RESEARCH REPORT

JUNE. 2013

TRANSPORT: PATHWAYS FOR REDUCING OIL CONSUMPTION IN THE U.S.

THE CARBON WAR ROOM | FUEL FREEDOM FOUNDATION

LEAD AUTHOR:
SABRINA T. HOWELL

EDITORS:
MATTHEW CULLINEN
SENIOR ASSOCIATE
HILARY MCMAHON
DIRECTOR OF RESEARCH

FUEL FREEDOM™

CARBON WAR ROOM

Pathways for Reducing Oil Consumption in the U.S.

Lead Author:
Sabrina T. Howell

Design: www.grahampeacedesign.com
Images: Shutterstock, Thinkstock
Mario Santoro-Woith. mario@santoro-woith.com

Contents

PICTURE: MARIO SANTORO-WOITH. WWW.SANTORO-WOITH.COM

Report Takeaways

1 Transportation accounts for 71 percent of United States (U.S.) oil consumption, with 94 percent of transportation fuel being petroleum. Of every seven gallons of gas that are put into gas tanks, only one actually moves the car. This inefficiency costs the U.S. not only in terms of consumption, but also in terms of securing its oil supply.

2 A wide variety of incremental and radical cost-effective technologies exist today that can improve vehicle fuel economy and the transition to new fuels:

- Lightweight vehicles = 12-20% in fuel savings.
- Powertrain technology = between 15–20 percent in fuel savings.
- Improved aerodynamics = up to 20 percent in fuel savings.
- Operational improvements = at least 9 percent in fuel savings.
- Advanced transport management systems = 10 percent in fuel savings.
- Pay-As-You-Drive schemes = 10 percent in fuel savings.

3 A successful strategy for reducing U.S. oil dependence has three prongs - remove the barriers that prevent widespread use of domestically produced and alternative power sources, on-road vehicles must catch up with available, cost-effective efficiency opportunities and incorporating the Information Technologies we use in every day life to reduce oil consumption in transport.

4 The barriers to implementation range from quick fixes to major challenges. These include:

- Principle agency problems.
- Inertia of incumbent policies and business models.
- Bad pricing.
- Inefficient policy.

5 Government support can help to promote new technologies. New technologies work when they either improve the consumer experience or decrease costs in a given market environment. Government policy is most effective when it employs market levers to accomplish either one of these goals.

6 Various policy tools offer significant fuel savings today, including:

- Innovative, performance-based financing.
- An open fuel standard.
- Alternative fuel pump requirements.
- A feebate program for vehicle sales.

7 Mobilizing the U.S.'s highly functional Intellectual Property Protection Regime and the World's largest capital market, could yield results with powerful implications for job creation.

EXECUTIVE SUMMARY

A wide variety of cost-effective technologies exist that can substantially reduce oil consumption in the U.S. transportation sector in the near term while also lowering emissions and providing a much-needed boost to the country's economic dynamism. These technologies can be deployed in a way that enlarges the consumer's choice set.

A successful strategy for reducing U.S. oil dependence has three prongs. First, the U.S. must remove the barriers that prevent widespread use of domestically produced and alternative power sources, including biofuels, methanol, and electricity. Second, on-road vehicles must catch up with available, cost-effective efficiency opportunities. The third component is the reduction of wasteful and expensive driving habits. A variety of market-based policy tools are available that would send the right signals to the private sector to implement these strategies. Beyond offering tremendous economic opportunities, reducing oil consumption has positive environmental and security benefits.

This report focuses on technologies that can have a meaningful impact on reducing oil consumption in the next decade. Where possible, options that are cost negative from the operator perspective are stressed. However, intervention from government and civil society is necessary because price signals under the current market structure are insufficient to incentivize the deployment of technologies that offer major fuel savings.

Complex trade-offs are the rule in energy decisions. It is very difficult to identify the "right" alternative to gasoline and diesel given the uncertainty of technological change, commodity prices, and environmental impacts. Where possible, the government should only lay the framework for alternative fuel vehicles, allowing industry, experts, and consumers to take the lead in developing successful ventures in alternative fuel transportation.

Investing in energy innovation exploits a comparative advantage for the U.S.: including its outstanding research institutions, a broad array of major universities and national labs. The U.S. also has a highly functional intellectual property protection regime and the world's largest capital market. Mobilizing these assets in the concerted service of reducing oil consumption could yield results with powerful implications for job creation.

Oil and transportation are tightly linked: transportation represents 71% of U.S.oil consumption

Technology Road Map	
Lightweight Vehicle Materials	Replace the ferrous metals that dominate vehicle weight with strong, lighter-weight materials like aluminum, high-strength steel, and composites.
More Efficient Propulsion	Exploit available engine technologies to make today's internal combustion engine more efficient.
Improved Truck Powertrains	Apply existing transmission, hybridization, and other diesel engine technologies to truck powertrains.
Better Truck Aerodynamics and Reduced Friction	Deploy cost-saving tires, side skirts, and other simple add-ons that reduce resistance.
Efficient Truck Operations	Implement driving techniques and vehicle management strategies to maximize fuel savings.
Corn and Sugar Cane Biofuel	Displace gasoline with expanded use of conventional biofuels, using state-of-the-art processes to minimize environmental impacts.
Cellulosic Ethanol and Advanced Drop-in Biofuels	Produce sustainable biofuels from non-food feed stocks grown on marginal land.
Methanol-Fueled Vehicles	Transform natural gas into methanol, an alcohol available today that can be mixed with ethanol and/or gasoline.
Electric Vehicles	Delink parts of the transportation system from oil altogether by deploying battery-powered vehicles.
Natural Gas Vehicles	Use natural gas as a fuel directly, especially in heavy-duty vehicles.
Intelligent Transportation Systems (ITS)	Apply modern information technology to transportation systems. ITS solutions can reduce congestion, increase capacity, and enhance safety without major capital investment.
Pay-As-You-Drive (PAYD) Auto Insurance	Make premiums depend on miles driven to reduce the cross-subsidization and distortions in auto insurance that lead to excess mileage.
Bus Rapid Transit (BRT)	Build BRT systems, ideally fueled by natural gas, in urban areas. BRT is energy efficient, cost effective, and attractive to consumers.
Freight Rail	Reinvest in the nation's freight rail system, which moves goods at very low energy intensities.

Policy Solution Road Map	
Open Fuel Standards	Level the playing field for alternative fuels by requiring more vehicles to be capable of running on alternative fuels (e.g. electricity, methanol, ethanol, natural gas, or some mixture).
Alternative Fuel Infrastructure	Transform gas stations into multi-fuel vendors.
Feebate for Vehicle Sales	Reduce the price of efficient and alternative fuel vehicles and raise the price of "gas guzzlers".
Innovative Financing	Help new technologies overcome the financing "valley of death" through streamlined, technology-neutral and performance-based funding and new financing structures, like Master Limited Partnerships (MLPs) for alternative fuel companies.
Advanced Biofuel Financial and Permitting Support	Speed the development of advanced and cellulosic bio-refineries via better permitting and financing support.
Efficiency and Technology Standards	Consistently raise technology standards, such as the Corporate Average Fuel Economy (CAFE) program, in ways that are technology neutral and cost effective.
Gas Tax	Consider using the available market lever—taxes—to internalize the costs of oil.
Tolling and Congestion Pricing	Begin to implement road pricing strategies, including tolling, cordon pricing, and ultimately a vehicle miles traveled (VMT) fee in ways that are geared towards saving fuel.
Smart Infrastructure	Encourage the deployment of ITS, incorporating oil savings into performance standards.
Electric Vehicle (EV) Charging	Bring down a major barrier to EV diffusion by supporting the build-out of charging stations.
Government Procurement	Use federal purchasing power, especially the Department of Defense, as an initial market for new technology.
Research & Development	Leverage the federal government's sponsorship of path-breaking R&D with greater R&D funding directed to the challenge of reducing oil consumption.
Permit Informed Choices	Remove market distortions from suboptimal decisions by providing more and clearer information to consumers about their energy choices.

Introduction

The U.S. accounts for 22% of global oil demand

Per capita, Americans consume about 2.7 gallons of oil per day, compared to a global average of 0.5 gallons

A wide variety of cost-effective technologies exist that can substantially reduce oil consumption in the U.S. transportation sector in the near term while also lowering emissions and providing a much-needed boost to the country's economic dynamism. Consumers' choice sets can be enlarged by careful deployment of these technologies.

A serious strategy to reduce oil dependence must achieve three objectives. First, barriers to widespread use of domestically produced and alternative power sources, including methanol, biofuels, and electricity, must be removed. Second, on-road vehicles must catch up with available, cost-effective vehicle efficiency opportunities. Third, the amount of wasteful and expensive miles driven must be reduced. A variety of market-based policy tools are available to signal to the private sector to implement these strategies. Beyond offering tremendous economic opportunities, reducing oil consumption has positive environmental and security benefits.

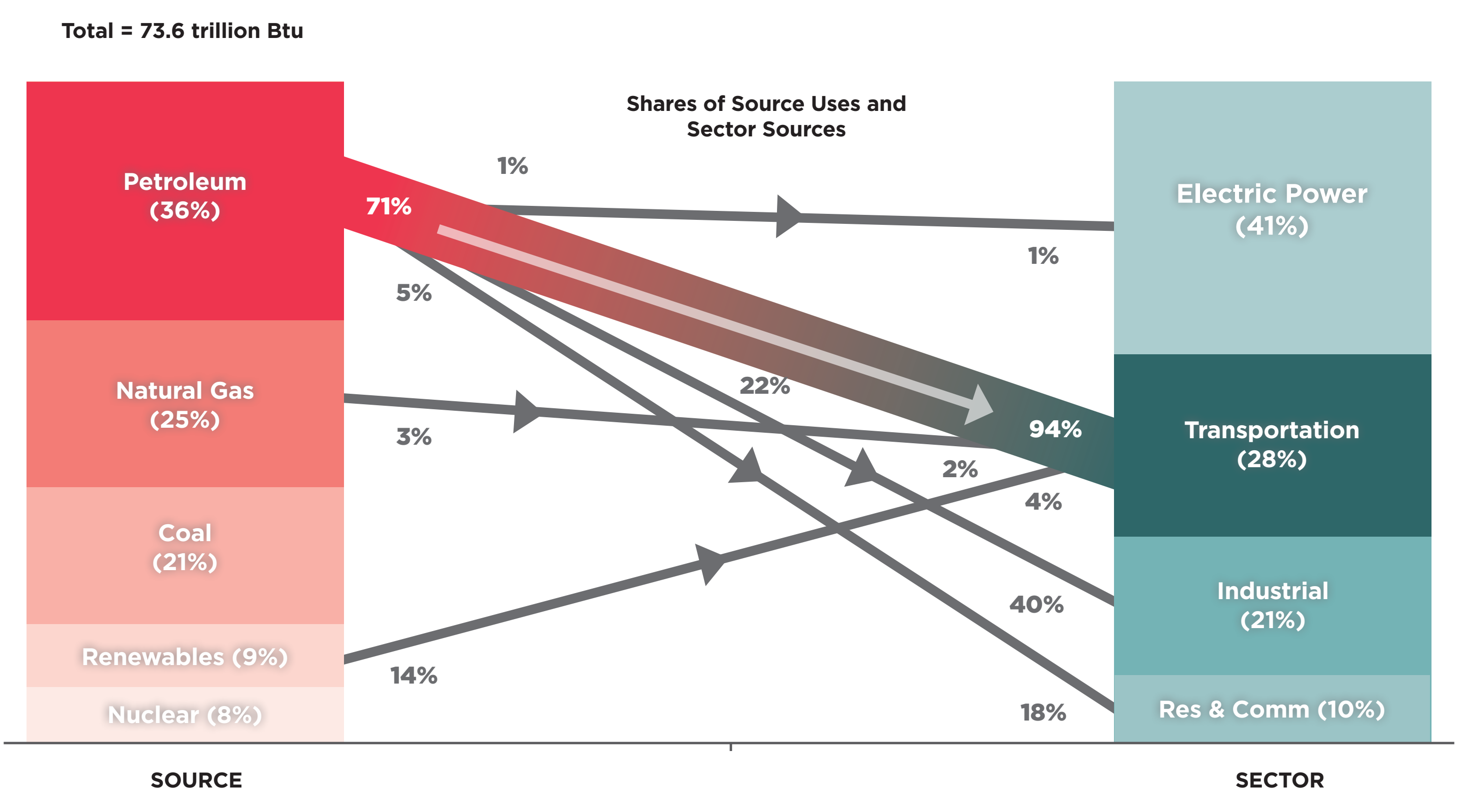
DRIVERS OF CHANGE

In 2011, total U.S. gasoline consumption fell by 2.7 percent (a decrease of 240 thousand barrels per day) compared to 2010, and total U.S. liquid fuel consumption fell by 1.6 percent (EIA 2012d). Yet the average price of regular gasoline was $3.53 per gallon in 2011, compared to $2.78 in 2010 (EIA 2012d).

The U.S. accounts for 22 percent of global oil demand. Per capita, Americans consume about 2.7 gallons of oil per day, compared to a global average of 0.5 gallons (U.S. Census Bureau 2012a; EIA 2011a; UNPF 2011). Despite the outsize position of the U.S. as an oil consumer, it has little control over the global oil price (EIA 2011a). The U.S. does not have the resources to be oil independent at current usage rates, so it must contend with a global supply and demand system driven by complex economics and national priorities.

Oil and transportation are tightly linked. As Figure 1 shows, 94 percent of transportation fuel is derived from petroleum and the transportation sector consumes 71 percent of petroleum in the United States. Today, renewable fuels, predominantly corn ethanol, make up only 4 percent of transportation fuel (Gruenspecht 2012).

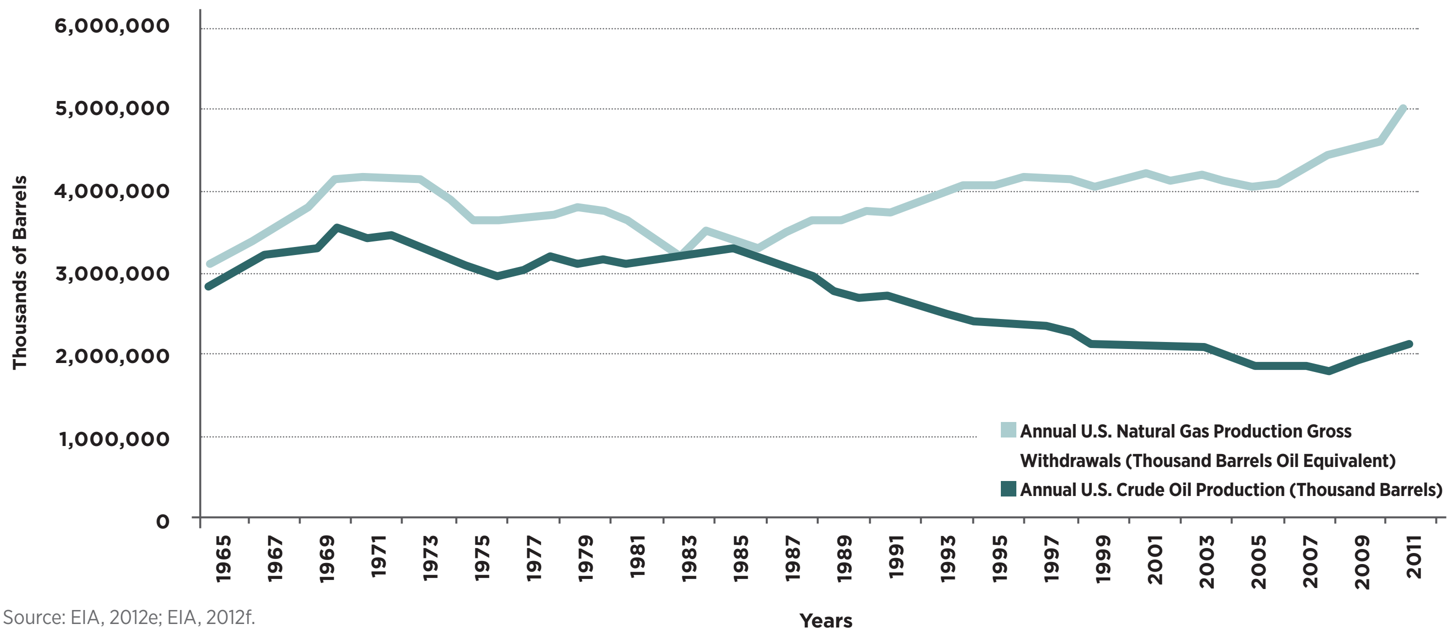
Figure 1: U.S. Primary Energy Consumption by Source and Sector, January–September 2011[1]



Source: EIA, 2011b.

[1] Percentages of source uses and sector sources are for 2010.

Figure 2: U.S. Oil and Gas Production



Source: EIA, 2012e; EIA, 2012f.

Over the past decades, warnings of "peak oil" have come and gone. In this context, it is clear that the problem is not a shortage of oil resources but rather the steadily rising cost of the most expensive barrel extracted to meet demand (the last, or marginal barrel). The recent shale oil boom in the U.S. has led to suggestions that the country may be able to return to the days of energy independence. Oil imports as a percentage of total domestic demand fell from over 60 percent in 2005 to 45 percent in 2011 (Citi Commodities Strategy 2012). As Figure 2 (above) shows, after decades of sharp decline, U.S. oil production is on an upswing (Plumer 2012). Combined with greater Canadian imports, primarily from oil sands, it is likely that U.S. imports will continue to decline. Yet in 2011, even as the economy and greater fuel efficiency caused U.S. demand for oil to decrease, foreign crude oil still cost the United States $326.5 billion, a figure matched only in 2008 (U.S. Census Bureau 2012b). This demonstrates that decreased import volume does not necessarily translate into decreased expenditure.

Even according to the most optimistic estimates, shale oil and other domestic sources are unlikely to come remotely close to actually meeting domestic demand. Further, there is evidence that well decline rates in shale formations are much higher than in conventional reservoirs and, according to some experts, oil prices will need to be between $150–200 in order for drilling to be economical in the less optimal areas of the Bakken Formation (Levine 2012; Citi Commodities Strategy 2012). Consequently, in a world of highly liquid global crude oil markets, it is probably impossible for the U.S. to fence itself off from the economical in the less optimal areas of the Bakken Formation (Levine 2012; Citi Commodities Strategy 2012).

Natural gas production also has surged in recent years, as depicted in Figure 2, and it is clear that the United States has truly abundant resources of this comparatively low-carbon fuel. Many of the available technologies highlighted in this report to seriously displace oil rely on natural gas, either by powering vehicles with natural gas-fueled electricity, natural gas-derived methanol, or compressed natural gas itself.

Economic Vulnerability

Oil dependence is harmful because there is no substitute in the short or medium term. A sudden spike in the price of oil has much less impact on fuel demand than other commodities, indicating in economic terms that demand for oil is relatively price inelastic. Estimates of the short-run elasticity of vehicle fuel demand in the U.S. are typically around -0.1, which means that if all other factors remain constant and the price of gasoline rises by 10 percent, consumption will fall by only 1 percent (Crane *et al.* 2009). Even a relatively minor shortfall in production in an oil-producing nation, such as Nigeria, can lead to a price spike that forces many Americans to cut back on buying domestic goods and services because they have no way to get to work other than to drive.

On the demand side, increases in oil consumption in other markets will affect the price for the whole world. China's unprecedented demand increase in 2004 and 2005 played a role in the subsequent price spike, which in turn is thought to have contributed to the recession of 2008–2009 (Yergin 2011).

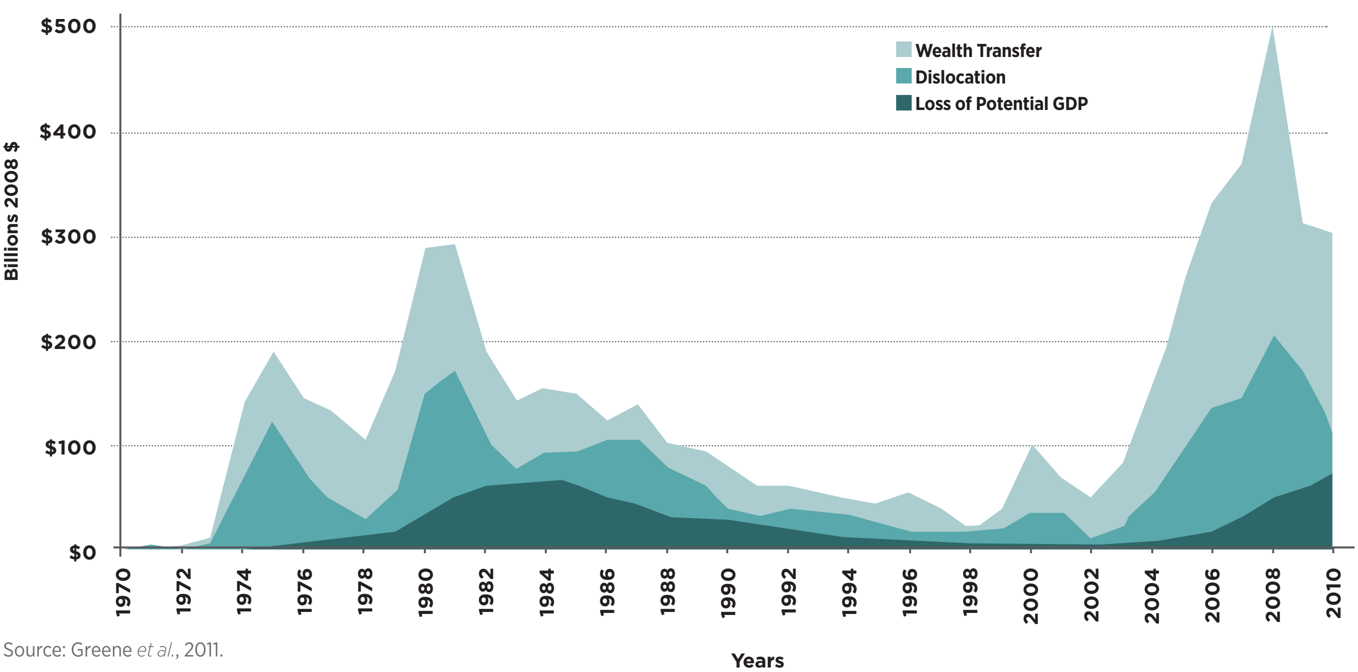
The price of oil is also distorted by a cartel of oil-producing nations known as the Organization of the Petroleum Exporting Countries (OPEC). OPEC has been known to withhold supplies from the market (spare capacity) that would otherwise be produced in a competitive environment.

Given the fundamental role of oil and its byproducts in the lives of most Americans, U.S. residents expect the government to play a role in ensuring adequate, affordable, and stable supplies of oil. Examples of such expectations are the oil crises of the 1970s that plagued the U.S. economy. Since the early 1970s, the government has implemented myriad interventions, such as import quotas, import tariffs, price regulation, producer subsidies, gasoline taxes, and subsidies for alternative fuels. None of these have prevented the five major oil shocks of the last 30 years—1973–1974, 1979–1980, 1990–1991, 1999–2000, and 2008—from being followed by recessions.

Energy Security

Over the past decade, economists have tried to calculate the cost that the U.S. incurs in protecting world oil infrastructure, particularly in policing the key oil-shipping lanes. Efforts have also been made to understand how much less the U.S. would spend on defense if it were not as dependent on oil. Perhaps the most definitive cost estimate we have for the defense imperative of oil dependence is a 2009 RAND Corporation study, which estimated the effect that the U.S. not relying on the global oil market would have on force reduction and avoiding periodic military operations. A bottom-up examination estimated annual costs at $67.5 billion in forces and $8 billion in operations. A simultaneous, independent, top-down investigation yielded $83 billion in force costs and $8 billion (See Figure 3) in operations. These figures are 12–15 percent of the 2008 U.S. defense budget (Crane *et al.* 2009). By comparison, total outlays by the federal government in 2009 for energy, general science, and basic research were $15.8 billion—an abnormally high figure, buoyed by unprecedented energy spending in the American Recovery and Reinvestment Act of 2009 (OMB 2012).

Figure 3: Costs of Oil Dependence to the U.S. Economy



Source: Greene *et al.*, 2011.


009

THE ROLE OF POLICY IN MITIGATING MARKET FAILURE

U.S. history is one of staggering innovation in energy production and distribution, having developed new energy resources and then extracted them with greater efficiency, leading to greater economic development. In recent decades, the arc of energy progress in the industrialized world has turned towards trying to consume less energy while continuing to achieve gains in growth and well-being. Since 1980, the amount of energy used in producing a dollar of gross domestic product (GDP) in the United States has been falling by about 1.1 percent per year (Henderson & Newell 2011).

In this period, new and better ways to produce energy have been developed, from 400-foot wind turbines to the world's largest land vehicle—the 13,500-tonne bucket-wheel coal excavator. Only a few years ago, solar panels were an exotic and knowledge-intensive product manufactured at great expense in industrialized countries. Today, they are commodities, with manufacturers competing to shave costs ever lower. Cheap panels have been bad news for some manufacturers, but this sort of competition has enabled much more rapid deployment around the world and there is evidence that solar is close to grid parity in some markets (Henderson & Newell 2011).

In particular, there is a tremendous opportunity to achieve large efficiency gains in transportation, yet so far potential savings have been too often ignored. The transportation market has not adequately priced many of the benefits of alternative fuels and efficiency improvements. Inertia, high barriers to entry, and imperfect competition have led to under-investment in the energy sector, in particular in the areas of engine efficiency and petroleum alternatives.

The combination of free roads and very low fuel taxes has created a system in which there is little incentive for more efficient vehicles and infrastructure. In sharp contrast, airlines and railroad companies operate in a private, competitive environment. Since 1990 they have reduced their energy intensity, or the amount of fuel they use per passenger mile or freight tonne-mile, by 37 percent and 22 percent respectively (BTS 2010). In order to work, energy policy must leverage the discipline and power of the market, as well as what in recent years has become one of America's strongest assets—having the best capital markets in the world.

There is no silver bullet for clean and affordable transportation, at least not yet. Petroleum products are not going to be displaced entirely in the coming decades. Recognizing this, a basket of currently available technologies, combined with greater access to alternative travel choices and more information about the costs of using oil, can meaningfully reduce our dependence on oil.

METHODOLOGY

Across the transportation sector there are a range of technologies that are widely believed to be cost competitive with business-as-usual practices that are available today and have support from important stakeholders. This analysis focuses on technologies that can have a meaningful impact on oil consumption in the next decade. Where possible, options that are cost negative from the operator perspective are stressed. However, intervention from government and civil society is necessary because price signals under the current market structure are insufficient to incentivize the deployment of technologies that offer major fuel savings. While implementation of some of the technologies simply requires better co-ordination or information exchange among private sector participants, others will require minor or major policy changes.

The scope of technologies and solutions presented in this report is thus neither comprehensive nor cost consistent. For an in depth review of trucking efficiency technologies, please visit our website to read our report 'Road Transport: Unlocking Fuel-Saving Technologies in Trucking and Fleets. They represent a snapshot of what is available today to reduce oil consumption and motivate economic growth. Not all technologies are considered and emphasis is placed on those with a broad support base, which are therefore more likely to be deployed at scale in the near term. The emphasis is also on the major domestic sources of oil demand. Aviation and Shipping are not included, as they have a large international component and make up less than 10 percent of U.S. oil consumption. However, shipping is a tremendously efficient form of transportation and reinvesting in shipping routes and encouraging more fuel-efficient ships will be important in the coming years. This is one reason the Carbon War Room helped build a shipping efficiency data tool, Shippingefficiency.org, used by private sector players to identify more efficient vessels in order to reduce costs. Aviation is a growing source of oil consumption worldwide and is seen as a good first-deployment opportunity for advanced biofuels. The Carbon War Room has developed an online market information service, RenewableJetfuels.org, to analyze companies in the advanced renewable jet fuel supply chain.

This report, however, focuses on the largest source of oil demand and the most economically and politically challenging one to confront: ground vehicle transportation. In years to come, the set of options will develop through technological innovation and changes to the global marketplace. This report aims to provide background and policy options for the near term.

> Currently available technologies combined with greater access to alternative travel choices and more information about oil costs, can reduce our dependence on oil

Near-Term Solutions

After engine losses, idling, and driveline losses, only about 16 percent of the energy potential of the gas in the tank makes it into the wheels

This section describes relatively mature technologies available to reduce oil consumption in transportation at plausible costs (see importance of light duty vehicles represented in Figure 4). The importance of efficiency cannot be overstated. Of every seven gallons of gas that we put in our tanks, only one actually moves the car (Bandivadekar 2008). That is—after engine losses, idling, and driveline losses—only about 16 percent of the energy potential of the gas in the tank that makes it to the wheels (Bandivadekar 2008).

In the following sections, this report will consider other market levers, such as informing consumers about the true costs of oil consumption and expanding their choice sets.

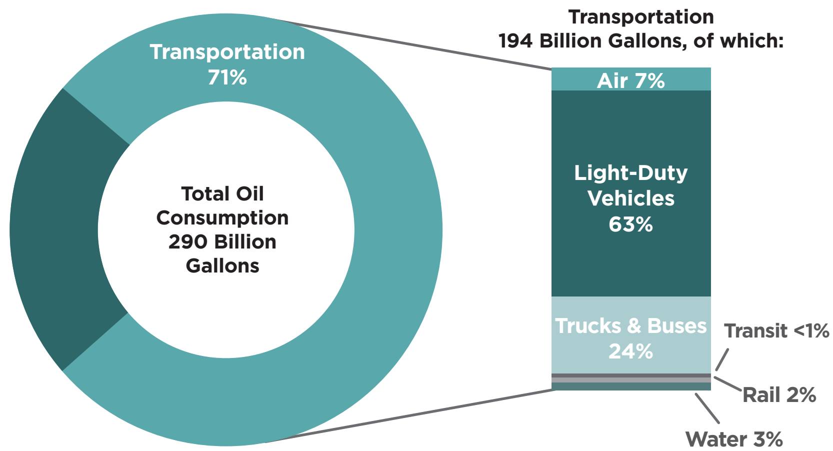
Make Today's Light-Duty Vehicle More Efficient

There are a broad range of vehicle technologies that could make light-duty vehicles much more efficient without sacrificing design or power.[2] Automobiles are a durable good, so when a consumer buys a car, he or she "locks in" at a particular fuel efficiency rate for roughly 10 years. Therefore, a new technology in today's new vehicles will require this same amount of time to be fully deployed across the U.S. transportation fleet. In order to deploy transformative technologies like electric vehicles, the U.S. needs to aggressively prepare and invest now to have them on the road in large numbers by the 2020s. Policies that encourage faster turnover will enable greater savings in the near term.

A complicating factor in identifying the best technologies to make the transportation sector more efficient is that there is a nonlinear relationship between fuel economy and consumption—a 10 percent improvement in fuel economy yields a 9.1 percent decrease in fuel consumption, but a 100 percent improvement only yields a 50 percent decrease in fuel consumption (National Research Council 2010a). That is, multiplying the improvement by a factor of ten only yields around five times the decrease in fuel. Therefore, in the absence of transformative changes that exploit breakthrough technologies, it is often much less costly to make incremental improvements to many vehicles rather than try to generate huge fuel economy improvements in a small segment.

[2] More efficient vehicles offer a lower cost per mile driven, which could cause people to drive more (the "rebound effect"). Efforts to test the "rebound effect" have found that it does exist, but is relatively small (somewhere between 10 percent and 30 percent over the long term) and has declined over time. Additionally, while people do seem to drive more when gasoline prices are lower, they do not seem to drive more in response to a cost-comparable increase in fuel economy.

Figure 4: Transportation's Role in U.S. Oil Consumption, 2009



Source: The White House, 2011.

Lightweight Materials

One of the simplest ways to improve fuel economy is to replace the ferrous metals that dominate vehicle weight with strong, lighter-weight materials like aluminum, high-strength steel, and polymer composites like carbon fiber. Composite materials have high strength-to-weight ratios, and are already used in a wide variety of settings from prosthetic legs to aerospace. It is cost effective to reduce vehicle weight by roughly 20 percent solely via materials substitution (Bandivadekar *et al.* 2008).

Savings

Including a range of weight-reducing strategies and allowing for the additional weight from future safety requirements and improved performance, a Massachusetts Institute of Technology (MIT) integrated cost-benefit assessment found that sales-weighted average vehicle weight could be reduced by 20–35 percent over the following 25 years, providing a 12–20 percent reduction in vehicle fuel consumption (Bandivadekar *et al.* 2008).

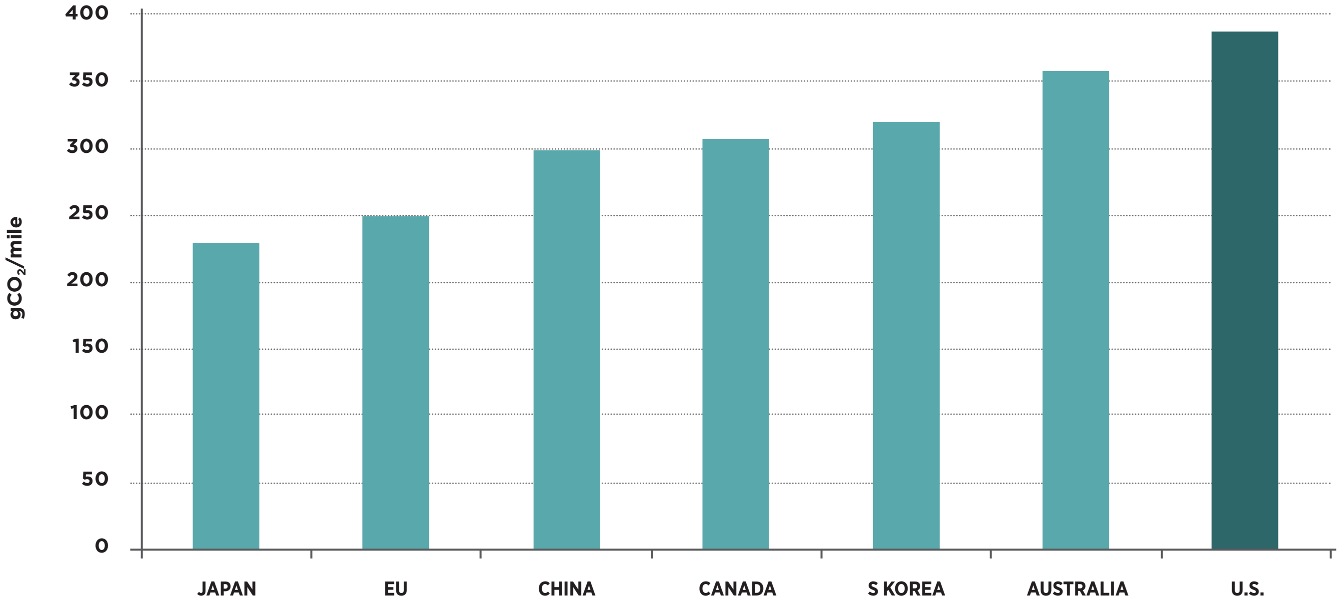
Barriers

Lower-weight materials come at a small cost—reducing a vehicle's weight by a pound is estimated to cost between $1.30 and $2.30 (Bandivadekar *et al.* 2008). Automakers drastically reduced vehicle weight between 1976 and 1982 without substantially increasing costs in response to the new, stringent Corporate Average Fuel Economy (CAFE) requirements. However, since then, average weight has increased at about 1 percent per year. The increasing weight, even as plastics and other lighter materials were introduced, is in large part due to new features and the rise of SUVs.

While the design of light-duty vehicles is expected to continually improve, if there is going to be a meaningful reduction in fuel consumption for conventional, spark-ignited internal combustion engines, technological advances will have to be directed primarily towards efficiency.

This obviously requires a change in consumer sentiment, which is no easy feat in the absence of much higher fuel prices. There is, however, evidence that preferences are already moving in this direction. J.D. Power expects compact and subcompact cars, like the Honda Fit and the Chevrolet Cruze, which have historically commanded a far smaller market than midsize cars, to account for 20 percent of all auto sales in 2015, far outpacing their midsize competitors (Durbin 2011).

Figure 5: Emissions per Mile, Selected Countries, 2008[3]



Source: ICCT, 2011a.

Efficient Propulsion

There is substantial room for improvement in the standard engine of an American car (see Figure 5). Mature technologies, like more efficient transmissions that have six or seven speeds instead of four or five, better hydraulics, bearings, and gear-sealing elements, can take transmission efficiency from the current level of 89 percent up to 94 percent in the future (Bandivadekar *et al.* 2008).

However, some experts have argued that the emphasis should not be on peak efficiency, since most engines operate well below peak efficiency, but rather on higher lifecycle average fuel efficiency. This is best accomplished via improved overall vehicle system integration and lower combustion temperatures, as in lean combustion. Further, there are substantial opportunities for friction reduction, improved engine materials, smarter cooling to reduce heat loss, gasoline direct injection, and intake valve and cylinder deactivation systems, which use modern electronics to adjust engine operation to maximize fuel economy based on the car's speed and driving conditions. Better engine architectures are also currently under development, such as free-piston engines and the compact compression ignition engine. A 2010 report from Oak Ridge National Laboratory (ORNL) suggested that a reasonable goal for average drive cycle energy efficiency is 50 percent (Daw *et al.* 2010).

Savings

A current gasoline-powered car consumes around 3.7 gallons per 100 miles. By 2035, a gasoline car could be expected to get 100 miles per 2.3 gallons, while a 2035 turbo gasoline car might get 100 miles per two gallons. The retail price equivalent increase of the 2035 gasoline car technology improvements was estimated at $2,000, though this does not reflect the cost curves that would no doubt prevail in a competitive market (Bandivadekar *et al.* 2008). While diesel engines can provide greater fuel economy—currently around 62 miles on two gallons—they produce higher emissions, and there seems to be greater scope for improving internal combustion engine (ICE) efficiency rather than attempting to switch to diesel engines.

In general, it is worth noting that the cheaper, initial gains in fuel economy can save a great deal of fuel. If average fuel efficiency could be raised from approximately today's value of 21.5 mpg (4.6 gallons/100 miles) to 30 mpg (3.3 gallons/100 miles), that would provide the same oil savings as the next 20 mpg (from 30 to 50 mpg) and the subsequent 100 mpg (from 50 to 150 mpg) (DOE 2011a).

Barriers

Automakers have suggested that the varying fuel standards around the country have hampered the deployment of more efficient engines and increased vehicle production costs. They propose eliminating the current "boutique fuel" system in favor of a national gasoline standard, which would apply the same emissions requirements across the country (AAM 2009). Other barriers include inadequate experimental platforms and analytical simulation tools, the high cost of materials, and the high cost of in-vehicle sensors to control drive cycle function (Daw *et al.* 2010).

[3] Data for Canada is the average of the 2006 value and the target for 2016.

BUILD BETTER TRUCKS

There are a wide variety of incremental technologies that can improve the fuel efficiency of heavy-duty vehicles, such as work trucks, buses, and freight trucks, which are almost uniformly powered by diesel engines that, while more efficient than their gasoline counterparts, emit higher levels of criteria pollutants like nitrogen oxide (NOx) (Schubert & Kromer 2008). Heavy-duty vehicles account for around 20 percent of all on-road transportation fuel consumption, though they comprise just 4 percent of the vehicles on the road (Union of Concerned Scientists 2010).

Many technologies for freight truck efficiency are cost negative; within a reasonable payback period, they often offer significant savings for truck operators. The biggest potential gains are for long-haul tractors pulling van trailers, which consume around 30 times more fuel annually than the average passenger car (Union of Concerned Scientists 2010).

In recent years, even limited uptake of newly available technologies has proven successful at reducing fuel use. In 2012, the North American Council for Freight Efficiency (NACFE) released their analysis of the penetration of 60 technologies among eight large truck fleets, comprising 75,000 tractors and 130,000 trailers. The technologies ranged from minor add-ons like skirts and better tires to improved driving practices, major upgrades like alternative power units (APUs), and new transmission systems. They found that the average purchased adoption rate of the technologies increased from 31 percent to 48 percent between 2003 and 2010, causing the trucks' average fuel economy to improve by 0.4 mpg, compared to a business-as-usual scenario, in which there was no new uptake, the improvement generated $4,400 in fuel saved per truck per year at $4 per gallon diesel fuel (NACFE 2011). It is clear that the cost savings are there for the taking, so what is possible in the future?

A 2010 study from the National Academy of Sciences (NAS) examined the potential for improving the fuel efficiency of long-haul tractors, and found that fuel consumption could be decreased by at least 35 percent by 2017, and that the costs of the new technologies—roughly $44,000—would be recouped in two years. After five years, assuming a 7 percent discount rate, the net savings would be $56,000. The study concluded that these fuel savings, plus improving the efficiency of other trucks by 20 percent, would save 5.6 billion gallons of oil annually by 2030, the equivalent of taking approximately ten million light-duty vehicles off the road, and reducing greenhouse gas (GHG) emissions by 70 million tonnes annually (Union of Concerned Scientists 2010).

Since the purpose of trucks is to carry loads, the most meaningful metric of their efficiency is how much fuel they use per unit payload. This is described as "load-specific fuel consumption" (LSFC). Current fuel efficiency standards for trucks are not based on this type of metric, which is problematic (National Research Council 2010a). The technologies considered below aim to improve LSFC based on a truck's specific duty cycle.

Powertrains

Improvements to transmission systems, hybridization, and new engine technologies offer cost-effective improvements to fuel efficiency. Adopting a 6x2 transmission, which uses only two wheels to drive the truck, instead of the more common 6x4 transmission that uses four wheels, can reduce fuel consumption by approximately 6 percent. Hybridizing is particularly important for trucks with stop-and-go duty cycles in urban areas, like transit buses and garbage trucks. Idle-specific hybrid systems, particularly those that can run and warm the cab of a tractor-trailer on battery power while the driver is taking a break or sleeping, can provide significant gains.

Enhancing diesel engines through better fuel injection, air handling, and new waste heat recovery systems apply to all trucks. Electric vehicle (EV) technology is probably not yet cost effective for most trucking applications. Some companies with fleets that typically travel in urban areas with stop-and-go cycles for 50 miles or less a day, such as FedEx and AT&T, have already incorporated EVs into their truck fleet. These electric trucks offer lower maintenance costs, while their cost premium of roughly $30,000 over conventional alternatives is paid back by using cheap electricity rather than diesel after about three years (Ramsey 2010). While electrifying Class 8 trucks (anything above 33,000 lbs or 14,969 kg) is not currently feasible, encouraging more urban fleets of medium-size trucks to go electric would provide substantial reductions in GHG and local pollutant emissions while also generating cost savings.

Savings

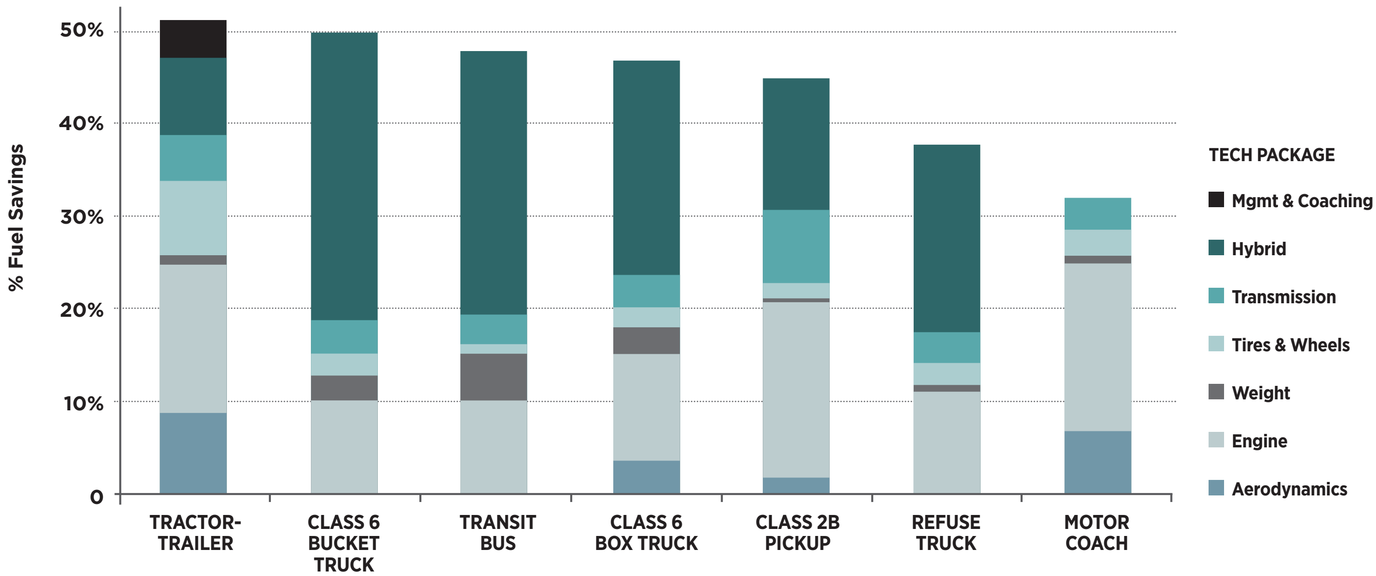
Powertrain technologies offer payback periods that depend on the type of truck and its duty cycle, as seen in Figure 6 (which also includes resistance and use improvements). For example, one study found that trucks could potentially save $44,000 over their lifetimes by switching to 6x2 transmissions (NACFE 2010a).

The National Research Council study in 2010 that produced the data in Figure 7 shows that technology packages have a range of trade-offs between fuel consumption reduction, capital costs, and break-even fuel prices. For example, if diesel prices are only $2.50 per gallon, then the package for the transit bus requires twice the lifetime of the bus to pay off—20 years—while the capital cost for the motor coach package would be repaid in less than five years.

Trucks could potentially save $44,000 over their lifetimes by switching to 6x2 transmissions

Figure 6: Heavy-Duty Vehicle Fuel Savings Technology Packages and Cost Effectiveness

$84,600	$49,870	$250,400	$43,120	$14,710	$50,800	$36,350	Capital Cost
1.10	5.40	6.80	4.20	4.80	2.70	1.70	Break-Even Fuel Price ($/Gal)

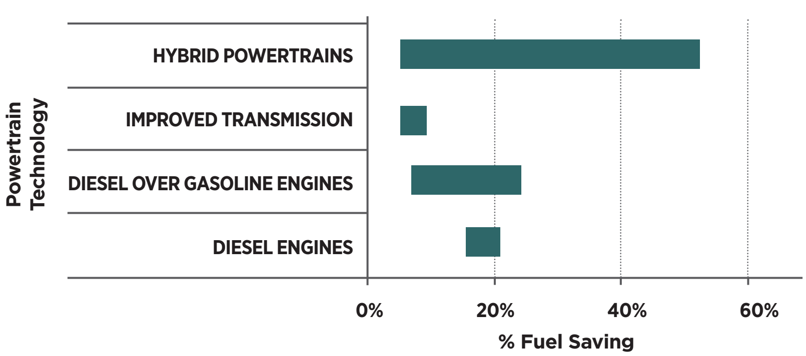


Source: National Research Council, 2010.

While the estimates for potential fuel savings and payback periods are uncertain, the clear takeaway is that there is a great deal of room for improvement. The upper limit on fuel efficiency improvement from hybridizing is nearly 50 percent, while adopting existing technologies to improve diesel engines would provide gains of 15–20 percent.

A 2011 Rocky Mountain Institute study estimates the additive potential efficiency improvements from both design and use through 2050. The study suggests that combining improved engines, auxiliary power units, and better transmission could together provide around a 25 percent increase in fuel economy (RMI 2009a).

Figure 7: Fuel Saving Potential of Powertrain Technologies for Medium- and Heavy-Duty Vehicles, 2015-2020[4]



Source: National Research Council, 2010.

[4] Ranges in efficiency estimates reflect in part the difficulty to obtain good estimates due to operational variances, as well as remaining technology uncertainty.

Barriers

While it is possible to consider one-size-fits-all fuel-saving technologies for the light-duty vehicle fleet, such an approach simply does not apply to the much more complex and diverse truck fleet, where diffuse component manufacturing makes technology standards for powertrains very difficult. The optimal technology will vary based on the truck's use and location. For example, while 6x2 transmissions are about $300 cheaper than 6x4, they provide less traction in extreme weather conditions. While they may seem like an easy fix for trucks in Florida, they may not be ideal for trucks operating primarily in North Dakota.

This example illustrates the fact that the break-even fuel prices may not be relevant for all vehicle owners—some may not plan to use the truck for its full life expectancy and may have varying operating costs, maintenance expectations, and discount rates. The importance of application and duty cycle suggests that improving the powertrains of trucks is most easily achieved via market mechanisms that incentivize fuel economy rather than command-and-control technology regulation.

Lower Resistance

The majority of fuel burned in a truck's engine is lost to friction with the air and the ground as a result of inefficient tires and poor aerodynamics. Simple fixes that provide meaningful fuel economy benefits are low rolling resistance tires and weight reduction. Simply switching from traditional double-wide tires to wide-gauge single tires can provide up to 6 percent better fuel efficiency and, though there is a small cost to switching wheels, the single tires are actually cheaper and require less maintenance (NACFE 2011).

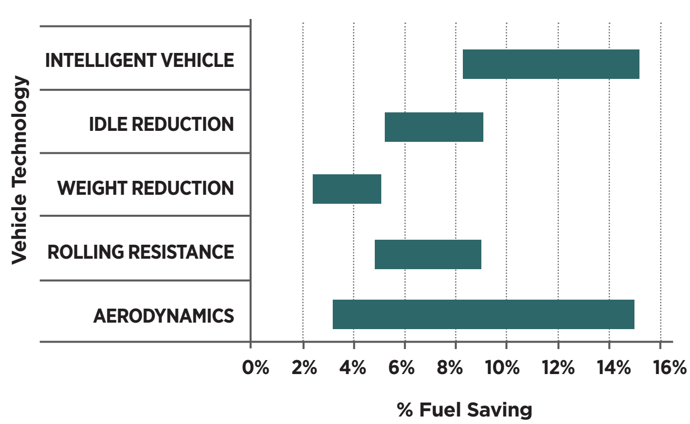
There are a wide variety of trailer aerodynamic devices, although many of them have only been made available recently. For tractors, a study by NACFE found that fleets had aggressively adopted available aerodynamic features. Some improvements can be as minor as filling gaps between bumpers and fenders and sealing the area between the tractor and the trailer. For trailers, one relatively simple fix is side skirts, which are panels that hang from the sides of the trailer between the axes. These have been adopted quickly over the past three years, in part due to the California Air Resources Board requirement, and the NACFE study found that these skirts have improved real-world fuel economy performance by 2–5 percent (NACFE 2011). Some companies, like AeroFlex, claim that their EPA SmartWay-certified skirts improve fuel economy by up to 7 percent.

The NACFE study concluded that aerodynamic technologies for trailers have not been widely adopted, making trailer aerodynamics fertile ground for introduction and benefit (NACFE 2011). A 2010 National Academy of Sciences (NAS) study estimated that the fuel consumption improvement available today for trailer aerodynamics is 5.5 percent and could grow to 11.5 percent in just a few years. If trailer aerodynamics adoption would grow to 50 percent for the eight fleets analyzed in the study, the savings would be 9.3 to 19.4 million gallons of fuel per year (NACFE 2011).

Savings

Figure 8 shows that better aerodynamics, weight reduction, and reducing rolling resistance can yield fuel savings of over 20 percent.

Figure 8: Range of Fuel Consumption Reduction Potential for Medium- and Heavy-Duty Vehicle Design, 2015–2020



Source: National Research Council, 2010a.

These estimates reflect the maximum achievable and would likely take decades to fully implement. A more realistic short-term estimate comes from a 2008 Union of Concerned Scientists study. This report found that implementing a cost-effective retrofit program that would decrease rolling resistance, improve aerodynamics, and lower weight could reduce California's heavy-duty fleet fuel use by between 1.2 to 1.8 billion gallons between 2010 and 2020, which would lower fuel consumption and GHG emissions by around 5 percent compared to a reference scenario (Schubert & Kromer 2008).

Barriers

Trucking is an area where there are genuinely mature technologies that could reduce diesel consumption and save money for the trucking industry. However, market frictions such as adjustment costs, lack of information, and agency issues prevent technology deployment at scale.

One specific issue is that new technology deployment tends to lag for trailers because they are often left idle and thus get far fewer miles than tractors. It can be difficult for fleets to devote certain trailers to higher-mileage routes, where it makes more sense to have the fuel-saving technologies. In general, if a return-on-investment calculation uses 100,000 annual miles driven for the tractor, investment in new technologies for trailers must be cost effective with an annual mileage of 33,000 (NACFE 2011).

Trucking is a very competitive industry, leaving owner-operators with very tight profit margins that often make upgrades prohibitive, even if the payback period is less than two years. In the current economic environment, it is often difficult for small trucking companies or tractor-trailer owner-operators to access credit.

Furthermore, there is often a principal-agent problem in which freight companies that own the trucks have little incentive to invest in fuel efficiency because it is the drivers who pay for fuel. This applies to both powertrain and operational technologies as well as those aimed at reducing resistance. Further, trucks have complicated lifecycles. They are not produced in a standardized way like automobiles and often intermediaries assemble various pre-made components. Component suppliers and original equipment manufacturers (OEMs) should work with fleets to more efficiently add the technologies at the time of manufacture, since it is more expensive and less reliable to add them on at later stages. Additionally, trucks are often resold at least once, if not more often, over the course of their lifetimes, and it is hard to forecast whether a given fuel-saving add-on will increase the resale value of the truck.

Efficient Operation

Driver management and coaching is critical to ensure that drivers know how to get the best results from their vehicles (National Research Council 2010a). Efficient driving techniques include speed reduction, route optimization, and smoother braking and acceleration. These techniques either require driver education or the installation of new devices in vehicles. Drivers can be incentivized to reach fuel economy goals either by tying their pay directly to fuel economy or through creative incentive programs. One fleet, for example, radically changed its driver culture when it began offering a new Harley Davidson motorcycle each year to the driver with the highest miles per gallon.

Another example is using vehicle-to-vehicle communication to allow trucks to travel very close together in order to reduce wind resistance. According to the director of General Motor's Electrical and Controls Integration Lab, spacing trucks four meters apart can reduce fuel consumption by 10–15 percent (Bullis 2011). This requires what is essentially more advanced cruise control—an intermediate step towards driverless vehicles—because the trucks must be able to brake automatically if the truck in front of them brakes. One company that sells this type of technology, Peloton, employs a combination of radar and GPS, and reports that installation costs around $5,000 per truck.

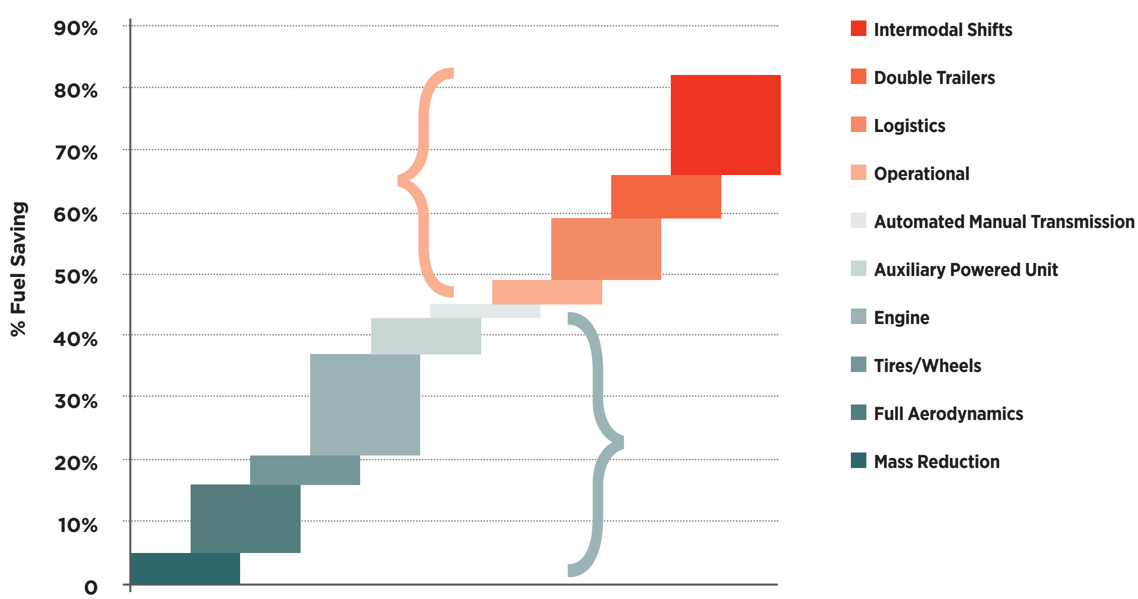
Savings

Providing drivers with both the information and the incentives to save fuel is one of the cheapest fixes, particularly for tractor-trailers. For example, trucks achieve the greatest fuel efficiency near 55 mph and lose about 0.1 mpg for each mile-per-hour increase in speed. Thus, slowing from 68 mph to 63 mph can provide a 9 percent increase in fuel efficiency, saving $7,200 annually per average vehicle (NACFE 2011). A recent survey of four major U.S. fleets found that 98 percent of their freight shipments would not be affected by a five mph decline in travel speeds (NACFE 2011). Other solutions can be driven at very low cost by modern information technology (IT)—better logistics that eliminate backhauls and consolidate loads could reduce truck tonne-miles by 15 percent (RMI 2011). See Figure 9.

Barriers

While operational strategies can provide benefits, the reality is that growing freight traffic over recent decades has contributed to increasing congestion. A study conducted by Cambridge Systematics in 2006 found that 195 million hours of delay occurred annually on urban highway freight bottlenecks and 30.5 million hours occurred on intercity freight corridors. A conservative delay cost of $32.15 per hour (using a Federal Highway Administration highway cost-benefit model) brings the direct user cost of bottlenecks to $7.3 billion per year. The actual cost is likely much higher, as many experts believe that the actual value of truck time is closer to $70 per hour (Cambridge Systematics & Battelle Memorial Institute 2008). Since much of this delay occurs on a few bottlenecks, investing in modal switching and better highway infrastructure in targeted locations may be a more cost-effective means to achieve fuel savings.

Figure 9: Heavy Truck Design and Use-Potential Percent Reduction in Fuel Consumption by 2050



Source: RMI, 2011.

Table 1: Costs and Net Returns for an Iowa Dry Mill Ethanol Plant[5]

	PRICES				COST PER GALLON		REVENUE			RETURNS OVER	
Year	Ethanol ($/Gal)	DDGS ($/tonne)	Corn ($/bu)	Nat Gas ($/mcf)	Corn	Total All Costs	Ethanol ($/Gal)	DDGS ($/Gal)	Total ($/Gal)	Variable Costs	All Costs
2005	$1.57	$74.06	$1.75	$9.22	$0.62	$1.32	$1.58	$0.22	$1.81	$0.70	$0.48
2006	$2.30	$88.49	$2.23	$8.36	$0.80	$1.47	$2.30	$0.27	$2.57	$1.31	$1.10
2007	$1.94	$115.04	$3.47	$8.20	$1.24	$1.91	$1.94	$0.35	$2.29	$0.60	$0.38
2008	$2.18	$156.11	$4.94	$9.46	$1.76	$2.47	$2.18	$0.47	$2.65	$0.39	$0.18
2009	$1.63	$111.76	$3.56	$5.62	$1.27	$1.86	$1.63	$0.34	$1.97	$0.32	$0.11
2010	$1.68	$109.00	$3.69	$6.05	$1.32	$1.92	$1.68	$0.33	$2.01	$0.30	$0.09

Source: DOE, 2010.

[5] The assumptions of the Iowa State University model include a 100-million-gallon plant operating at 110 percent of nameplate 2007 capacity (the year the plant was built), and the production of 2.8 gallons of ethanol and 16.5 pounds of dried distillers grains (sold for livestock feed) per bushel of corn. Fixed cost is constant at $0.21 per gallon. The plant is assumed to be dry mill (as most existing plants are), which is cheaper than the alternative, wet milling.

DEPLOY NEW FUELS

This section describes five available substitutes for petroleum products: conventional biofuels, advanced biofuels, methanol made from natural gas, electricity delivered to vehicle batteries, and natural gas as a direct fuel.

The first two sub-sections describe two types of biofuel, which is fuel derived from biological pathways, usually employing agricultural commodities as feed stocks. There are two basic categories of conventional biofuels in widespread use today: bioethanol, an alcohol made by fermenting and distilling the sugars in plants such as corn and sugar cane; and biodiesel, which is made from oils, such as palm oil, soybean oil, or animal fats. Unlike ethanol, which contains less energy than gasoline and is more corrosive, biodiesel is a near-perfect substitute for diesel.

Biofuel today, however, is produced largely from corn in the United States and sugar cane in Brazil. Though ethanol can be made from cellulosic material, like grasses, the technology is not yet commercial. Biofuels have complex impacts on land use and the environment. As a result, a responsible scale-up of biofuels requires regulation to ensure standards of sustainability.

Corn and Sugar Cane Ethanol

Ethanol is the only alternative to petroleum that has been deployed at scale since the advent of the internal combustion engine. Corn ethanol meets about 10 percent of domestic fuel demand by volume, or 7 percent by energy content, since ethanol has a lower energy density than gasoline or diesel.

Decades of significant government support for corn ethanol in the U.S. have caused the industry to grow dramatically. Production of less than 2 billion gallons in 2000 has risen to an annual rate of 14.2 billion gallons in 2011 (Gilliam 2011). Whether produced from corn, sugar cane, or any other sugar- or starch-based feedstock, ethanol production involves the same series of steps. After separating the sugars from the rest of the feedstock, yeast is added. Once the sugars are fermented into alcohol, it is distilled, producing "wet" or hydrous ethanol. It is then dehydrated to be used in gasoline (Seelke & Yacobucci 2007).

Most ethanol is both produced and consumed in the U.S. Midwest, in proximity to corn feedstock (Seelke & Yacobucci 2007). A large increase in corn production accommodated this new demand. Average yields have increased from 81 bushels per acre in 1983 to more than 164 bushels per acre in 2009 (Jessup 2011). In addition to corn yields, ethanol yields in the refinery have increased about 10 percent between 1990 and 2010 (DOE 2010). See Table 1.

Since ethanol is corrosive and tends to absorb water, it cannot travel in oil pipelines and cannot be mixed with other products. This need to segregate the products substantially increases costs and reduces flexibility for pipeline operators, so thus far almost no ethanol has been transported via pipeline.

Corn ethanol's economic viability, its impact on land use, corn prices, overall food prices, and emissions are all subjects of debate.

Going forward, ethanol's ability to be cost competitive with gasoline and other fuels will be tested. It will depend in large part on the price path of oil and corn. It will also depend on whether regulation permits the widespread deployment of E85 pumps, which would deliver fuel that is 85 percent ethanol and 15 percent gasoline. Using an analytical tool from Iowa State University of a typical ethanol plant, it is possible to get a sense of the returns to ethanol production based on different corn and other input prices. Table 1 shows that profitability is closely linked to the price of corn, which accounts for around 70 percent of variable costs.

Savings

Until early 2011, when the EPA approved the use of E15 (and ethanol blend) for 2011 model year and later vehicles, it was clear that U.S. ethanol production had hit the legal limit of 10 percent ethanol in gasoline—roughly 14 billion gallons (EIA 2011c). See Figure 10.

Despite its issues, continuing to expand ethanol production and potentially importing sugar cane-based ethanol from Brazil offers a commercially viable mechanism to displace imported oil and reduce emissions. As a main source of global petroleum supply additions outside of OPEC over the last decade, ethanol can and does mitigate demand increases for oil and thus moderates oil prices (NREL 2008). In 2012, renewable fuels in total are expected to supply 1,290 trillion British thermal units (Btu) of energy to the transportation sector, of which 1,160 trillion Btu is ethanol blended with gasoline (EIA 2012a). Meanwhile, total light-duty gasoline and diesel consumption is expected to be 15,562 trillion Btu (EIA 2012b).

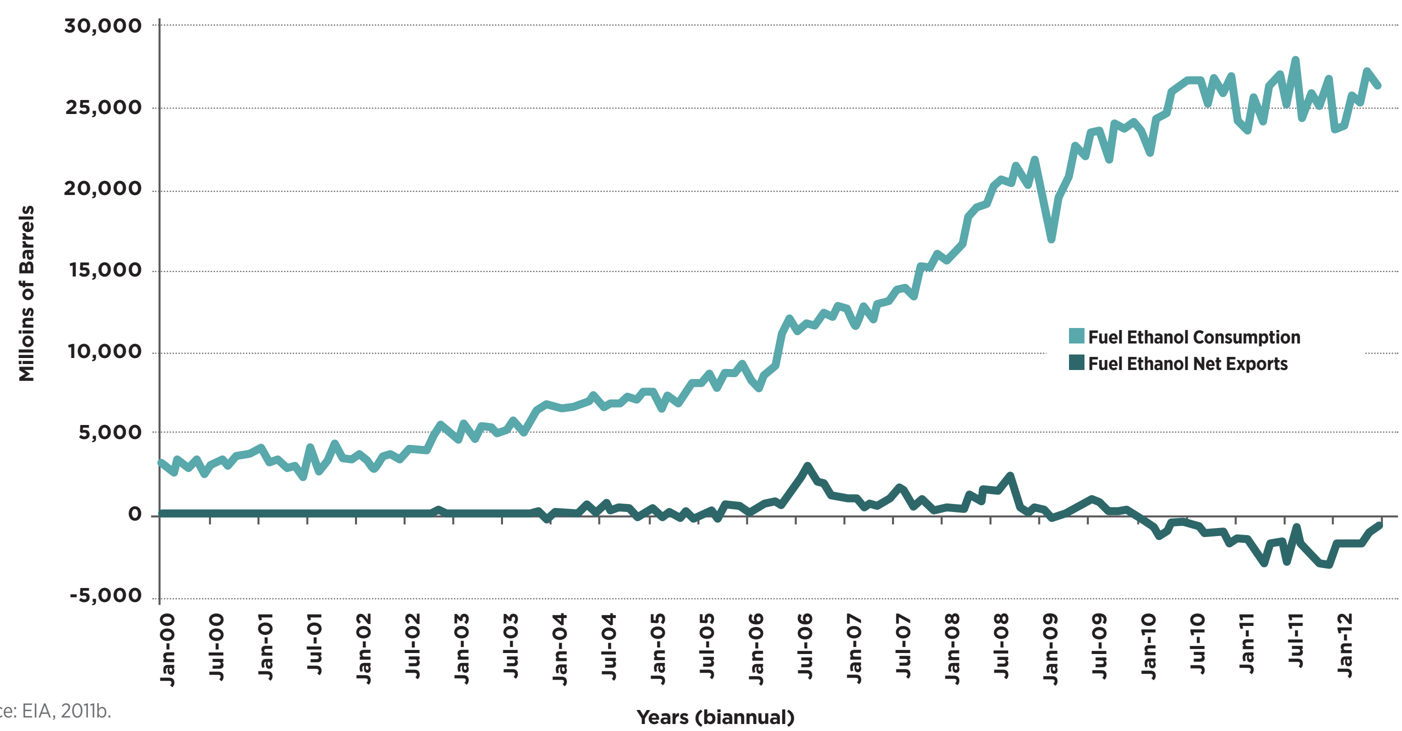
Ethanol seems to have reduced recent gasoline prices in the U.S even though it only makes up 10 percent of "gasoline". A recent study from the Departments of Energy and Agriculture found effects ranging from $0.20–0.35 per gallon, and a separate, more comprehensive study from the National Renewable Energy Laboratory (NREL) found that ethanol keeps retail U.S. gasoline prices about $0.17 per gallon lower than they would be otherwise, or $0.14 when the ethanol subsidy was subtracted. Further, if all national gasoline contained 20 percent ethanol by volume, the per-gallon savings (mileage adjusted) could reach $0.18 to $0.63 (NREL 2008).

However, beyond displacing petroleum products there is a second side to ethanol's energy accounting—its net energy value or balance and its GHG emissions when compared to gasoline. While any usable power source requires energy to produce and distribute, ethanol is particularly energy intensive to make because its feedstock must be grown, unlike oil and coal (Liska *et al.* 2009).

According to researchers at the University of Nebraska, ethanol's GHG emissions reductions range from 40 percent below gasoline in coal-fired Nebraskan plants to between 60–70 percent below gasoline using natural gas in Iowa or using closed loop processes in with anaerobic digestion in Nebraska (Liska *et al.* 2009). Models developed by Argonne National Laboratory (GREET) have put the reduction percentage around 24 percent (Liska *et al.* 2009). Accounting for these changes is important, since the current Renewable Fuels Standard—established in the Energy Independence and Security Act (EISA) of 2007—requires that lifecycle GHG emissions of corn-ethanol and cellulosic ethanol be respectively 20 percent and 60 percent lower than gasoline.

Calculations of GHG emissions produced per unit of ethanol depend on the fuel used for refining, how the co-products from distilling are counted, and what milling process (wet or dry) is used (Knittel 2012). Unfortunately, evidence thus far has not incorporated land use impacts. There is evidence that corn ethanol production may cause farmers in tropical countries to cut down rainforest to grow food plants. Deforestation is a major and preventable source of carbon emissions, so careful study is needed to ensure that any unintended consequences of ethanol are acceptable.

Figure 10: Fuel Ethanol Domestic Consumption and Net Exports



Source: EIA, 2011b.

Barriers

The problem for U.S. ethanol production today—and potential future Brazilian imports—is not the economics of production, particularly if oil prices remain above $80 or $90 per barrel. Instead the problem is market access, according to some ethanol trade group leaders. Limits on the amount of ethanol that can be blended into gasoline vary by state (though the EPA is raising the federal limit from 10 percent to 15 percent this year) and the absence of a distribution mechanism for pure ethanol makes it impossible for producers to deliver greater quantities to consumers.

The CAFE standards are designed to encourage the manufacture of light-duty vehicles that can run on fuel with up to 85 percent ethanol. In recent years, automakers have used this route to meet their fleet-wide fuel economy requirements, and flex-fuel vehicles have become much more common. However, there are very few E85 pumps and these are concentrated in the Midwest. It costs roughly $72,000 to add E85 storage and equipment to a gas station, though a much larger potential barrier is that oil companies may, or do, prevent gas stations from offering alternative fuel pumps. Thus flex-fuel vehicles (FFVs) almost always run on a standard E10, despite providing automakers with as much as a 1.2 CAFE mpg increase for their fleet (Andress *et al.* 2011). The technology to convert a conventional vehicle into an E85 FFV is mature and relatively inexpensive, and General Motors, Ford, and Chrysler have suggested they will try to produce half of their vehicles as E85 FFVs. However, these vehicles do not qualify as super-low-emission vehicles (SULEVs) under California's more stringent vehicle emissions standards, because without direct fuel injection, E85 FFVs have greater evaporative emissions (Andress *et al.* 2011). E85 is also more expensive on a gasoline-equivalent basis because it has roughly 20 percent less energy content than gasoline.

The ability of corn ethanol to further scale is not yet clear. If all light-duty vehicles ran on E85 with ethanol from U.S. corn feedstock, we would need 415 million acres of corn crop. The total area of farmed land in the U.S. is only 406 million acres (Knittel 2012). In the 2010–2011 marketing year, 40.3 percent of U.S. corn production was used to make ethanol, and a very similar figure is projected for 2011–2012 (USDA 2012).

Additionally, inadequate rail infrastructure has hindered ethanol transport. Rail is by far the cheapest and most energy-efficient way to transport grains and processed ethanol, but in recent years costs have escalated for shippers, as railroads require them to build their own large loading terminals (Jessup 2011). This generates higher costs for the ethanol and rail industries compared to oil tanker trucks driving from terminals to gas stations, for example, since nearly all highway infrastructure is provided by the government.

A third issue is cheap natural gas. While it seems clear that oil prices will remain sufficiently high for ethanol to compete with gasoline, the shale gas revolution and subsequent gas supply glut have meant that fuel derived from natural gas, as will be discussed below, could potentially undercut ethanol.

Biofuels can serve to improve energy security and can be a consistent source of high-energy-density liquid fuel. Yet while conventional biofuels are clearly superior to gasoline on emissions, there is still a question of whether they can truly be considered "renewable" or "sustainable" in the sense of contributing to climate change mitigation (Holland *et al.* 2011; Searchinger *et al.* 2008). It is important to assess the full costs and benefits of all fuels. In this case that includes potential impacts on soil erosion, food prices, and deforestation abroad (Fargione *et al.* 2009).

Cellulosic Ethanol and Advanced Drop-in Biofuels

More advanced biofuels can potentially solve both the infrastructure and resource-intensity quandaries currently facing ethanol. There are many possible feedstocks for advanced biofuel, such as switch grass for cellulosic ethanol and soybean oil for biodiesel. The most mature advanced biofuel technology in the U.S. today is cellulosic biofuel, also called "second generation" biofuel. Cellulosic biofuels do not require much irrigation or fertilizer and have less than half the GHG emissions of gasoline on a lifecycle basis (Knittel 2012).

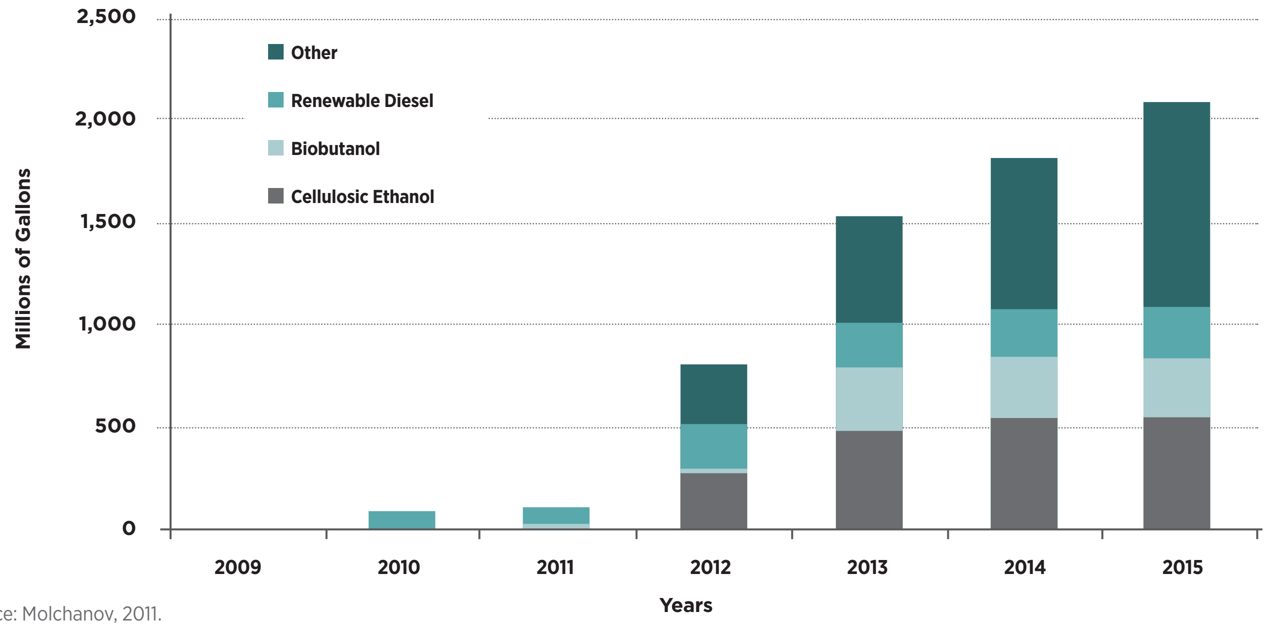
Cellulosic biofuel is derived from cellulose (also called lignin), the cell wall or woody part of a plant. This biomass can be broken down into sugars that can then be fermented into ethanol. There are currently three basic pathways to get at the sugars. In acid hydrolysis, an acid solution (usually sulfuric acid) is combined with the cellulose under high temperatures and pressures. In enzymatic hydrolysis, the lignin is removed and then the cellulose is exposed to enzymes, which break it down. In the thermochemical process, the biomass is gasified and then passed through fermenters, where micro-organisms or catalysts ferment it into ethanol.

Recent evidence suggests that thermo-chemical conversion has distinct advantages over fermentation, one of which is that it can use a wider array of potential feedstocks, such as forestry residues and organic municipal waste. Additionally, the final products are more compatible with existing petroleum infrastructure (DOE 2010). Indeed, the thermo-chemical process is one route to drop-in biofuels, which have essentially the same molecular structure as gasoline or diesel and thus can be "dropped in" to current pipelines, pumps, and vehicles. There are a variety of ways to do this, including gasification of the biomass and then conversion of the syngas into gasoline or diesel. Recent processes have been developed to remove CO_2 and other pollutants, producing a much cleaner syngas. Additionally, it is possible to use concentrated solar power to gasify the biomass, eliminating the need to burn a fossil fuel to achieve the required high heat levels.

However, powerful new biofuel pathways are under development, see Figure 11 overleaf. One promising such pathway exploits advances in synthetic biology, where hydrocarbon chains or organisms that can produce them are fabricated. For example, Amyris Inc. has developed a synthetic sugar cane-derived biodiesel and jet fuel that it sells in Brazil. In the U.S., Virent and Shell have built the first bio-gasoline demonstration plant in Wisconsin, which similarly converts plant-based sugars to gasoline. ExxonMobil also has a drop-in biofuels program using algae.

The Joint Bio-Energy Institute, a partnership between national laboratories and universities in California, discovered genes that encode enzymes to catalyze the conversion of plant sugar into hydrocarbons. These and other advanced drop-in biofuels seem to be finding their initial market in aviation as a replacement for jet fuel. Multiple air carriers and the U.S. Air Force and Navy have demonstrated that these fuels perform well as jet fuel substitutes.

Figure 11: Projected U.S. Advanced Biofuels Capacity Expansion, 2011



Source: Molchanov, 2011.

Savings

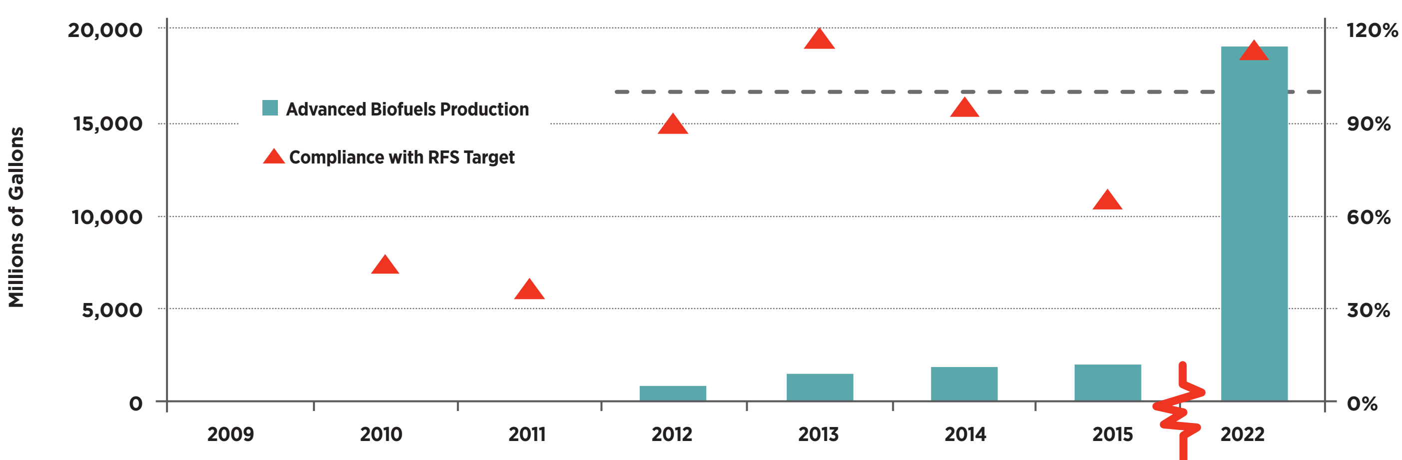
Cellulosic biofuels can potentially displace petroleum fuels with substantially lower CO_2 emissions. Indeed, it is possible to have net-zero lifecycle biofuel emissions if the biomass could be converted to fuel without producing GHGs (Knittel 2012). EISA increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022. As of 2010, there were 28 cellulosic ethanol plants in development and construction in the U.S., and total production capacity was 340 million gallons (Andress 2011).

Barriers

In order to be a truly viable transportation fuel, advanced biofuels must become much cheaper. Though the technologies to produce them exist, commercial-scale fuel production remains distant. In 2010 and 2011, the EPA reduced the cellulosic ethanol Renewable Fuel Standard (RFS) requirement dramatically because industry seemed unable to meet the established targets, see Figure 12. Even so, in 2011 the reduced required volumes did not materialize and the EPA issued waiver credits.

In the future, oil price uncertainty may be as problematic for advanced biofuels as for conventional fuels, unless alternative fuels can be sold separately rather than mixed into gasoline. It may be that that advanced biofuels will need to operate on non-crop materials, such as grasses, wood refuse, or waste, if they are to be economic and environmentally sustainable (CNA Military Advisory Board 2011).

Figure 12: Advanced Biofuel RFS Requirements and Actual Expected Production, 2011



Source: Molchanov, 2011.

Methanol Fueled Vehicles

Methanol (also known as wood alcohol) can be produced from natural gas, coal, or biomass. It is most often produced from natural gas via a catalytic reaction. Methanol today is mainly used as a chemical feedstock to produce substances like formaldehyde, paint, and refrigerant. For transportation, methanol can be used directly as fuel or blended with gasoline (it is a popular drag racing fuel). It can also be converted to a diesel replacement or used in the biodiesel production process. Some researchers are investigating methanol as a feedstock for producing hydrogen, which could then power fuel-cell vehicles.

Around the world, there are around 90 methanol plants with a collective production capacity of around 24 billion gallons (Methanol Institute 2012). Methanol use is growing most rapidly in China, where it is mostly made from coal rather than natural gas (Research in China 2010). The U.S. consumed 1.8 billion gallons of methanol in 2010 (mostly as a chemical feedstock), about 12 percent of the world total (Knittel 2012). Recently, economic shale gas drilling has vastly expanded domestic U.S. natural gas resources, and using methanol as an alternative to gasoline has entered the national discourse.

Methanol is produced from syngas, a mixture of hydrogen (H), CO_2, and carbon monoxide (CO), usually via a steam-methane-reforming (SMR) technology that requires a great deal of steam and thus is very energy intensive. In large plants, SMR can be combined with oxygen to more easily obtain the desired syngas, a process called "two-step reforming". Either way, the reaction is exothermic, so hypothetically plants could capture excess steam and use it for electricity generation.

While methanol offers advantages as a transportation fuel—it is cheaper than ethanol or gasoline, less flammable, does not require agricultural land, and emits fewer conventional pollutants—its consumption in the U.S. has declined substantially since the early 1990s, when corn ethanol began to replace methyl tertiary butyl ether (MTBE).

Savings

It is possible to use methanol to displace oil in the near term. In theory, methanol also has the potential for diversity of supply, because it can be produced from gasifying a range of feedstock, including trash, biomass, and coal. Additionally, while methanol produces roughly the same GHG emissions as gasoline, it burns much more cleanly. Methanol feedstock should optimally contain CO_2, which may ultimately be a means of sequestering carbon (Wang & Huang 1999).

Large plants of the kind that would be built to supply vehicle fuel for the U.S. automotive sector would likely be fairly efficient—the produced ethanol would contain around 70 percent of the energy contained in the original natural gas that was used as a feedstock to produce syngas (Wang & Huang 1999). While not an exact comparison, the most advanced gas-fired electric power plants achieve efficiencies of around 50 percent.

According to some calculations, using current spot prices for methanol of around $1.10 per gallon—after accounting for methanol's lower energy content and the costs of distribution, taxes, and infrastructure—it is possible to provide an amount of methanol equivalent to a gallon of gasoline to the consumer for around $3 (Ridge & Peters 2012). With pre-tax gasoline prices of $2.30 per gallon, it would be possible to produce methanol from domestic natural gas profitably. Given 67 percent energy conversion efficiency and natural gas prices of up to $8 per million Btu, methanol production is still cost effective (MIT 2011). However, methanol takes up roughly twice the room for the same energy content, resulting in shorter ranges for converted vehicles.

An advantage of methanol is that it can be deployed in conventional spark-ignition engines, and its high-octane rating yields high power (hence its use in drag racing). Some experts have advocated using methanol in tri-flex-fuel light-duty vehicles (LDVs). By blending gasoline, ethanol, and methanol, drivers can maximize the price, emissions, and range advantages of each. LDVs could be equipped to handle all three fuels or a blend for only $100–200 in extra vehicle costs. Long-haul trucks might also benefit from a mixture of gasoline and methanol. By switching from diesel to a 70 percent methanol and 30 percent gasoline mixture, the average long-haul truck could save $5,200 per year in fuel costs, and an additional $4,800 from less costly fuel injection and exhaust treatment (MIT 2011).

Barriers

As with ethanol, a primary problem is market access. Consumers aren't able to buy cars that can run on methanol—flex-fuel vehicles are only warranted to use gasoline and ethanol. Methanol presents some of the same challenges as other alternative vehicles. As is the problem for electric vehicles (EVs) and natural gas vehicles (NGVs), automakers will be unwilling to market vehicles capable of handling methanol until there is an infrastructure in place to supply methanol to consumers.

Methanol also faces an uphill battle against gasoline due to its much lower energy content. To provide the same miles delivered per dollar spent as gasoline, methanol needs to be made available to consumers at less than half the cost of gasoline. Its lower energy content means that the cost savings must be enough to merit either a larger tank or a shorter range. Further, a danger of methanol—as with NGVs—is that it ties consumers to a single fuel. Producing methanol from alternative sources, such as coal, is either not economic or unacceptable from an emissions standpoint. Natural gas prices, though currently very low, have historically been volatile, which might complicate methanol production investment and profitability.

Table 2: Price, Range, and Overall GHG Emissions for Five Vehicle Types

Vehicle Type	Fuel Type	Initial Price	Specific Fuel Price (per 100 miles)	Driving Range (miles)	Overall Lifecycle GHG Emissions (kg/100 miles)
Conventional	Gasoline	$15,300	$4.73	336	34.4
HEV	Gasoline	$20,000	$2.75	578	21.4
EV	Electricity	$42,000	$1.45	102	19.3
Fuel Cell	Hydrogen	$100,000	$2.72	221	24.5
H2-ICE	Hydrogen	$60,000	$13.52	186	18.5
NH3-H2-ICE	Ammonia	$40,000	$10.30	267	2.3

Source: Dincer *et al.*, 2010.

Electric Vehicles

EVs, which are available today from a variety of manufacturers, offer the tantalizing prospect of completely displacing oil with a diverse, domestic array of fuels. One problem with mixing petroleum-based fuel with biofuels is that the price of the mixture is determined by the cost of the "last drop" needed to meet demand. This marginal cost will be the global price of oil.

Electricity offers the opportunity to decouple a great deal of the U.S. transportation infrastructure and price system from oil altogether and power many vehicles with a diverse range of domestically produced energy.

It is possible to deploy EVs at scale in the next decade, but this would require strong government support to remove the market barriers, in particular the powerful incumbency of gas stations. Even under the most optimistic scenario in which expanded demand drives battery costs down and incentivizes cost-reducing innovation, only new vehicle fleets can be meaningfully changed by EVs over the next ten years. Impacting the overall fleet will take longer due to slow turnover.

Purely battery-powered electric vehicles (BEVs) are beholden to the limits of battery technology, implying a trade-off between features such as cost, weight, energy storage, and acceleration and torque. The best battery chemistry today is lithium-ion, though new chemistries are under development. Current lithium-ion batteries have limited range (about 100 miles in the case of the Nissan Leaf BEV) and take many hours to recharge, even at 240 volts.

Plug-in hybrid electric vehicles (PHEVs), like the Chevrolet Volt, try to overcome the range anxiety problem by including two drivetrains—a smaller battery and electric motor, and a gas tank to take over from the battery once it is depleted. While many consumers are accustomed to a car that can travel hundreds of miles on a tank, in fact the vast majority of trips in the U.S. are short distances—68 percent of cars travel less than 40 miles per day (Vyas *et al.* 2009). Thus PHEVs with ranges of only 40 miles could serve most consumers' needs.

Hybrid vehicles (HEVs), like the familiar Toyota Prius, are the third type of electric vehicle. HEVs rely primarily on a gasoline ICE. They charge their battery with energy released in braking and by the ICE, and the stored power then assists the ICE in start-up, acceleration, and sometimes for driving short distances. HEVs have typically used nickel metal hydride (NiMH) batteries, though future models may use lithium-ion instead.

If connected to the grid, EVs can become distributed electricity storage, which could make the power system considerably more efficient, lowering the costs and capacity needs for power generation during peak demand hours. It would also enable more variable, renewable energy sources. Pilot tests have demonstrated that this vehicle-to-grid technology (V2G) works (Kempton *et al.* 2009).

Most major automakers now have at least an EV concept car, see Table 2. The most widely produced U.S. EVs were first sold at the end of 2010—the Nissan Leaf and the Chevrolet Volt. Nissan has sold 20,000 Leafs thus far in the U.S. and Japan and hopes to double that number in 2012. General Motors sold 6,142 Chevrolet Volts in the U.S. between January and November 2011, and is unlikely to reach its target for the year of 10,000 units (Reed 2011). Initially, it appears that commercial fleets, especially medium-duty delivery vehicles in urban areas, are best poised for adoption. These vehicles can go to the same depot to recharge and can become a cluster of battery power storage that negotiates directly with the utility. Fleet adoption could provide crucial early infrastructure build-out, reducing costs for later adopters.

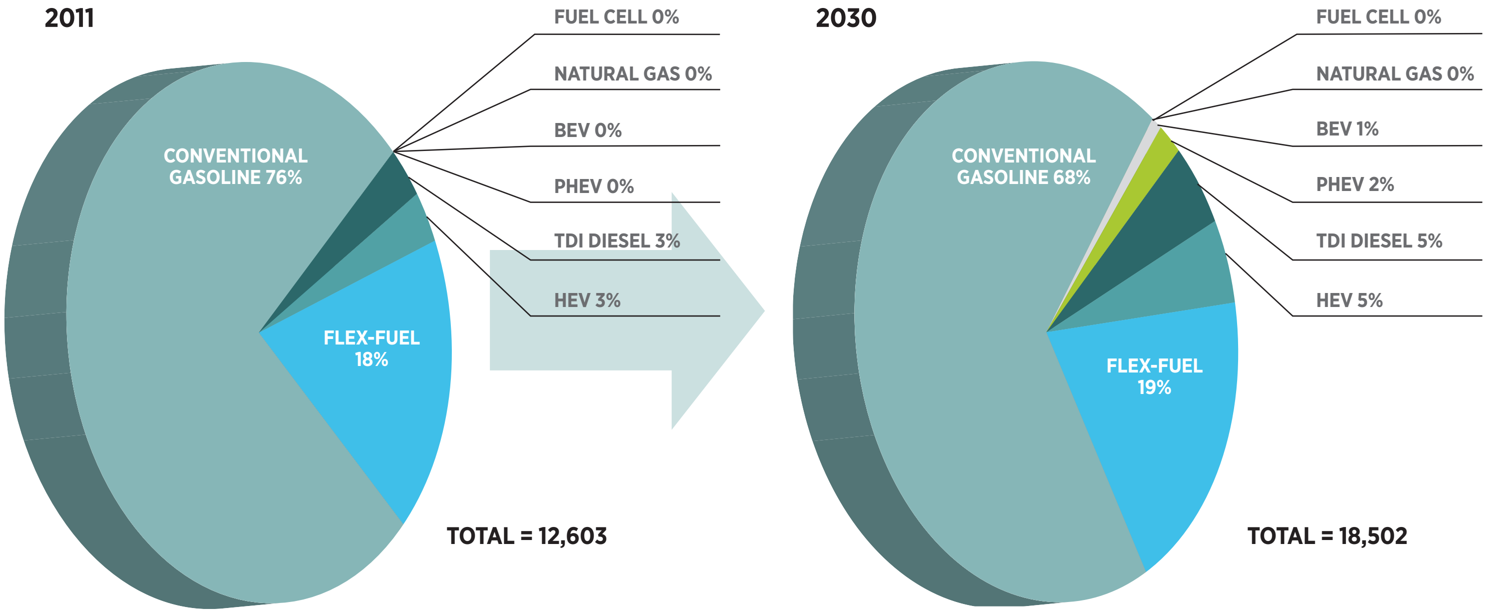
Savings

While they require gasoline and do not plug in, HEVs are an important bridge technology. A 2010 study using EPA fuel economy data suggested that fuel economy for HEVs is between 25 percent and 50 percent greater than for conventional vehicle counterparts (Andress 2011). A second MIT study predicts that HEVs will be more effective than either turbocharged gasoline or diesel vehicles at reducing fleet fuel consumption and GHG emissions, providing greater efficiency at a narrowing price premium (Bandivadekar *et al.* 2008).

Electrically charged EVs directly displace oil with a domestic energy source whose price has historically been stable and relatively low. Depending on the electricity mix, EV GHG emissions range from roughly equivalent to those from gasoline, when the electricity is primarily from coal-fired power plants, to much lower than gasoline when the electricity is primarily from natural gas-fired plant (Andress 2011). EVs powered by renewable or nuclear electricity would, of course, produce no emissions at all.

While there are clearly long-term macroeconomic benefits to an electric vehicle infrastructure, for the individual consumer the important number is the payback period—how long it takes for the car's reduced operating costs to make up for the extra sticker price of the EV. This number varies depending on the kind of EV and assumptions about oil prices.

Figure 13: Total U.S. Car and Light Truck Sales, 2011 and 2030



Source: EIA, 2011d.

Barriers

The largest barriers to EV deployment are battery costs and the absence of a public infrastructure for fast charging. Yet there are also more subtle principal-agent problems that bedevil distribution. For example, auto dealers make the lion's share of their profits servicing vehicles they sold. Yet EVs require almost no maintenance. Therefore, a viable business model must find a way to incentivize dealers to sell them. A second issue is that after the battery has exhausted its useful life in a vehicle, it holds significant value either as stationary energy storage or for recycling. Yet drivers cannot currently monetize this expected value in advance, and thus must assume the full cost of production.

The network nature of EV infrastructure presents a challenge in building both production of EVs and consumer demand for them. Without adequate charging infrastructure and battery power, consumers are less interested in purchasing EVs, and without consumer demand, companies are wary of investing large sums in better technologies or charging stations.

History suggests, however, that there is substantial scope for battery improvement and more rapid charging technology. The Department of Energy's EV R&D goals are to make EVs cost competitive with HEVs and conventional vehicles by reducing the cost of high-energy batteries from around $800 per kWh in 2010 to $300 by 2014, and reducing the cost of a high-powered electric drive system from $22 per kW in 2009 to $12 per kW in 2015 (Andress 2011).

Conservative projections from a 2010 National Research Council report suggests that PHEV battery packs will likely drop to $400 per kWh in 2020 (National Research Council 2010b). Economies of scale are critical—when mass produced, battery costs will decline dramatically. A growing market will also drive the development of new battery chemistries.

Charging stations are also expensive, ranging from $2,000 for a Level 2 (240 volts) charger installed at home to $30,000 for a Level 3 (480 volts) public charging station (Electrification Coalition 2009). Widespread adoption will hinge on a successful business model for public charging and/or battery swapping. In the future, it may be possible to avoid some of the physical infrastructure cost of charging through wireless charging stations. One version of this is being developed by Momentum Dynamics, which claims that its wireless charging systems can be operated automatically, with payment similar to EZ-Pass toll collection, and that charging at lower voltages (240V) is much faster than with a comparable plug-in charger.

As depicted in Figure 13, without policy changes or very high oil prices, EVs will not even dent new car sales—and since the fleet takes about 10 years to turn over, that means they will have an even more marginal impact on oil consumption.

The V2G technology described above can improve the value proposition, but the familiar chicken-and-egg problem arises: building the smart grid connections that enable V2G is not worthwhile for the utility unless there is a critical mass of EVs in the area. The ominous alternative to V2G is that without adequate price signals and utility interaction with vehicles, EVs might overload the grid if too many are charged at times of peak demand.

Natural Gas Vehicles

Despite strong support from certain stakeholders, and numerous supporting bills in Congress, natural gas vehicles (NGVs) have not thus far succeeded in penetrating the U.S. fleet—there are only about 110,000 NGVs in the U.S., less than a tenth of 1 percent of the vehicle fleet. Countries like Pakistan, Iran, India, and China have invested more heavily in NGVs, and at the end of 2010 there were nearly 13 million worldwide (NGV Global 2011).

Natural gas vehicles can use either compressed natural gas (CNG)—the most common—or liquefied natural gas (LNG), which is so compressed that it becomes a liquid. It is expensive to cool methane to such low levels, so the more compact LNG tanks are currently only economic for tractor-trailers that require long ranges from their fuel tanks, balancing the benefits of higher freight capacity from lower fuel tank weight (Andress 2011).

Like EVs, NGVs offer longer service lives and lower maintenance costs, as well as lower emissions, compared to conventional ICE vehicles. They are also quite safe, since leaked methane dissipates quickly and does not form a flammable pool. Light-duty NGVs use spark-ignited engines like conventional ICEs, but heavy-duty vehicles often use high-pressure direct injection engines in a compression-ignition (diesel) cycle (DOE 2011c). Both systems achieve roughly the same performance, albeit with shorter ranges, as an equivalent conventional vehicle.

The only light-duty car marketed to consumers is the Honda Civic NG (formerly the Civic GX), which retails at about $6,000 more than its conventional counterpart, at $26,155. Honda only sells around 1,000 Civic NGs each year (Woodyard 2011). A much broader infrastructure system and stronger incentives would be required for other automakers to invest in NGVs. The U.S. currently has about 1,500 natural gas fueling stations.

For the time being, NGVs make economic sense in heavy-duty fleet vehicles, where they offer meaningful fuel savings, improve urban air quality, and provide greater price certainty for fleet operators.

The T. Boone Pickens-backed Clean Energy Fuels has sought to kick-start municipal NGVs by offering fueling services for over 500 fleets of taxis, school buses, refuse trucks, and other vehicles around the country. The company is trying to expand this model to the private sector long-haul trucking industry, and in 2012 and 2013 plans to install liquefied natural gas pumps at 150 truck stops nationwide (Woodyard 2011).

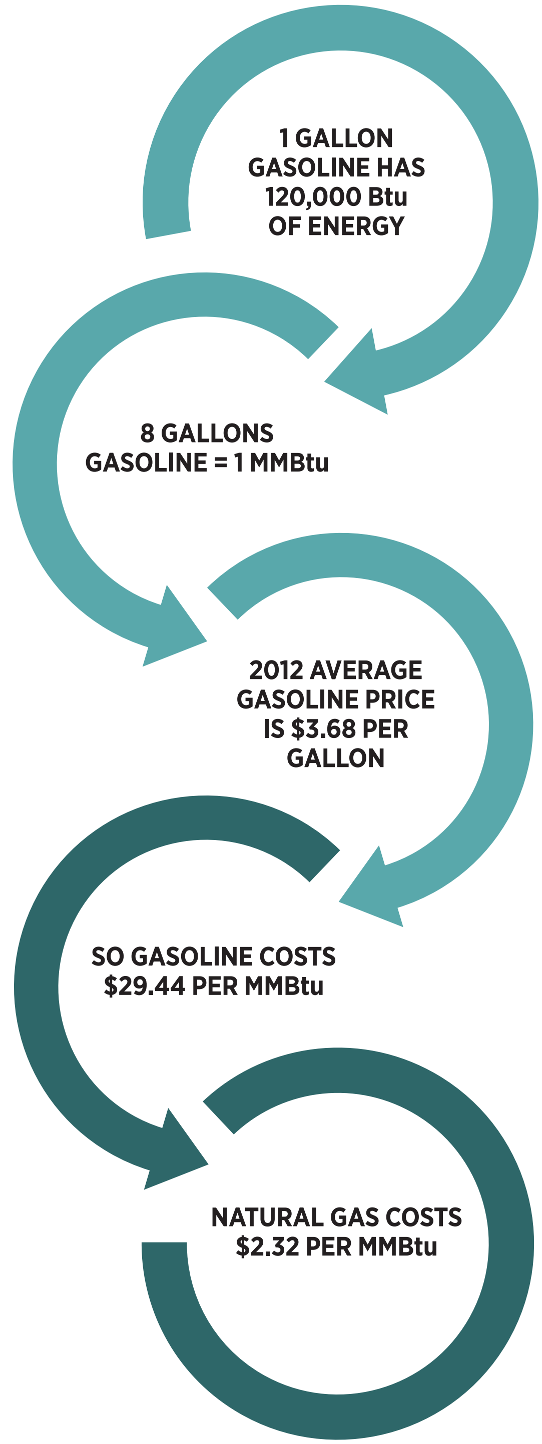
Savings

On an energy-equivalent basis, natural gas is far cheaper than gasoline, which costs almost 13 times more than natural gas based on average prices through mid-May 2012.[6]

Now that abundant shale gas and other unconventional gas resources are economically viable, it is clear that the U.S. possesses a great deal of gas. Assuming that it is not funneled into a much more gas-intensive power sector, this gas could presumably fuel a cheaper, cleaner transportation system.

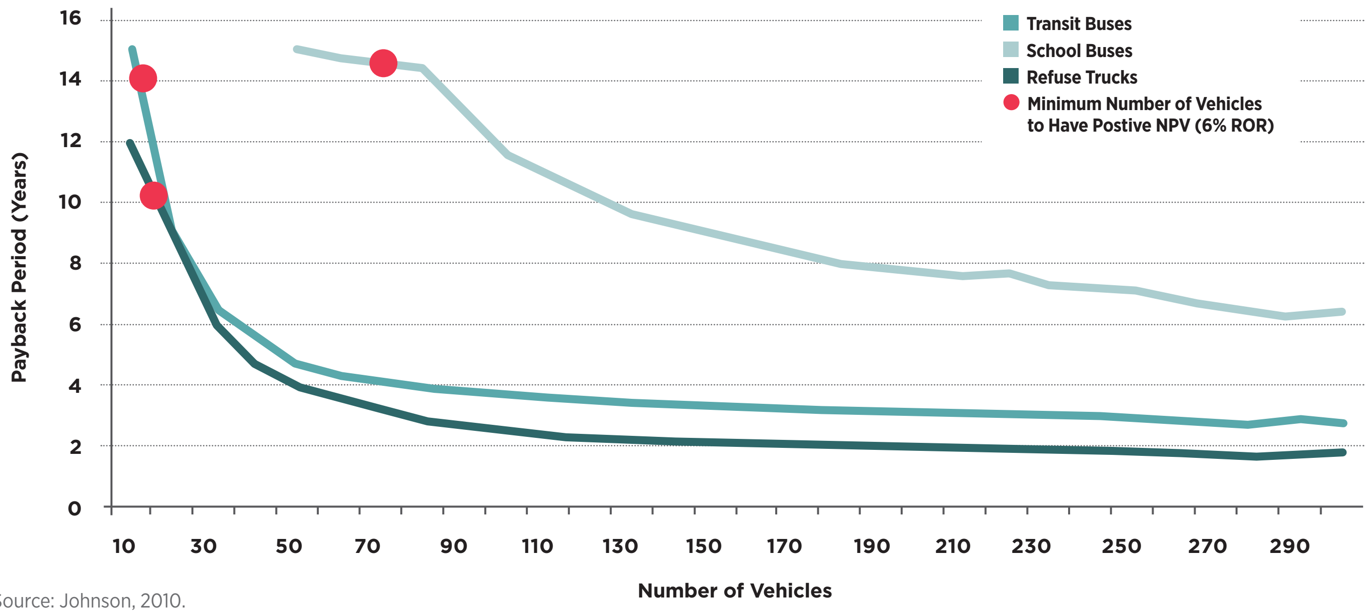
Tractor-trailers that use LNG save, depending on diesel prices, between $1.50 and $2 per gallon equivalent, with roughly the same fuel use in terms of equivalent gallons. According to C.R. England, a refrigerated carrier, its recently deployed five LNG-fired tractors for its trucks in Southern California have payback periods of one to two years (Woodyard 2011).

Price Comparison of National Gas to Gasoline



[6] Average weekly price between 1/1/2012 and 5/14/2012 for regular all formulations retail gasoline from the EIA. Natural gas price is Henry Hub daily spot price averaged between 1/3/2012 and 5/14/2012 from EIA.

Figure 14: Municipal Compressed Natural Gas Fleet Payback Period by Fleet Size[7]



Source: Johnson, 2010.

Currently, CNG vehicles make the most sense for public sector fleets of school buses, transit buses, and refuse trucks. They offer lower air and noise pollution, consistent operational costs, and long-term cost effectiveness for operators with a higher tolerance for longer payback periods. Once there are roughly 30 vehicles in the fleet, payback periods drop substantially (Johnson 2010). In order to achieve a 6 percent return on revenue, which is generally considered an acceptable threshold for positive net present value (NPV) private investment, it is only necessary to have, for example, 14 refuse trucks. If a municipal government has a fleet that consists of one-third transit buses, one-third school buses, and one-third refuse trucks, then it need only have 22 vehicles total to generate a positive NPV (Johnson 2010).

Barriers

NGVs for light-duty vehicles suffer from distinct disadvantages: they have limited range due to the lower energy content of natural gas compared to gasoline, and their large CNG tanks generally permit little trunk space (DOE 2011e). More importantly, consumers currently have no way to refuel. Scale adoption would require a whole new fueling infrastructure. There already exists a 305,000-mile network of gas pipelines, but many more miles would have to be built to serve individual gas stations (EIA 2007). With EVs by contrast, consumers typically already have 240V outlets in their house for their washer-dryers and a simple extension to the garage is possible for home charging.

NGVs are more expensive than conventional gasoline vehicles or HEVs, so consumers must expect a very low cost of refueling in order to obtain a reasonable payback period (CNA Military Advisory Board 2011). Natural gas prices have been quite volatile in the U.S. over the last 30 years, unlike electricity, which has experienced generally stable retail prices. Therefore, it may be difficult to convince consumers that today's historically low prices due to large investment in shale gas drilling in recent years will be here to stay.

Supply insecurity and price volatility are functions of relying with non-substitutable infrastructure on a single, globally traded fossil fuel for transportation. This is a serious downside of NGVs compared to EVs. Using electricity instead would offer a diverse fuel source, of which natural gas will be an increasing share.

Highlight on Congestion

According to the Texas Transportation Institute, drivers in urban areas experienced 4.8 billion hours of delay in 2010, wasting 1.9 billion gallons of fuel (TTI 2011). However, these figures do not account for fuel losses in acceleration, deceleration, and idling. Additionally, even with these conservative estimates, the cost to the average commuter in 2010 was $713. TTI projects that wasted fuel will increase to 2.5 billion gallons in 2015, causing congestion-related fuel costs of $13 billion (assuming $5 per gallon gasoline). see Figure 15.

In coming years, congestion is expected to increase dramatically, eroding expected fuel savings from recent and projected increases in federal fuel economy standards. At current rates, by 2030 58 urban areas in the U.S. will have regional congestion levels high enough to qualify as "severe", compared to 28 in 2003. And in the absence of action, between 2010 and 2020 the nation will waste a total of more than 1.6 billion barrels of oil in the top 90 urban areas. This is in excess of the fuel economy losses due to standard road conditions, which are already accounted for using a reduction factor from EPA testing fuel economy levels.

GETTING MORE OUT OF OUR MILES

We can apply modern computing power and human ingenuity to doing what we currently do, but with a lot less oil. Conventional internal combustion engine cars are tremendously inefficient—for every gallon that put into the tank, 72 percent is lost in the engine, and another 9 percent is lost between the gearbox and the wheels, see Figure 15 overleaf. That leaves only 19 percent of the original energy to move the wheels. On top of the 81 percent of the gallon wasted in the vehicle, for each gallon pulled from an oil field, another 14 percent of a gallon is used in refining and distribution; that is, each gallon that does not go into a car means 1.14 gallons stay in the oil field (Tertzakian 2009). Eliminating wasteful oil consumption by the end user in driving is the cheapest, fastest means to reducing oil dependence.

[7] NPV is an abbreviation for net present value, and ROR is an abbreviation for return on revenue.

Intelligent Transportation Systems

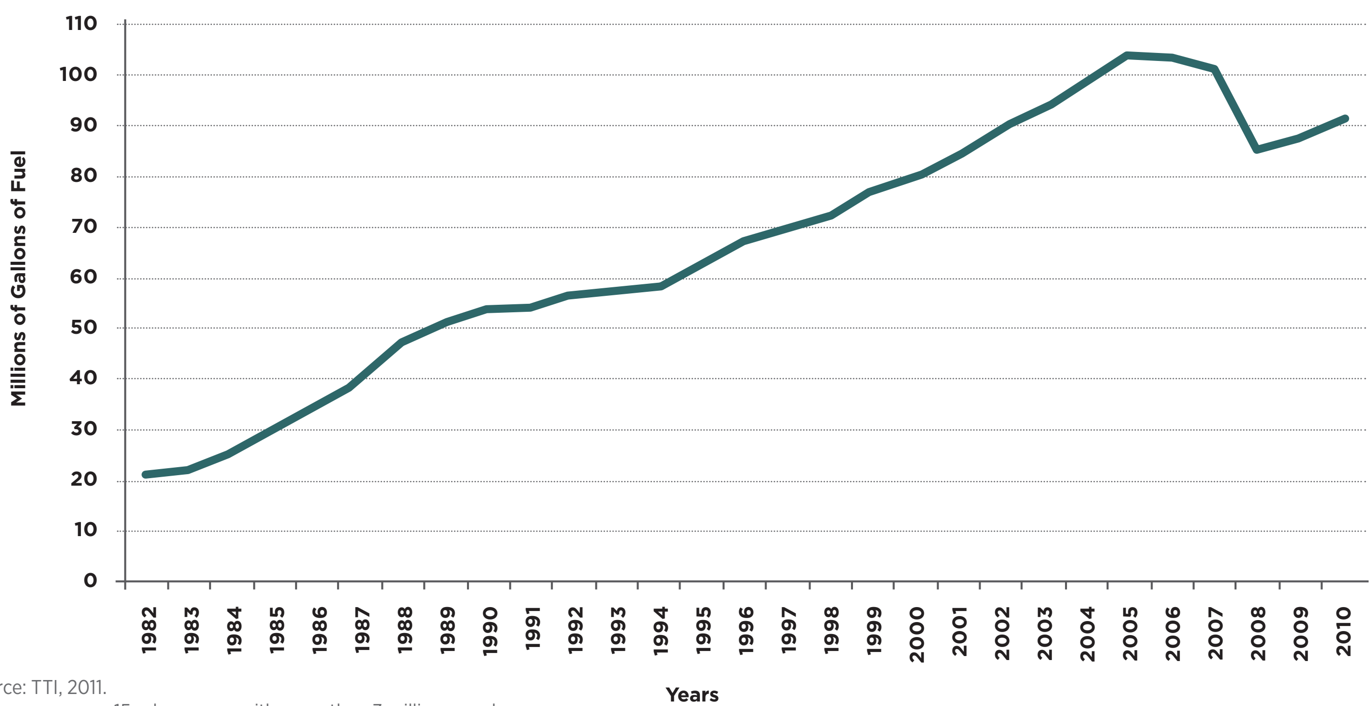
Applying modern information technology to our transportation system is likely a cost-negative way to improve the efficiency of our aging transportation infrastructure, reducing congestion, increasing capacity, and enhancing safety without major capital investment. Intelligent Transportation Systems (ITS) solutions cover a wide range of applications, but two important areas where the technology is already mature are Advanced Traveler Information Systems (ATIS) and Advanced Transportation Management Systems (ATMS). In general, the aim is to combine new capabilities in communications, locational information technology, and advanced modeling to improve transportation system performance.

Advanced Traveler Information Systems

ATIS provide drivers and transit riders with real-time information and directions. They can also inform users about congestion, road repair work, or accidents ahead. By laying the infrastructure for ITS deployment—in this case, placing GPS units on buses—the government can enable the private sector to build services that are immensely useful.

A 2009 report from a joint European-Japanese task force on using ITS to reduce CO_2 emissions found that on-board navigation can reduce vehicle miles traveled (VMT) by 16 percent and parking space search miles by 30 percent (Spence *et al.* 2009).

Figure 15: Wasted Motor Fuel in Very Large Urban Areas, 1982–2010[8]



Source: TTI, 2011.
[8] Average among 15 urban areas with more than 3 million people.

New navigation systems should combine navigation with real-time travel information to enable more efficient routes. Some navigation systems already have such capabilities. Ford recently announced that its "MyFord Touch" technology incorporates an "Eco-Route" option that maximizes efficient rates of speed. When tested in Europe by Ford engineers, they reported a 15 percent improvement in fuel economy (DOT 2011). These systems are especially beneficial for trucks, where the economic incentives and benefits should be larger than for personal automobiles (Shladover 2011). Particularly helpful and cost effective is information to drivers about non-recurrent traffic incidents and limited parking.

Savings

Reducing delay from congestion yields the majority of benefits from ATIS: faster travel, better trip planning, on-time delivery, and lower travel costs. Increasingly, ATIS is being vaunted for another benefit of reduced congestion: fuel savings. While it is not possible to calculate aggregate fuel savings from various permutations and regional application of different ATIS strategies, they are likely among the most cost-effective mechanisms for reducing the fuel wasted in congestion.

Barriers

Effective deployment of routing algorithms require more consistently available and integrated environmental data, information about alternative modes of transportation, and parking availability information. Traffic data is also currently incomplete and often inaccurate (DOT 2011). Building and distributing user-friendly ITS platforms, such as Google Traffic, will be most effective with the engagement of the private sector. The absence of open information standards across the country is a barrier to private sector initiatives. With open standards, a wide variety of actors can draw real-time information from various types of transportation infrastructure and sensors, and provide it to travelers in a format suited to individual devices and travel needs.

Advanced Transportation Management Systems

ATMS are used by transportation authorities to improve traffic flow and safety. This includes a wide array of technologies and software programs, which are ideally combined to yield synergistic gains. Key elements are optimized traffic signals, and incident detection and response technologies.

Smart traffic signals can significantly reduce idling time. Some intersection stoplights are already controlled by transportation authority computers, which program their cycles to respond to rush hour and other regular conditions. Adaptive signal control systems could adjust the lengths of red and green lights based on traffic conditions, and then co-ordinate the signals to maximize flow across a network—also called "retiming and synchronizing" lights (DOT 2011). For instance, if a long line of cars were waiting to turn left, the green left-arrow signal could automatically extend. According to one study, computerized co-ordination of traffic signal lights using real-time traffic data would decrease drivers' stops at red lights by 40 percent, reducing gasoline consumption by 10 percent (Staley & Moore 2009).

A broader application of ATMS with much larger benefits is integrated corridor management, where authorities manage the transportation corridor as a system rather than as a wholly autonomous set of individual assets. This can offer much more powerful opportunities to reduce delay and manage congestion by giving travelers more choice in their mode of travel and how long it will take, in real time.

Fully integrated ITS systems is a futuristic vision for linking all vehicles to infrastructure and to each other, enabling constant communication and automated responses to traffic signals and roadway conditions (Ezell 2010). While not available today, it is likely that such systems will be deployed in the not so distant future.

Savings

Improved signal timing is perhaps the most cost-effective ITS application today, as it reduces vehicle idling and stops. The most basic improvements yield a 15–20 percent delay reduction, and more advanced automated signal controls, which detect in which direction cars are waiting, can eliminate up to 40 percent of delay (Moore *et al.* 2010). A number of traffic signal co-ordination pilot projects have been highly effective; a program in Los Angeles, California achieved fuel savings of 13 percent, for example (DOT 2009a). A national study suggested that applying real-time traffic data could save 1.1 million gallons of gas a day nationally, cutting daily CO_2 emissions by 9,600 tonnes (Halsey III 2010).

Updating signal timing to achieve emissions gains of up to 22 percent costs less than $3,000 per intersection and yields a high return on investment: for each dollar spent on traffic signal co-ordination, $40 or more is earned in saved time and fuel (DOT 2011).

Integrating traveler information with incident management systems can reduce emissions an additional 3 percent and improve fuel economy by 1.5 percent (Birdsall 2010). According to the Federal Highway Administration, an incident management program in Georgia called NaviGAtor saved 5.2 million gallons of gasoline and 1.7 million gallons of diesel between May 2003 and April 2004 (URS 2006).

More generally, a literature review from the Information Technology and Innovation Foundation found that the overall benefit-cost ratio of systems operations technology is nine to one (URS 2006). This is far higher than capacity-expansion projects, particularly from the perspective of reduced travel delay and oil savings. A Tucson, Arizona study of 35 transportation technologies found that while they would require $72 million to deploy, the benefits would be $455 million annually, a 6.3 to one benefit-cost ratio (Ezell 2010).

Barriers

In recent years, the development of these technologies has been slow, largely due to low levels of investment, wasteful duplication of research efforts, and poor co-ordination in the development process. ITS technologies will not reach critical mass or the commercial application stage unless larger research, demonstration, and deployment projects are carried out, as opposed to small independent projects that collectively do not encompass a system. Current spending is just $110 million per year (DOT 2009b). Furthermore, in the past, ITS deployment resources have been entirely earmarked, preventing any sort of coherent national deployment strategy.

In general, quantitative data to analyze ITS effectiveness has been insufficient. The Department of Transportation's Research and Innovative Technology Administration ITS Joint Program Office has sought to fill this information gap through its Applications for the Environment: Real-time Information Synthesis (AERIS) research program, whose purpose is to produce environmentally relevant real-time transportation data and use it to "facilitate 'green' transportation choices".

Pay-As-You-Drive Auto Insurance

Vehicle insurance policies that more adequately reflect crash risk by pricing miles driven would provide meaningful oil savings. Pay-As-You-Drive (PAYD) insurance replaces flat annual premiums with premiums calculated on a per-mile basis, in addition to the standard risk factors, so higher-risk motorists pay more per mile than lower-risk drivers.

Accident risk increases with the vehicle miles traveled, so the current flat-rate system means that vehicle owners who drive fewer miles subsidize those who drive more miles than average. Thus there is actually an implicit incentive in existing insurance premiums to drive more.

Some companies, like Progressive, have already begun to offer this kind of product, and PAYD insurance is now offered in some form in most U.S. states. Given the extent to which auto insurance is already regulated, some experts have called for mandating that all major auto insurance providers offer a PAYD option. The program could be implemented either through installation of in-vehicle transponders or via odometer readings.

Savings

PAYD insurance is a mechanism for improving the efficiency of insurance by more closely aligning marginal cost with price. By increasing the per-mile cost of driving, PAYD insurance is expected to encourage price-sensitive drivers to avoid unnecessary miles. According to Todd Litman of the Victoria Transportation Policy Institute, a shift to PAYD insurance should reduce vehicles' average annual mileage by around 10 percent. Along with miles, fuel consumption is expected to fall by at least 10 percent. However, a Brookings Institution analysis found that it would reduce oil consumption by around 4 percent (Bordoff & Pascal 2008). According to Environment America, PAYD insurance could save 58 million barrels of oil per year by 2020 (Dutzik *et al.* 2011).

Additionally, the average driver will pay less for insurance under a PAYD policy (Bordoff & Pascal 2008). Since PAYD insurance would also reduce traffic crashes, congestion, and consumer costs, it has a very high benefit-cost ratio and is thus among the most attractive demand-side management policies available. It also helps to offset any rebound effect from policies to improve vehicle fuel efficiency (since switching to a hybrid lowers operating costs, the owner might drive more).

Barriers

The barriers to implementing PAYD as a voluntary option available to all drivers are not very high. Insurance companies would need to collect mileage data, which could be done by vehicle owners with random verification spot checks, or by electronic in-vehicle devices. Newer cars generally already have odometer data in the engine computer as well as GPS transponders, so data collection would require increasingly minimal costs. One current method used by at least two insurance companies is to transfer mileage data automatically when vehicles are refueled (Greenberg 2008).

A more significant policy issue is that since current vehicle insurance pricing overcharges motorists who drive their vehicles less than average within a certain vehicle class, while undercharging those who drive more, this latter group will oppose a shift to PAYD insurance.

Third, if PAYD insurance were indeed superior from an actuarial perspective, there must be an explanation why most insurance companies do not already offer it. Insurers face barriers to implementing PAYD, including the fact that if only one insurer switches to the program it can be costly to deploy an odometer auditing system. They also face regulators who make pricing innovation difficult. Finally, insurance companies would capture only a small fraction of the total social benefits, which include fewer crashes, greater equity, lower congestion, and reduced oil consumption. Most of the direct savings would be passed through to customers (TDM Encyclopedia 2011).

> **Advanced Transport Management Systems include a wide array of technologies and software programs, which are ideally combined to yield synergistic gains**

Bus Rapid Transit

Some transportation experts have argued that rather than continuing to invest the vast majority of our transportation tax dollars in more highways, we should instead be giving metropolitan areas greater flexibility to meet the needs of their growing and changing populations, with bike lanes, bus rapid transit (BRT) systems, and pedestrian improvements (Leinberger 2011). These are promising options that would expand, rather than constrain, people's transportation choice set.

Mass transit plays an important role in facilitating oil savings in some U.S. metropolitan areas. Because of the ubiquity of cars and the flexibility they provide drivers, public transit is more likely to have a positive return on investment where demand already exists, such as in dense metropolitan areas where people can live and work close to fixed bus and rail stops. In such locations, expanding transit capacity can improve quality of life and the economy while reducing per capita oil consumption. A 2008 study by ICF International found that transit reduces VMT by 102 billion each year, or 3.4 percent of total VMT in 2007. The gasoline equivalent to these annual VMT savings is 1.4 billion gallons. According to ICF International, when reduced congestion and changes in land use patterns are also taken into account, 4.2 billion gallons of gasoline per year are saved by transit (Bailey *et al.* 2008).

Public transit systems in the past have sometimes failed standard benefit-cost analyses. Fixed rail systems are inflexible to changing commuting patterns—typically away from the traditional hub-and-spoke model—that have occurred in many metropolitan areas over the last 20 years. They are also very costly and energy intensive to build and operate. Research suggests that perhaps the most cost-effective, near-term mechanism to reduce road transportation energy consumption is to improve bus systems, which offer much higher energy efficiency per passenger mile and the potential to pay for themselves in user fees and social benefits (Hensher 2007; Zargari & Khan 2003). Bus rapid transit can combine the reliability, right of way, and frequency of a rail transit system with the cost savings of a bus system (GAO 2001). BRT uses a combination of dedicated bus lanes, careful scheduling, and new vehicles to provide a higher-quality service than an ordinary bus line. The vehicles are high capacity (as many as 160 passengers) and often incorporate stations for off-vehicle vending, traffic signal adjustment to limit stops for red lights, and GPS systems that inform passengers when the next bus will arrive.

Other developments include the use of automatic fare machines (on- or off-bus) which can speed up the boarding process; bi-articulated or double-decker buses to increase capacity; boarding and fare collection improvements such as wider doors, low floors, and electronic passes; and electronic drivetrain control to improve ride smoothness. BRT systems do not require immediate network-wide implementation. The fact that capacity can be phased in over time makes them fundamentally more flexible than other modes of urban transit.

> Because of the ubiquity of cars, public transit is more likely to have a positive return on investment where demand already exists, such as in dense metropolitan areas

BRT systems were first implemented abroad, but a number of American cities—including Cleveland, Charlotte, Miami, Los Angeles, Boston, and Portland—sport partial BRT services that operate alongside traditional bus and transit systems. The main differentiating feature of BRT is its use of dedicated lanes with bus-only right of way. This enables BRT networks to provide greater service speed in comparison to traditional urban bus services and deliver more passenger miles with the same number of vehicles, personnel, and quantity of fuel. The dedicated rights of way permit faster speeds and have been found to reduce travel times by between 17–29 percent (Peak *et al.* 2005).

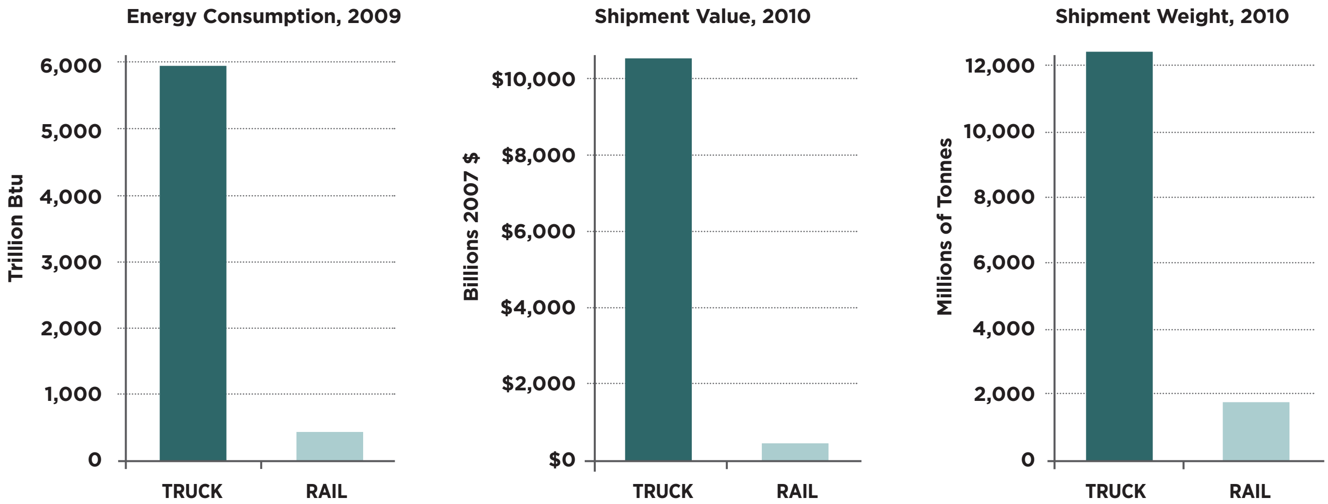
A survey of BRT systems suggest they are more appealing as a transit alternative to drivers than other forms of transit and that they have thus far been effective in increasing transit ridership. For example, the Las Vegas RTC "MAX" system resulted in a 35–40 percent increase in transit ridership along its bus corridor. By switching regular bus routes to BRT lines, transit authorities in Boston, Los Angeles, and elsewhere have reported transit ridership increases ranging from 27 percent to 84 percent (DOT 2005). These users have switched from personal automobiles, reducing oil consumption.

Savings

As with automobiles, there are large potential efficiency gains within the standard model—for example, since buses in cities tend to have a slow, stop-and-go duty cycle, hybridization can be cost effective. NREL conducted an experimental deployment of alternative fuel buses in New York City between 1998 and 2005. In 2006, they reported that over the previous two years, hybrid buses showed an average fuel economy 45 percent higher than the diesel baseline (Barnitt & Chandler 2006).

A 2011 cost-benefit analysis of converting an arterial traffic lane into a bus-only BRT system found that with a 3 percent discount rate, the hypothetical BRT produced a positive net benefit if the daily number of people using the system is between 30,000 and 50,000. The optimal corridors for implementing a bus-only lane are those with relatively high volume and pre-project transit mode share of at least 15 percent (Transportation Research Board 2011). However, BRT is inexpensive compared to other traditional mass transit options. According to the Government Accountability Office (GAO), when compared on a cost-per-mile basis, capital costs—planning, design and construction—for BRT projects were less than half of those for light rail (GAO 2011).

Figure 16: Truck and Rail Freight Comparison



Source: FHWA, 2011.

Though the overall cost-benefit results may be ambiguous, the energy savings from BRT are not. A 2005 study conducted by California transit agencies calculated the potential environmental benefits and energy savings for a typical 40-mile BRT corridor based on Los Angeles "Metro Rapid" BRT demonstration data (DOT 2005). The agencies looked at the growth in bus passenger miles along the corridor before and after the establishment of BRT service, and then calculated the extra energy used if all of those passenger miles were instead taken by personal automobile (according to the average distribution of number of occupants per private vehicle). They found that BRT cut annual emissions by 70 percent and 74 percent, using ultra-low-diesel sulfur buses and CNG buses respectively. These reductions equate to roughly 970,000 gallons of gasoline equivalent annually.

The authors suggest that if 200 similar 40-mile BRT corridors were established by 2020, annual fuel savings could be around 200 million gallons of gasoline equivalent. They conclude that BRT may be "among the top 15 options for reducing national consumption of petroleum-based fuels and one of the most cost-effective and easily implemented options from a public investment and policy perspective" (DOT 2005).

Barriers

To maximize efficiency, BRT requires a lane exclusively for bus use, entailing either the build-out of a new lane or the conversion of a mixed-flow arterial lane to dedicated BRT use. Both options will be controversial and potentially difficult. In many urban areas there simply isn't room for a new lane, and converting a lane will negatively impact drivers, because there might be significant increases in transit time. Additionally, the benefits of BRT accrue over decades, while much of the cost must be borne initially. In a constrained public finance environment, such capital investments may be difficult to achieve.

Freight Rail

Today the United States' complex, multimodal freight transport network moves more than 50 million tonnes of freight valued at $36 billion dollars each day (Federal Highway Administration 2008a). Whether a certain mode—truck, ship, or rail—or combination thereof will be most economic depends on the length and location of transport. Some goods, such as perishable food or express mail, must travel by truck. However, the way transportation infrastructure is funded has resulted in the subsidy and consequent expansion of trucking at the expense of rail.

Over the past few decades, taxpayer-funded highway infrastructure has enabled the growth of trucking. Some transportation experts suggest that at the same time complex permitting has made private sector railroad expansion more difficult. To the extent that this is true, it is problematic from an oil-dependence perspective because freight trains achieve on average 400 tonne-miles per gallon of diesel fuel, whereas trucks average approximately 130 tonne-miles per gallon (RMI 2009a). That is, a train can move as many containers as 280 trucks while using one-third as much energy.

In the 1970s, a shift away from rail and toward freight trucking occurred. This happened for a number of reasons, including the continued heavy government subsidy of highways, while railroads built their own tracks. The total number of trucks increased 71 percent between 1980 and 2000, and truck VMT increased 115 percent (FHWA 2008a), see Figure 16. The market has also increasingly demanded just-in-time delivery, which in some cases means trucks that are only partially filled. This is one reason why the energy intensity of large trucks has increased since 1990 (BTS 2010). Between 1985 and 2005, 131,723 miles of roads were built (Longman 2009).

Meanwhile, railroads improved their efficiency and reduced the excess capacity that had been built up over the previous century. Class 1 freight railroad track mileage dropped dramatically from 271,000 miles in 1980 to 162,000 miles in 2006, but improved logistics, load factors, and efficiency permitted freight rail tonne-miles to increase by 93 percent over the same period (AAR 2007). Alongside these gains, rail freight energy intensity was halved between the 1970s and 2010 (Davis *et al.* 2010), see Table 3.

Table 3: Freight Energy Intensity, 2009

Truck (Btu per vehicle mile)	21,127
Rail (Btu per freight car mile)	13,907
Rail (Btu per tonne-mile)	291
Truck (Btu per tonne-mile if vehicle weighs 40 tonnes)	528

Source: FHWA, 2011.

The federal gross weight limit for a Class 8 (combination tractor-trailer) truck is 40 tonnes. Most of the trucks in the first row of Table 3 above would weigh far less than this, but the fourth row shows the amount of energy that trucks would use per tonne-mile if all trucks weighed the absolute maximum possible. Even with this high assumption, rail still uses about half the energy to transport a tonne of freight one mile.

Electrifying and Improving Rail

The vast majority of American locomotives today employ a main diesel engine, which generates alternating current (AC) electric power via an alternator. This is converted into direct current (DC) power by a solid-state rectifier, which supplies power to traction motor controls and thence to traction motors mounted on the trucks (ICF International 2009). Railroads achieved a 21.5 percent improvement between 1990 and 2006 in gallons of fuel consumed per 1,000 revenue tonne-miles (a single tonne of goods transported for one mile), chiefly through better diesel engines (including low-emission models to meet new EPA standards), AC traction systems, development of higher-horsepower engines, and the adoption of electronic controls.

There is broad consensus that there are further gains to be had, most importantly in the power system. Incremental changes include deploying lighter-weight cars, expanding car double-stacking, covering empty cars to improve aerodynamics, steerable or radial rail car trucks that lower rolling resistance, and electronically controlled pneumatic brakes that enable simultaneous brake application and release on all cars in a train. A 2010 DOT study found that together, lightweight cars, aerodynamic improvements, and wheel/rail lubrication could offer 18–24 percent fuel savings (DOT 2010). Expanding use of AC current to a larger proportion of the fleet would reduce electricity loses and permit lower horsepower. Another area to explore is switching to alternative fuels, such as biodiesel and liquefied natural gas. Finally, expanding capacity to reduce the congestion that currently generates inefficient idling and stop-and-go travel would improve fuel efficiency.

The biggest gains can be found by tackling the power system. One already-deployed technology is the Genset locomotive, which has two to three independent diesel-alternator sets, only one of which is running at all times for basic functions. The others are used only when full power is needed, which for locomotives is only intermittently and for fairly short lengths of time. The Genset also uses advanced computer technology to more precisely control the engines to maximize efficiency. First delivered in 2005, there are hundreds in service and they provide fuel savings of around 20 percent.

Today, much of the world's freight rail is electrified, unlike the diesel-dominated market in the U.S. Advocates for electrifying rail point out that not only are electric locomotives completely delinked from oil, they are also more powerful, faster, easier to maintain, and more efficient because they do not have to carry the weight of their own fuel. In addition to eliminating oil consumption, electrifying rail would exchange 2.6–3 Btu of diesel fuel for one BTU of electricity. According to an advocate for rail electrification, it would only require about 1 percent of current total U.S. electricity generation to electrify 80 percent of existing railroad tonne-miles and transfer half of current truck freight to rail (Drake 2008).

Electrifying freight railroads would require building high-voltage transmission lines along right of ways, as Amtrak has done in the Northeast Corridor. This would be costly, but also represents an opportunity to begin building a more advanced transmission grid that enables greater use of renewable energy. The railroads themselves would be an obvious market for renewable energy, since railroad right of way corridors could be an excellent place for long lines of wind turbines. The trains would be an immediate market for the electricity, "not in my backyard" issues would likely be much less problematic, and the high-voltage lines along the railroad would connect to main lines and the grid. Wind turbine construction might be easier and cheaper if the turbines were brought in on rail cars—one of the challenges in building the most powerful wind turbines is that their size makes trucking them in complicated and costly.

Savings

The EPA has suggested that between 2010 and 2030 it is possible to reduce GHG emission rates by 15 percent from grid-capable hybrid locomotives, if phased in during 2015–2016. Targeted rail segment electrification, phased in between 2020 and 2029, could yield a further 10 percent reduction; railcar improvements and operational measures (e.g. track lubrication, improved bearings and brakes, optimized logistics, and increased double-stacking), phased in between 2015 and 2029, could provide a further 15 percent (EPA 2010b). A Pew 2011 report concluded that it is possible to reduced rail energy intensity by 15–30 percent by 2030 and 20–40 percent by 2050 through more efficient locomotives, greater use of regenerative braking, reductions in the empty weight of rolling stock, and improved operations (Greene & Plotkin 2011).

For locomotives tasked with yard operations, which involve a stop-and-go duty cycle, hybrids and Gensets are cost effective today. For example, the non-discounted payback period of a yard locomotive converted to have a hybrid or Genset power system would be between five and 10 years (DOT 2010), see Table 4.

Barriers

The primary barrier to deploying existing technology is capital cost. According to Genesee and Wyoming, a railroad company, a new Genset locomotive is around six times more expensive than the cost of a traditional diesel locomotive. Genesee and Wyoming has come up with an innovative solution: it is building its own Genset locomotives using older locomotives and off-the-shelf new components, reducing costs by 30–40 percent and enabling an economically viable public–private partnership. While this may change, Gensets and hybrids are currently too expensive for Class 1 line-haul (long-distance) railroads to purchase without government financial support (DOT 2010).

Table 4: Rail Fuel Economy Strategies (Non-Additive)

Technology	Per-Vehicle GHG Reduction Potential Range
Genset Engines	35–50%
Hybrid Yard Engines	35–57%
Hybrid Line-Haul Operations	10–15%
Lightweight Railcars	5–10%
Aerodynamics	> 10%
Wheel/Rail Lubrication	4–6%
Improving Load Configuration for Intermodal Trains	Up to 27%

Source: DOT, 2010.

A second important barrier is the long turnover time of the locomotive fleet—a typical lifespan for a locomotive is usually 30–40 years, with overhauls every 600,000 to 1,000,000 miles. There are about 24,000 locomotives in operation and only 900 new ones are manufactured every year, so without accelerated replacement, it would take more than 25 years to replace the current fleet with more efficient alternatives (DOT 2010).

The implementation of some technologies has been delayed by industry structure, such as in the case of electronically controlled pneumatic (ECP) brakes. All the cars in a train must have the ECP brake equipment, but this is only possible when all the cars have the same owner (often the cars in a train have various owners).

Another barrier to further efficiency gains through vehicle technology improvements is increasing congestion, which has reduced average train speed due to idling and extra stops and starts. As of 2009, congestion is increasing annually by 2–4 percent (ICF International 2009). Improved logistics, communications, and ultimately capacity expansion may be needed to complement technological deployment.

Advocates for electrifying rail point out that not only are electric locomotives completely delinked from oil, they are more powerful, faster, easier to maintain and more efficient

Market-Based Policies

Myriad market failures in the energy sector motivate government involvement. These market failures range from the natural monopoly of the electric transmission grid to the pollution costs to society of internal combustion engines. Unfortunately, the U.S. government has too often tried to rectify these failures by "picking winners" in energy technology, often for periods of time too brief to generate serious private sector engagement.

When public energy policy works, it typically is performance-based, flexible, and consistent over time. Good policy levels the playing field for entrepreneurs, and regulation that imposes performance standards has worked in the past—CAFE and other tailpipe emissions standards have drastically reduced pollution in the U.S., motivating automakers to find smart, cheap ways to improve engine combustion, like the catalytic converter. But recent debates and delays making energy policy in Washington, D.C. have served to increase risk and uncertainty for the private sector. Instead, the best role for government in energy markets is to be a force for stability, mitigating risk and offering long-term rules of the game to drive the direction of innovation.

The policy opportunities described below would help to level the playing field for new technologies and business models that can achieve meaningful near-term reductions in oil consumption. They seek to correct the private sector's failure to adequately price the externalities of petroleum in ways that leverage the private sector's ability to innovate and efficiently allocate resources.

OPEN FUEL STANDARDS

One mechanism that has been proposed to level the playing field for alternative fuels is an open fuel standard requiring a certain fraction of all vehicle models sold in the U.S. to be able to run on either an oil alternative or on a blend of fuels. Such blends might include ethanol and methanol in varying blends with gasoline, ranging all the way up to pure ethanol or a pure ethanol-methanol blend. Natural gas vehicles, electric vehicles, and hydrogen-powered vehicles would also qualify.

There are obviously challenges to this policy, and in the near term it would probably favor alcohol-based fuels. It is not clear that alcohol-based fuels are necessarily the best choice when compared to drop-in biofuels that have the same energy density and molecular composition as petroleum products. An argument for an open fuel standard is that drop-in biofuels are just beginning to be commercialized, whereas ethanol and methanol are mature technologies that can reach scale in the near term. Though much less energy dense than gasoline (a tank filled with an ethanol-methanol mixture will have to be filled up to twice as often), these fuels can probably compete on an energy-equivalent price basis with gasoline.

An open fuel standard would need to complement and reinforce efficiency and emissions goals, not undermine them. It would also have to be carefully designed so as not to simply favor one or two new liquid fuels and bar entry to the rest. EVs, NGVs, and vehicles that run on biodiesel or hydrogen should also count towards an automaker's quota. Within a relatively short time, all new vehicles could potentially be completely flex-fuel or powered by an alternative energy source. The former is relatively cheap; recall that the additional cost of building a car to run on ethanol or methanol—altering the fuel sensor and making the fuel line corrosion resistant—is currently around $100. The latter would likely occur in smaller quantities, at least initially.

An open fuel standard could also include a provision incentivizing the retrofitting of existing vehicles to run on alternative fuels. For specific fuels, like methanol, the government could work with private sector players to develop protocols and standards for converting vehicles in the current fleet to run, for example, on high-methanol concentration fuels. Support for an open fuel standard is increasing in both parties, particularly now that both the blending subsidy and the import tariff expired at the end of 2011. The blending subsidy was a tax expenditure that increased the federal deficit, was not performance based, and "picked a winner".

> The best role for government in energy markets is to be a force for stability, mitigating risk and offering long-term rules of the game to drive the direction of innovation

Complex trade-offs are the rule in energy decisions. With great uncertainty about the future pace of technological change, commodity prices, and environmental impacts, it is very difficult to identify the "right" alternative to gasoline and diesel. The downside to an open fuel standard is that if drop-in biofuels are actually the most promising alternative, investment in alcohol-based fuels may be a poor allocation of resources. Drop-in biofuels closely resemble today's fuels and are compatible with today's infrastructure and thus do not require flex-fuel vehicles. Unlike ethanol, their feedstocks will likely be biomass, such as forest residue, not primary food crops that require a great deal of water and other resources. If sustainable drop-in biofuels can be quickly scaled, our rich resources of natural gas may be better used in the power sector rather than for methanol.

ALTERNATIVE FUEL INFRASTRUCTURE

Perhaps more important than working with automakers to ensure vehicles are compatible with alternative fuels is transforming gas stations into multi-fuel vendors, as they are in Brazil. There are about 162,000 fueling stations selling gasoline in the U.S. and among them there are around 2,500 ethanol fuel pumps. These are mostly concentrated in a few Midwest states, where the lion's share of ethanol is produced. Additionally, there are around 6,700 public EV charging stations and 988 CNG fueling stations (DOE 2012).

E85 and biodiesel require only slightly modified versions of the pumps currently used for self-service gasoline and diesel. Self-service pumps exist to handle pressurized gases and fuels, specifically CNG, hydrogen, and LNG. Estimates of the cost to install blender pumps, which can dispense either ethanol or gasoline with two fueling positions, vary depending on whether current gasoline pumps are modified or replaced, and whether new underground storage tanks need to be modified or installed. A standard conventional fuel pump costs about $14,000 and an E85 dispenser costs around $23,000 (USDA 2010).

Converting a standard pump to a blender pump would cost around $11,775 (USDA 2010). Meanwhile, combining a new E85 pump with a new underground storage tank costs around $122,000 according to the EPA, but an NREL survey in 2008 found that the median cost to install a new tank was only $59,000 (USDA 2010). In a report on meeting RFS standards, the USDA concluded that given the widely varying installation costs, support programs must be flexible (USDA 2010).

It may require government intervention to ensure that gas stations can install alternative fuel infrastructure without risking losing their access to gasoline and diesel. The government can also help to establish refueling infrastructure standards and identify compatibility protocols. For example, many existing tanks are compatible with E85 once cleaned (DOE 2011d).

The combination of a flexible, performance-based open fuel standard and a requirement that gasoline stations install alternative fuel pumps or charging stations (likely with government financial support) suggests the possibility of an open market for alternatives in which ecosystems of infrastructure supporting certain technologies would likely wind up geographically localized. Methanol- and natural gas-powered vehicles could be concentrated where natural gas is plentiful, in the south and east, while electric vehicle ecosystems might arise in the Pacific Northwest, and E85 might reign supreme in the Midwest. Indeed, the majority of FFVs are located in the Midwest, though there are also counties with high concentrations (near 10 percent) in Texas (USDA 2010).

> By rewarding both efficiency and alternative fuels, a feebate could help Americans exploit available, cost-effective technologies

FEEBATE FOR VEHICLE SALES

A more thoroughly technology-neutral policy is a feebate that reduces the price of more efficient and alternative fuel vehicles and raises the price of less efficient vehicles. A feebate would impose a time-of-sale surcharge on vehicles whose fuel consumption per mile is below a certain pivot point and grant a time-of-sale rebate to purchasers of vehicles with mileage ratings above the pivot. Both the "fee" and the "bate" would be graduated, with higher values further from the pivot.

Feebates, which are essentially a combined tax and subsidy, can be revenue neutral. A feebate may be more politically tractable than other instruments, the gasoline tax in particular.

By rewarding both efficiency and alternative fuels, a feebate could help Americans exploit the available, cost-effective technologies that can make the gasoline-fueled ICE vastly more efficient. A feebate program could also reward alternative fuel vehicles. If enacted in isolation, however, a feebate should not treat flex-fuel vehicles as though they are alternatively fueled because without mandated E85 pumps a flex-fuel vehicle simply runs on gasoline.

The metric for determining a vehicle's fuel efficiency should not be miles-per-gallon-equivalent (mpg-e), but rather proportional to fuel consumption per mile. This is because incentives should be constant for every gallon of fuel that is saved, regardless of whether that gallon is saved in a small vehicle or a large one. That is, we do not want to give disproportionately small subsidies to low-mpg vehicles where there is the greatest opportunity for fuel economy improvement. As discussed above, fuel economy improvements measured in mpg are nonlinear, because gallons per mile are not the same as miles per gallon. Upgrading from a 10 mpg car to a 20 mpg vehicle will save more for the same miles traveled than to upgrade a 20 mpg car to a 40 mpg vehicle.

INNOVATIVE FINANCING

In what has often been dubbed the energy technology financing "valley of death", there is a clear dearth of credit for innovative clean energy technologies that have been proven in the lab but that require between $100–300 million for the first commercial-scale plant. These first-of-a-kind commercial plants are typically too large for many venture capital firms, but large banks, pension funds, and private equity firms are unfamiliar with the clean tech sector and unwilling to try to price the technology performance risk.

In general, financing clean energy projects is challenging because they tend to be capital intensive and have long lead times (it takes years for investors to realize a return on investment). They typically do not have the very high private returns that normally justify illiquid, expensive projects, even though their social expected returns, which include innovation spillovers, could be very high. One of the most market-friendly and least intrusive ways that the federal government can support new energy technologies is to use its large access to credit to support any project in a certain class, so that the private sector will choose which projects are closest to commercial viability.

Loan guarantees, grants and other programs run by the Department of Agriculture and the Department of Energy have played an important role in clean energy innovation and development over the last few years, particularly due to the surge in funding in the American Recovery and Reinvestment Act of 2009.

However, many of these programs (especially the loan guarantee program) have led to the government spending a great deal of time and resources in order to pick certain projects and negotiate terms with companies. The loans and grants are typically awarded in advance, with only a tentative project timeline. None of the advanced biofuel projects awarded funding in 2008 and after have actually commenced operations.

Subsidy programs that have worked are typically technology neutral, like the 1603 Program, which offered grants in lieu of tax credits for qualifying energy properties between 2009 and 2011. The grants reimbursed eligible projects for the cost of installation and the payment was made after the project entered into service, not during construction. Thus the onus to start up was on the companies, mitigating an important principal-agent problem present in other programs. The 5,197 projects that utilized the credit prove the success of the 1603 Program. Yet nearly all were in electricity—4,469 were for solar power and 525 were for wind (Department of the Treasury 2012). A program like 1603 that was bigger and aimed at technologies that displaced oil might be very successful. Under an expanded version of 1603, any plant producing alternatives to oil would qualify. The grant could increase proportionately to the percentage reduction in lifecycle GHG emissions compared with the petroleum product displaced.

> One of the most market-friendly ways the federal government can support new energy technologies is to use its large access to credit to support any project in a certain class

Another successful program is the tax credit for advanced energy manufacturing projects, often called the "48C" due to its section in the tax code. Like 1603, this tax credit is technology neutral. Nearly two-thirds of qualified applicants have been unable to benefit from the credit, however, because it has quickly reached its $2.3 billion limit. The 48C tax credit could be expanded and extended, and even focused primarily on clean energy technologies that reduce oil consumption in transportation. Removing tax loopholes for the energy industry at large could fund it and it has the co-benefit of promoting domestic manufacturing.

Tax credits offer the powerful advantage of being easy to administer while also being relatively simple to make technology neutral. Tax credits have been actively used in recent years to promote clean energy, particularly wind and solar, but one problem with them is that the renewable energy sector does not have much tax liability and thus has difficulty taking advantage of them. There is a very small pool of what is called "tax equity" or third parties with a lot of tax liability that are willing to buy the tax credit from the small clean energy project. The result is an added cost of around 7 percent to the taxpayer to provide tax credits for renewable projects, which goes to large banks. A major advantage of 1603 was that it did not require the complex and costly financing arrangement of tax equity players.

A different avenue that would not require tax expenditure is to permit renewable energy projects access to the Master Limited Partnership (MLP) business organizational form. An MLP is a publicly traded partnership, or an LLC that employs partnership taxation and trades on an exchange or over the counter. MLPs must derive more than 90 percent of their income from a few clearly defined categories, which mostly involve the transportation of fossil fuels. MLPs typically have thousands of shareholders, called "unit holders", that only pay income taxes on MLP income. This tax treatment is favorable when compared to C corporations—corporations that, under U.S. federal income tax law, are taxed separately from their owners—meaning that MLPs are able to secure lower-cost capital and access a large pool of capital at the same time: precisely what is needed for alternative fuel projects.

The tax-favored MLP status was established in the 1970s in order to encourage oil and gas investment following the energy crisis. As of 2012, 45 percent of MLPs were in oil and gas midstream, 12 percent in oil and gas exploration and production, and a further 19 percent in other fossil fuel industry segments (NAPTP 2012). MLPs have been a high-growth investment vehicle over the past decades, increasing in number by a factor of 10 since 1994, with over $100 billion in capital (Freed & Stevens 2011). In 2008, Congress expanded qualifying income to the storage and transportation of ethanol and biodiesel. Extending this provision to the manufacturing and sale of alternative vehicle fuel, and also extending it to cover all alternative vehicle fuels, could greatly increase the ability of projects like drop-in biofuel refineries to access capital.

A downside is that if the projects would have gone ahead anyway as corporations, MLP status narrows the tax base. Additionally, there have been concerns that alternative fuel MLPs could act as tax shelters.

Many successful energy programs have occurred at state level in the past decade. But in the current tight budget environment it is proving harder for states to support energy projects. Currently, state and local governments are permitted to issue tax-exempt bonds only to fund certain types of public goods, such as airports and solid waste facilities (Coalition for Green Capital 2010). Expanding this to clean energy infrastructure could provide impetus for supporting alternatives to oil upstream and downstream. States and localities could be given maximum flexibility to build what they deem best for the community, whether that means providing funding for methanol pumps at gas stations or a waste-to-energy drop-in biofuel plant. The bonds would simply be subject to certain performance requirements—providing alternative vehicle fuel or distribution infrastructure that is cleaner than gasoline and diesel.

One option might be to make the Qualified Energy Conservation Bonds, which Congress established in 2008, available to alternative fuel transportation projects. These bonds, which are available to city and county governments to pay for energy conservation or renewable electricity investments, have largely gone unused. As of May 2012, only about 20 percent of the $3.2 billion available for bonds has been issued (Cardwell 2012). These bonds should be targeted to investments that reduce oil consumption, for instance, by purchasing natural gas buses, and not just used for conservation and renewable energy.

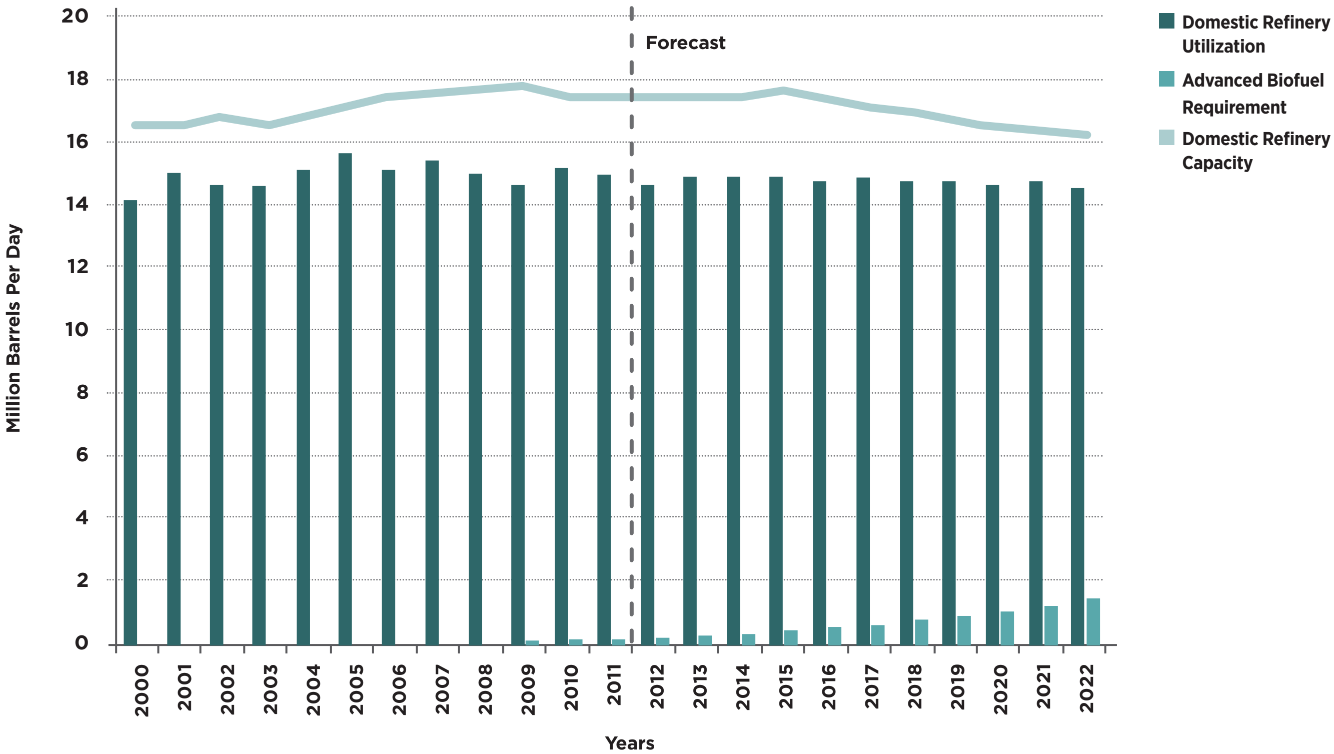
The federal government can also help to organize innovative business models for overcoming market barriers in the area of energy storage for utilities and vehicle batteries. The automotive and power sectors today are very separate, but in the future could have important intersections. One of the most significant barriers to electric vehicle deployment is the high upfront cost to purchase the battery. By comparison, gasoline ICEs are cheap to buy but expensive to operate. While an EV's operating costs are essentially negligible at current electricity prices, the cost of the battery on a pure BEV can be upwards of $15,000, though this is expected to decrease dramatically once there is a clear market for EVs. So while the payback period on an EV may make it economically viable for a forward-looking customer, many vehicle buyers are hesitant to pay more for a car, since it can be difficult to be fully informed about the benefits of very low, stable operating costs.

Yet after the battery has exhausted its useful life in a vehicle, it holds significant value either as stationary energy storage or for recycling. Indeed, as wind and solar electricity make up increasing portions of utilities' generation portfolios, they are expected to need to purchase stationary storage. There may be a business model in which utilities actually own the batteries for their entire life and lease them to consumers, but this model would take time to develop.

For now, auto consumers cannot currently monetize this expected value in advance and thus must assume the full cost of production. The government could remove some of the risk by offering a guaranteed price for used EV batteries. During the early period of EV deployment, the government could commit to buying used batteries and then sell them to utilities or to recyclers. Since this would incentivize all EVs, not just specific companies building specific plants, this sort of policy would be a fairly non-distortionary way to support EV deployment.

States and localities could be given flexibility to build what they deem best for the community, whether that's methanol pumps or a waste-to-energy drop-in biofuel plant

Figure 17: U.S. Domestic Refinery Distillation Capacity, Utilization, and the Advanced Biofuel Requirement



Source: EIA, 2012c; EIA, 2011d.

ADVANCED BIOFUEL FINANCIAL AND PERMITTING SUPPORT

The revised National RFS program, as laid out in 2007 legislation, is very ambitious. Responding to criticisms of the questionable GHG advantages of ethanol, the EPA established mandatory emissions thresholds to determine whether a fuel can be categorized as one of four types of renewable fuels. Compared to the baseline GHG emissions for gasoline or diesel in 2005, any renewable fuel produced at a post-2007 plant must have at least a 20 percent reduction in lifecycle GHG emissions. The EPA later determined that when corn ethanol is produced at a natural gas-fired facility it complies with the 20 percent reduction requirement (EPA 2010c). Lifecycle GHG emissions must be 50 percent lower to qualify as an advanced biofuel and 60 percent lower to qualify as a cellulosic biofuel.

The RFS calls for 36 billion gallons of biofuel to be supplied by 2022, 21 billion of which is supposed to come from advanced biofuel (EPA 2012a). 527 new bio-refineries need to be built to meet these new RFS standards, at a cost of $168 billion, assuming an average bio-refinery size of 40 million gallons (USDA 2010). Thus far, the industry has not been able to meet federal targets. The requirement for cellulosic ethanol in 2010 was 100 million gallons, but output was nearly zero. The 2011 target of 250 million gallons was waived and replaced with 6 million gallons (or 0.0003 percent of total fuel demand), increasing to 13 million gallons for 2012 (Molchanov 2011).

While a number of plants will come online in the next couple of years, greater financial and permitting support for this capital-intensive industry is needed in order to compete with established oil refineries, many of which have been in operation for the better part of a century. Thus the government could follow Brazil's lead, imposing a suite of policies that both make the RFS requirements truly obligatory and also give industry the necessary tools to meet them.

An alternative approach to building new bio-refineries is to employ oil refineries for producing drop-in biofuels. As shown in Figure 17 below, the U.S. has excess refining capacity and this is likely to continue to be the case unless there are more refinery closures. Refiners such as Tesoro have pointed out that while the refining industry traditionally viewed renewable fuels as a competitive threat and an added cost, today a new perspective presents biofuel as a potential growth market for refiners and an opportunity to produce transportation fuel from lower-cost feedstock (Weyen 2012).

It may be possible to use the existing petroleum refining industry's infrastructure to make drop-in biofuel production much cheaper and more streamlined. Biomass can be converted to the equivalent of "crude oil".

A policy change that might facilitate more such leveraging of existing refinery capacity is to treat co-processed renewable fuel in the same way as other advanced biofuels. In particular, Tesoro has suggested that current subsidies and tax credits give pure biodiesel plants a $2-per-gallon advantage compared to co-processing. They suggest that the reinstated biodiesel blender's tax credit should also apply to co-processed renewable diesel (Weyen 2012).

EFFICIENCY AND TECHNOLOGY STANDARDS

CAFE Standards

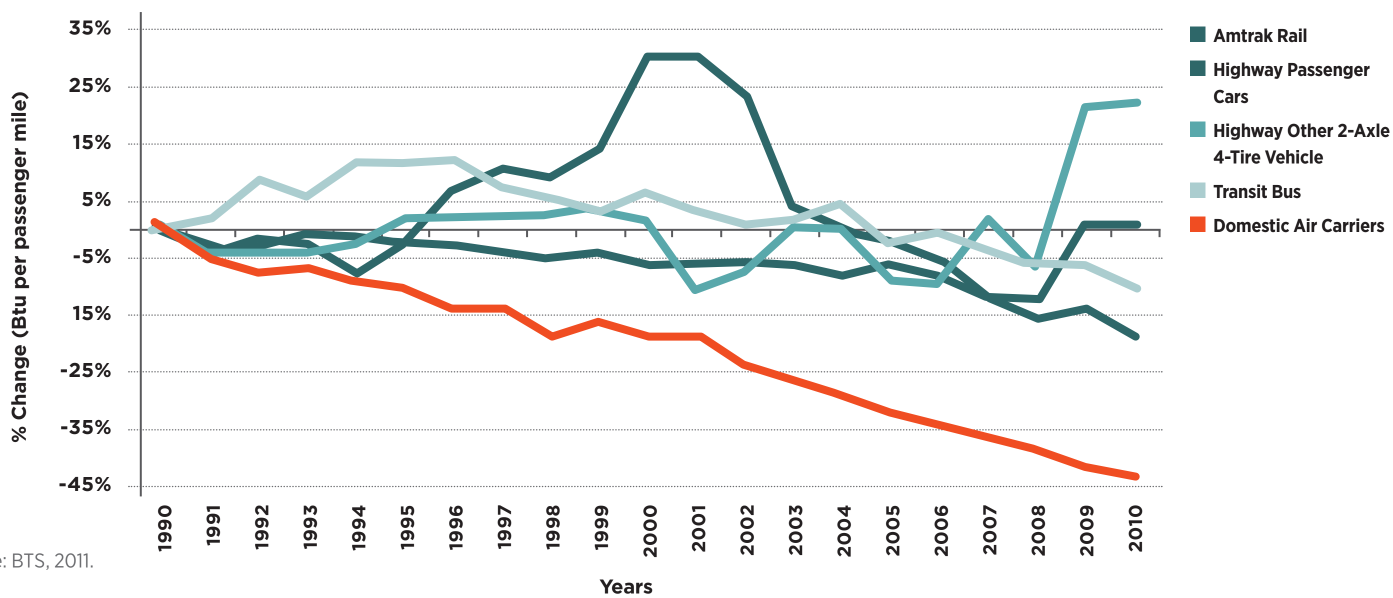
Stagnant U.S. fuel economy standards in recent decades caused our vehicle fleet and auto manufacturers to fall far behind the rest of the world in terms of efficiency. With more rigorous standards, would have been possible to have achieved today's levels of safety, power, and comfort without sending so much money overseas to oil-exporting countries. As seen in Figure 18 below, highway vehicles have lagged behind other sectors in reducing the energy used per passenger mile due to different profit incentives and business models across transport modes.

The Bush administration's 2007 higher fuel economy standards and the added stringency imposed in 2011 by the Obama administration will help to close the gap. However, the U.S. is still far behind its competitors, see Figure 19.

It is also not clear how well U.S. fuel economy standards are adapted to electric and alternative fuel vehicles. They should account for upstream emissions and should avoid giving credits to vehicles that are capable of running on alternative fuels but in practice may not.

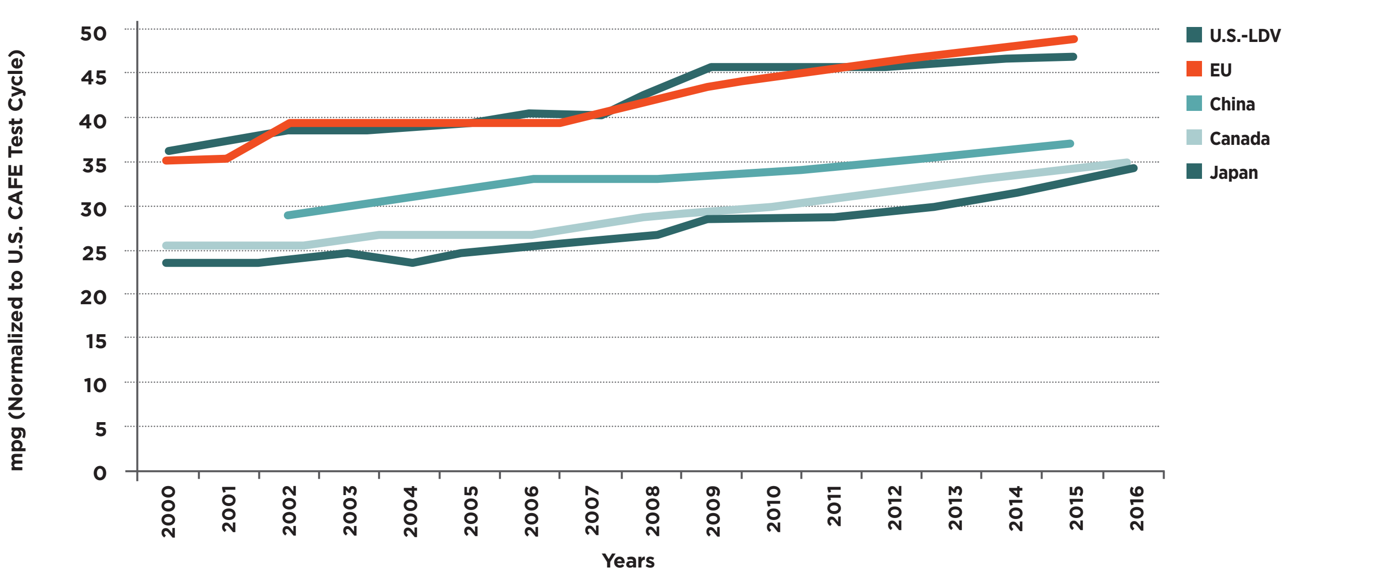
An increase on standards on a mileage-equivalent basis has been proposed—for example, enacting a 100 mpg-e standard for 2030, which would provide a certain and strong motivation for a radical transformation of the fleet (RMI 2009b). See Figure 19.

Figure 18: Change in Energy Intensity of Passenger Modes, 1990–2008



Source: BTS, 2011.

Figure 19: New Light Duty Vehicle Fuel Economy Enacted Standards by Country



PICTURE: MARIO SANTORO-WOITH. WWW.SANTORO-WOITH.COM

Energy-Efficient Tires

One relatively simply policy is to require future replacement tires to be energy efficient, with low rolling resistance. While new cars are often equipped with energy-efficient tires in order to help manufacturers meet CAFE standards, there is limited availability of energy-efficient replacement tires. It is possible to require replacement tires to meet stringent efficiency standards without any impact on vehicle safety (Dutzik *et al.* 2011). A similar policy could apply to truck tires, with incentives or mandates for trucks to switch from traditional double-wide tires to more energy-efficient wide-gauge single tires.

Focus on Freight

Beyond tires, there are certain freight-specific policies that the government could employ to target freight efficiency. Some relate to transportation infrastructure—simply improving the intermodal connections between highways, ports, and freight rail could meaningfully reduce transport costs for goods, contributing to the nation's economic growth while reducing freight-related fuel consumption.

Similarly, fleet operators can be incentivized to reduce fuel consumption. For example, the government could subsidize retrofitting Class 8 trucks with oil-efficient or oil-independent engines, such as mild hybrids or CNG engines. It could also provide financing support for technologies like battery-powered cabs so that truckers can sleep in a climate-controlled cab without the engine running.

Government programs like SmartWay could be expanded to encourage driver-training programs in fuel efficiency and greater awareness among fleet operators and owners about the payback periods of certain technologies. Permitting trucks to carry more weight is another rapid way to increase efficiency. Though the impacts of road wear and tear, as well as safety, need to be addressed, there have been proposals to raise the interstate gross vehicle weight rating by 50 percent (RMI 2009b).

GAS TAX

The most technology-neutral and economically efficient way to reduce oil in transportation is to raise the fuel tax. Gasoline taxes do not need to be revenue-raising taxes; indeed, a fuel tax that is remitted lump sum to all Americans need not even be called a tax. It could be considered a market failure-mitigating redistribution, incentivizing the substitution of imported oil with alternative domestic fuels and greater efficiency. In addition to its security benefits, from an economic perspective the presence of the rebound effect, combined with gradual fleet turnover, means that fuel taxation is far less costly than fuel economy standards (Anderson *et al.* 2010).

A further argument for raising the tax in the near term is that its real value has declined by more than 33 percent since it was last raised in 1993 (National Surface Transportation Infrastructure Financing Commission 2009). If the price of gasoline and diesel more accurately reflect their true costs, consumers and firms could make their own decisions about whether to switch to a different technology or buy a more efficient vehicle. Norway, the world's seventh largest oil exporter, currently has gasoline prices above $9 per gallon. In Germany, premium gasoline costs $8.56. Brazil, a major oil producer and leading ethanol producer, charges $6.41. Even China has higher gas prices than the U.S. at $5.31 (Randall 2012). Thus, U.S. gas prices are extraordinarily low (a gallon of premium gasoline cost $4.19 in May 2012).

Gasoline taxes do not need to be revenue-raising taxes. It could be considered a market failure-mitigating redistribution

TOLLING AND CONGESTION PRICING

ITS-enabled transportation pricing systems are critical to efficiently pricing roads in a way that reduces congestion and provides fuel savings. There are three basic road-pricing strategies that have been proposed either regionally or nationally: tolling; cordon or area pricing; and a VMT fee.

Since as much as 30 percent of highway congestion is due to toll stops, deploying Electronic Toll Collection (ETC) systems can significantly reduce congestion (Ezell 2010). ETC using dedicated short-range communication that connects with transponders on vehicles, is the best current option for totally free-flowing toll facilities and has proven successful in a variety of locations in the U.S., such as the Dallas North Toll Road and San Francisco bridges and tunnels (DOT 2011). ETC systems that require vehicles to slow include the E-ZPass system in the northeast and Midwest. By eliminating idling time for some drivers and shortening queues, E-ZPass saved an estimated 30 million gallons of fuel in 2007 (Birdsall 2010).

Similarly, the PrePass ETC system, in use at 288 sites in 29 states allows participating commercial vehicles to bypass designated weigh stations, port-of-entry facilities, and agricultural interdiction facilities. Vehicles are cleared via an on-board transponder without having to slow down. In 2011, PrePass enabled fuel savings for commercial vehicles of nearly 20 million gallons through 50,000 avoided screenings (PrePass 2012).

Tolling can be applied in two main ways: either through a charge on turnpikes, bridges, tunnels or links, or through the use of High Occupancy Toll (HOT) lanes. HOT lanes are High Occupancy Vehicle (HOV) lanes in which non-HOV users can travel for a fee. In recent years, the combination of improved technology and a growing gap between highway investment needs and available revenues have made toll roads and lanes an important means for funding highway investment, especially through public-private partnerships. In the last decade, about one-third of all new limited-access lane miles built in the United States were tolled; in states such as Texas and Florida, the proportion is much higher (Perez & Lockwood 2006).

Unlike building new highway lanes, a congestion charge works to raise the price-volume curve, decreasing demand for the facility. One way to charge for congestion is through "cordon pricing" or "area-wide pricing", designed to alleviate traffic congestion and encourage the use of alternative transportation. A fee is charged electronically on vehicles entering or traveling within a designated zone. The fee varies by time of day and is designed to encourage people to travel in off-peak hours, use public transport, or increase trip chaining (e.g. running two errands on the same trip), thereby reducing traffic, emissions, and use of fuel.

Cordon-area congestion pricing has already been implemented in a number of cities around the world, including London, Singapore, and Stockholm. A few small-scale congestion pricing programs that are toll-based already exist in the U.S.—for example, at the Midpoint and Cape Coral bridges in Lee County, Florida, motorists can pay half the toll if they travel during off-peak hours and pay electronically.

A comprehensive pricing approach that incorporates variable pricing tied to travel demand levels could provide significant congestion benefits. Some travel, such as commutes for people with rigid work schedules, is highly inelastic. Yet because traffic functions nonlinearly, reducing the number of vehicles on the roads at peak times by just 5 percent would all but eliminate current system congestion and create free-flowing traffic.

The most comprehensive—and administratively complex—way to price roads and potentially replace the fuel tax is with a VMT fee. There are myriad methods for organizing a VMT fee, and some are more efficient than others. The simplest VMT fee is a fixed number of cents per mile and would not reflect the driver's energy consumption or contribution to congestion at any particular moment. Alternatively, a more advanced VMT can capture more of the costs and externalities associated with different vehicles at different times of the day on different roads, ensuring that users pay for the costs of congestion, emissions, oil consumption, and road maintenance.

A 2006 12-month pilot program in Oregon successfully proved the viability and cost effectiveness of a mileage-based fee with congestion zone pricing. Of the 300 motorists in the study, 91 percent said they would like to continue with the VMT system rather than the fuel tax if they could, and the program organizers concluded that privacy had been effectively protected. Despite paying the same amount as they did for fuel on a per-mile basis, the study participants reduced peak travel miles by 14 percent and total miles by 12 percent (Rufolo & Kimpel 2008).

Dynamic road pricing has the potential to improve the performance of our highway system, leading to more efficient driving behavior and reduced oil consumption. An aggressive national dynamic tolling program charging no more than the current average toll on most interstates, freeways, and expressways could save 123,000–167,000 barrels of oil per day by 2020 if implemented nationally (SAFE 2011). According to the Texas Transportation Institute, if cordon congestion pricing could be applied to the top 43 urban areas during peak times starting in 2012, a conservative estimate of cumulative oil savings would be 3.8 billion barrels of oil by 2020 and 11.2 billion barrels by 2035 (TTI 2009).

Finally, the largest savings may be gleaned by providing drivers with constant, real-time information about the costs of driving on a given road. This can be accomplished through a dynamic, smart VMT, which would dramatically increase the efficiency of the road system and reduce unnecessary miles traveled. A Rocky Mountain Institute study found that a VMT fee could reduce oil consumption by 12–15 percent by 2050 relative to the EIA baseline, at a cost in 2009 dollars of $168 billion (RMI 2011).

The issue of public acceptance is also important. A cordon congestion toll initiative in 2007 for the central business district in Manhattan was strongly supported by local residents but ultimately abandoned after facing steep opposition from New York City Council members (Confessore 2008). To implement cordon congestion pricing or a VMT fee, authorities would need to show that a new road pricing system, as compared to the current fuel taxes, will provide Americans with more freedom, not less, to control the costs of their driving habits.

Long-Term Opportunities

SMART INFRASTRUCTURE

It is clear that ITS technologies are a very cost-effective mechanism to improve traffic flow and save substantial amounts of fuel that would otherwise have been wasted in congestion. The executive branch, through the Department of Transportation (DOT) and other agencies, controls access to large sums of infrastructure dollars. The ITS Joint Program Office falls under the DOT's Research and Innovative Technology Administration. This federal ITS program could be expanded beyond research to more actively drive policy for the national and interstate highway systems, as well as co-ordinate and encourage metropolitan area ITS implementation. ITS technology implementation can complement telecommuting and car sharing, which eliminate vehicle trips. One proposal has been to provide the same tax-free benefits for parking and commuting to telecommuting infrastructure set-up and maintenance costs (Korin & Lovaas 2010).

Changing federal transit policy—and the allocation of the Highway Trust Fund that goes to transit—towards programs with performance standards that explicitly incorporate oil savings is one way to encourage a more efficient and hopefully more cost-effective transit sector.

When buses and trains have a high load factor (most of the seats are filled), they consume radically less fuel per passenger mile traveled than automobiles. Increasingly, bus fleets are run on natural gas or electricity, and fixed rail transit (e.g. the New York City subway system) already runs on electricity. To the extent that transit vehicles run on electricity or natural gas, they are already delinked from oil. Yet transit systems are also often highly inefficient, both from an economic and an energy consumption perspective. Too many diesel buses and new light rail systems today operate mostly empty.

Simply bringing together the disparate groups that are responsible for the transportation energy system to outline specific desired results can have large impacts

ELECTRIC VEHICLE CHARGING

Just as they have historically funded roads, ports, and potable water lines, governments around the world are beginning to invest in electric vehicle infrastructure. Consumers are likely to be wary of purchasing EVs until they have access to fast-charging stations at home and in public parking lots. Companies like Coulomb Technologies and ECOtality that build charging stations do not have a viable business model unless they can be certain that there will be EVs on the roads.

Recent programs, including the American Reinvestment and Recovery Act, have made significant progress. When the bill was passed in 2009 there were only around 500 charging stations in the U.S. (Recovery.gov 2011). Various programs, including the EV Project, Clean Cities, and other public-private partnerships have resulted in there being around 6,711 public charging stations available for use at the end of February 2012 (DOE 2012). The DOE is also offering to install a small number of free home chargers in certain cities in exchange for access to data from EV purchasers on their charging habits, which is critical to knowing where and how to build out future infrastructure. It is not known whether people will charge at home, where they work, or where they shop. Initiatives like the department store Kohl's decision to install 33 charging stations in their parking lots in 2012, with financial support from DOE, will help begin the knowledge-collecting process (BusinessWire 2011).

The "stimulus" funding is running out, however. Its success in deploying EV infrastructure thus far should motivate either expanding and continuing the program or finding ways to support more innovative, private sector-based mechanisms for deploying EVs. For example, the Electrification Coalition has proposed "electrification ecosystems" in which financial incentives for purchasing vehicles, as well as public funds for charging stations, would be focused on a small number of cities (Electrification Coalition 2009). Essentially, the ecosystems would act as large-scale demonstration projects and benefit from the at-scale deployment that resource concentration would permit. An important part of ecosystem design, somewhat similar to the existing Clean Cities program, is that local governments, utilities, auto dealers, and other private sector actors would need to come together to apply for funding and develop a deployment plan. Funding should be performance based, with a principal metric being how much oil a plan is intended to save.

Simply bringing together the disparate groups that are responsible for the transportation energy system to outline specific desired results can have large impacts. Rather than distributing transportation infrastructure funds to diffuse projects around the country, new policy might encourage competition, innovation and the efficient use of funds.

Funding EVs and their infrastructure may be more politically feasible than more hands-off options like a higher gas tax with rebate, but a downside is that it is not technology neutral. EV supporters, however, argue that the fuel diversity, zero local emissions and other benefits of EVs cannot be ignored. Good policy initiatives should, then, at least be neutral with respect to the business model for charging and batteries within the EV space. Finally, the government can support rollout of EVs and efficient electricity pricing by mandating that new buildings be equipped with real-time metering and communication devices so that utilities can better monitor demand.

GOVERNMENT PROCUREMENT

Perhaps the most powerful near-term tool for cost reduction that is available to the federal government is procurement of advanced alternative fuels and refueling infrastructure to reduce its own oil consumption. The federal government spent $104.5 billion on transportation equipment in the 2009 Fiscal Year (FY), and $13.1 billion on petroleum and coal products (Fischer 2010). Its fleet totals around 600,000 vehicles (Keane & Green 2012).

The government has a long history of using its procurement power to promote new energy technologies. State and local governments can be especially powerful, since they command the vast majority of non-military vehicles. Not all procurement programs catch on, like California's purchases of methanol-fueled cars in the 1980s, but they can have an impact and help to bring down costs.

Motivated by a suite of policies, including EISA 2007, the National Defense Authorization Act for the 2008 Fiscal Year, and Executive Order 13514 of 2009 (Federal Leadership in Environmental, Energy, and Economic Performance), federal agencies are now required to, among other things, reduce petroleum consumption in fleets by 2 percent per year through 2020, compared to a 2005 baseline, and increase alternative fuel consumption 10 percent per year through 2015.

It is not yet clear whether either the intent or the letter of these policies have been implemented. Among the 53,843 vehicles purchased by the U.S. government in 2011, less than 5 percent (2,645 vehicles) were hybrid, electric, or fuel cell vehicles—a decline from 9 percent in the two previous years because stimulus funds had been exhausted. Instead, a high proportion of the new vehicles were flex-fuel, which means that they can potentially run on ethanol. But most fleets do not yet have access to an E85 pump, so in practice the vehicles run on gasoline. Officially, waivers were provided to federal employees in 2010 to use gasoline in 55 percent of flex-fuel fleet vehicles kept in areas without access to E85 pumps (Keane & Green 2012). Yet EISA 2007 required every fleet-fueling center to have a renewable fuel pump by 2010 (DOE 2011d). To make matters worse, many of the 70 2011 flex-fuel models purchased by the government are SUVs that operate at less than 20 mpg when using gasoline (Keane & Green 2012). More broadly, according to a Congressional Research Service report, in 2009 a survey of public and private organizations suggested that while "green procurement" initiatives were present in over three-quarters of organizations, less than one-fifth of procurement budgets were actually affected by the policies (Fischer 2010).

Of the 737 trillion Btu of petroleum products consumed by the federal government in the 2009 Fiscal (the latest year for which there is data), 680 trillion Btu were used by the Department of Defense (DOD), accounting for around 2 percent of national oil consumption (BTS 2011). The DOD is the logical organization through which to use the government's procurement power. Not only is procurement via the DOD by far the most politically tractable option, it also offers a direct route to enhancing national security. DOD projected spending was around $88 for a barrel of oil in 2012, and for every dollar above $88 the Pentagon must find another $31 million (Miller 2012). Between January and March 2012, the average daily West Texas Intermediate (WTI) spot price was $102 per barrel (EIA 2012c). According to the DOD comptroller, higher than expected oil prices means less money for other, worthy programs (Miller 2012).

The DOD has already been critical to new renewable fuel development, both at the demonstration and deployment phases. The department overall has committed to sourcing 25 percent of its total energy from renewables by 2025. The Air Force promises to get half its jet fuel from alternative blends by 2016, and the Navy and Marines have each committed to achieving 50 percent non-nuclear energy needs with renewable fuel by 2020 (EESI 2011). The Navy is planning to conduct an exercise in July 2012 in which the fleet and planes will run solely on biofuels, nuclear, or alternative energy. And the Marines have reduced fuel consumption at forward operating bases in Afghanistan by 25 percent, partly by using solar energy (Miller 2012).

These goals generate an initial, definitive market for advanced biofuels. Rather than setting targets that can be waived, or providing loans upfront with ambiguous performance objectives, the Navy can simply offer to buy biofuel at a certain price, incentivizing industry to make it happen. As with the 1603 grant program, this is a good use of public funds to deploy mature technologies because the funds are only disbursed after the private sector has successfully completed the goal. In 2009, the Navy ordered 20,000 gallons of algae-based biodiesel produced by Solazyme, and another 150,000 gallons the following year (Molchanov 2011).

RESEARCH & DEVELOPMENT

Though it may seem counterintuitive, one of the most market-friendly and growth-enhancing activities of government is to support the R&D of new technologies. Early stage R&D is something that the government is genuinely good at, and where it can use taxpayer dollars to provide one of the purest public goods: knowledge, see Figure 20.

Indeed, it is the impact on the public good that makes government support for R&D a market-based policy; it corrects a market failure and sets the stage for domestic private companies to grow and thrive. Private firms would grossly underinvest in energy

> There is strong evidence to suggest that expanding R&D funding will yield benefits that are many multiples of the costs

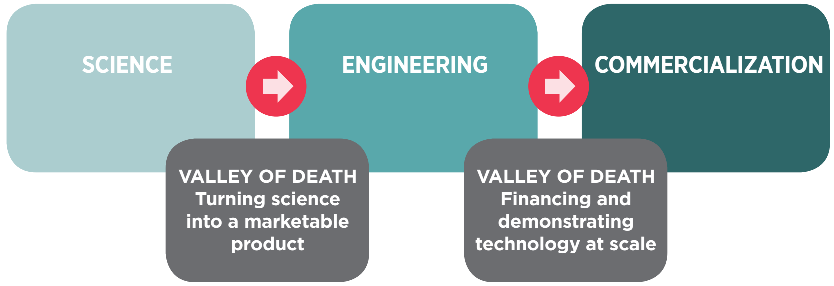
innovation on their own, but new energy technologies will be vital to the U.S. economy in the next century just as in the last, see Figure 21. DOE R&D support was partially responsible for the U.S.-based shale gas revolution: the DOE first demonstrated massive hydraulic fracturing in 1977 (fracturing had been done before, but not in shale rock), and the DOE helped to pay for Mitchell's first horizontal well in 1991 (Trembath 2012).

In the coming decades, government support will be crucial to improve batteries and solar panels. Just like highways or airports, private firms will underinvest on their own. The need to mobilize America's R&D apparatus in the service of commercializing new technologies is especially salient in today's world, where more players like China, India, Korea, Germany, and Brazil are engaging in active industrial policy to make home-country advanced technology firms more competitive.

In the commercialization of new technologies, it is easy for government to incorrectly identify market failures and effectively leverage private sector incentives. However, in both funding and directly performing basic energy research, usually at universities and national laboratories, the government has consistently played a productive and irreplaceable role. Even as we cut back on the inefficient parts of government, there is strong evidence to suggest that expanding R&D funding will yield benefits that are many multiples of the costs. While not every idea or research avenue pursued with government funding comes to fruition, the few that do are typically of great use to the private sector, such as GPS, composite materials, or gas turbines.

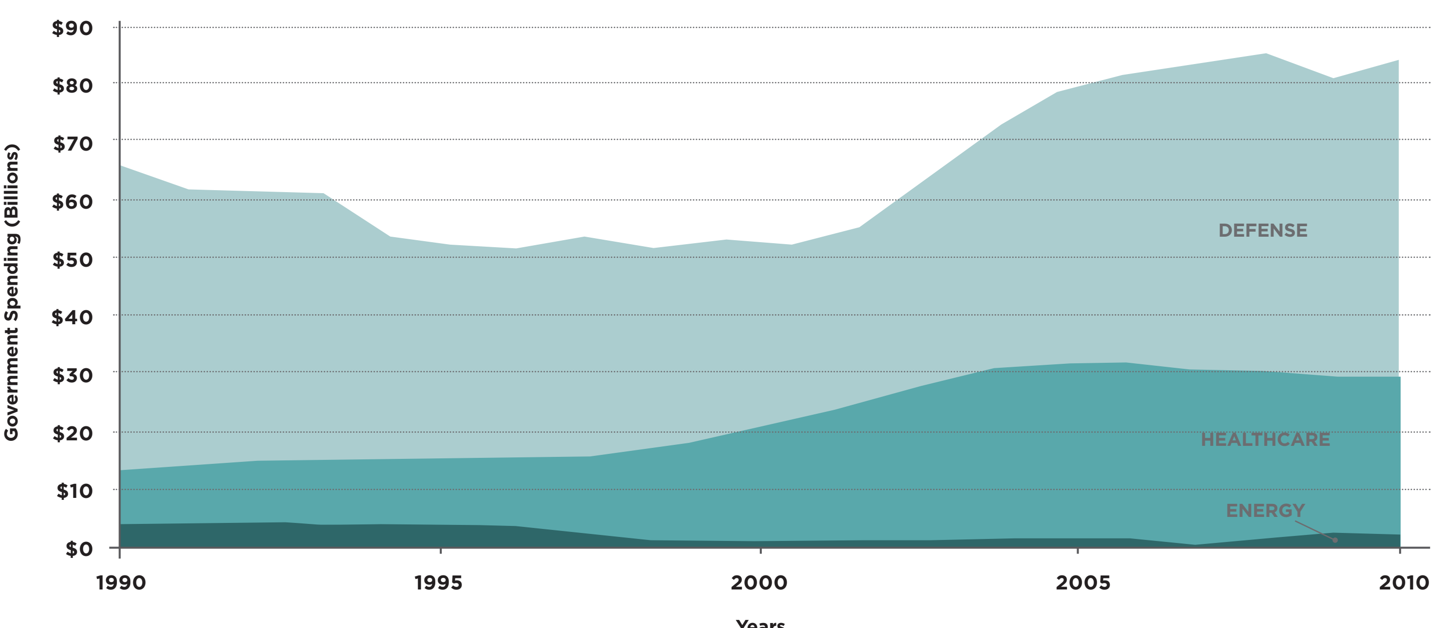
The private sector systematically under-invests in energy R&D. Energy is an undifferentiated commodity, unlike other products such as smart phones or pharmaceuticals. Whereas the pharmaceutical industry spends 19 percent of revenue on R&D, and U.S. industries 2.6 percent overall, the energy industry—including all conventional energy, such as ultra-deep-water oil platforms—spends only 0.23 percent of revenue on research (Freed *et al.* 2010). It is more difficult for private actors to monetize basic R&D output. The power of incumbent infrastructure and high barriers to entry for new business models or technologies leads to much higher inertia than other sectors. Volatile prices and an uncertain regulatory environment only add to the financing challenges.

Figure 20: Innovation Pathway



Source: AEIC, 2011.

Figure 21: U.S. Federal Government R&D Funding on Energy, Health, and Defense, 1990—2009



Source: Freed *et al.*, 2010.

Currently, federal energy R&D funds flows through many disparate agencies, some of which are outside direct control of the executive branch, like the National Science Foundation and NASA. Less than 2 percent of the federal R&D budget is used for energy and, as Figure 23 shows, it is swamped by research in health and defense. Responding to the barriers to private sector energy investments, other countries are investing substantial public funds in energy R&D, many because they see it as the critical industry of the next few decades. China announced in 2010 that it will spend $738 billion over 10 years on clean energy R&D—the unprecedented Recovery Act funds for energy ($70 billion) have already run out and are not being replaced. While the U.S. invests 0.13 percent of GDP in clean energy, China stands at 0.7 percent, and the United Kingdom at 0.51 percent (Freed *et al.* 2010).

Investing in energy R&D exploits a U.S. comparative advantage: the U.S. has the world's finest research institutions, including a broad array of major universities and national labs. Mobilizing these assets in the concerted service of reducing oil consumption could yield results with powerful implications for job creation and the country's position in the global economic hierarchy.

The American Energy Innovation Council (AEIC)—which includes Bill Gates and Jeff Immelt, among other business leaders, and is staffed by the Bipartisan Policy Center—rejects the idea that innovation should be the sole province of the private sector or that government is ill equipped to direct dollars in promising directions. Instead, they argue for expanding on the successes of the new Advanced Research Projects Agency-Energy (ARPA-E), which has proven to be efficient, results oriented, and capable of taking calculated risks (AEIC 2011). The ability to quickly hire the best people from outside at market rates, rather than having to use the cumbersome federal hiring process, is critical.

It is clear that a policy to hasten deployment of cost-competitive advanced biofuels and batteries requires expanding R&D support for any and all sustainable alternatives to petroleum. Some stakeholders have advocated a new organizational entity to support R&D and/or first commercialization. The non-governmental organization Third Way has promoted a National Institutes of Energy (NIE) along the lines of the National Institutes of Health to centralize and streamline federal research support in an efficient bureaucracy that has strong outside support (especially outside Congress). Third Way suggests that the NIE would set specific goals, such as reducing EV recharging time by 90 percent, and would conduct both early stage research and commercialization of new innovations (Freed *et al.* 2010).

As ACEI and others have stressed, it is important to use government programs to foster competition between researchers, entrepreneurs, and technologies. Government R&D programs could set broad performance-based goals and then fund multiple and competing approaches, with the fastest and best innovations receiving more funding. Additionally, it seems that any energy R&D funding organization will be most effective if it takes a portfolio approach with a healthy risk appetite. That means not focusing on the success of any individual project, but rather on the portfolio as a whole. A venture capital firm expects nine out of ten investments to be a dud and a waste of money; expectations on the government must be no more stringent if it is to catalyze transformative technology development.

Even in hard times, it is important to recognize that many experts see government support for the entire innovation value chain—ranging from the education system to the welcoming of highly talented immigrants to publicly funded R&D—not as a cost but as an investment that is likely to yield serious advances within the decade.

PERMIT INFORMED CHOICES

Transportation is generally considered an external cost to economic transactions. Explanations for the development of firm clustering (as in Silicon Valley), marketplaces, and cities rely in part on assuming that reduced transportation costs increase productivity. Transportation policy focused on economic growth and maximizing the choice set for travelers probably would not seek to limit travel or explicitly reduce vehicle miles traveled. Research suggests that such policies would likely be costly and ineffective. However, there is evidence that government regulation and inadequate information provision combine to generate more oil use than would be optimal if people had access to adequate information and if local zoning laws were encouraged to be more flexible and responsive to local demand.

An important market-based mechanism to improve the efficiency of private decisions is to make those decisions as informed as possible. Energy costs are frequently not very salient and subject to nonlinear pricing schedules. Research suggests that this causes consumers to use energy in ways that is suboptimal for them. While consumers clearly recognize the financial burden of high oil prices when they fill up their tank, most consumers are not able to calculate, or do not recognize, the expected operating costs when they purchase a car. The government can help to correct this program by increasing the salience of gasoline and diesel costs. Examples of this sort of initiative are the new fuel economy labels for new cars, which clearly state in large font what the expected annual fuel costs will be and how the vehicle compares to similar ones.

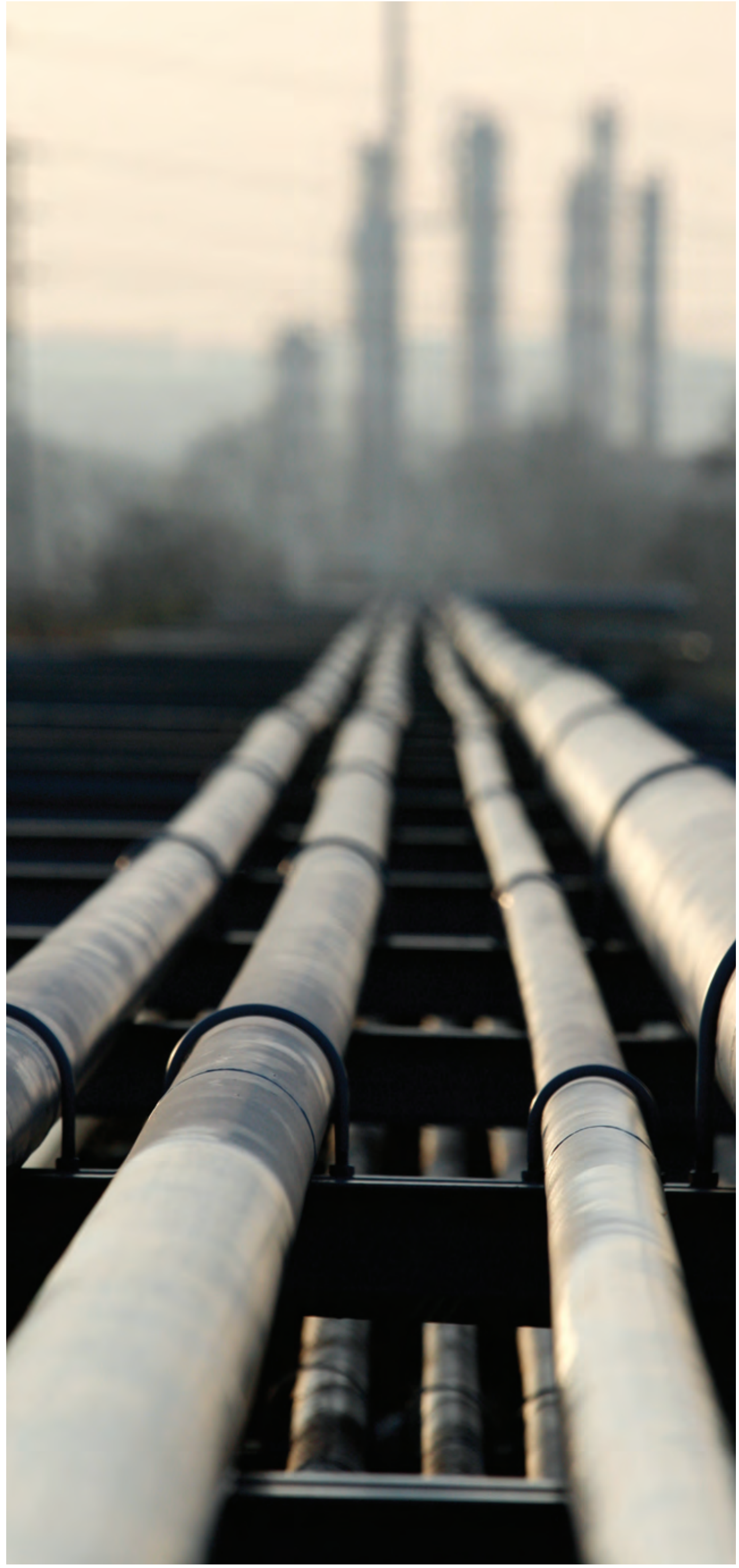
Consumers are also often unaware of behavior changes that can reduce fuel use, like trip chaining and minimal braking. Psychologists and behavioral economists have suggested that the human mind typically ignores most available information and relies instead on heuristics or rules of thumb to make a quick, "just good enough" decision. For many drivers, fuel is invisible and abstract except when they stand at the gas pump. Since information about energy costs is difficult to assimilate and often not immediately available (as compared to the cashback offer on a new car lease, for example), consumers may sometimes make suboptimal decisions.

High-frequency energy use feedback can have significant impacts on consumer actions (Froehlich 2009). Real-time in-vehicle information about fuel use per mile at the current speed could make fuel consumption more salient and encourage more efficient behavior. The government could require all vehicles to display current miles per gallon in the dashboard. Given that far more used cars are sold than new cars, a second way to increase information access is to require used cars, when up for sale, to display large stickers with fuel economy ratings on the window, just as new vehicles must do.

Public information campaigns about how reduced idling and braking can improve fuel economy might give drivers better tools to manage costs. Information dissemination could include programs aimed both at employers and employees that encourage telecommuting—one study conducted by Telework Exchange in 2005 found that two days per week of telecommuting by all white-collar workers would conserve over 233 million gallons of fuel per week (Telework Exchange 2005).

Advocates have also suggested that public information campaigns that detail not only the private costs of fuel consumption, but also the larger national security costs, would encourage people to improve the efficiency of their vehicle or switch to an alternative fuel. Educating people about the true costs of oil can begin in lower schools, be incorporated into driver's education programs, and take place in the workplace and the mass media (CFA 2006). Linking the constraints and burdens that oil dependence imposes on foreign policy, the military, and the economy to driving and new vehicle choices at home might have meaningful effects on decisions. Many Americans simply aren't aware of these trade-offs.

Public information campaigns about how reduced idling and braking can improve fuel economy might give drivers better tools to manage costs



Conclusion

We have at our disposal practical, currently available, and cost-effective technologies that can yield meaningful reductions in oil consumption in the next 10 years

A wide variety of cost-effective technologies exist that can substantially reduce oil consumption in the U.S. transportation sector in the near term, one of the most energy intensive sectors in the U.S.. This can be done while also lowering GHG emissions and providing a much-needed boost to the country's economic dynamism, and security. These technologies can be deployed in a way that enlarges the consumer's choice set and improves their driving experience.

Non-petroleum-based fuels can either substitute petroleum in an alternative powertrain (e.g. natural gas or electricity), or they can be blended with or displace petroleum products in conventional internal combustion engines (e.g. biofuels or methanol). The latter, particularly drop-in biofuels, allow oil to be displaced immediately with minimal new infrastructure. However, blended fuels, unlike electricity, usually remain hostage to the world oil price, produce similar or greater GHG emissions, or threaten dependence on a different, single fuel. Yet other options that are available today—limiting vehicle miles traveled, building expensive transit systems—are perhaps even less appetizing.

Three strategies are apparent winners today. A successful strategy for reducing U.S. oil dependence has three prongs - remove the barriers that prevent widespread use of domestically produced and alternative power sources,

Second, more efficient vehicles, while not generating displacement of oil, are important to mitigating its impact on the economy by reducing expenditures on oil as a percentage of disposable household income or unit of GDP. Third, incorporating the IT that we now rely on every day into transportation can meaningfully reduce oil consumption, such as online ride-share matching and more advanced telecommuting capabilities. The overall benefit-cost ratio of ITS solutions like co-ordinated stoplights is vastly higher than capacity expansion projects, particularly from the perspective of reduced travel delay and oil savings.

The U.S. government can learn from the examples set by other countries and choose policies that can help get the nation off oil in the near term while stimulating economic growth. The policies described in the previous section are just a few potential options for consideration. They were chosen, however, because they are generally technology neutral and aim at removing barriers to entry for new ideas, in ways that exploit the power of the market to innovate and commercialize solutions to problems. Many of them have considerable co-benefits, one of which is job creation.

There is no silver bullet and trade-offs are ubiquitous. But it is equally clear that we have at our disposal a wide array of practical, currently available, and cost-effective technologies for freight and personal transport that can yield meaningful reductions in oil consumption in the next 10 years. Where possible, the government should only build the framework for innovation. Regardless of which technology they choose, all the relevant players should have a role in making alternative fuel vehicles available to consumers.

Works Cited

Alliance of Automobile Manufacturers (AAM). 2009. "National Clean Gasoline: An Investigation of Costs and Benefits."

American Energy Innovation Council (AEIC). 2011. "Catalyzing American Ingenuity: The Role of Government in Energy Innovation."

Anderson, Soren, *et al.* 2010. "Automobile Fuel Economy Standards: Impacts, Efficiency, and Alternatives." NBER Working Paper No. 16370. Cambridge: National Bureau of Economic Research.

Andress, David *et al.* 2011. "Status of Advanced Light-Duty Transportation Technologies in the U.S." *Energy Policy,* 41:348-364.

Association of American Railroads (AAR). 2007. "Railroad Facts: 2008 Edition."

Bailey, Linday *et al.* 2008. "The Broader Connection between Public Transportation, Energy Conservation and Greenhouse Gas Reduction." Fairfax: ICF International.

Bandivadekar, Anup *et al.* 2008. "On the Road in 2035: Reducing Transportation's Petroleum Consumption and Greenhouse Gases." Cambridge: Massachusetts Institute of Technology Laboratory for Energy and the Environment.

Barnitt, R. and K. Chandler. 2006. "New York City Transit Hybrid and CNG Buses: Interim Evaluation Results." Golden, C.O.: National Renewable Energy Laboratory.

Birdsall, Michelle. 2010. "Gas Fizzling: ITS are Useful Tools to Weaken Greenhouse-Gas Emissions." *Roads and Bridges*, March: 32–34.

Bordoff, Jason and Pascal Noel. 2008. "Pay-As-You-Drive Auto Insurance: A Simple Way to Reduce Driving-Related Harms and Increase Equity." Washington: Brookings Institution.

Bullis, Kevin. 2011. "How Vehicle Automation Will Cut Fuel Consumption." MIT Technology Review, October 24.

Bureau of Transportation Statistics (BTS). 2010. *National Transportation Statistics 2010*. Washington: U.S. Department of Transportation.

——. 2011. *National Transportation Statistics 2011*. Washington: U.S. Department of Transportation.

BusinessWire. 2011. "Kohl's Department Stores Piloting Electric Vehicle Charging Stations at 33 Stores." December 15.

Cambridge Systematics and Battelle Memorial Institute. 2008. "Estimated Cost of Freight Involved in Highway Bottlenecks." November 12. Prepared for Federal Highway Administration, Office of Transportation Policy Studies.

Cardwell, Diane. 2012. "Few Seize on a U.S. Bond Program Backing Green Energy." *The New York Times*, May 7.

Citi Commodities Strategy. 2012. "Resurging North American Oil Production and the Death of the Peak Oil Hypothesis." Citi Investment Research & Analysis Report, February 15.

CNA Military Advisory Board. 2011. "Ensuring America's Freedom of Movement: A National Security Imperative to Reduce U.S. Oil Dependence."

Coalition for Green Capital. 2010. "Coalition for Green Capital Recommendations re: Tax Provisions to Encourage Investment in Clean, Efficient Energy Production and Consumption." Testimony before the Committee on Ways & Means, United States House of Representatives, April 28.

Confessore, Nicholas. 2008. "$8 Traffic Fee for Manhattan Gets Nowhere." *The New York Times*, April 8.

Consumer Federation of America (CFA). 2006. "A Blueprint for Energy Security: Addressing Consumer Concerns about Gasoline Prices and Supplies by Reducing Consumption and Imports."

Crane, Keith *et al.* 2009. *Imported Oil and National Security*. Santa Monica: The RAND Corporation.

Davis, Stacy *et al.* 2010. *Transportation Energy Databook*, Ed. 29. Oak Ridge: Oak Ridge National Laboratory.

Daw, Stuart *et al.* 2012. "Report on the Transportation Combustion Engine Efficiency Colloquium Held at USCAR, March 3–4, 2010." Oak Ridge: Oak Ridge National Laboratory.

Department of Energy (DOE). 2010. "Current State of the U.S. Ethanol Industry," DOE EERE Subcontract Report, November. Newcastle, DE: CardoENTRIX.

——. 2011a. 2011 *Quadrennial Technology Review*. Washington: DOE.

——. 2011b. "Methanol Basics." Washington: DOE, Energy Efficiency and Renewable Energy Office.

——. 2011c. "Natural Gas Vehicles." Accessed March 14, 2012. http://www.eere.energy.gov/basics/vehicles/natural_gas_vehicles.html

——. 2011d. "Guidance: Requirements for Installing Renewable Fuel Pumps at Federal Fleet Fueling Centers under EISA Section 246." Federal Energy Management Program, April.

——. 2012. "Alternative Fueling Station Total Counts by State and Fuel Type." EERE Alternative Fuels and Advanced Vehicles Data Center. Accessed March 16, 2012. http://www.afdc.energy.gov/afdc/fuels/stations_counts.html.

Dincer, Ibrahim, *et al.* 2010. "Economic and Environmental Comparison of Conventional and Alternative Vehicle Options." *Electric and Hybrid Vehicles: Power Sources, Models, Sustainability, Infrastructure and the Market*, edited by Pistoia Gianfranco, 1–18. Amsterdam: Elsevier.

Department of Transportation (DOT). 2009a. Benefits Database." Accessed December 29, 2010. www.itsbenefits.its.dot.gov

——. 2009b. "Fiscal Year 2010 Budget Highlights." Washington: DOT.

——. 2010. "Transportation's Role in Reducing U.S. Greenhouse Gas Emissions, Volume 1: Synthesis Report." Report to Congress prepared by the DOT Center for Climate Change and Environmental Forecasting. Washington: DOT.

——. 2011. "Applications for the Environment: Real-Time Information Synthesis (AERIS) Applications State of the Practice Assessment Report." Washington: DOT, Research and Innovative Technology Administration.

Department of the Treasury. 2012. "Section 1603—Payments for Specified Energy Property in Lieu of Tax Credits." Accessed February 21, 2012. http://www.treasury.gov/initiatives/recovery/Pages/1603.aspx

Drake, Alan. 2008. "Multiple Birds—One Silver BB: A synergistic Set of Solutions to Multiple Issues Focused on Electrified Railroads." *The Oil Drum*, July 15.

Dutzik, Tony *et al.* 2011. "Getting Off Oil: A 50-State Roadmap for Curbing our Dependence on Petroleum." Washington: Environment America.

Durbin, Dee-Ann. 2011. "Sales of Midsize Cars Shrink as Buyers Go Smaller." *The Houston Chronicle*, November 26.

Electrification Coalition. 2009. "Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security." Washington: The Electrification Coalition.

Energy Information Administration (EIA). 2007. "About U.S. Natural Gas Pipelines—Transporting Natural Gas." Natural Gas. Washington: EIA.

——. 2011a. "International Energy Outlook." Washington: EIA.

——. 2011b. "Monthly Energy Review." Washington: EIA, December.

——. 2011c. "This Week in Petroleum." Washington: EIA, November 23.

——. 2011d. "Annual Economic Outlook 2011." Washington: EIA.

——. 2012a. "Annual Economic Outlook 2012 Early Release: Renewable Energy Consumption by Sector and Source." Washington: EIA.

——. 2012b. "Annual Economic Outlook 2012 Early Release: Light-Duty Vehicle Energy Consumption by Technology Type and Fuel Type." Washington: EIA.

——. 2012c. "Petroleum & Other Liquids: Spot Prices." Washington: EIA.

——. 2012d. "Short-Term Energy Outlook." Washington: EIA, January 10.

——. 2012e. "Online Data-Tables: Natural Gas Gross Withdrawals and Production." Washington: Accessed November 1, 2012. http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_a.htm

——. 2012f. "U.S. Field Production of Crude Oil." Accessed November 1, 2012. http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS1&f=A

Environmental Protection Agency (EPA). 2010a. "EPA Analysis of the Transportation Sector: Greenhouse Gas and Oil Reduction Scenarios." Washington: EPA.

——. 2010b. "EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels." EPA-420-F-10-006. Washington: EPA, Office of Transportation and Air Quality.

——. 2012a. "Renewable Fuel Standard." Accessed February 19, 2012. http://www.epa.gov/otaq/fuels/renewablefuels/index.htm

——. 2012b. "Regulations and Standards." Accessed April 26, 2011. http://www.epa.gov/oms/climate/regulations.htm

Environmental and Energy Study Institute (EESI). 2011. "DoD's Energy Efficiency and Renewable Energy Initiatives." Washington: EESI.

Ezell, Stephen. 2010. "Explaining International IT Application Leadership: Intelligent Transportation Systems." Washington: The Information Technology & Innovation Foundation.

Fargione, Joseph *et al.* 2009. "Land Clearing and the Biofuel Carbon Debt." Science 326 (5952): 527–528.

Federal Highway Transportation Administration (FHWA). 2008a. "Freight Story." Washington: FHWA.

——. 2011. "Freight Facts and Figures 2011." Washington: FHWA.

Fischer, Eric. 2010. "Green Procurement: Overview and Issues for Congress." Washington: Congressional Research Service, April 20.

Freed, Josh *et al.* 2010. "Creating a Clean Energy Century: Recapturing the Lead in Clean Tech Innovation." Washington: Third Way.

Freed, Josh & Mae Stevens. 2011. "A Small Tax Change, Big Clean Energy Results." Washington: Third Way.

Froehlich, Jon. 2009. "Promoting Energy Efficient Behaviors in the Home through Feedback: The Role of Human-Computer Interaction." Paper presented at the 2009 HCIC Workshop, Fraser, Colorado, February 4–8.

General Accounting Office (GAO). 2001. "Mass Transit: Bus Rapid Transit Shows Promise." Report to Congressional Requesters. Washington: GAO.

Gillam, Carey. 2011. "Ethanol Production Capacity over 14 Billion Gallons." *Reuters*, November 29.

Greenberg, Allen. 2008. "Costs and Benefits of Varying Per-Mile Insurance Premiums Based Upon Measured Risks Specific to Each Mile Driven." Washington: FHWA.

Greene, David L. and Steven E. Plotkin 2011. "Reducing Greenhouse Gas Emissions from U.S. Transportation." Washington: Pew Center on Global Climate Change.

Greene, David L. *et al.* 2011. "OPEC and the Costs to the U.S. Economy of Oil Dependence: 1970–2010." Oak Ridge: Oak Ridge National Laboratory.

Gruenspecht, Howard. 2012. "Annual Energy Outlook 2012: Early Release Reference Case." Energy Information Administration, Presentation at the Johns Hopkins University School of Advanced International Affairs, January 23.

Halsey III, Ashley. 2010. "Smart Traffic Lights Ease Commuting. Except When They Don't." *The Washington Post*, January 5.

Henderson, Rebecca M. and Richard G. Newell, eds. 2011. *Accelerating Energy Innovation: Insights from Multiple Sectors*. Chicago: University of Chicago Press. 26.

Hensher, David A. 2007. "Sustainable Public Transport Systems: Moving Towards a Value for Money and Network-Based Approach and Away From Blind Commitment." Transport Policy 14: 98–102.

Holland, Stephen P. *et al.* 2011. "Inconvenient Truths about Climate Change Policy: The Distributional Impacts of Transportation Policies." Cambridge: MIT Center for Energy and Environmental Policy Research, Working Paper, August.

ICF International. 2009. "Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors." Washington: Department of Transportation, Federal Railroad Administration.

International Council on Clean Transportation (ICCT) 2011a. "Global Light-Duty Vehicles: Fuel Economy and Greenhouse Gas Emissions Standards." Washington: ICCT.

——. 2011b. "Info & Tools: Global Passenger Vehicle Standards Update." Washington: ICCT.

Jessup, Eric. 2011. "U.S. Renewable Fuels (Ethanol): Historical Policy and Future Prospects." Pullman: Washington State University Freight Policy Transportation Institute.

Johnson, Caley. 2010. "Business Case for Compressed Natural Gas in Municipal Fleets." Golden, C.O.: National Renewable Energy Laboratory.

Keane, Angela and Jeff Green. 2012. "Obama's Green-Car Plan Runs into Alternative Fuel Limits." *Bloomberg News*, February 24.

Kempton, Willett *et al.* 2009. "A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System." Results from an Industry-University Research Partnership.

Knittel, Christopher. 2012. "Reducing Petroleum Consumption from Transportation," Washington: National Bureau of Economic Research, Working Paper No. 17724, January.

Korin, Anne and Deron Lovaas. 2010. "Taking the Wheel: Achieving a Competitive Transportation Sector Through Mobility Choice." Potomac, M.D.: Institute for the Analysis of Global Security, Mobility Choice Coalition.

Leinberger, Christopher B. 2011. "The Death of the Fringe Suburb." *The New York Times*, November 26.

Levine, Steve. 2012. "The Weekly Wrap." *Foreign Policy*, February 17.

Liska, Adam *et al.* 2009. "Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol." *Journal of Industrial Ecology* 13(1): 58–74.

Litman, Todd. 2011. "Pay-As-You-Drive Pricing in British Columbia." Victoria: Victoria Transport Policy Institute.

Longman, Philip. 2009. "Back on Tracks." *Washington Monthly*, January–February.

Mcrae, Gregory S. and Carolyn Ruppel. 2011. "The Future of Natural Gas: An Interdisciplinary MIT Study." Cambridge: MIT.

Methanol Institute. 2012. "Methanol Industry." Accessed March 14, 2012. http://www.methanol.org/Methanol-Basics/The-Methanol-Industry.aspx

Miller, Jason. 2012. "Rising gas prices add more volatility to DoD budget." *Federal News Radio*, March 9.

Molchanov, Paul. 2011. "Gen2 Biofuels: Despite Growing Pains, Billion-Gallon Milestone Within Reach." New York: Raymond James & Associates.

Moore, Adrian *et al.* 2010. "The Role of VMT Reduction in Meeting Climate Change Policy Goals." *Transportation Research Part A*, Vol 44.

National Academy of Sciences (NAS). 2010. "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles." Washington: National Academies Press.

National Association of Publicly Traded Partnerships (NAPTP). 2012. "Master Limited Partnerships 101: Understanding MLPs." Arlington: NAPTP.

National Renewable Energy Laboratory (NREL). 2008. "The Impact of Ethanol Blending on U.S. Gasoline Prices." Golden, C.O.: NREL.

National Research Council. 2010a. "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles." Washington: National Academies Press.

——. 2010b. "Transitions to Alternative Transportation Technologies—Plug-In Hybrid Electric Vehicles." Washington: National Academies Press.

National Surface Transportation Infrastructure Financing Commission. 2009. "Paying Our Way: A New Framework for Transportation Finance." Report to Congress, February.

NGV Global. 2011. "Current Natural Gas Vehicle Statistics." April. Accessed March 14, 2012. http://www.iangv.org/current-ngv-stats/

——. 2011. “2011 Fleet Fuel Efficiency Benchmark Study.” Unpublished research study.

Office of Management and Budget (OMB). 2012. “Fiscal Year 2012 Historical Tables—Budget of the U.S. Government.” Washington: OMB.

Peak, Matt *et al.* 2005. “Bus Rapid Transit Ridership Analysis.” Prepared for the Federal Transit Administration. Pasadena, C.A.: WestStart-CALSTART.

Perez, Benjamin and Stephen Lockwood. 2006. “Current Toll Road Activity in the U.S.: A Survey and Analysis.” Washington: FHWA, Office of Transportation Studies.

PrePass. 2012. “About Us.” Accessed January 20, 2012. http://www.prepass.com/aboutus/Pages/AboutUs.aspx.

Plumer, Brad. 2012. “Has the United States Beaten Peak Oil? Not So Fast.” *The Washington Post*, February 17.

Ramsey, Mike. 2010. “As Electric Vehicles Arrive, Firms See Payback in Trucks.” *The Wall Street Journal*, December 7.

Randall, Tom. 2012. “Highest and Cheapest Gas Prices by Country.” *Bloomberg News*, May 12.

Recovery.gov. 2011. “Recovery Funds Support Electric Vehicle Technology.” July 27. Accessed March 14, 2012. http://www.recovery.gov/News/featured/Pages/Recovery-Funds-Support-Electric-Vehicle-Technology.aspx

Reed, John. 2011. “Nissan to Drive Sales of Leaf Electric Car.” *The Financial Times*, December 11.

Research in China. 2010. “China Methanol Industry Report 2009–2010.” Beijing: Research in China.

Ridge, Tom and Mary E. Peters. 2012. “The Methanol Alternative to Gasoline.” *The New York Times*, February 23.

Rocky Mountain Institute (RMI). 2009a. “Rail vs. Trucking: Who’s the Greenest Freight Carrier?” *Treehugger*, May 20.

——. 2009b. “Policy Goals and Objectives Developed Collaboratively by the Oil Solutions Initiative.” Snowmass, C.O.: RMI.

——. 2011. “Reinventing Fire Transportation Sector Methodology.” Snowmass, C.O.: RMI.

Rufolo, Anthony M. and Thomas J. Kimpel. 2008. “Responses to Oregon’s Experiment in Road Pricing.” *Transportation Research Record: Journal of the Transportation Research Board* 2079: 1–7.

Securing America’s Future Energy (SAFE). 2011. “Transportation Policies for America’s Future: Strengthening Energy Security and promoting Economic Growth.” Washington: SAFE.

Schubert, Raymond and Matt Kromer. 2008. “Heavy-Duty Truck Retrofit Technology: Assessment and Regulatory Approach.” Cupertino, C.A.: TIAX LLC.

Schrank, David *et al.* 2011. “Texas Transportation Institute 2011 Urban Mobility Report.” College Station, T.X.: Texas Transportation Institute.

Searchinger, Timothy *et al.* 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions From Land-Use Change.” *Science* 319(5900): 1238–1240.

Seelke, Clare R. and Brent D. Yacobucci. 2007. “Ethanol and Other Biofuels: Potential for U.S.-Brazil Energy Co-operation.” Washington: Congressional Research Service.

Shladover, Steven E. 2011. “Challenges to Evaluation of CO_2 Impacts of Intelligent Transportation Systems.” 2011 Paper presented at the IEEE Forum on Integrated and Sustainable Transportation Systems, Vienna, Austria, June 29–July 1.

Spence, Angela *et al.* 2009. “Methodologies for Assessing the Impact of ITS Applications on CO_2 Emissions: Technical Report.” Brussels: EC-METI Task Force.

Staley, Sam and Adrian Moore. 2009. *Mobility First: A New Vision for Transportation in a Globally Competitive 21st Century*. Lanham, M.D.: Rowman & Littlefield.

TDM Encyclopedia. 2011. “Pay-As-You-Drive Vehicle Insurance: Converting Vehicle Insurance Premiums Into Use-Based Charges.” http://www.vtpi.org/tdm/tdm79.htm

Telework Exchange. 2005. “Telework Exchange ‘Fuel Smart Economy: It’s No Gas’ Study Shows $5.7 Million Hike in Federal Employee and $105.8 Million Hike in White-Collar America Daily Commuting Costs.” Press Release, September.

Tertzakian, Peter. 2009. *The End of Energy Obesity: Breaking Today’s Energy Addition for a Prosperous and Secure Tomorrow*. Hoboken, N.J.: John Wiley & Sons.

Texas Transportation Institute (TTI). 2009. “Urban Mobility Report 2009.” College Station, T.X.: Texas Transportation Institute.

——. 2011. “Congestion Data for Your City.” Accessed March 14, 2011. http://mobility.tamu.edu/ums/congestion-data/

Transportation Research Board. 2011. “Cost-Benefit Analysis of Converting a Lane for Bus Rapid Transit—Phase II Evaluation and Methodology.” *Research Results Digest* 352.

Trembath, Alex. 2012. “U.S. Government Role in Shale Gas Fracking History: An Overview and Response to Our Critics.” Oakland, C.A.: The Breakthrough Institute, March 12.

Union of Concerned Scientists *et al.* 2010. “Delivering the Goods: Saving Oil and Cutting Pollution from Heavy-Duty Trucks.” Go60MPG Initiative.

United States Census Bureau. 2012a. “U.S. PopClock Projection.” Accessed March 14, 2012. http://www.census.gov/population/www/popclockus.html

——. 2012b. “U.S. International Trade in Goods and Services (FT900).” Accessed February 20, 2012. http://www.census.gov/foreign-trade/Press-Release/current_press_release/

United States Department of Agriculture (USDA). 2010. “A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022.” Washington: USDA.

——. 2012. "World Agricultural Supply and Demand Estimates." Commodity Forecasts, February. WASDE Report 503, Table 12. Accessed March 14, 2012. http://www.usda.gov/oce/commodity/wasde/

United Nations Population Fund (UNPF). 2011. "State of World Populations 2011: People and Possibilities in a World of 7 Billion." New York: United Nations.

URS Corporation. 2006. "Task Order 5.2 Benefits Analysis for the Georgia Department of Transportation NaviGAtor Program—Final Report." Prepared for the Georgia Department of Transportation.

Vyas, Anant D. *et al.* 2009. "Plug-In Hybrid Electric Vehicles' Potential for Petroleum Use Reduction: Issues Involved in Developing Reliable Estimates." Argonne National Laboratory, Paper submitted at the 88th Annual Meeting of the Transportation Research Board, Washington, January 11-29.

Wang, M.Q. and H.S. Huang. 1999. "A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Fuels from Natural Gas." Argonne, I.L.: Argonne National Laboratory, Center for Transportation Research.

Weyen, Rick. 2012. "Refiners Perspective on Advanced Biofuels." Biomass R&D Technical Advisory Committee, Tesoro Presentation, March.

The White House. 2011. "Driving Efficiency: Cutting Costs for Families at the Pump and Diminishing Dependence on Oil." Washington: The White House.

Woodyard, Chris. 2011. "Natural Gas Pumps Coming to More Filling Stations." USA Today, December 29.

Yergin, Daniel. 2011. *The Quest: Energy, Security, and the Remaking of the Modern World*. New York: Penguin Press.

Zargari, Shahriar A. and Ata M. Khan. 2003. "Optimization of Travel in Bus Rapid Transit-Based Multimodal Corridor." *Journal of Public Transportation* 6(2): 87–106.

NOTES

ABOUT FUEL FREEDOM

The Fuel Freedom Foundation is a nonpartisan, nonprofit organization dedicated to breaking the U.S. economy's oil addiction by powering cars and trucks with cheaper, cleaner, healthier American replacement fuels. Consumers could easily convert their cars from running on gasoline to replacement fuels, but outdated regulations and entrenched commercial interests stand in the way. the fuel freedom campaign works to remove barriers to competition so that natural gas, methanol, ethanol and electricity can compete on equal footing with gasoline at the pump and the dealership. Achieving fuel freedom will lower fuel prices, create jobs, spur economic growth, reduce pollution, and improve national and global security.

for more information go to the foundation's website at www.fuelfreedom.org.

ABOUT THE CARBON WAR ROOM

Carbon War Room works on breaking down market barriers for capital to flow to entrepreneurial solutions to climate change, by employing a sector-based approach focusing on the solutions that make economic sense right now. We target the movement of institutional capital into a working marketplace and the elimination of market inefficiencies (in the form of insufficient information and high transaction costs, among others). Policy and technology are necessary conditions to the solution, however, they are neither sufficient nor the bottleneck to progress.

Our vision is to see markets functioning properly and clean technology successfully scaling to promote climate wealth, business and economic growth. In the role of a climate wealth catalyst, Carbon War Room focuses on areas where a sector-by-sector approach to climate change can be applied to generate gigaton-scale carbon savings. We seek to complement existing efforts and organisations, leveraging our convening power, our market-driven, solutions-oriented focus, and our powerful global network to develop and implement catalytic change.

ACKNOWLEDGEMENTS

The author thanks Yossie Hollander for his support and spirited conversation.

Thank you to Jigar Shah for his advice and guidance on this project.

Many thanks to Mario Santoro-Woith for usage of his photography.

Carbon War Room
1020 19th Street NW, Suite 130
Washington DC 20036

P / 202.717.8448
F / 202.318.4770

Web: www.carbonwarroom.com

Twitter: www.twitter.com/cwarroom

Carbon War Room – LinkedIn Group: http://linkd.in/f3Zu1G