

8.0 Summary and Conclusions

8.1 The need for coordinated policies

This report envisions a transportation future in which light-duty vehicles attain substantial reductions in their rate of fuel consumption and greenhouse gas intensity by 2035. Even so, the potential for propulsion system technologies, weight reduction, and the supply of alternative fuels to limit emissions and save energy will not be realized without significant changes to business as usual. Achieving these goals will depend upon the following: 1) the ways in which industry implements new technologies, 2) the willingness of consumers to modify their personal mobility choices, and 3) the ability of decision-makers to implement appropriate and robust policy drivers.

Just as there is no “silver bullet” in the technology options available, it is unlikely that one dominant strategy or policy can satisfy the necessary political and economic constraints while achieving dramatic reductions in energy use and greenhouse gas emissions. As discussed in the introductory section to this report, a coordinated set of various measures could form a policy approach that would better account for the following factors:

1. Fiscal as well as regulatory approaches have a role to play. Alongside the push for new technologies and fuel options through mandatory requirements, fiscal policies can harness market forces to pull efficiency gains in vehicles toward reducing fuel consumption.

2. A broad base of stakeholders influences energy use and greenhouse gas emissions in light-duty vehicle transportation. Using incentives to align the interests of transportation consumers with the goals of a policy intervention would improve the effectiveness of regulations placed on smaller groups of industrial actors.

3. There are numerous opportunities to reduce energy use and emissions along the entire vehicle life-cycle. Policy drivers that influence the choices of manufacturers and consumers can be applied at the time of vehicle design, production, purchase, operation, and retirement. Without addressing these different life-cycle stages, a measure may unintentionally alter the behavior of stakeholders in ways that reduce the effectiveness of policy interventions.

8.2 Summary of available opportunities

As this report has described, a substantial research effort on the options for reducing petroleum consumption and greenhouse gas (GHG) emissions from transportation has been carried out at MIT for the past several years. While our focus has been primarily on the situation in the United States, comparative studies in major European countries have also been completed. Our focus has been on light-duty vehicles and their fuels, and on how engine and vehicle technology improvements and alternative fuels streams are likely to change future evolving fleet energy consumption patterns and GHG emissions.
Here we summarize the major conclusions that have emerged from our more recent studies. These studies have examined the potential for improved propulsion system and vehicle technologies, the introduction of alternative fuel streams to augment mainstream petroleum-based fuels, plausible time scales and rates at which improved technology production volumes could increase, how changes in the weighting of the vehicle attributes—performance, size, and on-the-road fuel consumption—affect the impact the technology improvements would have, and especially the evolving impacts of these vehicle technology, fuel, vehicle purchase, and use patterns, have on the fuel consumption and GHG emissions of the future U.S. in-use vehicle fleet. Our findings thus cover a wide range of topics. In addition, they allow us to provide a comprehensive summary, a set of conclusions, and broad recommendations as to how we can move forward.

1. **The challenge.** Petroleum use and greenhouse gas emissions are increasing steadily in the United States, the rest of the developed world, and especially in the developing world, due to seemingly inexorable growth in demand for land, air, passenger and freight transportation. Our first challenge is to offset this growth.

2. **Significant reductions are achievable through technology.** At constant vehicle performance and size, a 30–50% reduction in new light-duty vehicle fuel consumption is feasible over the next 20–30 years. Such a reduction in fuel consumption can be achieved by a combination of the following:
   a. Improved gasoline and diesel engines and transmissions, as well as gasoline hybrids in the nearer term
   b. Vehicle weight and drag reductions
   c. Plug-in electric hybrids and hydrogen fuel cells in the longer term

The lower end of this range is achievable through improvements in mainstream engines and transmissions, which could be deployed in high volumes in the nearer term. It would take longer for more complex or advanced technologies such as hybrids to achieve significant overall reductions in fuel consumption and GHG emissions, due to their higher cost and slower deployment build-up. Radically different technologies such as plug-in hybrids and hydrogen and fuel cells—if developed to the point where they are market-feasible—would at best take more than 30 years to have a significant impact.

The nearer-term changes, when combined in vehicles in appropriate combinations, will result in vehicle cost increases between $1,500–$4,500, if they are produced in significant volumes. The additional costs of plug-in hybrids and fuel cell vehicles are uncertain, but are anticipated to be significantly higher.

3. **Policy has a major role to play.** Policies developed to reduce vehicle fuel consumption will need to take into account the trade-offs between vehicle performance, size (and thus weight), and fuel consumption. Vehicle purchasers and users have shown a clear preference for increasing vehicle performance and size providing market “pull” for these attributes. The automobile companies compete among each other by offering ever-increasing performance and vehicle size, providing the “push.” In the United States, the
emphasis on enhanced performance has been so strong that (with some size increases) no significant fuel consumption gains have been realized over the past 25 years. In Europe, the emphasis on performance has not been as strong, and some half of the potential fuel consumption improvements have been achieved.

4. **Reducing vehicle weight and size has important benefits.** Vehicle weight and size reduction could contribute significantly to reduced petroleum consumption and greenhouse gas emissions. Direct weight reductions through substitution of lighter materials and basic vehicle design changes (which, for example, maximize the interior volume for a given vehicle length and width) enable secondary weight reductions as vehicle components are appropriately downsized. Much of this is straightforward engineering, and some of this weight reduction is relatively low cost. A shift in vehicle size distribution away from larger vehicles also reduces average weight and initially can be accomplished by changes in production volumes. Our estimates indicate that a 20% reduction in sales-weighted average vehicle weight could be achieved over about 25 years. This would cost about $800 per vehicle. The maximum potential for weight reduction at plausible cost is about 35%; this would cost significantly more. These estimates allow for the additional weight required by future safety requirements and convenience features. Vehicle weight reductions of 20–35% on their own result in some 12–20% reduction in vehicle fuel consumption.

5. **Emphasizing reduced fuel consumption over other attributes is critical.** Due to slow rates of fleet turnover, the fuel consumption of mainstream technology vehicles (improved internal combustion engines, transmissions, some weight reduction) will determine the near-term fleet fuel use and GHG emissions profiles. Directing the efficiency improvements thus achieved toward reducing in-use fuel consumption of these high-sales-volume vehicle technologies is therefore critical.

6. **Mainstream technologies will dominate near-term impact.** Due to high initial cost and strong competition from mainstream gasoline vehicles, market penetration rates of low-emission diesels and gasoline hybrids in the United States are likely to be slower than is widely believed. As a result, diesels and gasoline hybrids have only a modest, though growing potential for reducing U.S. fleet fuel use before 2025. In Europe, the potential for impact through improved mainstream engines and weight reduction is significantly less, due to the fact that roughly half the fleet is already diesel, and vehicle size and weight are some two-thirds of average U.S. vehicle values.

7. **Strategies and opportunities for longer-term impact must be explored as early as possible.** In the longer-term, the impact of advanced technology vehicles will be far larger than their near-term impact. However, the time scales to impact of new technologies are long, since they include the build-up to substantial production volumes and significant penetration into the in-use vehicle fleet. Thus, advanced vehicle technology development and introduction when market ready needs to start as early as possible if the long-term reductions in fuel use and GHG emissions that successful deployment would bring are to be realized.
8. **The future benefits of alternative liquid transportation fuels are uncertain.** Alternative liquid transportation fuels are widely viewed as an important and growing contribution to reducing petroleum use and GHG emissions. Currently, the Canadian oil-sands reserves are supplying about 3% of total U.S. petroleum use. This could expand to about 10% of total U.S. consumption in 2030, which would increase well-to-tank GHG emissions by about 5%. Both corn-grain based ethanol and cellulosic ethanol from, say, switchgrass, displace gasoline by two-thirds, volume for volume. The GHG emissions impacts are substantially different, with corn grain ethanol proving only modest GHG benefits and cellulosic biomass-based ethanol potentially providing substantial GHG benefits. Recent discussions of the GHG penalties associated with land use changes to produce the biomass material suggest that the presumed GHG benefits may not be realized. While ambitious targets for ethanol production and use have been set in many parts of the world (e.g., displacing 20% of gasoline by 2020 in the United States), it is unclear whether the targets for cellulosic ethanol (comparable volumes to corn ethanol by 2035) can be met, and what the GHG emissions benefits are going to be. Ethanol has not been cost competitive with past gasoline prices without significant subsidies. With the price of petroleum rising, that situation may be changing.

9. **GHG emission reduction poses additional challenges.** A greater number of vehicle and fuel alternatives are available to displace petroleum use than to reduce greenhouse gas emissions:

   a. Plug-in hybrids, at present a costly and heavy option, might over the longer term play an important role in reducing petroleum use. However, due to the likely GHG emissions from the electricity production required, the GHG emissions reduction that plug-ins would achieve are comparable to those available from change-sustaining gasoline hybrids at a lower cost.

   b. In the United States, ethanol might displace about 10% of gasoline by 2025. However, as explained above, increasing the biomass-to-liquids supply in the near term might help reduce well-to-wheels GHG emissions, but increased use of non-conventional oil is likely to negate this impact. Ethanol’s contribution is likely to be constrained by land availability and yields.

It is thus important that policy efforts be focused on measures that both improve energy security and reduce GHG emissions at the same time.

**8.3 What we should do**

From the results of this study, it is clear that fuel consumption and GHG emissions of our light-duty vehicle fleet can be reduced significantly in the United States. How rapidly that reduction occurs depends on the determination of the major stakeholder groups—vehicle and fuel suppliers, vehicle and fuel purchasers and users, and governments—to vigorously undertake the actions required.

Worldwide demand for transportation services is growing inexorably, and we foresee no single major development that alone can resolve the growing problems of vehicle fuel
consumption and GHG emissions. Therefore, progress must come from a comprehensive effort to 1) develop and market more efficient vehicles and more environmentally benign fuels, 2) find more sustainable ways to satisfy demands for transportation services, and 3) prompt all of us who use our vehicles and other transportation options to reduce our consumption. All of these changes will need to be implemented at very large scale to achieve significant reductions in petroleum, energy, and GHG emissions. Implementation will increase the cost of transportation to ultimate users, and will require government policies to encourage or require moving toward these goals while sharing the burdens more equitably and attempting to minimize total social costs.

1. The time scales for such changes vary, but all are long. Thus, a comprehensive program should include actions designed to achieve fuel and emissions reductions in the near term (up to 15 years), some in the mid-term (15–30 years), and some in the long term (more than 30 years). The preparatory work for both mid- and long-term programs—including extensive research and development—must begin now if we are to ensure that they will be ready to be implemented as currently planned.

2. An especially promising opportunity is the development and deployment of more efficient propulsion systems—engines and transmissions. Critical here is the need to use propulsion system efficiency gains to reduce real-world vehicle fuel consumption, rather than offset increases in vehicle power and size. The latter poses a serious problem of marketability to customers since the long-term market trend has been toward increasingly powerful, larger, and heavier vehicles. Changing that trend may well require both manufacturer and government incentives.

3. A second important opportunity to realize is vehicle weight and size reduction, along with reducing vehicle drag and tire rolling resistance. Weight reduction can be accomplished via the use of lighter materials and vehicle redesign. Vehicle size reduction can be attained by producing and popularizing smaller vehicles to replace larger ones. While some aspects of vehicle functionality may be diminished, the basic mobility attractions of personal transportation can be maintained.

4. Alternative fuels (fuels derived from raw materials other than petroleum) do reduce petroleum consumption, but in the U.S. and Europe they are more likely to increase GHG emissions, in the near term at least, than decrease them. The major near-term alternatives are derived from fossil raw materials (oil sands, very heavy oils, coal, natural gas). Their recovery and refining emissions range from high to roughly break-even with petroleum, even using advanced technologies. In principle, biofuels can reduce GHG emissions drastically to the extent of potential biomass supply. But biofuels production is largely set by agricultural policy as well as energy or environmental policy, and the overall environmental and economic benefits of some biofuels, notably corn-ethanol in the United States, are being increasingly questioned, as are other biofuels in Europe. It is important that we encourage research and development on biofuels with promising environmental and economic prospects and be realistic about their potential contribution.
5. Government policies will be needed to further the overall objectives of our road transportation system as well as reduce its energy and environmental impacts. These policies should be structured to achieve the following:

a. Both push development and deployment of appropriate technologies and generate market pull for those technologies with policies that reinforce each other through synergies. Incentives should be for outcomes, not particular technologies such as current incentives for hybrids, which put other vehicles with low fuel use and emissions at a competitive disadvantage. Such policies will need to be coordinated to achieve the desired progress.

b. Be transparent and appear fair to all stakeholders, especially those suffering the highest costs of the necessary transitions. Transportation-related taxes, fees, and credits should have clear objectives and be revenue-neutral to the extent feasible, and be distributed equitably among stakeholders and user groups.

c. Encourage conservation by users as they choose more efficient ways of using their transportation options, such as less aggressive driving, bundling of trips, and more carpooling.

Overall, this report makes clear that we have many options available for reducing petroleum consumption and greenhouse gas emissions from private motor vehicles in countries like the United States. By realizing these options, current consumption and emission growth patterns can be leveled off and reversed. However, not much will happen without appropriate policies to push and pull improved technologies and greener alternative fuels into the market place in high volume.

Transitioning from our current situation onto a path with declining fuel consumption and emissions, even in the developed world, will take several decades—much longer than we hope or realize. We must keep in mind that what matters is effecting changes that will have substantial impact on these issues. We will need much better technology, more appropriate types of vehicles, greener fuel streams, and changes in our behavior that emphasize conservation. We need nearer-term results that get us out of our currently worsening situation. We will need to transition to much more sustainable pathways in the longer term. And we will need to pursue all these opportunities with determination.