduction technology at the time of manufacturing or remanufacturing;
- **Train handling.** The operation of a train can affect fuel efficiency, just as the way in which a motor vehicle is driven affects fuel efficiency. Railroads train their engineers to operate their trains in a fuel efficient manner. In some cases, railroads reward those engineers who are top performers from a fuel-efficiency standpoint. Railroads also use onboard monitoring systems that provide information to engineers on operating a train efficiently, using information on topography, track curvature, and train length and weight; and
- **Rail lubrication.** Railroads lubricate rails to reduce friction and improve fuel efficiency.

CONCLUSION

Since most of the fuel consumed in the railroad industry is attributable to the largest railroads and fuel represents such a significant expense to those railroads, the railroad industry has a strong incentive to reduce GHG emissions. The strength of this incentive is clearly shown by the dramatic, continuous improvement in the industry's fuel efficiency over decades.

Given the industry's self-interest in reducing fuel consumption and GHG emissions, and the environmental advantages of transporting freight by rail, from a public policy perspective the challenge insofar as the railroad industry is concerned lies in facilitating railroad transportation. As Congress and EPA move towards GHG regulation, it will be interesting to see if they recognize the environmental benefits of rail transportation.

ACKNOWLEDGMENT

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3

Air Transportation

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The vast majority of commercial aircraft are jet powered with turbofan, or, to a lesser extent, turboprop engines. General aviation (recreational and business) aircraft are both piston propeller and jet powered.

TECHNOLOGY LANDSCAPE

According to the Bureau of Transportation Statistics, there were approximately 8,225 active commercial aircraft in operation in the United States in 2005 while the fleet of general aviation aircraft exceeded 200,000. Despite their smaller number, commercial aircraft account for at least 90% of aviation fuel consumption due to their larger size and constant use (Bureau of Transportation Statistics, 2008). Of the commercial aircraft, approximately 2,300 were small narrow-body aircraft with seating from 50 to150 seats (including turboprop, regional jets, and narrow-body jetliners), 770 were narrow-body jets with more than 150 seats, and 530 were wide-body (dual-aisle) aircraft. These three types of aircraft account for the majority of aircraft greenhouse emissions due to their size and extensive utilization in commercial operations.

EMISSION SOURCES

Roughly 90% of GHG emissions attributable to aviation result from aircraft in flight, typically above 3,000 feet, including operations at cruising altitude (FAA, Aviation & Emissions: A Primer, 2005). The remaining emissions take place at the airport from arriving, departing and taxiing aircraft, aircraft auxiliary power units (APU), ground service equipment (GSE), motor vehicles, and stationary sources from heating and cooling of airport buildings and electricity use.

EMISSIONS INVENTORY

Aviation jet engines are estimated to produce about 3% of the global GHG emissions from fossil fuels, and the Intergovernmental Panel on Climate Change (IPCC) projects this may grow to 5% by 2050. Estimates are similar in the United States, with 2005 commercial aviation emissions accounting for 158 million metric tons of CO_2, or 3% of total U.S. CO_2 emissions. This represents about 12% of the U.S. transportation total (EPA, 2007).

Aircraft engine exhaust is comprised of 70% CO_2, under 30% H_2O, and less than one percent of a mix of nitrogen oxides (NO_x), carbon monoxide (CO), oxides of sulfur (SO_x), unburned or partially combusted hydrocarbons (also known as volatile organic compounds (VOCs)), aerosols and soot particles (PM), and other trace compounds. The primary climate warming gas released by aircraft is $CO_{2.}$ Aircraft engines produce virtually no nitrous oxide (N_2O) or methane directly. However aviation NO_x emissions impact atmospheric ozone and methane concentrations indirectly. These NO_x emissions increase ozone, which has a warming effect, but also removes methane from the upper atmosphere, producing a climate cooling effect. On balance, NO_x is believed to produce an overall warming effect.

Aircraft movements are well tracked, which allows us to accurately predict total aircraft CO_2 emissions directly from the amount of fuel burned. The FAA System for assessing Aviation's Global Emissions (SAGE) is a high fidelity computer model used to predict aircraft fuel burn and emissions for all commercial (civil) flights globally in a given year. The model analyzes scenarios from a single flight to airport, country, regional, and global levels. It has the capability of modeling aircraft performance, fuel burn and emissions, capacity and delay at airports, as well as forecasts of future scenarios (FAA SAGE).

Based on such models, FAA has estimated that, even in the absence of regulation, U.S. aviation GHG emissions have actually decreased between 2000 and 2006 by about 4% (FAA SAGE inventory), while passengers and cargo have grown over the same period (ATA, 2008). This reduction has resulted from fleet turnover with more fuel-efficient aircraft, higher load factors, and a focus on fuel efficiency driven by high fuel prices (retrofits with winglets and other aerodynamic improvements, weight reduction, etc.).

A couple of important issues regarding the inventorying of emissions are the geographic and ownership boundaries. With the precedent set by the IPCC protocols on quantifying national GHG emissions, most aviation-related inventories tend to attribute the emissions to the departure point (e.g., country, region, airport, etc.). Similarly, the corporate-based protocols from the World Resource Institute (WRI) are adopted by most GHG inventory guidance materials in specifying the need to categorize emissions by ownership and control of the sources. Although these are adopted by guidance materials such as the Transportation Research Board's (TRB) airport inventory guidebook developed under the Airport Cooperative Research Program (ACRP), they are still points of contention among airports and their tenants.

EMISSIONS IMPACT AND UNCERTAINTIES

The climate effects of non-CO_2 aviation GHG emissions, especially those that take place at an altitude in the upper troposphere/lower stratosphere (UT/LS), are extremely complex and still not well understood. Neither is the role of NOx emissions, aircraft contrails, or particulates in enhancing cirrus cloudiness. Both aircraft contrails as well as cirrus clouds have been estimated to produce a warming or a cooling effect depending on the conditions—however, they are thought to have a net warming effect overall.

Some aircraft effects on climate are long-lived and felt on a global scale (CO_2, methane removal via NOx), and others are short-lived and felt on a regional scale (contrails/cirrus and ozone production via NOx), making comparisons of the different effects difficult. Metrics to assess the impact of these emissions and to determine their relative impact compared to CO_2 are being developed, but require enhanced scientific understanding.

The most recent Intergovernmental Panel on Climate Change (IPCC) estimates for the relative effect of different GHG emissions from aviation sources, in terms of radiative forcing (RF), are shown in Figure 6. Radiative forcing is a measure of how the energy balance of the Earth-atmosphere system is influenced by factors that affect climate. Increasing GHG concentrations affect the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere. Forcing values are expressed in watts per square meter (W/m^2). A positive number denotes a warming impact while a negative number denotes a cooling one. The error bars are indicative of the high uncertainty surrounding some of the effects.

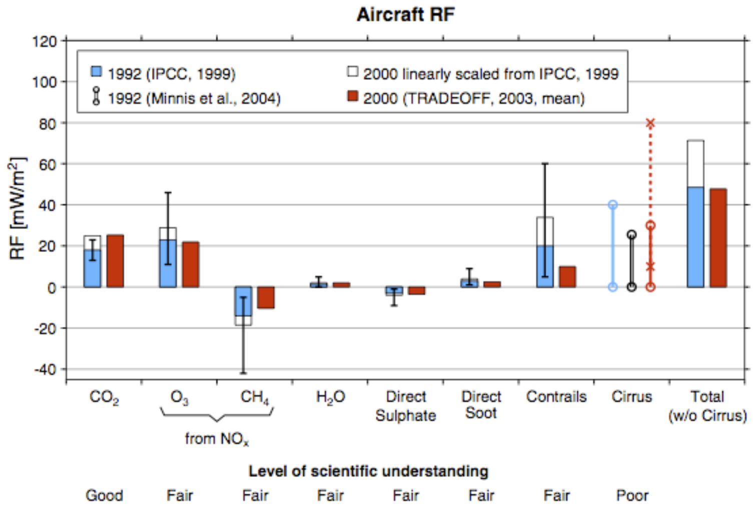

FIGURE 6 Radiative forcing for aviation for 1992 and 2000.
(Sausen, Isaksen et al. 2005)

As noted above, the relative effect of radiative forcing does not account for the longevity of the effect or the atmospheric residence time of the different pollutants. A recent study attempted to quantify these differences by monetizing (and discounting over time) the impact of the various GHG from aviation, assuming that all aviation activity is abruptly halted at one point in the future. According to its estimates, the dominant long-term effects are overwhelmingly dependent on the CO_2 emissions (Marais, Lukachko et al. 2008).

The practical effect of this uncertainty of relative impacts and residence times is compounded when it is considered that aviation is subject to interdependencies between emissions such that reduction in one GHG may increase another. For example, at a given level of technology, the optimization of an engine to reduce fuel burn (and thus CO_2) tends to increase the heat of combustion and emissions of NOx. Similarly, an operational solution such as flying at lower altitude (to reduce contrails/cirrus) results in higher fuel burn (more CO_2). An improved understanding of the relative impacts of these different emissions would be useful to policy makers to establish policies that will effectively address aircraft climate impacts.

REGULATORY LANDSCAPE

Regulatory Bodies

The aviation industry is inherently international, and therefore must comply with both domestic and international regulatory bodies.

Domestic—FAA/EPA

The Federal Aviation Administration (FAA) regulates U.S. aviation primarily for safety and noise considerations, and operates the national airspace system. The Environmental Protection Agency (EPA) regulates aircraft engine emissions affecting air quality under the Clean Air Act in consultation with the FAA. There is currently no U.S. federal government regulation by the FAA or EPA specifically for CO2 emissions, the primary GHG resulting from aircraft engines.

International—UN ICAO

The International Civil Aviation Organization (ICAO) is the official body of the United Nations that stewards all matters involving international aviation. International standards adopted by the ICAO are enforced by the appropriate governmental body(ies) within each of the respective signatory nations to ICAO: the FAA for the United States.

International flights originating in the United States may also be subject to regulation by destination airports or countries. For example, as discussed below, the European Union (EU) is developing regulations that would subject flights to and from its Member States to regulation under the European Emissions Trading Scheme (ETS). However, the jurisdiction of the EU or other bodies to engage in such regulation is disputed by the United States and other countries.

Current Regulatory Initiatives

U.S. Federal Aviation Administration As part of improvements to be made in the development of the U.S. Next Generation Air Transportation System (NextGen), the FAA is following a five-pillar strategy for addressing aviation GHG emissions:

1. Improve scientific understanding of the relative impacts of different aviation GHG emissions at altitude, and develop tools and metrics to weigh these impacts;
2. Improve air traffic control efficiency and implement new operational procedures to reduce fuel burn;
3. Support research, development and deployment of new efficient aircraft and engine technologies;
4. Develop alternative aviation fuels with GHG reductions; and
5. Consider market-based measures.

Taken together, FAA intends these measures to allow for continued aviation growth while addressing U.S. aviation GHG emissions.

Current initiatives in support of this strategy include: the Aviation Climate Change Research Initiative (ACCRI) which is focused on addressing aviation emission uncertainties through additional scientific research; emissions reducing operational improvements being developed under NextGen; cosponsorship of the Commercial Aviation Alternative Fuels Initiative (CAAFI), a coalition to develop and deploy alternative jet fuels; and “well to wake” environmental life cycle analysis of alternative fuels. In addition, the FAA’s reauthorization legislation includes a Continuous Low Energy, Emissions and Noise (CLEEN) research program to fund environmentally promising engine and aircraft technologies.

FAA programs such as the Voluntary Airport Low Emissions (VALE) program also fund emissions mitigation projects at airports such as conversion to low emissions ground support vehicles and gate electrification to reduce APU use. While VALE is aimed at the reduction of local or regional pollutants such as ozone, the funded projects will generally reduce GHG emissions as well.

Finally, two international collaborations, the EU–U.S. Atlantic Interoperability Initiative to Reduce Emissions (AIRE) and the U.S.–Australia–New Zealand Asia and South Pacific Initiative to Reduce Emissions (ASPIRE), are implementing demonstration of gate to gate air traffic operations improvements that maximize fuel efficiency and reduce GHG emissions.

U.S. Environmental Protection Agency (EPA) EPA is responsible for reporting U.S. GHG inventories under the United Nations Framework Convention on Climate Change (UNFCCC) to address global climate change. EPA produces an annual inventory of U.S. GHG emissions sources and sinks. In 2008, the U.S. Congress directed EPA to propose a rule on mandatory GHG emissions reporting by industry in all sectors of the economy including aviation (EPA, GHG Reporting Rule. 2008).

The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment. National standards currently exist for the six “criteria pollutants”: ozone, particulate matter, nitrogen oxides, carbon monoxide, sulfur dioxide, and lead. Following the Supreme Court decision Massachusetts v. EPA, which mandated that CO_2 be addressed under the Clean Air Act and petitions for GHG emissions limitations from aviation sources filed by a number of states and environmental organizations, EPA issued an Advanced Notice of Proposed Rulemaking (ANPR) to seek comment regarding how and whether to address aviation and other sources of GHGs under the Clean Air Act (EPA, Advanced Notice. 2008). In April, 2009 EPA released a proposed finding that GHG threatens human health and welfare. If finalized, this "endangerment" finding would make GHG subject to regulation under the Clean Air Act possibly triggering broad regulation of heat-trapping GHG emissions (EPA, Proposed Endangerment. 2009). However, EPA has expressed a preference for regulation under comprehensive legislation by Congress rather than through the Clean Air Act.

The 111th Congress has proposed comprehensive climate change regulation establishing a cap and trade framework and incentivizing clean energy development and jobs creation for the United States with the American Clean Energy and Security (ACES) Act of 2009. President Obama expressed his support for the ACES legislation in advance of its passage by the House of Representatives in June 2009. The proposed regulation must be passed by the Senate and will likely undergo changes before becoming law.

U.S. State and Local Regulations U.S. federal regulations largely supersede state regulations with regard to aviation. No aviation-specific regulations are anticipated by individual U.S. states (e.g., connection to state emissions-trading systems). However, some states have applied generally applicable state environmental laws to the assessment of the climate change implications of new airport capital projects. For example, California, Massachusetts, and Washington have required the quantification of GHG emissions under each state's National Environmental Policy Act (NEPA) studies. In California, the Global Warming Solutions Act of 2006 (Assembly Bill 32) has already started to affect some airports through local ordinances or other mandates requiring airports to develop climate action plans to meet emissions goals. Furthermore, a number of airports in the United States have begun to voluntarily develop GHG emissions inventories and climate action plans proactively in preparation for oncoming legislation and as part of their "green" initiatives. Some of these inventories are being registered through The Climate Registry (TCR). The California Climate Action Registry (CCAR) had also accepted submissions of GHG inventories, but is now a program under the Climate Action Reserve (CAR) that is transitioning the registry work to TCR to focus on GHG emissions reduction measures.

UNFCCC/Kyoto Protocol The United Nations Framework Convention on Climate Change (UNFCCC) created an international framework to address global climate change in 1994. The Kyoto Protocol (1997) to the UNFCCC entered into force in 2008, with the main objective of making GHG emission reductions from Annex I countries (industrialized nations listed in Annex I of the Protocol). CO2 emissions from domestic aviation are included in the inventories of each signatory nation. Each signatory is responsible for meeting the required targets by targeting emissions by sector as they see fit. The United States signed but did not ratify the Kyoto Protocol.

International aviation emissions (along with all maritime bunker fuel emissions) are excluded from the targets, and the responsibility for limiting them has been relegated to Annex I countries working through ICAO (Article 2, paragraph 2 Kyoto Protocol). Current discussions under the UNFCCC are focused on establishing a successor to Kyoto, which expires in 2012. This was the intent of the Conference of the Parties (COP-15) meeting of the UNFCCC in Copenhagen in December 2009.

International Civil Aviation Organization (ICAO) ICAO's founding charter was the 1944 Chicago Convention. Within ICAO, the Committee on Aviation Environmental Protection (CAEP) was established in 1984 comprised of members and observers from signatory states. CAEP provides technical expertise and recommendations on aircraft noise, aircraft engine emissions and related environmental issues. While ICAO's environmental policy has traditionally been focused on mitigating ground level effects of aviation emissions, the mandate from the Kyoto Protocol expanded ICAO's scope to include climate change impacts. (ICAO, 2007)

Agreement was reached during the 6th meeting of the ICAO Committee on Aviation Environmental Protection (2004) that an aviation-specific emissions trading scheme (ETS) under ICAO should not be pursued at that time. ICAO member states were given the option to include international aviation into their national ETS (Resolution A35-5 ICAO 35th Assembly 2004). This option was later limited to ICAO members that mutually agree to this inclusion. Emphasis was placed on technical solutions while discussions continue on the feasibility of market-based options (Resolution A36-22 ICAO 36th Assembly 2007 Appendices L and K).

The European Union member states joined with other European countries to reserve the right to apply nondiscriminatory market-based measures on all aircraft operators operating to and from their territory (both in domestic and international airspace). This right, they argued, commences from rights acknowledged in the Chicago Convention, under which every contracting state may apply the air laws and regulations of their choosing without discrimination to all operators within their borders. Other states, including the United States, have opposed the EU's position, arguing that it is in conflict with the Chicago Convention, and violates bilateral agreements and sovereign rights. They argue that any attempt to regulate aviation GHG in international airspace must be made only through mutual consent.

Following the 36th ICAO Assembly in October 2007, the Group on International Aviation and Climate Change (GIACC) was established at the ICAO as a high-level group of 15 countries to develop a comprehensive plan on international aviation and climate change. In June 2009 the group published a report recommending a global aspirational goal of 2% annual improvement in aircraft fuel efficiency to 2050. This would result in a cumulative improvement of 13% in the short term (2010–12), 26% in the medium term (2013–2020), and about 60% in the long term (2021-2050) from a 2005 base level. The GIACC also recommended that the ICAO Council establish a process to develop a framework for market-based measures in international aviation following an ICAO high-level meeting on the subject to be held from in October, 2009 and the outcome of the Conference of the Parties of the UNFCCC in Copenhagen, in December 2009. (ICAO, 2009).

European Union (EU) EU has stated three approaches for reducing GHG emissions from aviation:

1. Improve the fragmented air traffic management system of the European continent under the Single European Sky system,
2. Support research on improving aircraft efficiency, and
3. Include aviation in the European Emissions Trading Scheme (EETS).

The EU is the first government to establish a carbon market that incorporates CO_2 emissions from a number of stationary large emitters like fossil-fuel power plants, aluminum smelters, and refineries. After exploratory studies (e.g., Wit, Boon et al. 2005; Ehmer, Grimme et al. 2005), an impact assessment study (European Commission Communities 2006), and an open public consultation procedure (European Commission 2005), the European Commission, through Proposal COD/2006/0304, officially recommended the inclusion of aviation into the EETS. The original proposal has been reviewed by the European Parliament and Council, and the proposed amendments have been accepted by the Commission as announced by Communication COM (2008) 0548 as they did not alter the main thrust of the legislation.

Under the European Union’s legislation, which is scheduled to become effective by 2012, all commercial airlines operating flights to and from European airports will be required to surrender tradable emissions permits equal to the amount of CO_2 emissions their flights generate. It is likely that this will be challenged by one or more non-EU countries in an international legal process. An overview of the proposal is given in Figure 7.

The EU justified the inclusion of aviation to be the first nonstationary source of CO_2 included in the EETS by concern about aviation’s comparatively very high growth rates that, if continued, “could by 2012 offset more than a quarter of the environmental benefits of the reductions required by the Community's target under the Kyoto Protocol” (European Commission 2006). Other factors like the comparatively small number of stakeholders involved, the relatively low percentage of the anticipated increases in the fare prices compared to the total value of the ticket, the perception that aviation is benefiting from low fuel taxation, and public campaigns of environmental organizations may have contributed to this decision. In any event, once implemented, this system could serve as a blueprint for inclusion of nonstationary sources into an EETS.

Alliances, Industry Groups, NGOs, State and Local Governments

Airports Council International (ACI) ACI represents U.S. and foreign commercial airports and develops standards, policies, training and recommended practices. ACI encourages environmentally responsible measures taken by airports to reduce their environmental impact including: investing in low-emissions vehicles and energy-saving equipment; recycling building materials, water, and waste; charging more for inefficient and polluting aircraft to create financial incentives; participating in emissions trading in Europe; and providing emissions reducing services for aircraft at the gate. ACI also works with ICAO and the entire industry on reducing aircraft noise. ACI supports development of a long term climate change strategy via ICAO, a global emissions trading scheme, and technology and design developments to limit GHG emissions.

Air Transport Association of America (ATA) ATA, representing U.S. commercial passenger and cargo airlines, has made a commitment to achieve at least a 30% improvement in fuel efficiency from 2005 levels by 2025. ATA also supports the development of environmentally friendly alternative fuels, modernization of the air traffic management system in the United States and working with the International Civil Aviation Organization (ICAO) on next steps for addressing climate change at an international level.

Commercial Aviation Alternative Fuels Initiative (CAAFI) CAAFI is a coalition sponsored by the ATA, ACI-North America, the Aerospace Industries Association and the FAA. CAAFI’s

Objective

Stabilize emissions from aviation to the 2004–2006 levels. The emissions cap will be set at the average of CO_2 emissions between these 3 years. There is currently no provision for gradually reducing the cap.

Scope

The only greenhouse gas covered is CO_2. 'Flanking' instruments are expected to mitigate other emissions. The scheme covers all commercial aircraft operators to and from European airports and it exempts military flights, training flights and flights with small aircraft (<5,700 kg maximum takeoff weight), and general aviation.

Administration of Allowance Amount Units (AAUs)

Based on the European Parliament's recommendation, the aviation AAUs (AAAUs) will be handled by the member states to which a given airline is registered or, if registered in a non-EU country, the one in which they conduct the majority of their operations as is the case for the other participants in the EETS. Airlines will be responsible for reporting their fuel usage and surrendering the number of AAUs adequate to cover the flights anticipated emission. AAAUs can only be surrendered by airlines, but airlines can buy and surrender all non-aviation AAUs including Clean Development Mechanism certified emission reductions ("CERs") and emission reduction units ("ERUs).

Allocation of AAAUs will likely combine grandfathering, benchmarking, and auctioning processes. For airlines operating when the system is implemented, a number of AAAUs will be provided based on the amount of revenue ton-km traffic of the previous year for the given airline (passenger traffic will be converted to tonne-km by assigning 100 kg per passenger). The allocations will occur by benchmarking, i.e., airlines will receive allowances based on average performance, so if their efficiency is below average, they will be penalized. Only 97% of available allowances will be allocated initially and only 95% after 2013. The unallocated allowances will be banked to provide a margin for airlines that will commence operations after the system is put in operation. 15% of the AAAUs will be auctioned with proceeds going to emission reduction measures.

Airlines will not be required to surrender AAAUs for biomass-derived fuel approved by the EU. The same will be true for flights from a country that implements an equivalent program.

Verification and Policing

Airline reporting of emissions will be verified by an external verifier that can use Eurocontrol data for the process of verification.

If an airline fails to surrender the correct amount of allowances by the end of the operating year then the EU member states will act in concert and suspend its operating license for all airports in the Union.

FIGURE 7 Principal characteristics of EU legislations to include aviation in ETS.

mission is to enhance environmental sustainability and energy security for aviation through development and deployment of alternative jet fuels. With representation from all the leading stakeholders in the field of aviation, CAAFI focuses the efforts of the commercial aviation supply chain to engage the emerging alternative fuels industry. By building relationships, sharing and collecting data, and focusing research efforts, CAAFI is facilitating industry development and adoption of "drop-in" environmentally improved jet fuels for use in current aircraft and infrastructure.

International Air Transport Association (IATA) IATA has set a highly ambitious goal of making aircraft 25% more energy efficient by 2022, and to achieve "zero emissions" with reference to GHG within 50 years, presuming new fuel technologies emerge that will make this possible. The director general of IATA, Giovanni Bisignani, committed to air transportation that, "takes its environmental responsibility seriously," and stated IATA's vision for achieving air transport as "carbon neutral growth in the medium-term, on the way to a carbon-emission-free future." While IATA has noted the importance of ambitious goals for GHG emissions, it is insistent that international measures must be developed, as opposed to localized ones.

NGOs and U.S. State and Local Governments In December 2007, a coalition of environmental NGOs, states, and local governments jointly petitioned EPA to regulate aviation GHG under the Clean Air Act. Citing the contribution of aircraft to U.S. and global GHG emissions, high-altitude emissions impacts and the significant expected growth of aviation traffic in the coming decades, the coalition has urged EPA to evaluate the current impacts of aircraft emissions, seek public comment and develop rules to reduce aircraft emissions. The coalition government members included the Attorneys General of California, Connecticut and New Mexico, the South Coast Air Quality Management District (Southern California), the City of New York, the Pennsylvania Department of Environmental Protection and the District of Columbia. The NGO petitioners included Oceana, Earth Justice, Friends of the Earth, and the Center for Biological Diversity. As stakeholder voices, these groups will play a role in shaping policy going forward.

Industry Concerns

Overall, the industry stakeholders share a common interest in having to operate in a consistent and predictable international regulatory regime. This includes consistent global enforcement, a scheme that avoids duplication of environmental penalties, use of revenue generated for environmental impact mitigation, transparency in the allocation and costs of GHG permits, sufficient liquidity of permits that allow spreading of the effort across economic and transportation sectors, and a focus towards positive incentives for actually reducing emissions through technological measures rather than through demand destruction.

EMISSIONS MITIGATION

Since the large-scale introduction of jet engines in commercial aircraft, significant progress has been made to reduce energy intensity. Energy intensity is a measure of the energy used for a given amount of work, in this case megajoules per kilometer that one paying passenger is moved (EI expressed in MJ/Revenue Passenger Kilometer). These improvements, as shown in Figure 8, can be attributed to advancements in engine specific fuel consumption (57%), aerodynamics (22%), utilization through increasing load factors (17%) and others (Lee, Lukachko et al. 2001).

Going forward, the aviation industry has a number of options to pursue towards less carbon-intensive and more sustainable operations. These options involve technology, operations, network structure, revenue management, fleet management, demand management, and the use of nonfossil-based alternative fuels. Table 4 below lists a number of the available options under these categories. While the recent surge in fuel prices emphasized the incentive to achieve

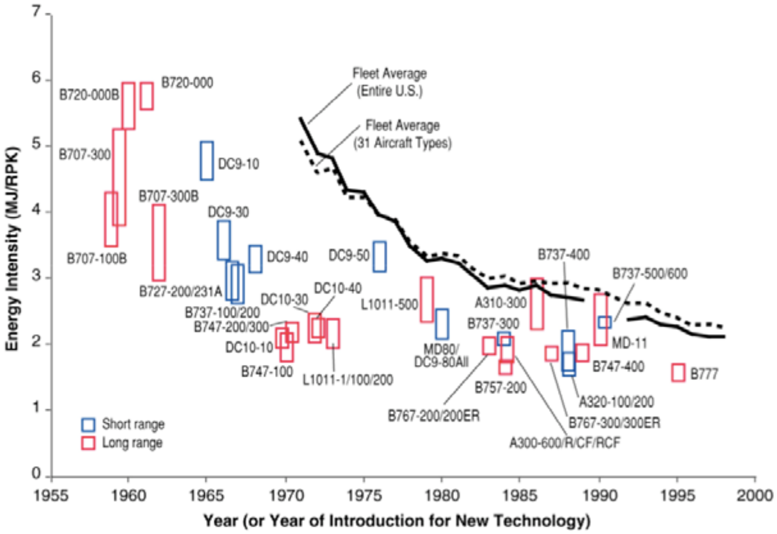

FIGURE 8 Improvements in jet aircraft energy intensity. (Lee, Lukachko et al. 2001)

further efficiency improvements, significant improvement requires a coordinated effort involving all stakeholders across the value chain. The industry will have to make extensive calculations and trials to identify which of the options listed here have a positive life cycle impact both environmentally and financially.

Fleet replacement is slow due to the inertia of thirty-year average service lives of aircraft, high equipment capital costs, and substantial lead time and development costs for new aircraft. The dominant manufacturers of larger commercial aircraft, Boeing and Airbus, have spent in excess of US$12 billion to design their newest aircraft families. Unless a radical innovation creates a discontinuity similar to the transition from piston engines to jets, fuel burn reduction by engine and aircraft technology will be steady but incremental.

Similarly, high capital–investment cost, established technological infrastructures, and political interest groups could delay the implementation of new technologies in air traffic control and operations. However, fuel savings technologies in air traffic operations are beginning to be implemented in the United States. and elsewhere. Examples are continuous descent approaches (CDA) and tailored arrivals (TAs), which optimize landing profiles and reduce emissions and noise; along with available dependent surveillance broadcast (ADS-B) that will replace radar tracking of aircraft with more accurate satellite tracking.

Aircraft performance is highly dependent on weight and jet fuel has the optimal combination of weight and energy content for today's aircraft. Since aircraft must carry their fuel for the entire flight onboard, even a slight decrease in the energy density of the fuel creates a substantial reduction in performance. For this reason, at least in the near term, only "drop-in" alternative fuels with similar properties to jet fuel are being considered for aviation. Key enabling activities that are ongoing include air quality emissions measurements, life cycle GHG assessments of fuel production and use, sustainable feedstock analysis and development of new fuel standards. Although there are still some technical hurdles and questions about production potential, low-carbon alternative jet fuels are being developed and flight tested today.

A combination of the various mitigation technologies will be necessary to meet the goals set by the various government, industry, and stakeholder groups. ATA's goal for fuel efficiency improvement is within reach judging by historical improvements. The achievement of the very ambitious goals set by IATA for zero greenhouse emissions by 2050 will probably require a combination of extremes: radical technological innovation, widespread availability of alternative fuels, and strong market-based incentives to moderate demand and provide the consistent incentive to make the above transitions. Successful mitigation of aviation GHG emissions will require the careful balancing of costs and benefits and the employment of a comprehensive suite of multiple and complementary technologies and tools.

For airports, mitigation measures are reflected in the use of efficient energy strategies in facilities and other airport-owned sources. Whether it is to meet future emissions goals set by

TABLE 4 List of Measures for Reducing Aviation's GHG Emissions

Aircraft and Engines	
Near-term technology	Design optimized for reduced fuel consumption: Winglets, riblets Engine washing Materials (e.g., carbon composite for lighter weight structures, lightweight interiors) New Engines (e.g., geared turbofan, turboprop)
Longer term technologies	Alternative engine/wing configurations (blended-wing-bodies, wing-in-ground-effect, hybrid airships) New engines (open rotor, etc.)
Alternative fuels for aircraft	Drop-in: Biofuels (including advanced feedstocks with lower life-cycle emissions) Synthetic fuels (biomass-to-liquids and coal or gas-to-liquids with cofiring of biomass and carbon sequestration) New fuels: hydrogen
Operations	Optimized surface operations • One engine or assisted taxiing, gate holding, programmed taxis • More efficient airfield layouts and infrastructure Landing, take-off (LTO) cycle improvements: • Continuous decent approach • Tailored arrivals Air traffic control en route optimization: • Reducing fuel consumption • Reducing contrail/cirrus/O_3 formation Refueling stops for ultra long flights when optimal for fuel consumption Aircraft slowing (trade-off with equipment utilization and higher labor costs)
Network	Network structure, scheduling, fleet composition and utilization Choice of less-congested airports
Demand management	CO_2 surcharges on fare prices or fuel Voluntary or mandatory participation in carbon exchange systems Promotion of voluntary offsets for passengers combined with perhaps some complimentary appreciation in service (i.e., prioritization, enhanced service) and recognition (e.g., green badges) Service reductions—natural consolidation Modal shifting
Airports	Energy efficiency/renewable energy use in facilities Alternative fueled and low emission vehicles and GSE Gate electrification, preconditioned air Recycling programs Intermodal transportation planning to reduce GHGs

local ordinances or implementation of voluntary programs to help prepare for future regulation, airports are coming under increasing scrutiny to explore various options in reducing their carbon footprint. As reductions from sources owned by the airports may not suffice, they may begin looking for opportunities from sources not owned by the airports but over which they may have some influence. The electrification of gates with the use of preconditioned air is one example where an airport may be able to take credit for aircraft (airline) emissions reductions through the contribution of funds to implement the reduction measure. Credit for these types of improvements is an evolving area of contention that will need to be monitored as airports continue to work with tenants and other stakeholders in developing protocols to reduce GHG emissions.

ACKNOWLEDGMENT

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4

Marine Transportation

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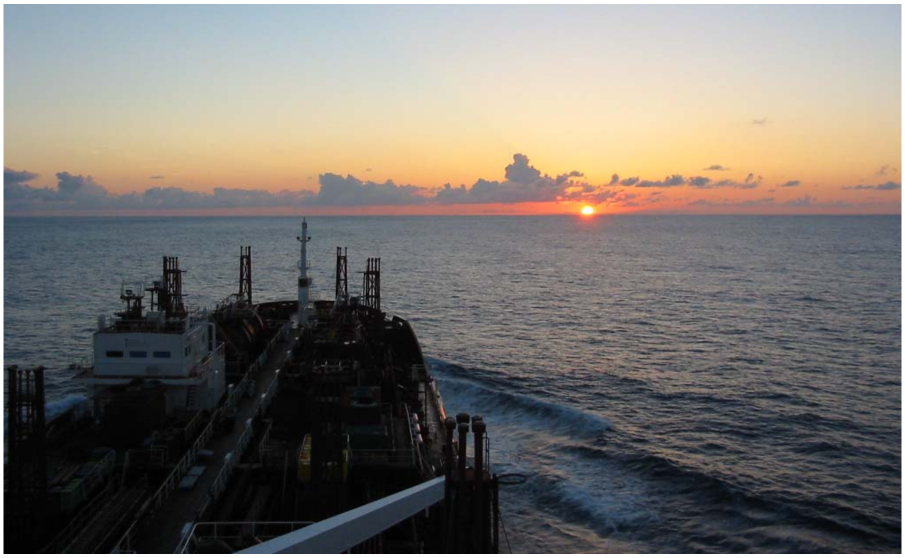
The world's marine fleet is comprised of many ship types that differ predominantly based on the cargo that they carry. A cargo's value, time dependence, and stowage requirements drive the design of the vessel that carries it, including size, hull design, and cargo handling equipment. Most of the world's fleet of 60,000 ships (>400 GT)[1] can be grouped into about ten general categories (containership, tanker, bulker, etc.).

Containerized cargo, for example, is typically finished goods that are lightweight, high-value, and often part of a "just in time" supply chain. Consequently, containerships generally have relatively shallow draft, are high-speed, and operate on a regular schedule (a "liner trade"). The need to provide integrated logistics drives ownership toward large companies with large fleets. Finally, the balance of world trade and number of parcels on a given containership (up to ~12,000) challenges vessel utilization.

Conversely, crude oil is heavier, relatively lower in value, and is traded as a generally interchangeable bulk market commodity. Crude carriers may be time chartered with fairly regular schedules, or alternatively may follow an unpredictable schedule determined by where the cargo has been sold (a "spot trade"). The cargo's weight and lower relative value, as well as the tanker's hull form, drive tankers to operate slower. Further, operating on the spot trade presents lower resistance to market penetration, hence tanker owners range from large operators to single ship owners.



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[1] Marine Environmental Protection Committee 2007, p. 8.

Every other waterborne cargo has similar peculiarities that dominate the operation of the respective vessels on which it is carried. The individual vessel characteristics, ownership style, and operational considerations all affect both the contribution by each vessel type to GHG generation as well as the cost of reducing its emissions. While it is important to have uniform and predictable regulation throughout the industry, the solutions realistically available to each ship type will vary. A few illustrations of this point include

- Port-specific regulations that require upgraded equipment on ships is challenging for spot-traders that regularly call on different ports;
- "Cold ironing," or using shore power while a vessel is moored, may be feasible for cruise ships where most energy generation is electrical but is less effective for large crude tankers that typically use large steam-powered pumps to discharge cargo; and
- Propulsion energy intensity increases roughly quadratically with speed; while this is an opportunity for higher-speed ships (containerships, passenger ferries, RO/RO ships, etc.) to reduce energy consumption by slowing down, that yields an effective tonnage loss with very real commercial implications (which can in turn lead to more shipbuilding activity).

SHIPBOARD EQUIPMENT

While equipment type, size, and use vary depending on the ship and its mission, generally the primary emissions-generators for modern, large commercial ships are

- Main diesel engine: typically a slow-speed diesel engine that directly drives the propeller shaft for vessel propulsion and consumes heavy fuel oil (HFO);
- Auxiliary diesel engines: typically 3 to 4 medium-speed diesel engine generators (gensets) that provide electrical power for hotel load and cargo services and may burn marine diesel oil (MDO), HFO, or a mix, depending on engine type and operator's preference;
- Steam boiler: generates steam for consumers (bunker fuel heating, cargo heating/pumping on a tanker, hotel service heating, etc.), typically burns HFO, and may use engine waste heat; and
- Incinerator: for disposal of various onboard waste streams.

Notable exceptions to slow-speed diesel propulsion include gas turbines, medium-speed diesels (either through a gearbox to the propeller or in a diesel–electric ship), and steam ships (many LNG ships, co-generation ships, and older ships).

Tables 5 and 6 list common ship types and their representative onboard equipment. These variations within the world's fleet may drive different emission–mitigation opportunities for different vessels.

EMISSIONS INVENTORY

The aggregate emissions output of the global maritime fleet has been estimated several times, and remains an area of study. Two approaches have surfaced: "top-down" where global bunker receipts are tallied, and "bottom-up" where a model is made of the global fleet, its estimated operational utilization, and its engine data/specific fuel oil consumption to calculate global fuel consumption. These estimate approaches have led to a range of 1.5% to 3.0% of global CO_2 contribution as shown in Table 7. The emissions intensity of various ship types versus other transportation modes is provided in Figure 9.

Outside of the deep-sea ship industry, there are several other regional significant marine-related emission sources, such as ports, shipyards, the inland waterway fleet, harbor and coastal fleets, the recreational boat industry, etc. Although these sources cannot be ignored, their collective GHG emissions all currently fall under the jurisdiction of their respective host countries, and are therefore not discussed here.

REGULATORY LANDSCAPE

Regulatory Sources

The maritime industry is inherently global, and therefore falls under various jurisdictions internationally.

Flag States

A flag state is the country to which a vessel is registered, and hence whose flag the ship will fly. The flag state always has jurisdiction over its vessels, including enforcement responsibility for the IMO instruments (described below) to which the state is a party.

Port States

A port state is the country hosting a vessel on a particular port call, which retains jurisdiction over the vessel while it is in the country's territorial waters. Most IMO instruments give port states the jurisdiction to enforce those instruments to which it is a party over visiting vessels, regardless of the vessel's flag state.

UN/International Maritime Organization (IMO)

The United Nations International Maritime Organization (IMO) is the Official body of the United Nations that develops regulatory instruments for international shipping to address maritime safety, security, and environmental protection issues. Primarily, it does so through standards for ship design and operation; and seafarer training, certification, and watchkeep. Codes ratified by the IMO are enforced by the appropriate governmental body(ies) within each of the respective signatory nations to that code, such as the U.S. Coast Guard in the United States. Countries may enforce these regulations on vessels as either a port state or a flag state, as described above. Much of the work regarding GHG emissions has been carried out through the IMO's Marine Environmental Protection Committee (MEPC).

Though the intention of IMO provisions is to provide consistent international regulation regardless of country, country-specific unilateral regulation is possible and often occurs.

TABLE 5 Common Vessel Types and Their Equipment

Ship Type	**Container**	**Tanker: Oil (crude/product)**	**Tanker: Chemical**	**Dry Bulk**	**RO/RO or Car Carrier**
Trade characteristic					
Typical cargo	Finished consumer goods	Crude oil/refined petroleum products	High-grade petroleum products and chemicals	Dry bulk cargoes, e.g., grain, iron ore, coal, etc.	Road vehicles (heavy eqp't, trucks, cars, etc.)
Trade type	Liner	Charter/spot	Liner, spot	Spot	Liner
Consistent port-call locations	**High** (fleet of sister ships often serve a regular route)	**Medium** (spot traders, but may only serve a handful of ports)	**Medium/High** (typically liner trade, but do take cargoes on a spot basis)	**Medium/Low** (primarily spot)	**High** (liner operation)
Ownership	About 10–15 large operators dominate	Mix of both large and small owners	Two operators dominate	Mix of both large and small owners	A few large and various regional operators
Primary energy conversion equipment (newbuilds and the modern fleet; ships built before the mid 1970's were mostly steam-powered)					
Propulsion	Slow speed diesel	Slow speed diesel	Slow speed diesel	Slow speed diesel	Slow speed diesel
SFOC[2]	~170g/kW-hr	~170g/kW-hr	~170g/kW-hr	~170g/kW-hr	~170g/kW-hr
Auxiliary power	High-spd diesel gensets	High-spd diesel gensets	High-spd diesel gensets	High-spd diesel gensets	High-spd diesel gensets
SFOC	~185g/kW-hr	~185g/kW-hr	~185g/kW-hr	~185g/kW-hr	~185g/kW-hr
Steam/heating	Steam boiler	Steam boiler	Steam boiler	Steam boiler	Steam boiler
SFOC	~109g/kW-hr	~109g/kW-hr	~109g/kW-hr	~109g/kW-hr	~109g/kW-hr
Major nonpropulsion power consumers					
Consumer (and its supplier)	Reefer loads (auxiliaries)	Cargo pumps (steam), cargo heating (steam)	Cargo pumps (auxiliaries or steam), cargo cooling (auxiliaries), cargo heating (steam)	Negligible	Deck exhaust system (auxiliaries)
Power requirements[3]	**12MW** (0.012MW/container x 1000 cont)[4] (36-19)	**5-20MW**[4] (varies on ship size)	**1.5MW** (300kW/hydraulic pump x 5 pumps)	-	**1.5MW** (typ aux capacity)[4] (35-45)
Emissions considerations					
Existing incentives to reduce GHGs	Fuel cost	Fuel cost	Fuel cost	Fuel cost	Fuel cost

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[2] Specific Fuel Oil Consumption (SFOC) is representative of a typical, nominal piece of equipment as-installed; actual usage will drive actual SFOC.

[3] Power requirements vary greatly per vessel, even throughout a given voyage; these numbers merely provide an order-of-magnitude.

[4] Aalborg Industries website. http://aalborg-industries.com/marine_solutions/pro_sb_mission_d_type.php. and Shinko Pumps website. http://www.shinkohir.co.jp.

TABLE 6 Common Vessel Types and Their Equipment

Ship Type	**LNG/LPG**	**Cruise (Passenger)**	**Reefer Ships**	**Harbor Service, OSVs, Research, Ferry, etc.**	**Inland and Intracoastal Waterway Boats/Barges[5]**
Trade characteristic					
Typical cargo	Liquefied gas (natural gas [methane], petroleum gas [butane])	People	Refrigerated agriculture (fruit, meat, etc.)	N/A (service vessels)	Grain, bulk materials, crude and refined petroleum products, containers
Trade type	Liner, possibly spot in future	Liner	Liner	Local/Regional	Affreightment, time chartered
Consistent port-call locations	**High/Medium** (primarily liner market, but new trade lanes in future)	**High** (typically weekly service to same ports)	**High** (primarily liner)	**High** (typically remain-in or return-daily-to homeport)	**High** regular ports and usually remain domestic
Ownership	Varies: shipowners, energy companies, and governments	Many ferry operators/3-4 major cruise companies	Small segment with diverse ownership	Varies by segment	U.S.: Both public and private owners, several energy companies, about 20 in all
Primary energy conversion equipment					
Propulsion	Traditional: Dual-fuel steam for propulsion with ship svc's turbine generator Emerging: Slow speed diesel engine or dual-fuel medium spd diesel–electric	Medium speed diesel–electric for propulsion and hotel load	Slow speed diesel	Medium or high-speed diesels, may be diesel–electric, small boiler if any	High and medium speed diesels
SFOC			~170g/kW-hr		~177-185g/kW-hr
Auxiliary power			High speed diesel gensets		High and medium speed diesels
SFOC		~177g/kW-hr	~185g/kW-hr		~177-185g/kW-hr
Steam/heating	Steam boiler	Steam boiler	Steam boiler		Boats: electric heat; Barges: some w/diesel-fired heaters, some w/coils and shoreside-steam
SFOC	~109g/kW-hr	~109g/kW-hr	~109g/kW-hr		
Major nonpropulsion power consumers					
Consumer (and its supplier)	Traditional: Negligible Emerging: Reliquifaction plant	Air-con (main diesel electric generators); water/heating (boiler)	Refrigeration, cranes (auxiliaries)[3 (28-18)]	Harbor service/OSV's: Mooring equipment, specialty systems (auxiliaries)	
Power requirements[6]	**Emerging: 3-5 MW** [7(6)]	**3-10 MW**	**9.60MW** (0.160kW/m^3 x 30m x 200m x 10,000m^3)[8 (28-23,29)]	Varies greatly	
Emissions considerations					
Existing incentives to reduce GHGs	Fuel cost	Fuel cost; green branding	Fuel cost	Fuel cost; port emissions reduction program	Fuel cost

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[5] Figures compiled with guidance from Kirby Inland Marine.
[6] Power requirements vary greatly per vessel, even throughout a given voyage; these numbers merely provide an order-of-magnitude.
[7] Wayne 2006.
[8] Lamb 2004.

TABLE 7 Estimates of Maritime's Contribution to Various Emissions (aggregate of both international and domestic shipping)

Source	Year of Publication	Inventory Year	Fuel Consumption	NO_X	SO_X	PM_{10}	CO_2
			10^6 MT	10^6 MT (% tot)	10^6 MT (% tot)	10^6 MT (% tot)	10^6 MT (% tot)
Eyring et al.	2005	2001	280	21.4 (29%)	12 (9%)	1.7	813 (3)
Corbett and Koehler	2003	2001	289	22.6 (31%)	13 (9%)	1.6	912 (3)
Endresen et al.	2003	2000	158	12 (17%)	6.8 (5%)	0.9	501 (2%
IMO	2000	1996	120–147	10 (14%)	5 (4%)		419 (1.5)
MEPC 57 Working Group	2007	2007	369	25.8	16.2	1.8	1,120
		2020[a]	486	34.2	22.7	2.4	1,475

Source: Adapted from Friedrich and Heinen 2007; Marine Environmental Protection Committee 2008.
[a] Estimated using a business-as-usual approach.

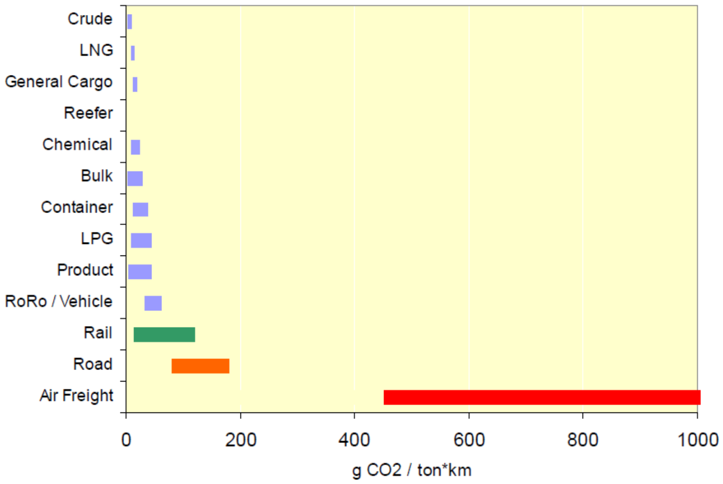


FIGURE 9 CO_2 intensity of various vessel types against other transportation modes. (Marine Environmental Protection Committee 2008, p. 14)

Classification Societies

Classification societies are independent organizations (some are not-for-profit) that serve as the primary source of engineering quality standards for the construction and inspection of ocean going vessels. It is absolutely critical for a carrier to maintain class certification for its ships before any shipper, port, or insurer will do business with it. Class societies must stay at the forefront of the industry to ensure safe and effective implementation of new technologies, regulations, etc. In addition, some class societies offer "alternative compliance," where the society has been certified by a governmental body (i.e., U.S. Coast Guard) to inspect and certify ships on behalf of that government.

Current Regulatory Initiatives

International: UN/IMO Efforts

Overview Driven by the Kyoto Protocol (discussed below) and based upon a study of GHG emissions from international shipping completed in 2000, the IMO has been executing a work plan to reduce GHG emissions from international shipping through technical, operational, and market-based measures. Specifically,

- Technical measures include an energy efficiency design index (EEDI) for new ships.
- Operational measures include
  - Energy efficiency operational index (EEOI) for existing ships,
  - Best practices such as speed reduction and weather routing, and
  - Possible ship efficiency management plan (SEMP).
- Market-based measures proposed to date include
  - International GHG compensation fund based upon a fuel levy, and
  - Maritime emissions trading scheme (METS) as a "cap and trade" approach.

Further, IMO has developed nine "principles" it believes any instrument should reflect:

1. Effectiveness in contributing to reduction of total GHG emissions,
2. Binding and equal applicability to all flag states in order to avoid evasion,
3. Cost-effectiveness,
4. Ability to limit, or at least effectively minimize competitive distortion,
5. Basis of sustainable environmental development without penalizing global trade and growth,
6. Construction on a goal-based approach rather than prescriptive, specific methods,
7. Supportiveness of promoting and facilitating technical innovations and R&D in the entire shipping sector,
8. Accommodation to leading technologies in the field of energy efficiency, and
9. Administration that is practical, transparent, fraud-free and easy.

Kyoto Protocol The 1997 Kyoto Protocol (Kyoto) to the 1994 United Nations Framework Convention on Climate Change (UNFCCC), among other things, delegated responsibility to regulate and monitor GHG emissions from international maritime activity to the IMO, while domestic shipping remained the responsibility of the respective signatory states. Per Kyoto's overall structure, nations are regarded as either "developed," and subject to national emissions reduction quotas (Annex I parties), or "developing," and only subject to emissions reporting. This division between Annex I and non-Annex I responsibilities has been referred to as "common but differentiated responsibilities (CBDR)."

CBDR, however, has created disagreement at the IMO, specifically with Principle 2 above. While historically IMO instruments have always applied equally to all parties, a number of developing countries believe that CBDR should apply to IMO instruments such that only ships flagged in Annex I countries would be responsible to reduce emissions. However, only about 25% of the world's current tonnage is registered to an Annex I nation, and ship ownership needn't be aligned with its registry. Further, outside of some niche regional markets where ship registry may be important for legal or commercial reasons, there is little reason beyond administrative burden and cost to prevent most international operators from reflagging a ship from an Annex I to a non-Annex I nation.

Current Status The technical and operational instruments have been debated and developed over a number of years, while the market-based instruments are newer and less developed. Additionally, the IMO commissioned a study that was received at the July 2009 MEPC meeting to update the 2000 emissions inventory, which has since been released. However, further significant work on these items is delayed as there exists a great deal of uncertainty as to what the UNFCCC will ultimately rule on marine's inclusion or exclusion into the global GHG cap system at the UNFCCC COP 15 meeting in Copenhagen in December, 2009.

In particular, the question of "application," i.e., CBDR approach or the IMO concept of "equal application" remains unsettled, particularly between delegates from Annex I and non-Annex I nations. IMO will provide an update of its activities at the Copenhagen meeting.

International: European Union (EU)

The European Union states that its IMO-participating member states will push the IMO toward tough ship emission reduction measures. If it is dissatisfied with the progress made at IMO, the EU has also indicated that it may include international shipping in its current Emissions Trading System (ETS) by the 2011 timeframe.

National: U.S. Environmental Protection Agency (EPA)

EPA has issued an Advanced Noticed of Proposed Rulemaking (ANPR) discussing potential activities to address GHGs as a pollutant under the Clean Air Act. The ANRP either references or includes comments from the U.S. Department of Transportation (DOT), Energy (DOE), the California Air Resources Board (CARB), and various other organizations. While some of those organizations and others have commented on their views of potential marine regulation, the ANPR mostly proposes areas of potential emissions reduction and requests comment.

State: California Air Resources Board (CARB)

The California Air Resources Board has instituted and supported various initiatives in California, including ship electrification at ports ("cold-ironing"), vessel speed reduction (VSR), an educational program for commercial harbor craft operators to improve efficiencies, and a proposed measure to address residual refrigerant in the decommissioning of reefer boxes.

Port-Specific Regulations

The Ports of Los Angeles and Long Beach have, under their Clean Air Action Plan, begun requiring clauses in their terminal lease contracts to limit emissions from ships calling to their ports through fuel-switching, speed reductions, and cold-ironing. Though the focus has only been for some of the original EPA criteria pollutants to date (i.e., not CO_2), the plan sets a precedent for future GHG emission regulations.

Sweden currently uses port-cost differentiation as a deterrent to emit NO_X and SO_X by charging more for vessels that emit more. The effect of this effort, however, can be diminished by the leverage that large operators bring to price negotiations.

Additionally, these port-specific approaches can lead to a distortion of competition, and inconsistent regulation remains a challenge for operators whose ships may call on hundreds of ports in various countries throughout the world.

Industry Activities

There are many industry groups and activities focused on GHG emissions:

- International Association of Independent Tanker Owners (INTERTANKO),
- International Chamber of Shipping (ICS),
- European Community Shipowners Association (ECSA),
- Chamber of Shipping of America (CSA),
- American Petroleum Institute (API),
- Pacific Merchant Shippers Association (PMSA),
- Ship Emissions Abatement and Trading (SEAAT) cooperative, and
- *Marine Log* magazine’s annual Global Greenship Conference.

EMISSIONS MITIGATION

There are three primary approaches to reducing the GHG emissions of the world’s fleet:

1. Operational efficiency (existing fleet): modify operational practices to reduce fuel oil consumption of current and future vessels;
2. Design efficiency (today’s newbuilds): improve the fuel efficiency of existing designs/technologies (to reduce CO_2) and consider the deployment of after-treatment technologies to reduce non-CO_2 GHGs; and
3. Advanced technology (future newbuilds): consider next-generation fuels and technologies.

Some of the primary challenges facing the industry include

- High industry ownership fragmentation, varying industry segmentation, and the employment of capital-intensive equipment with long service lives have traditionally created a cautious approach to implementing new technology;
- Regulations that prematurely remove ships from the market may have global

economic implications and will generate “upstream” emissions as shipbuilding activity increases;

- The need to reduce GHGs could create design challenges that will compete with other engineering and safety demands in ship design, production, and operation;
- Energy costs and other commercial implications already drive ship design towards ever-greater efficiency;
- There is presently no identifiable, leading, practical alternative to the diesel engine as a primary propulsion source with a lower GHG emission profile;
- Regionally inconsistent regulations are both administratively and operationally challenging, especially for vessels that spot trade, and hence do not necessarily visit the same ports regularly; and
- Though the industry is unique and is therefore regulated as such, if emissions mitigation mechanisms are isolated from other industries, lower-cost mitigation opportunities may be missed (e.g., purchasing emissions credits).

Operational Efficiency

Speed and Navigation Management

A vessel’s energy intensity, hence fuel consumption, generally grows quadratically with speed (power demand grows cubically while the resulting transit time decreases linearly, for a net quadratic energy consumption). There are two primary areas of speed management: (1) intentional speed reduction and (2) weather routing.

The intentional slowing of ships to reduce fuel consumption has already been done by some operators of higher-speed vessels like container and passenger ships (18 to 22+ knots), though commercial considerations limit how much extra time a vessel can realistically add to its voyage. Conversely, dry bulk ships may be able to absorb slightly slower transit times into their schedules, though the returns would be smaller since they already generally operate relatively slowly (14 to 16 knots). However, speed reduction creates an effective capacity loss that, on an industrywide basis, creates an artificial tonnage shortage requiring construction of more ships.

The second method of speed management is weather routing, or the effective use of meteorological data to better forecast wind and current conditions the vessel will experience throughout a voyage. This information allows captains to optimize the vessel’s speed and heading to arrive on time with minimized fuel consumption.

In addition to vessel speed, good navigational practice can reduce fuel consumption as well. For instance, vessel auto-pilots already allow wind and waves to push the vessel slightly off course while underway. This reduces the amount of rudder refinement, which reduces energy consumption.

Fleet Utilization

Productive output per unit fuel consumption can be maximized by improving fleet utilization, effectively optimizing the use of vessels to reduce empty or light-loaded backhauls. Utilization is already driven largely by maximizing return on assets, and this has always been a challenge because markets can fluctuate rapidly and global economics drive large imbalances in world trade. Still, ships are movable assets that can be shifted to where they are most needed.

Onboard Energy Management

Effective onboard equipment management by crew can reduce energy intensity. Identifying energy leaks, turning off unused equipment, recovering waste heat where possible, and load-matching, such as running one discharge pump at a greater capacity versus two at low capacity, can all help to reduce energy intensity.

Design Efficiency

Hull and Propeller Design

Hull and propeller design efficiency has always been a primary goal for naval architects. However, as in any engineering discipline, there are tradeoffs: hull strength, cargo capacity, seakeeping/stability, fabrication producability, arrangements, etc. must all be considered. Similarly, for propeller design, material strength, cavitation erosion, propeller overloading, etc. may limit realizable efficiency gains.

Perhaps most promising at this point is wider implementation of some proven, hydrodynamically-creative hull fittings (e.g., a wake improvement duct or preswirl stator) that improve propeller performance (both wake into the propeller and reclamation of otherwise lost energy). These fittings can both be applied to new vessels and retrofitted to existing ones. Unfortunately, most of these modifications must be specifically designed for every unique hull–propeller combination. Also, the region local to the propeller is prone to vibration, creating potential steel fatigue challenges for such appendages. These reasons are likely why these designs are not as widespread as might be expected. Finally, propeller/rudder interaction also remains a promising area of possible improvement.

Hull Coatings and Maintenance

Ship hulls are cleaned and recoated, typically ever five years at each major drydocking, to protect the hull from corrosion, deter marine growth, and consequently reduce frictional resistance. Coatings have developed significantly over time, and silicon-based paints are now gaining popularity with the claim that they can reduce fuel consumption up to 4% versus traditional copper-based paints. Though currently rare in practice, propellers can also be treated with a durable coating.

Power Plant Efficiency

Slow-speed, direct-drive diesel engines replaced steam as the dominant power plant choice for ships in the 1970’s. This was a step-change improvement in overall plant efficiency, and engines have continued to improve ever since. This is evident in Figure 10, though recent regulations on nitrogen oxides have partially stalled fuel economy improvements.

Common-rail, higher-pressure fuel injection; higher compression ratios; shorter fuel-injection periods; improved turbocharging; electronic fuel and air management; and improved cylinder head and piston shape have already contributed to reducing specific fuel oil consumption (SFOC).

Perhaps the most ambitious effort of late was the HERCULES project, where the world's two slow-speed diesel engine manufacturers (Wärtsilä and MAN B&W) partnered with leading universities to study common-platform engine improvements and heat-recovery technologies. Some of these technologies were well known, but have historically been cost-prohibitive or operationally infeasible on a large scale.

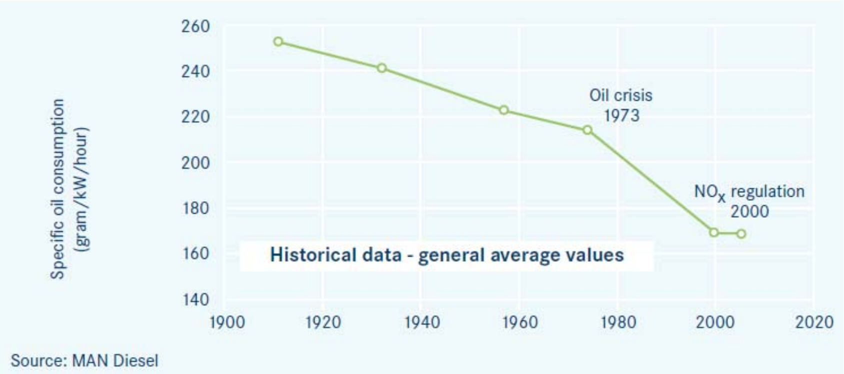
Waste Heat Recovery

Efficiencies are gained where possible by utilizing waste heat, which has been estimated to improve power plant efficiency up to 5%. Yet, there are practical limitations, such as the need for equipment redundancy, over-sizing for peak loads, available space in the engine room, cost, and misalignment of when equipment is used. For instance, while a tanker's main engine exhaust typically generates steam via a waste-heat boiler, steam is most-needed in port for cargo discharge operations, when the main engine is not running. However, main engine cooling media is often used to generate fresh water onboard (needed at all times). Figure 11 illustrates the energy balance for a typical, slow-speed marine diesel engine.

Cargo and Ancillary Equipment GHG Reduction

Ancillary shipboard equipment also provides room for improvement. For instance

- Estimates suggest that refrigerated container boxes ("reefers") could significantly reduce the refrigeration load with improved insulation (this adds up quickly on a ship hauling 1000 reefers) and
- HFC- or HCFC-refrigerant leaks from shipboard refrigeration plant are not only an energy loss, but a direct GHG emission.



Source: MAN Diesel

FIGURE 10 Historic specific fuel oil consumption for slow-speed diesel engines.
(Reproduced with permission from Climate Change and Shipping
ECSA Position Paper, 2008)

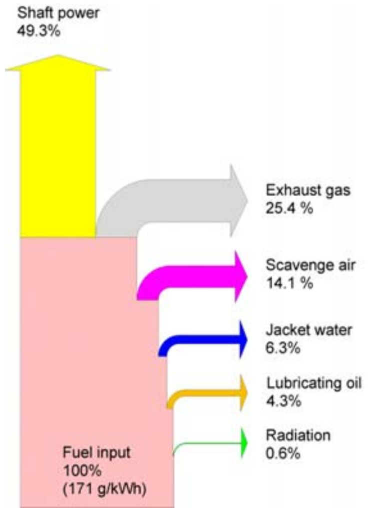


FIGURE 11 Energy balance for a typical slow-speed marine diesel engine.
(Reproduced with permission from Wärtsilä)

Advanced Technology

Although new technologies are promising in the long term, there are currently no identified, large-scale, practical alternatives to the traditional marine propulsion portfolio.

Alternative Fuels

HFO is the dominant fuel of choice for large-ship propulsion, though it is heavy, carbon-intense, and has impurities (namely sulfur) that cannot currently be practically filtered out. HFO is a necessary refinery output that is too heavy and viscous to be used for much other than marine fuel, and, even there, application is limited to medium- or slow-speed diesel engines and steam boilers. The most likely alternate market for HFO would be in shoreside power plants that, because of their size, could add more heat-recovery capacity and after-treatment equipment than ships, resulting in more efficient and cleaner use of the fuel, albeit requiring a large capital investment.

However, a realistic alternative to HFO for marine remains difficult when considering issues like cost, storage options, distribution infrastructure, and existing equipment.

Lighter Fossil Fuel Switching

Fuel-switching to a lighter fossil fuel has been widely debated, primarily in response to greater focus on common “criteria pollutants” like SO_X and NO_X. The primary issue is that the refining process leaves a high-concentration of sulfur in heavier products like HFO. Sulfur removal from HFO is only feasible to a certain point, until it becomes more economical to burn MDO that can be scrubbed of sulfur more easily.

The most pervasive global push to reduce these non-CO_2 pollutants concluded with a 2008 amendment to IMO’s International Convention for the Prevention of Pollution from Ships (MARPOL) that mandated various changes in engine technology, and reductions in bunker sulfur content. While it is recognized that a lighter fuel like marine diesel oil (MDO) could reduce a ship's carbon and sulfur intensity, a global switch from HFO to MDO has been estimated to require a $126 billion investment in global refining capacity likely to take over 13 years. Further, from a life cycle-emissions standpoint, the carbon emissions generated by refineries to produce more MDO has been estimated to have a net-negative, or at best negligible overall effect on CO_2 emissions from the maritime industry, at about a 1% to 2% increase (7% if the increase in coke production is considered).[9]

Biofuels

The focus on biofuels in the road sector has been highly publicized, though, depending on the source crop, serious issues exist about net carbon emissions, potential competition with the agriculture sector, and scalability. Although sulfur-free and operationally sound, it is unlikely that the maritime industry would make a significant investment in this technology until these fundamental questions are definitively resolved.

Nuclear Power

Nuclear power has been utilized safely, effectively, and without incident by the U.S. Navy for decades. However, a widespread implementation of marine nuclear power would require high capital-investment and drive significant demand for highly-qualified, nuclear-trained crews, which is likely to be nuclear's greatest hurdle. Further, complex legal and security concerns would be likely to arise. For these reasons, commercial shipboard nuclear power seems an unlikely replacement for marine diesels.

Liquefied Natural Gas (LNG)

Liquefied natural gas is transported on deep-sea ships in mass quantities safely and effectively. However, the extremely low storage temperatures require "floating tanks," or tanks that are entirely contained inside the ship's hull with room on all sides to allow for complete exterior tank inspection. The insulation is costly and the arrangement requires significant space; conversely, conventional bunker tanks are often a good use of space that is otherwise difficult to utilize due to hull shape. Additionally, natural gas liquefaction is not a trivial effort, and requires significant investment in cryogenic refrigeration technology.

Compressed natural gas (CNG) may find applications as a sole- or dual-fuel (mixed with diesel) aboard smaller ships and ferries with limited ranges and a regular homeport.

All-Electric Ship

Traditionally, diesel–electric propulsion plants have been limited to vessels with high nonpropulsion loads, high-maneuverability control requirements, and/or restrictive general arrangements (e.g., cruise ships and dynamically positioned ships). These power systems are comprised of several diesel gensets, typically medium-speed, that provide power to the ship's electrical bus from which all electronic consumers then feed. Engine governors regulate speed by

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[9] EnSys Energy & Systems, Inc., 2007

controlling fuel input (and hence torque), while larger load changes require engines to be paralleled on- and off-line.

Conversely, most cargo vessels with small nonpropulsion loads are more-efficiently propelled by direct-drive, slow-speed diesel engines that avoid the complexity and inefficiencies introduced by generators, motors, and electrical transmission. However, if designed and operated properly, and fitted with a large energy storage device that can reduce peak-loads on the prime movers, it is believed that the “all-electric ship” may offer greater efficiencies than previously recognized. A joint academic and industry effort is underway to study this new approach. The technology gained from this study can also serve as a bridge platform should traditional internal combustion power plants be replaced as the prime mover of the future.

Sails and Kites

Though wind is regarded as neither consistent nor powerful enough to be used as a reliable sole power source for today’s larger cargo vessels, sail and kite designs have been proposed and successfully tested to supplement ship’s traditional power plants. Several companies have begun conducting experiments using “ship kites,” and claim fuel savings of between 10% and 35%, depending on sailing direction and wind conditions.

CONCLUSION

The maritime industry, like many, has been driven to improve efficiencies in response to economic drivers since its inception. It is also a very mature industry that innovates conservatively due to high capital costs, long equipment operating lives, relatively tight margins, an ever-fluctuating market, and various potential regulatory regimes depending on where the vessel trades.

Though larger than virtually all vehicles in other transportation modes, ships are still limited on space, and any equipment addition or modification must be considered from standpoints of safety, cost, reliability, structure, stability, remaining ship life, and appropriate rules and regulations. Further, not all ships are created equal; ships come in a wide variety of sizes, arrangements, and with different types of equipment and operating procedures to safely and effectively handle its cargo. For today’s fleet of vessels, the most promising technologies will be those that improve efficiency at reasonable cost. In some cases, these design modifications and operational changes would be financially justifiable even without any cost placed on GHG emissions.

There are many parties with varied concerns that take an interest in how the industry will eventually respond:

- IMO and owner’s organizations concerned with ensuring consistent and predictable regulations with reasonable cost implications;
- Shipyards, ship design firms, and class societies concerned with the safety, reliability, and effectiveness of future ship designs;
- Governments of coastal regions concerned with limiting emissions generated by the ships visiting their port areas;

- Marine suppliers and equipment manufacturers that will ultimately develop and produce the next generation of products to meet these goals;
- Cargo shippers concerned with the emissions of the transportation system that moves their cargo for cost, green-branding concerns, and their own emissions targets; and
- Environmental groups and general public concerned with effects of climate change.

Internationally, the IMO has been making progress at developing a globally consistent approach to address GHG emissions. At the national and regional levels, policies should remain consistent with the IMO's to reduce the burden placed on all interested parties.

Fortunately, the industry remains in a competitive position, as it is the least GHG-intense method of primary freight transport available. This is particularly relevant with short-sea-shipping, where coastal vessels can help displace the burden that trucks place on already-congested highways, and do so at significantly reduced emission levels versus truck and even rail transportation.

The future of marine GHG emissions continues to be shaped by regulation and available technology, and the next few years will prove particularly critical.

ACKNOWLEDGMENT

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5

Transit

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The United States' public transit sector consists of more than 150,000 revenue vehicles spread across six major modes and several minor modes. Table 8 illustrates current revenue vehicle inventory for transit buses, commuter rail, paratransit, heavy rail, light rail, trolleybuses and a combination of the remaining minor modes. As Table 9 illustrates, these modes represent the more than 4.8 billion vehicle miles traveled (VMT) in 2006, slightly more than 3% of all VMT in the United States.

U.S. REVENUE VEHICLES

Transit Buses

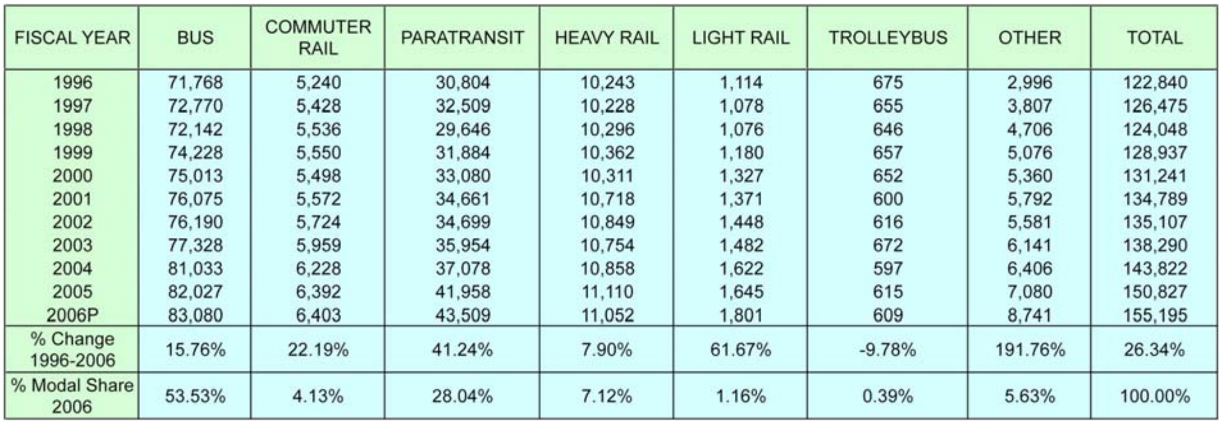
Transit buses come in a variety of sizes, typically in the 35 to 45 foot range with "articulated" buses usually 60 feet in length being used on high-volume routes and on designated Bus Rapid Transit (BRT) routes. BRT routes are particularly promising as they allow busses to travel at increased travel speeds, which has a greater potential of attracting riders away from private vehicles. Data in this section of the primer does not include intercity (e.g., Greyhound, Peter Pan, BoltBus) buses. The majority of transit buses are powered by diesel fuel, though many transit agencies are migrating to other fuels such as CNG, gasoline, LNG, and liquefied petroleum gas

(LPG, propane). Note that while at the tailpipe some of the liquid fuels (such as LNG) other than diesel may appear less carbon-intensive, carbon intensity must be considered on a life cycle basis.

Commuter Rail

Commuter rail systems typically serve short-haul routes between suburban communities, downtown core areas and major employment centers, usually operating on regular railroads or former railroad rights-of-way. They differ from intercity passenger rail (e.g., Amtrak) in terms of route length, frequency and ridership.[1] Trains are powered by diesel fuel or electricity,

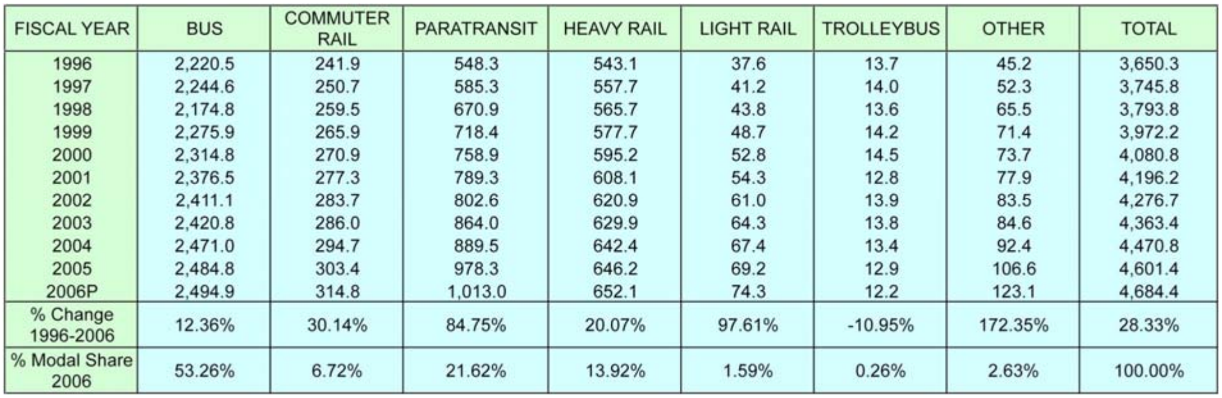
TABLE 8 Public Transit Revenue Vehicles by Mode, 1996–2006



FISCAL YEAR	BUS	COMMUTER RAIL	PARATRANSIT	HEAVY RAIL	LIGHT RAIL	TROLLEYBUS	OTHER	TOTAL
1996	71,768	5,240	30,804	10,243	1,114	675	2,996	122,840
1997	72,770	5,428	32,509	10,228	1,078	655	3,807	126,475
1998	72,142	5,536	29,646	10,296	1,076	646	4,706	124,048
1999	74,228	5,550	31,884	10,362	1,180	657	5,076	128,937
2000	75,013	5,498	33,080	10,311	1,327	652	5,360	131,241
2001	76,075	5,572	34,661	10,718	1,371	600	5,792	134,789
2002	76,190	5,724	34,699	10,849	1,448	616	5,581	135,107
2003	77,328	5,959	35,954	10,754	1,482	672	6,141	138,290
2004	81,033	6,228	37,078	10,858	1,622	597	6,406	143,822
2005	82,027	6,392	41,958	11,110	1,645	615	7,080	150,827
2006P	83,080	6,403	43,509	11,052	1,801	609	8,741	155,195
% Change 1996-2006	15.76%	22.19%	41.24%	7.90%	61.67%	-9.78%	191.76%	26.34%
% Modal Share 2006	53.53%	4.13%	28.04%	7.12%	1.16%	0.39%	5.63%	100.00%

Source: American Public Transportation Association June 2008.

TABLE 9 Public Transit Vehicle Miles Traveled, 1996–2006 (millions)



FISCAL YEAR	BUS	COMMUTER RAIL	PARATRANSIT	HEAVY RAIL	LIGHT RAIL	TROLLEYBUS	OTHER	TOTAL
1996	2,220.5	241.9	548.3	543.1	37.6	13.7	45.2	3,650.3
1997	2,244.6	250.7	585.3	557.7	41.2	14.0	52.3	3,745.8
1998	2,174.8	259.5	670.9	565.7	43.8	13.6	65.5	3,793.8
1999	2,275.9	265.9	718.4	577.7	48.7	14.2	71.4	3,972.2
2000	2,314.8	270.9	758.9	595.2	52.8	14.5	73.7	4,080.8
2001	2,376.5	277.3	789.3	608.1	54.3	12.8	77.9	4,196.2
2002	2,411.1	283.7	802.6	620.9	61.0	13.9	83.5	4,276.7
2003	2,420.8	286.0	864.0	629.9	64.3	13.8	84.6	4,363.4
2004	2,471.0	294.7	889.5	642.4	67.4	13.4	92.4	4,470.8
2005	2,484.8	303.4	978.3	646.2	69.2	12.9	106.6	4,601.4
2006P	2,494.9	314.8	1,013.0	652.1	74.3	12.2	123.1	4,684.4
% Change 1996-2006	12.36%	30.14%	84.75%	20.07%	97.61%	-10.95%	172.35%	28.33%
% Modal Share 2006	53.26%	6.72%	21.62%	13.92%	1.59%	0.26%	2.63%	100.00%

Source: American Public Transportation Association June 2008.

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[1] Three notable exceptions: Rail services provided by the Peninsula corridor Joint Powers Board between Roseville–Oakland–San Jose, California, and the Northern New England Passenger Rail Authority between Portland, Maine, and Boston, Massachusetts, are categorized by FTA as commuter rail services but are operated by Amtrak as intercity service. The Alaska Railroad is also categorized by FTA as commuter rail but is similar to the intercity rail services operated by Amtrak.

with a small number of hybrid diesel electrics making their way into the fleet. Data in this section include commuter train passenger cars and locomotives.

Paratransit

Paratransit vehicles, also known as demand response vehicles (or more commonly "Dial-a-Ride"), are slightly more ad-hoc in nature and include small, purpose-built buses and motor coaches as well as 9 to 15 passenger vans, drop-floor minivans, and four door sedan-style automobiles. The vast majority of demand response vehicles are powered by diesel fuel and gasoline, while alternative fuels and propulsion systems represent less than 12% of all fuel consumed.

Heavy Rail

Heavy rail systems are high-capacity, intracity or metropolitan area systems that run in dedicated rights-of-way underground, at grade (but barrier separated), and above grade (elevated), or some combination of the three such as San Francisco's BART system, the MBTA's "T" system in Boston, or the Washington, D.C. Metropolitan area metro system. Heavy rail systems are almost entirely powered by electricity, usually in the form of a third rail, running parallel to standard gauge track.

Light Rail

Light rail systems are typically low-medium intracity systems that run underground and at grade either in dedicated rights-of-way or in roadways. As a mode, light rail also usually includes vehicles commonly known as streetcars. Light rail runs almost exclusively on electricity, both through third-rail type systems as well as overhead wiring. A very small number of light rail systems are powered by diesel, such as the recently approved (November 2008) system traversing Marin and Sonoma counties in California, or the 30-mile diesel light rail New Jersey Transit's River Line between Trenton and Camden, N.J., which has been operational for more than several years.

Trolleybus

Trolleybuses are rubber-tired vehicles similar in form to transit buses, however instead of using fossil fuel for propulsion, they are powered by (electrified) overhead catenary wires, or more modern trolleys are buses fitted with electric propulsion and catenary poles.

Other

The "other" category found in Table 8 and Table 9 includes ferry boats, monorails, aerial tramways, and several other less-common modes.

Table 8 indicates that, as a measure of total revenue vehicles, rubber-tire modes (bus, paratransit, and trolleybus) have more than 80% mode share, some 127,000 vehicles. By comparison, Table 9, which details the number of vehicle miles traveled (VMT), the same three modes have roughly 75% share. As these modes represent a large majority share of both vehicles and vehicle miles traveled, as well as exhibit a strong reliance on fossil fuels (particularly diesel), they represent the largest potential area for increasing efficiencies and mitigation emissions. By similar measures, Table 8 light rail and paratransit are the two fastest growing modes in terms of fleet size, with growth rates of 61% and 41% over the 1996–2006 period. Table 9 shows light rail and paratransit are simultaneously experiencing large gains in VMT with growth rates of 97% and 84%. The growth of light rail is commendable, however, as paratransit's VMT growth has outstripped growth in fleet size by roughly a 2-to-1 ratio, close attention must be paid to this mode in terms of fuel economy and emissions control.

Relative to cars, public transportation can be a very efficient mode of transportation. Table 10 shows a crude average of passenger miles per vehicle per day. The crude average does not account for vehicle sizes and seating capacity and loading factors by time of day (more people riding public transit during peak hour) of the different public modes of transport, though it does illustrate one point as follows. From Table 1 (in the road primer), it is shown that 135E6 vehicles traveled 2.6E12 passenger miles in 2006, or 54 passenger-miles per vehicle per day. Compare this to 753 passenger-miles per vehicle per day in 2006 for buses, more than 4,000 for commuter rail, 68 for paratransit, and so forth for the rest of the public transit modes. Similarly, the total number of passenger-miles traveled is divided by total vehicle-miles traveled we get average occupancies for both cars and public transit. Again from Table 1, we know this average occupancy or load factor to be 1.57 for cars, whereas this value is much higher for public transit as is shown in Table 11.

Because of its capacity, capital cost subsidies, predictable routes, and centralized fueling and maintenance infrastructure, public transit is an ideal way to pioneer new technologies. On a nominal basis, public transit's higher load factors are virtually always less energy-intensive, per passenger mile, than automobiles. According to the 2008 Public Transportation Fact Book, ridership of public transit has increased at a rate faster than population growth. However, increases in suburbanization and income typically yield an increase in vehicle ownership and use.

ENERGY CONSUMPTION

The transportation sector in the United States is broadly defined by the Bureau of Transportation Statistics (BTS) to include air transportation, highway transportation (automobiles, light-duty trucks, freight trucks, etc), transit (the modes concerned in this section of the primer), rail (freight), Amtrak, water, and pipeline.[2] As of 2006, the U.S. transportation sector was responsible for 29% of nationwide energy consumption. Of that 29%, roughly 96% came from petroleum-based fuels, 2% from natural gas (including compressed and liquefied) and 2% from renewable sources (including biodiesel and ethanol).[3]

The BTS also compares energy consumption between transportation modes. Public transit was responsible for consuming 154 petajoules of energy in 2006, just 0.55% of all energy consumed in the transportation sector. In the same year, energy intensity measured as Btu per passenger-mile for public transit was 2,913 (see Table 12), whereas for cars it was 3,512, or

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[2] *National Transportation Statistics 2008.* Bureau of Transportation Statistics, Washington, D.C., 2008. Table 4-6M.

[3] *Annual Energy Review 2007.* Energy Information Administration, Washington, D.C., June 2008.

TABLE 10 Crude Average of Passenger Miles per Vehicle per Day

FISCAL YEAR	BUS	COMMUTER RAIL	PARATRANSIT	HEAVY RAIL	LIGHT RAIL	TROLLEY BUS	OTHER
1996	729.90	4366.31	58.35	3083.96	2353.61	746.83	552.33
1997	738.07	4058.59	63.54	3229.38	2630.44	790.55	477.13
1998	773.21	4307.55	67.92	3268.73	2872.13	771.87	427.90
1999	782.67	4327.29	69.86	3411.31	2800.09	775.63	420.46
2000	775.79	4685.14	69.49	3678.48	2799.60	806.79	404.83
2001	793.09	4694.71	67.58	3624.17	2871.62	853.88	398.76
2002	785.38	4548.98	67.35	3450.35	2709.45	836.15	413.83
2003	753.31	4394.87	70.87	3466.31	2728.63	717.55	398.40
2004	722.76	4275.43	71.08	3621.85	2662.03	793.92	389.62
2005	728.96	4060.30	69.08	3555.48	2831.33	770.69	399.74
2006	752.57	4433.28	67.88	3649.25	2838.61	737.79	358.25
% Change 1996-2006	3.11%	1.53%	16.34%	18.33%	20.61%	-1.21%	-35.14%

Source: American Public Transportation Association June 2008.

TABLE 11 Load Factor for Public Transit

FISCAL YEAR	BUS	COMMUTER RAIL	PARATRANSIT	HEAVY RAIL	LIGHT RAIL	TROLLEY BUS	OTHER	TOTAL
1996	8.60	34.52	1.20	21.23	25.45	13.43	13.36	11.34
1997	8.73	32.06	1.29	21.62	25.12	13.50	12.68	11.30
1998	9.36	33.54	1.10	21.71	25.75	13.38	11.22	11.63
1999	9.32	32.97	1.13	22.33	24.76	13.10	10.91	11.54
2000	9.18	34.71	1.11	23.26	25.68	13.24	10.75	11.68
2001	9.27	34.43	1.08	23.32	26.46	14.61	10.82	11.69
2002	9.06	33.50	1.06	22.01	23.48	13.53	10.10	11.30
2003	8.78	33.42	1.08	21.60	22.95	12.75	10.56	10.98
2004	8.65	32.98	1.08	22.34	23.38	12.91	9.86	10.98
2005	8.78	31.22	1.08	22.31	24.57	13.41	9.69	10.80
2006	9.15	32.91	1.06	22.57	25.11	13.44	9.29	11.13
% Change 1996-2006	6.36%	-4.66%	-11.05%	6.33%	-1.33%	0.09%	-30.52%	-1.78%

Source: American Public Transportation Association June 2008.

about 21% greater (see Table 1). The amount of energy required to power the movement of public transportation has decreased in the past decade.

While public transit consumes a relatively small amount of energy as compared to cars, there still exists room to increase efficiencies and reduce emissions. The tables in this section detail fuel consumption for transit buses and paratransit as well as energy consumption across rail transit modes.

Table 13 illustrates fuel consumption of transit buses between 1996 and 2006. In 2006, diesel fuel powered almost 75% of the transit bus fleet, down from a 95% share just a decade earlier as transit agencies have rushed to adopt cleaner and cheaper fuels. CNG has experienced tremendous growth, with consumption increasing by more than 1100% between 1996 and 2006, leaving it with an overall share of more than 19%.

In addition to adopting CNG as a less carbon-intense alternative to diesel, transit agencies are also rapidly purchasing new vehicles powered by LNG, LPG, biodiesel, fuel cells, and hybrid drive systems. What is even more remarkable is that diesel fuel consumption has decreased by more than 7% since 1996, or by more than 15% since diesel consumption peaked in 2000. At the same time, consumption of alternative fuels has increased by more than 560%.

While transit bus fuel consumption trends are heading in a positive direction with regard to carbon-intense fuels, further efforts are needed to encourage and incentivize adoption of alternate fuels and technologies.

The paratransit, or demand response sector warrants special attention due to its rapid growth. Between 1996 and 2006, the number of vehicles in the fleet increased by 41% while VMT increased by 84% (see Tables 8 and 9). As Table 14 indicates, overall fuel consumption increased by roughly 52%. The increase in VMT exceeded the increase in fuel consumption over the same period. One reason for this could be that newer vehicles generally have better fuel economies than their predecessors. On the other hand, diesel has quickly become the fuel of choice, registering 178% growth between 1996 and 2006, and currently accounting for 73% of all paratransit fuel consumption.

Demand response vehicles serve a segment of the population (e.g., senior citizens and the disabled) that other public transit services do not reach and is thus an important part of the sector. As America's population ages, the demand for Dial-a-Ride services will likely continue to increase. It is therefore important that efforts be made to adopt cleaner and more efficient fuels.

As Table 8 and Table 9 show, each of the individual elements (commuter, heavy, light) have experienced modest growth in terms of fleet size and VMT. Between 1996 and 2006, light rail VMT growth bested fleet growth by a margin of 2-to-1 while heavy rail had a margin of nearly 3-to-1. Table 15 indicates that as new systems come online to ease demand for rail transit, energy consumption is moderately increasing at the same time.

A comparison of the light rail 1996 to 2006 percentage change values from Table 15 and Table 9 show that VMT growth and the increase in electricity consumption in the light rail sector between 1996 and 2006 are nearly identical at 97%. Using the same data, VMT growth and increasing energy consumption amongst diesel powered commuter rail are also closely aligned at 30% and 27% respectively. What is most interesting, however, is comparing VMT growth and energy consumption in electrified commuter rail and heavy rail. It seems that VMT growth noticeably exceeds increased energy consumption in both cases. In the case of electrified commuter rail, VMT increased by 30% while energy consumption increased by 18%. Similarly, in the case of heavy rail, VMT increased by 20% while energy consumption increased by only 11%. These results seem to suggest that electrified systems have become more energy efficient than diesel powered commuter rail. The commuter and heavy rail electrified systems have also been able to become more efficient in terms of VMT generated per energy consumption when compared to light rail, due to their ability to more easily add cars to existing trains than light rail in order to accommodate greater demand.

EMISSIONS OVERVIEW

Transportation GHG emissions include both energy-related CO_2 emissions and other GHG such as methane and nitrous oxide emissions from combustion, and HFC emissions from refrigerants used in air-conditioning units in the vehicles. As of 2006, the transportation sector in the United States was responsible for 28% of total GHG emissions (up from 27% in 2003) and 33% of total energy-related CO_2 emissions.[4] These figures illustrate that the transportation sector is the second largest source of total GHG emissions in the country, while it is the largest source of energy-related CO_2 emissions. By comparison, globally speaking, the transportation sector is

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[4] See *Emissions of Greenhouse Gases in the United States 2006*. Energy Information Administration, Washington, D.C., November 2007, and *World Energy Outlook 2007: China and India Insights*, International Energy Agency, Paris, France, 2007.

responsible for 18% to 24% of energy-related CO_2 emissions.[5]

Rubber-Tire Modes

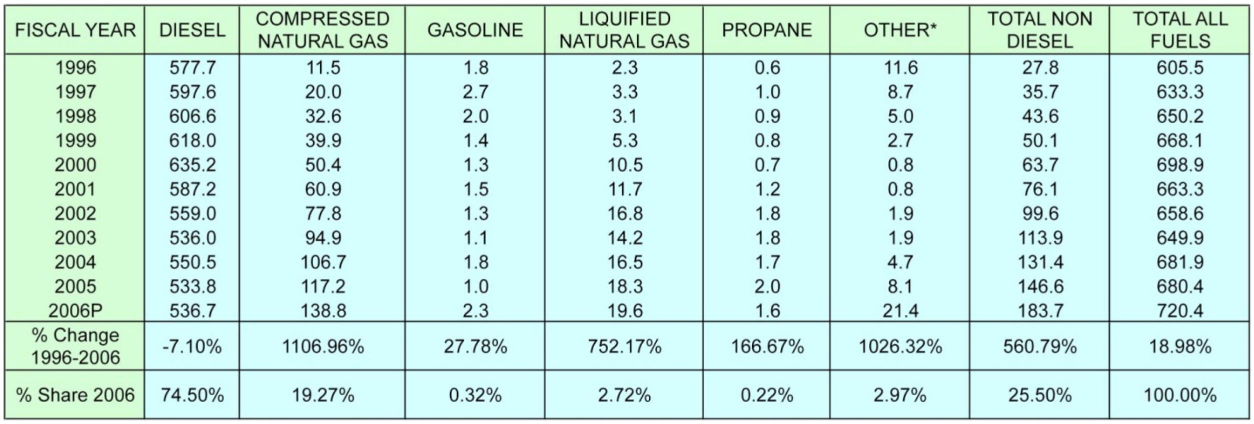
Emissions data at the national level indicate that, as of 2003, “heavy-duty” vehicles, including trucks and transit buses accounted for 19% (343 Tg CO_2 equivalent) of transportation-related GHG emissions. Within the heavy-duty vehicles category, transit buses are responsible for 3% (~10 Tg CO_2 equivalent) of overall GHG emissions. Put into perspective, transit buses are responsible for roughly 0.5% of all transportation-related GHG emissions. Best estimates (2003) suggest that transit buses produce about 46% of total bus GHG emissions, followed by school

TABLE 12 Public Transit Activity and Energy

	Activity (Million)		Energy Consumption (Trillion Btu)					Energy Intensity	
Year	Passenger Miles	Vehicle-Miles	Electricity	Diesel	Gasoline and other nondiesel fuels	Compressed natural gas	Total (Trillion Btu)	BTU/Passenger-Miles	BTU/Vehicle Miles
1996	41378.00	3650.30	17.08	96.08	7.65	2.09	122.91	2970.32	33670.04
1997	42339.00	3745.80	17.02	99.45	7.44	3.31	127.22	3004.78	33963.21
1998	44128.00	3793.60	17.31	102.58	6.58	5.17	131.64	2983.14	34700.58
1999	45857.00	3972.20	17.87	105.88	6.09	6.16	136.00	2965.70	34237.45
2000	47666.00	4080.80	18.80	109.02	6.04	7.60	141.46	2967.66	34663.93
2001	49070.00	4196.20	19.14	103.28	5.74	9.18	137.34	2798.79	32728.85
2002	48324.00	4276.70	19.27	100.49	6.39	11.25	137.40	2843.28	32127.25
2003	47903.00	4363.40	19.25	98.85	5.79	13.88	137.78	2876.16	31575.55
2004	49073.00	4470.80	19.87	101.35	6.61	15.51	143.34	2921.00	32061.86
2005	49678.00	4601.40	20.32	101.24	7.26	17.07	145.89	2936.69	31705.27
2006	52154.00	4684.20	20.31	101.96	9.35	20.33	151.95	2913.49	32438.84
% Change 1996-2006	26.04%	28.32%	18.87%	6.12%	22.22%	870.86%	23.63%	-1.91%	-3.66%

Source: Calculations based on data from the *2008 Public Transportation Fact Book.* American Public Transportation Association, Washington, D.C., June 2008 and on the *2008 National Transportation Statistics*, Bureau of Transportation Statistics, Chapter 4.

TABLE 13 Bus Fossil Fuel Consumption, 1996-2006 (millions of gallons)



FISCAL YEAR	DIESEL	COMPRESSED NATURAL GAS	GASOLINE	LIQUIFIED NATURAL GAS	PROPANE	OTHER*	TOTAL NON DIESEL	TOTAL ALL FUELS
1996	577.7	11.5	1.8	2.3	0.6	11.6	27.8	605.5
1997	597.6	20.0	2.7	3.3	1.0	8.7	35.7	633.3
1998	606.6	32.6	2.0	3.1	0.9	5.0	43.6	650.2
1999	618.0	39.9	1.4	5.3	0.8	2.7	50.1	668.1
2000	635.2	50.4	1.3	10.5	0.7	0.8	63.7	698.9
2001	587.2	60.9	1.5	11.7	1.2	0.8	76.1	663.3
2002	559.0	77.8	1.3	16.8	1.8	1.9	99.6	658.6
2003	536.0	94.9	1.1	14.2	1.8	1.9	113.9	649.9
2004	550.5	106.7	1.8	16.5	1.7	4.7	131.4	681.9
2005	533.8	117.2	1.0	18.3	2.0	8.1	146.6	680.4
2006P	536.7	138.8	2.3	19.6	1.6	21.4	183.7	720.4
% Change 1996-2006	-7.10%	1106.96%	27.78%	752.17%	166.67%	1026.32%	560.79%	18.98%
% Share 2006	74.50%	19.27%	0.32%	2.72%	0.22%	2.97%	25.50%	100.00%

Source: American Public Transportation Association June 2008.

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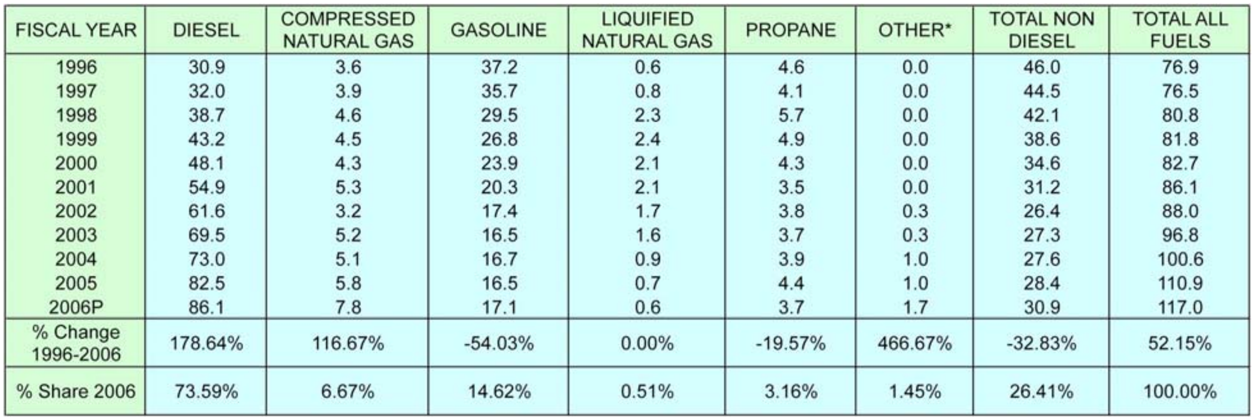
[5] Climate and Atmosphere 2005 and Carbon Dioxide Emissions by Economics Sector 2005. *Earthtrends Data Tables: Climate and Atmosphere*, World Resources Institute. http://earthtrends.wri.org/datatables/index.php?theme=3.

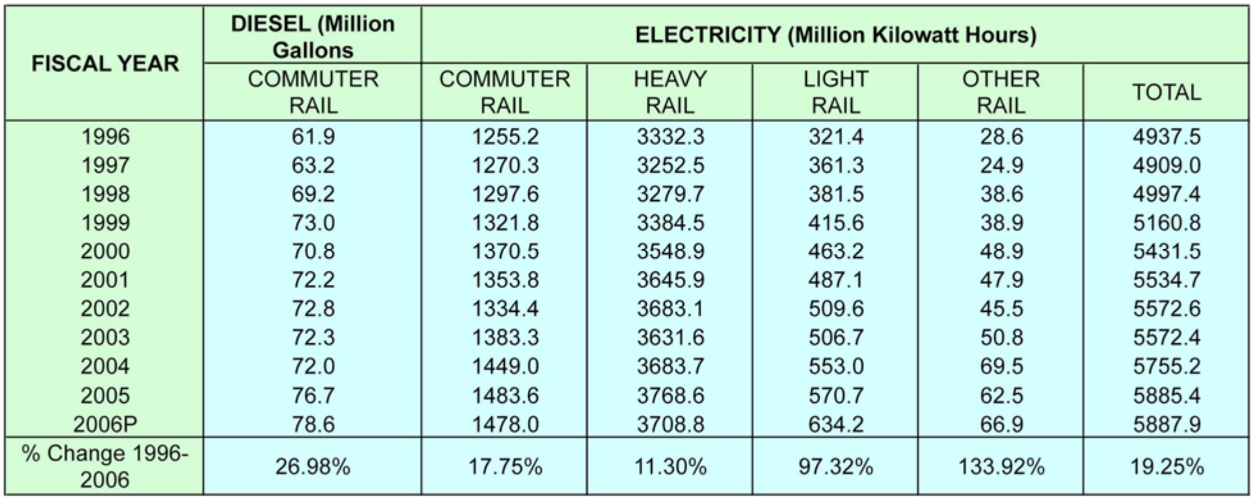
TABLE 14 ParaTransit Fossil Fuel Consumption, 1996-2006 (millions of gallons)



FISCAL YEAR	DIESEL	COMPRESSED NATURAL GAS	GASOLINE	LIQUIFIED NATURAL GAS	PROPANE	OTHER*	TOTAL NON DIESEL	TOTAL ALL FUELS
1996	30.9	3.6	37.2	0.6	4.6	0.0	46.0	76.9
1997	32.0	3.9	35.7	0.8	4.1	0.0	44.5	76.5
1998	38.7	4.6	29.5	2.3	5.7	0.0	42.1	80.8
1999	43.2	4.5	26.8	2.4	4.9	0.0	38.6	81.8
2000	48.1	4.3	23.9	2.1	4.3	0.0	34.6	82.7
2001	54.9	5.3	20.3	2.1	3.5	0.0	31.2	86.1
2002	61.6	3.2	17.4	1.7	3.8	0.3	26.4	88.0
2003	69.5	5.2	16.5	1.6	3.7	0.3	27.3	96.8
2004	73.0	5.1	16.7	0.9	3.9	1.0	27.6	100.6
2005	82.5	5.8	16.5	0.7	4.4	1.0	28.4	110.9
2006P	86.1	7.8	17.1	0.6	3.7	1.7	30.9	117.0
% Change 1996-2006	178.64%	116.67%	-54.03%	0.00%	-19.57%	466.67%	-32.83%	52.15%
% Share 2006	73.59%	6.67%	14.62%	0.51%	3.16%	1.45%	26.41%	100.00%

Source: American Public Transportation Association June 2008.

TABLE 15 Rail Transit Energy Consumption, 1996–2006



FISCAL YEAR	DIESEL (Million Gallons	ELECTRICITY (Million Kilowatt Hours)				
	COMMUTER RAIL	COMMUTER RAIL	HEAVY RAIL	LIGHT RAIL	OTHER RAIL	TOTAL
1996	61.9	1255.2	3332.3	321.4	28.6	4937.5
1997	63.2	1270.3	3252.5	361.3	24.9	4909.0
1998	69.2	1297.6	3279.7	381.5	38.6	4997.4
1999	73.0	1321.8	3384.5	415.6	38.9	5160.8
2000	70.8	1370.5	3548.9	463.2	48.9	5431.5
2001	72.2	1353.8	3645.9	487.1	47.9	5534.7
2002	72.8	1334.4	3683.1	509.6	45.5	5572.6
2003	72.3	1383.3	3631.6	506.7	50.8	5572.4
2004	72.0	1449.0	3683.7	553.0	69.5	5755.2
2005	76.7	1483.6	3768.6	570.7	62.5	5885.4
2006P	78.6	1478.0	3708.8	634.2	66.9	5887.9
% Change 1996-2006	26.98%	17.75%	11.30%	97.32%	133.92%	19.25%

Source: American Public Transportation Association June 2008.

buses at 38%, and intercity (e.g., Greyhound) buses at 16%.[6] Despite bus's small contribution to overall GHG emissions, it is important to note that transit bus GHG emissions increased by about 15% between 1990 and 2003, roughly in line with both fleet size increases (see Table 8) and VMT growth (see Table 9). Trolleybuses are not included in these figures as they draw electricity from the grid (see discussion below).

Diesel fuel is the primary fuel that powers rubber-tire fleets. It is also among the most carbon-intense. Alternate fuels and propulsion that have been mentioned previously are briefly

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[6] *Greenhouse Gas Emissions from the U.S. Transportation Sector 1990–2003*. United States Environmental Protection Agency, Washington, D.C., March 2006.

introduced below.[7] Table 16 illustrates baseline diesel, as well as potential alternative options against the current EPA emissions standards for new transit buses.

Diesel

In model year 2006, EPA-certified diesel transit bus engines produce, on average, 0.026 grams per brake horsepower-hour (g/bhp-hr) PM; 2.36 g/bhp-hr NO_X; and 0.11 g/bhp-hr NMHC emissions. These engines are equipped with emission control systems including engine modifications, electronic controls, charge air cooling, exhaust gas recirculation (EGR), particulate traps, and oxidation catalysts (OC).

Biodiesel

Biodiesel is produced from biologically-derived fats or oils through a process called transesterification. Biodiesel can be used as a stand-alone fuel (B100), however it is more commonly found in diesel and biodiesel blends like B20 which are 20% biodiesel and 80% regular petroleum-based diesel. EPA estimates that use of B20 results in a 10.1 % decrease in the PM emission rate, a 2.0% increase in the NO_X rate, and a 21.1% reduction in the NMHC rate compared to the diesel baseline.

Ethanol

While ethanol-blended fuel is currently mandated in the light-duty vehicle sector by federal regulation, there are no EPA-certified ethanol transit bus engines available in the 2006 model year, and no transit agencies today (2006) operate ethanol vehicles. When ethanol engines were available in the 1990s, they offered about the same PM emission rate as diesels and a 25% lower NO_X rate. In 1996 emission tests, NMHC rates were 3.4 to 4.7 times as high as similar diesel bus engines at that time. If an ethanol bus engine were manufactured today and equipped with modern emission controls, it would probably achieve the same emission rates relative to today's diesel baseline.

Propane (LPG)

No current model-year (2006) buses use LPG engines,[8] however there is one medium heavy-duty diesel engine, the Cummins B Gas Plus, that is LPG-certified for use and is typically found in midsize and smaller transit buses. The engine is equipped with a relatively simple emission control system including engine modifications, electronic controls, and oxidation catalysts. It is certified at a 62% lower PM emission rate, a 50% lower NO_X rate, and a 3.5 times higher NMHC rate than the diesel baseline. Further emissions reductions are expected for propane engines with today's emission controls.

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[7] This section draws heavily on *Alternative Fuels Study: A report to Congress on Policy Options for Increasing the Use of Alternative Fuels in Transit Vehicles*. Federal Transit Administration, Washington, D.C., December 2006.

[8] 2006 emissions levels represent almost two-generations-old emissions technology.

Compressed/Liquefied Natural Gas (CNG/LNG)

In model year 2006, three EPA-certified natural gas transit bus engine models were available. These engines were equipped with relatively simple emission control systems, including engine modifications, electronic controls, oxidation catalysts, and oxygen sensors. On average, they were certified at a 77% lower PM emission rate, a 47% lower NO_X rate, and an 18% higher NMHC rate than the diesel baseline. Further emissions reductions could be achieved with more sophisticated emission controls. To meet 2010 standards, natural gas engine manufacturers expect to use cooled exhaust gas recirculation or other charge dilution technology, similar to the expected 2007 diesel NO_X emission controls.

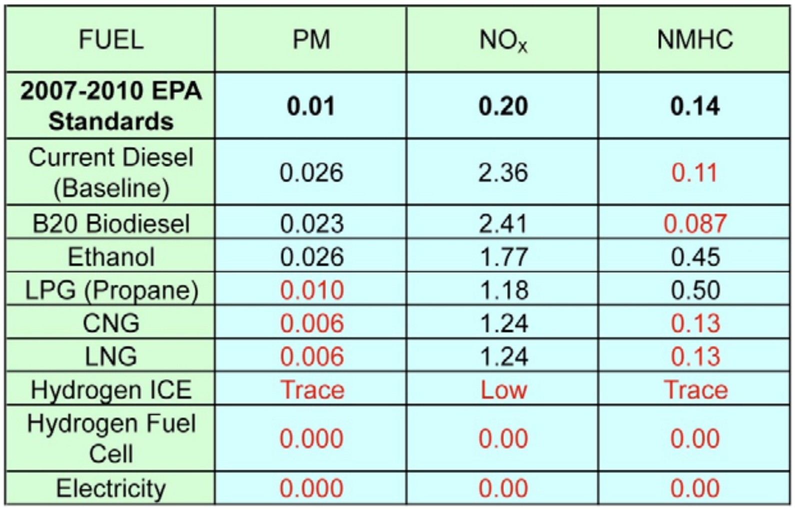
Hydrogen

Hydrogen can power two types of bus engines: internal combustion engine (ICE) or fuel cell. Exhaust from a hydrogen fuel cell engine contains only water vapor and oxygen. A hydrogen ICE produces trace amounts of PM and NMHC emissions from engine oil ingestion. Hydrogen ICEs can be tuned for very low NO_X emission rates.

Electricity

Buses powered by electricity shift their emissions upstream. While the grid's power source will determine how much will be emitted, from virtually all sources it is less than from an ICE. There is also the question of whether an electric motor itself is more efficient (uses more or less energy per level of effort) than an internal combustion engine. However, on a life cycle basis, it is not clear that one fuel is preferred to the other given its upstream emissions and its emissions of other pollutants (not just GHG) from tailpipe emissions.

TABLE 16 Comparison of Bus Engine Emissions with 2007–2010 EPA Standards



FUEL	PM	NO_x	NMHC
2007-2010 EPA Standards	**0.01**	**0.20**	**0.14**
Current Diesel (Baseline)	0.026	2.36	0.11
B20 Biodiesel	0.023	2.41	0.087
Ethanol	0.026	1.77	0.45
LPG (Propane)	0.010	1.18	0.50
CNG	0.006	1.24	0.13
LNG	0.006	1.24	0.13
Hydrogen ICE	Trace	Low	Trace
Hydrogen Fuel Cell	0.000	0.00	0.00
Electricity	0.000	0.00	0.00

NOTE: Adapted from *Alternative Fuels Study: A Report to Congress on Policy Options for Increasing the Use of Alternative Fuels in Transit Vehicles*. Federal Transit Administration, Washington, D.C., December 2006. Figures in red denote levels meeting 2007–2010 emissions standards.

Rail Modes

National level data (2003) indicates that rail-based transportation, including freight and long-haul passenger modes, account for 2% (43 Tg CO_2 equivalent) of transportation-related GHG emissions. More than 90% of these GHG emissions come from the combustion of diesel fuel, while the remainder is from electricity use. The vast majority of emissions come from the freight rail sector (89%), while the remaining 11% (5 Tg CO_2 equivalent) is shared between mass rapid transit, commuter rail, and intercity rail (e.g., Amtrak).[9] Further delineating emissions between the different modes of rail transit is a difficult task given that most rail transit vehicles are powered with electricity.

Rail transit energy consumption is easily tracked on the micro level by measuring how much electricity vehicles draw from the surrounding electric grid, typically measured in kilowatt hours per kilometer (KW-h/km). Thus, obtaining total energy consumption, as detailed in Table 15, is a relatively simple mathematical exercise. What is significantly more challenging is determining the grid's source or mix of sources of electricity in all parts of the country. While some power generating authorities may only rely on a single source of energy, say coal, a significant number rely on a mix of coal, natural gas, nuclear, wind, hydro, solar, and more. The source of the electricity has relatively large implications on emissions, as nuclear power (which supports France's TGV rail system) produces little if any GHG emissions, while coal (which supports much of China's electrified rail infrastructure and is available in great abundance in the United States as well)[10] generates large amounts of GHG emissions.

Controlling emissions attributed to electrified rail modes[11] is just as much, if not more the responsibility of electricity generating authorities than that of a transit agency or vehicle manufacturer. That said, manufacturers can choose sturdy, light-weight materials in vehicle construction as well as electrical systems that are more energy efficient (including systems with regenerative braking). Transit agencies can also train drivers or operators to maintain proper operational patterns and speeds, much like 55 mph is the agreed upon speed for maximum highway fuel economy of automobiles.

REGULATORY LANDSCAPE

Emissions standards in the United States are primarily the domain of the U.S. Environmental Protection Agency. Some state-level agencies such as the California Air Resources Board (CARB) have tried to implement more stringent emissions standards, though with limited success. Table 17 outlines changes in national-level emissions standards over recent years with specific regard to the model year of the bus (engines) in service.

As Table 17 shows, increasingly strict standards have significantly reduced particulate matter (PM) and nitrous oxide (NO_X) emissions on the order of 50 to 60 times. NHMC emissions

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[9] 2006 emissions levels represent almost two-generations-old emissions technology, EPA 2006.

[10] Even though the United States has better criteria pollutant controls and may have more energy-efficient technologies at its disposal, coal-fired power plants are still major producers of substantial amounts of greenhouse gases per KWh.

[11] This also applies to trolley buses.

standards for new vehicles are about 10 times lower than when regulation began. By comparison, however, carbon monoxide (CO) regulations have not changed in many years.

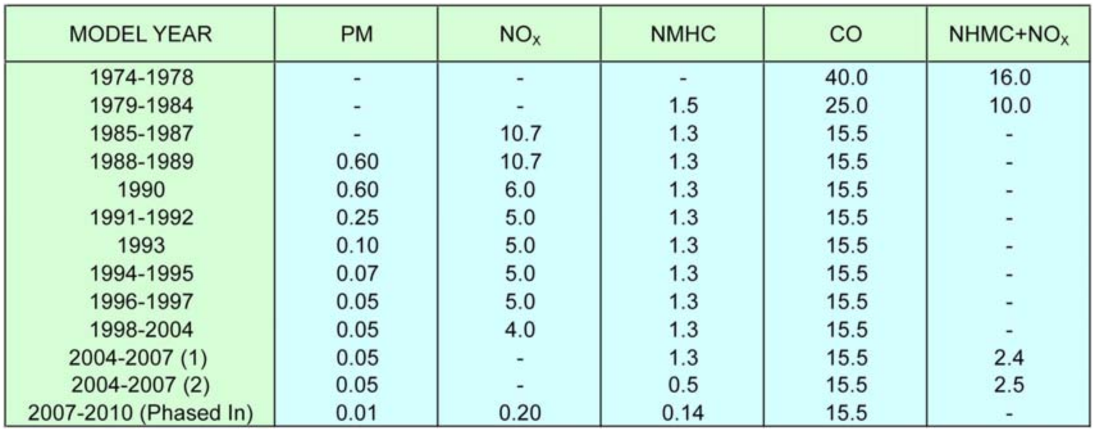
In addition to the emissions measures listed above, fossil fuels also produce large amounts of GHG, including carbon dioxide and methane. Diesel fuel is a significant contributor of CO_2 tailpipe emissions, and though it is important to note that methane is a key byproduct of natural gas (CNG/LNG) combustion and has greater warming potential than CO_2, emissions from natural gas engines are still lower overall than those from diesel.

Table 18 presents emissions from primary land-based modes of transportation. It is shown that in 2006, passenger cars represented almost 40% of overall GHG emissions from the group of modes profiled. Note that here rail includes not just public transit rail, but also intracity rail, making any further per capita comparisons problematic. Table 19 shows a more detailed breakdown of CO_2 emissions by mode and fuel type. Note that gasoline and diesel have the highest emissions.

EMISSIONS MITIGATION

From previous discussions on energy use per capita in the public transport sector versus the use of private automobiles, it is clear that public transit has a high potential to combat climate change. According to the American Public Transportation Association, for example, the most powerful tool to combat global warming might be a daily transit pass. Together with other actions taken at the household level to reduce CO_2 emissions, using transit can have a dramatic impact. On average, each solo auto commuter can reduce CO_2 emissions by nearly 2.5 tons per year by switching to public transit. Individuals may not always have an easy choice in deciding to use transit and it is therefore up to transit providers, manufacturers, the government, and other actors to further enable emissions mitigation through modal shift policies. Complementary policies that address urban growth, land use change and energy efficiency in other sectors would assist in this process.

TABLE 17 Federal Emissions Standards for Transit Bus Engines (g/bhp-hr)



MODEL YEAR	PM	NO_x	NMHC	CO	NHMC+NO_x
1974-1978	-	-	-	40.0	16.0
1979-1984	-	-	1.5	25.0	10.0
1985-1987	-	10.7	1.3	15.5	-
1988-1989	0.60	10.7	1.3	15.5	-
1990	0.60	6.0	1.3	15.5	-
1991-1992	0.25	5.0	1.3	15.5	-
1993	0.10	5.0	1.3	15.5	-
1994-1995	0.07	5.0	1.3	15.5	-
1996-1997	0.05	5.0	1.3	15.5	-
1998-2004	0.05	4.0	1.3	15.5	-
2004-2007 (1)	0.05	-	1.3	15.5	2.4
2004-2007 (2)	0.05	-	0.5	15.5	2.5
2007-2010 (Phased In)	0.01	0.20	0.14	15.5	-

Source: *Alternative Fuels Study: A Report to Congress on Policy Options for Increasing the use of Alternative Fuels in Transit Vehicles*. Federal Transit Administration, Washington, D.C., December 2006.
NOTE: While the standards apply mainly to diesel engines, other types of engines may be included for some years.

TABLE 18 Primary Land-based Transportation-Related GHG Emissions (Tg CO_2 Eq.)

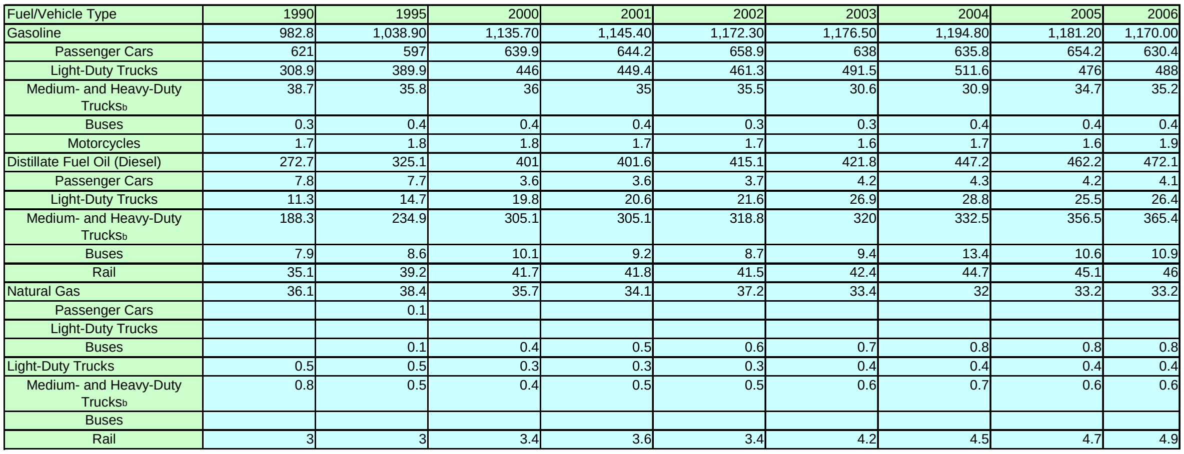
Gas/Vehicle Type	2000	2001	2002	2003	2004	2005	2006	%Total 2006
Passenger Cars	694.6	699.1	713.7	692.4	689.5	705.8	678.4	39.63%
CO2	643.5	647.9	662.6	642.1	640	658.4	634.5	37.06%
CH4	1.6	1.5	1.4	1.3	1.2	1.1	1	0.06%
N2O	25.2	23.8	22.5	21	19.5	17.8	15.6	0.91%
HFCs	24.3	25.9	27.2	28	28.8	28.5	27.2	1.59%
Light-Duty Trucks	508.1	513.3	525.1	560.4	583	544	556.6	32.51%
CO2	466	470.3	483.2	518.8	540.8	501.9	514.9	30.08%
CH4	1.1	1.1	0.9	0.8	0.7	0.7	0.7	0.04%
N2O	22.4	21.3	18.5	16.6	15.3	13.7	12.7	0.74%
HFCs	18.6	20.6	22.5	24.2	26.1	27.7	28.3	1.65%
Medium-and Heavy-Duty Trucks	344.3	343.6	357.9	354.4	367.4	395.2	404.6	23.63%
CO2	341.5	340.6	354.8	351.2	364.1	391.9	401.3	23.44%
CH4								0.00%
N2O	1.2	1.2	1.2	1.3	1.2	1.2	1.1	0.06%
HFCs	1.6	1.7	1.8	1.9	2.1	2.1	2.2	0.13%
Buses	11.2	10.3	10	10.8	15.1	12.1	12.5	0.73%
CO2	10.9	10	9.6	10.5	14.7	11.8	12.1	0.71%
CH4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01%
N2O								0.00%
HFCs	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.02%
Motorcycles	1.9	1.7	1.7	1.7	1.8	1.6	1.9	0.11%
CO2	1.8	1.7	1.7	1.6	1.7	1.6	1.9	0.11%
CH4								
N2O								
Rail	50.1	50.8	50.7	52.8	55.8	56.6	57.9	3.38%
CO2	45.1	45.4	44.9	46.6	49.2	49.8	51	2.98%
CH4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01%
N2O	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.02%
HFCs	4.6	5	5.4	5.8	6.1	6.4	6.5	0.38%
Total								
CO2	1508.8	1515.9	1556.8	1570.8	1610.5	1615.4	1615.7	94.38%
CH4	2.9	2.8	2.5	2.3	2.1	2	1.9	0.11%
N2O	49.1	46.6	42.5	39.2	36.4	33.1	29.8	1.74%
HFCs	49.2	53.4	57.1	60.1	63.3	64.9	64.5	3.77%
TOTAL	1610	1618.7	1658.9	1672.4	1712.3	1715.4	1711.9	100.00%

Rubber-Tire Modes

Primary emissions mitigation opportunities should focus on

- Encouraging transit providers to expand transit service in locations with adequate ridership potential and provide riders with a more attractive alternative to personal vehicles;
- Encouraging transit providers to adopt vehicles powered by less carbon intense fuels based on life cycle analyses;
- Requiring transit providers to maximize fuel efficiencies and minimize emissions from existing fleet vehicles, especially those that are diesel-powered;
- Providing incentive for the development of supply infrastructures in the case of advanced fuel technologies like LNG and hydrogen fuel cells;
- Increasing deployment of GPS and ICT infrastructures integrated with better route modeling to reduce dwell times, congestion, etc.;

TABLE 19 CO_2 Emissions from Fossil Fuel Combustion in Transportation End-Use Sector (Tg CO_2 Eq.)



Fuel/Vehicle Type	1990	1995	2000	2001	2002	2003	2004	2005	2006
Gasoline	982.8	1,038.90	1,135.70	1,145.40	1,172.30	1,176.50	1,194.80	1,181.20	1,170.00
Passenger Cars	621	597	639.9	644.2	658.9	638	635.8	654.2	630.4
Light-Duty Trucks	308.9	389.9	446	449.4	461.3	491.5	511.6	476	488
Medium- and Heavy-Duty Trucks[b]	38.7	35.8	36	35	35.5	30.6	30.9	34.7	35.2
Buses	0.3	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.4
Motorcycles	1.7	1.8	1.8	1.7	1.7	1.6	1.7	1.6	1.9
Distillate Fuel Oil (Diesel)	272.7	325.1	401	401.6	415.1	421.8	447.2	462.2	472.1
Passenger Cars	7.8	7.7	3.6	3.6	3.7	4.2	4.3	4.2	4.1
Light-Duty Trucks	11.3	14.7	19.8	20.6	21.6	26.9	28.8	25.5	26.4
Medium- and Heavy-Duty Trucks[b]	188.3	234.9	305.1	305.1	318.8	320	332.5	356.5	365.4
Buses	7.9	8.6	10.1	9.2	8.7	9.4	13.4	10.6	10.9
Rail	35.1	39.2	41.7	41.8	41.5	42.4	44.7	45.1	46
Natural Gas	36.1	38.4	35.7	34.1	37.2	33.4	32	33.2	33.2
Passenger Cars		0.1							
Light-Duty Trucks									
Buses		0.1	0.4	0.5	0.6	0.7	0.8	0.8	0.8
Light-Duty Trucks	0.5	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Medium- and Heavy-Duty Trucks[b]	0.8	0.5	0.4	0.5	0.5	0.6	0.7	0.6	0.6
Buses									
Rail	3	3	3.4	3.6	3.4	4.2	4.5	4.7	4.9

- Requiring and incentivizing traffic-generating locations such as employment centers, hospitals, and shopping malls to improve and encourage transit use as a viable travel option (such as requiring or incentivizing employers to provide mass transit passes as a commuting option to employees); and
- Encouraging planning for land use and urban development such as “smart growth” instead of urban sprawl to make trips shorter and public transit more accessible and convenient.

Typical actions taken generally revolve around federal subsidy and tax relief[12] toward the adoption of cleaner technologies. These incentives include

- Federal subsidies for research and development of new and existing alternative fuel technologies,
- Tax incentives for purchasing alternative fuel heavy-duty vehicles (current incentives are almost entirely for light-duty vehicles),
- Excise tax credits for alternative fuel consumption, and
- Infrastructure tax credits to further develop supply infrastructure for technologies like LNG and hydrogen fuel cell.

Rail Modes

Both mass rapid transit (heavy and light rail) and commuter rail effectively demonstrate how emissions can be reduced vis a vis using transit buses and private automobiles.

Emissions mitigation strategies could include

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[12] See http://www.afdc.energy.gov/afdc/progs/fed_summary.php/U.S. for more information on current federal incentive and subsidy programs.

- Encouraging nontraditional capital financing methods that do not rely on the FTA New Starts program nor place a heavy burden on states and municipalities to raise taxes or user fees,
- Fostering more coordination between land use planning and transportation planning to increase densities and land use characteristics supportive of high-capacity mass rapid transit,
- Improving operational efficiencies through regular operator training (to better manage vehicle speeds and subsequent power usage), and
- Encouraging the use of energy and operationally efficient transport technologies such as magnetic levitation (maglev) that are also low maintenance.

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APPENDIX A

TRB Special Task Force on Climate Change and Energy

Initiated in January of 2008, the Special Task Force on Climate Change and Energy (STF) coordinates activities and facilitates communications related to climate change and energy among TRB standing committees. It conducts activities to augment the work of existing committees on climate change and energy topics, and maintains a road map for ongoing and potential TRB activities in those areas.

The STF reports directly to the TRB Technical Activities Council. STF membership is drawn from representatives of 15 TRB committees with strong interest in climate change and energy issues, supplemented by 15 at-large members, including subject matter specialists from constituencies outside TRB whose expertise provides needed perspectives.

The STF has

1. Developed a road map for TRB activities in the area of global climate change and energy;
2. Facilitated communications among all TRB standing committees having an interest in energy and climate change, including
   - Conducting surveys of all standing committees and shared results and
   - Involving representatives of a cross section of committees from almost all groups on STF activities, who in turn reported back to their committees;
3. Coordinated the development of sessions that comprised the energy–climate change spotlight theme for the 2009 TRB Annual Meeting, including
   - Delivering spotlight theme that included more than 60 sessions and
   - Initiating new process of surveying all committees on anticipated spotlight theme-related sessions and sharing results to facilitate collaboration in session planning (nearly 100 committees);
4. Developed sessions for TRB summer conference and other meetings;
5. Contributed to the TRB bimonthly magazine *TR News*; including
   - Sponsoring development of article on climate change in the November–December 2008 issue and
   - Preparing an outline and initiating the development of theme issue on climate change (Energy and Sustainability committees preparing content for issue to be published in mid-2010);
6. Developed volumes of the *Transportation Research Record* on climate change and energy;
7. Established and conducted a series of TRB webinars;
8. Prepared primer on climate change mitigation issues for each transportation mode to be published as a TRB e-circular;
9. Reached out and coordinated with other organizations, including
   - DOE, EPA, and USDOT, who have representatives on STF who have been actively involved in TRB activities and
   - Coordinating activities with AASHTO, ITS America, ITE, STPP, Bipartisan

Policy Center, and others;

10. Contributed to TRB technical and policy studies, including
    - Providing names of individuals to serve on TRB policy study committees, cooperative research panels, and
    - Providing comments on white papers that led to TRB *Special Report 299: A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy*;
11. Prompted the development of a website for tracking climate change activities across TRB divisions; and
12. Developed a set of approximately 40 Research Needs Statements to address climate change and transportation that were
    - Included in the collaborative website and January 2010 workshop, and
    - Published in a forthcoming TRB e-circular and posted on TRB Research Needs Statements database.

THE NATIONAL ACADEMIES

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The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters.
Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

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