Global Climate Change and the Transportation Sector: An Update on Issues and Mitigation Options

9th Diesel Engine Emissions Reduction Conference

CA Geffen, JJ Dooley and SH Kim
Joint Global Change Research Institute
Battelle, Pacific Northwest National Laboratory

Abstract

It is clear from numerous energy/economic modeling exercises that addressing the challenges posed by global climate change will eventually require the active participation of all industrial sectors and all consumers on the planet. Yet, these and similar modeling exercises indicate that large stationary CO_2 point sources (e.g., refineries and fossil-fired electric power plants) are often the first targets considered for serious CO_2 emissions mitigation. Without participation of all sectors of the global economy, however, the challenges of climate change mitigation will not be met. Because of its operating characteristics, price structure, dependence on virtually one energy source (oil), enormous installed infrastructure, and limited technology alternatives, at least in the near-term, the transportation sector will likely represent a particularly difficult challenge for CO_2 emissions mitigation. Our research shows that climate change induced price signals (i.e., putting a price on carbon that is emitted to the atmosphere) are in the near term insufficient to drive fundamental shifts in demand for energy services or to transform the way these services are provided in the transportation sector. We believe that a technological revolution will be necessary to accomplish the significant reduction of greenhouse gas emissions from the transportation sector. This paper presents an update of ongoing research into a variety of technological options that exist for decarbonizing the transportation sector and the various tradeoffs among them.

Background and Motivation

The 1992 United Nations Framework Convention on Climate Change (UNFCCC), ratified by more than 194 nations, was ratified by the U.S. Senate in the fall of 1992.[1] The UNFCCC commits its signatories to undertake actions to achieve the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[2] The U.S. has reaffirmed that commitment in recent years, stating that "our approach must be consistent with the long-term goal of stabilizing greenhouse gas concentrations in the atmosphere".[3]

[1] United Nations Framework Convention on Climate Change official website. http://unfccc.int/resource/conv/ratlist.pdf.
[2] United Nations Framework Convention on Climate Change, Article II. It is important to note that the Framework Convention on Climate Change is silent on what would be a "safe" atmospheric concentration for greenhouse gases and that these levels remain a subject of debate.
[3] "President Bush Discusses Climate Change", comment taken from speech by President Bush, June 11, 2001, http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html.

The focus on stabilizing *concentrations* of greenhouse gases as opposed to leveling out annual emissions is important for a number of reasons. First, it is the rising cumulative concentrations of greenhouse gases in the atmosphere that will determine the extent and magnitude of adverse environmental damage resulting from climate change. The avoidance of these environmental impacts is the primary reason for attempts to control greenhouse gas emissions. Second, as demonstrated by Wigley, Richels and Edmonds (1996)[4] and more recently Edmonds (2002)[5], stabilizing atmospheric concentrations will require that net emissions of CO_2 at some point peak and then decline, eventually approaching zero. The implication is that eventually (and this could unfold over the course of hundreds of years) the entire *global* economy must approach net zero emissions of CO_2. This paper focuses on the challenges posed by moving the global transportation system and associated infrastructures from its current state, essentially entirely dependent on fossil fuels, to a future state where the integrated system yields near zero emissions. A preliminary analysis of the contribution that diesel technology can make, at least in the near term, to addressing these challenges is also included in this paper.

The Transportation Sector and Climate Change

Addressing climate change will require a fundamental transformation of the way in which we obtain and use energy if we are to achieve stabilization of CO_2 in the atmosphere. The magnitude of the change that will be required to accomplish this transformation of the global energy system is sometimes not well understood. While the specific stabilization level of concern has not been identified, projections of the amount of carbon that would need to be removed from our current system under almost any stabilization regime suggest this challenge is on the order of hundreds of gigatons (1 billion tons of carbon). To put this amount in perspective, one gigaton would be the equivalent of the amount of coal it would take to power the entire U.S. residential sector for 20 months (2002 Billion kWh)[6]. While incremental improvements in technology can certainly help reduce emissions over time, ultimately the large scale deployment of advanced technological alternatives, that are currently not large parts of our energy system, will be needed to achieve these stabilization goals.

Reducing greenhouse gas emissions from the transportation sector presents some particularly difficult challenges due in part to the immense scale of this sector of the global economy. Motor vehicles are the major form of transportation in the developed world, delivering over 90% of all passenger miles in Europe, Canada and the US, and almost 60% in Japan. Freight shipments by truck average 60-70% of all ton-miles in Europe and the US and 40% in Japan.[7] The primary source of energy (over 95%) for the transportation sector is fossil fuels – principally petroleum products.

[4] Wigley, T.M.L., Richels, R., & Edmonds, J. (1996) "Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations." Nature, 379, 240-243.
[5] Edmonds, J. 2002. "Atmospheric Stabilization: Technology Needs, Opportunities, and Timing," in U.S. Policy on Climate Change: What Next? J.A. Riggs (ed.), The Aspen Institute, Aspen, CO. pp. 46-71.
[6] From EIA historical data
[7] U.S. Department of Transportation, Bureau of Transportation Statistics, G-7 Countries: Transportation Highlights, BTS 99-01, Washington D.C., November 1999.

The transportation sector currently accounts for approximately one-third of US CO_2 emissions, and is a significant source of other emissions of environmental concern, including carbon monoxide, nitrogen and sulfur oxides, volatile organic compounds and particulate matter.[8] On-road vehicles contribute the largest share of air pollutants among all modes. However, many air emissions from transportation in the U.S., specifically carbon dioxide, volatile organic compounds, particulates and lead, have declined since 1980 despite significant increases in population, GDP and vehicle miles traveled.[9] While there is an ongoing debate as to whether technological change or regulation has been more effective in driving the increases in fuel efficiency and environmental performance in motor vehicles over the last decades, it is clear that both technological innovation and policy via fuel efficiency and fuel content standards have contributed to these improvements, and that a portfolio of technology and policy options will be required to effect future change.[10]

A recent report from the OECD predicts that the total motor vehicle stock in developed countries will increase from 552 million vehicles in 1998 to approximately 730 million vehicles in 2020, a total growth of 32%.[11] Growth in population and level of affluence is expected to drive significant growth in motor vehicle production and use in emerging economies as well. The demand for freight and passenger transport (primarily by road) in most developing and transition economies is growing 1.5-2 times faster than their gross domestic product.[12] The projected growth in transportation demands highlights the magnitude of the challenges ahead if we are to effectively address the energy needs of this sector and at the same time mitigate carbon emissions.

The Transportation Sector—An Integrated System

The transportation sector is often described as including the production, maintenance and use of both transport infrastructure and mobile equipment, including passenger vehicles. Under this definition, this sector contributes between four and eight percent of GDP in OECD countries. This view, however, provides only part of the story of the contribution of transportation to the economy, and certainly is incomplete when addressing the challenge of climate change. Transport also accounts for over a third of final energy consumption (in OECD countries) and has represented almost two-thirds of the growth in energy consumption since the early 1970's.[13] Thus, while it can be instructive to focus

[8] U.S. Department of Transportation, Bureau of Transportation Statistics, U.S. Carbon Dioxide Emissions, Washington, DC, December 2002, p. 124.
[9] U.S. Department of Transportation, Bureau of Transportation Statistics, Pocket Guide to Transportation 2003, BTS03-01, Washington, DC, January 2003, p. 40.
[10] DeCicco, John and Jason Mark, "Meeting the Energy and Climate Challenge for Transportation in the United States", Energy Policy, Vol. 26, No. 5, pp. 395-412, 1998; and Massachsetts Institute of Technology and Charles River Associates, "Mobility 2001, World Mobility at the End of the 21st Century and its Sustainability", prepare for the World Business Council for Sustainable Development, Switzerland, August 2001.
[11] Organization for Economic Co-Operation and Development (OECD), OECD Environmental Outlook, OECD 2001.
[12] Lester Brown, et al., State of the World 2001, Worldwatch Institute, W.W. Norton & Company, Inc., New York, p. 106.
[13] Organization for Economic Co-Operation and Development (OECD), OECD Environmental Outlook, OECD 2001, pp. 146 and 170.

attention on the traditional definition of the transportation sector in evaluating alternative technological advances, long-term technology options must address the broader system implications of this sector, which are integrally linked to the choice of fuel source. This broader definition of the transportation sector, which includes consideration of fuel sources and the competitive economics of those options, is particularly relevant to analyses regarding climate change and is the basis for the integrated analysis techniques used in this research activity. Clearly, introducing new technological options to this sector that can significantly reduce carbon emissions will have broad implications both for an integrated technological system and its associated infrastructure, and for national and international economic systems.

The transportation sector has proved remarkably robust over the last 75-100 years, and has established a technological paradigm that is likely to prove difficult to change. The foundation of the system is the gasoline-powered internal combustion engine (ICE); the standard of living in the US and other OECD nations as well as large segments of these nations' economic infrastructures have developed around and are predicated on this ICE technological paradigm. Incremental changes to both vehicle technologies and fuel formulations have delivered significant environmental benefits over the years, reducing emissions of a variety of pollutants and increasing fleet fuel efficiency. Yet the system remains fundamentally carbon-based, and as travel demand increases, with more vehicle miles traveled, these efficiency improvements are often outpaced by greater vehicle use. Turnover in vehicle stock is relatively slow, with automobiles serving useful lives of up to twenty years or more. Average fleet efficiencies are thus heavily influenced by the continued operation of older, less fuel efficient vehicles. A study on worldwide mobility trends by MIT suggests that up to half of the total emissions from the passenger fleet, worldwide, may be generated from ten percent or less of the operating vehicles.[14] In addition, recent trends in the U.S. toward consumer preference for larger, less fuel efficient vehicles have initiated a decline in overall fleet fuel efficiencies, after having remained essentially stable for the last ten years.

Alternatives for the Future

While there may be a number of options for reducing carbon emissions in the transportation sector by increasing fuel efficiency, ultimately the sector faces the challenge of shifting away from fossil fuels as a direct energy source. Hydrogen as a fuel source may provide new possibilities for serving the growing energy needs of the transportation sector in the long term, but will clearly require significant research and development before such a significant technological shift might be achieved. Transition to a hydrogen-based transportation system will require concurrent availability of appropriate fuel sources, fuel cells and/or internal combustion engines that can be fueled by hydrogen, and related infrastructure, at a cost and performance that is competitive with the existing petroleum-based system.

[14] Massachsetts Institute of Technology and Charles River Associates, "Mobility 2001, World Mobility at the End of the 21st Century and its Sustainability", prepare for the World Business Council for Sustainable Development, Switzerland, August 2001.

Because hydrogen systems will have the biggest impact in the long-term (the next 25 to 50 or more years) it is important that a broad set of options that include alternative fuels and related vehicle designs be evaluated as interim technologies to serve as a bridge to this hydrogen-based decarbonized future for the transportation sector.[15] If the end game is hydrogen, what does the transition path look like? A number of technological options are emerging for delivering increased fuel efficiency and reducing carbon emissions in the near term while long-term technology solutions are designed and deployed. These options include more extensive penetration of diesel technology in passenger transportation; alternative fuels such as ethanol and biodiesel; and hybrid vehicles, among others.

Diesel engines are beginning to receive some attention as a near-term strategy for meeting fuel economy and climate change goals, based in part on recent improvements in the technology and also on the experiences of the European market, where diesels make up almost 40% of the light duty vehicle fleet (passenger vehicles and light duty trucks).[16] They are currently used in the U.S. primarily for freight transportation in trucks, freight locomotives and marine vessels. There has been a growing trend, however, to use diesel engines in light duty trucks and sport utility vehicles (SUVs) in U.S. markets. Diesel technology can achieve, on average, a 30% improvement in fuel efficiency over traditional gasoline powered engines.[17] Diesels, however, generate other pollutants in greater numbers, including particulates, nitrogen oxides and hydrocarbons. New emission standards scheduled to take effect in 2007 together with related emissions and engine technology improvements should help reduce these pollutants, but these tradeoffs relative to CO_2 emissions should be kept in mind when evaluating diesel technology options.

Given the nature of the transportation sector and the challenges of displacing an incumbent technological system that is highly integrated, identifying potential pathways for change for the transportation sector is a complex challenge. Any analysis of potential change must be done within a long-term perspective; yet an understanding of near term options must be included within this longer term context. The PNNL integrated assessment model (MiniCAM) provides a unique tool for evaluating integrated technological systems (alternative fuel sources, conversion technologies, end use applications and infrastructure options) and was used to conduct this analysis.

The MiniCAM is a long-term, partial-equilibrium model of the energy, agriculture, and climate system. The model can produce an end-to-end analysis of energy supply and demand, emissions of greenhouse gases and local air pollutants, and mitigation costs. It contains an emissions model that considers both energy and land use emissions, as well as the full range of greenhouse gases. The MiniCAM is used for modeling over long time scales, and can model a wide range of technologies, fuels, and energy carriers to supply end-use energy demands. The MiniCAM operates on a 15-year time step starting from the year 1990 as a baseline, and projects out to the year 2095.

---

[15] It is worth noting that the transition to a hydrogen based transportation sector is not preordained nor is a hydrogen based transportation sector the only way to decarbonize this sector of the economy.
[16] McCann, Richard and Eric Cutter, *Reducing California Petroleum Consumption with Increased Use of High Efficiency Clean Diesel Technology*, Final Report, Davis, CA, August 2002, p. 1.
[17] This figure can be significantly higher, depending on engine type and operating conditions. The 30% figure is used in this analysis to provide a conservative estimate.

Previous research in this program, reported on at last year's DEER conference, identified the importance of technological change for achieving environmental improvements in the transportation sector[18]. In the current analysis, the MiniCAM model was used to extend our analysis of transportation technology options, exploring the impact on carbon emissions of a near term shift to diesel technology in passenger transportation, as well as a preliminary analysis of the long-term implications of moving to a hydrogen-based transportation system. Any long term view of the dynamic interactions among environment, economic activity, and social and institutional characteristics of a world one hundred years or more in the future demands the use of scenarios to lend insight to the potential implications of various policy actions or technological advances. Each of the analyses discussed in this paper were conducted against a baseline scenario, termed the "business as usual" scenario. The characteristics and resulting analyses of the baseline scenario and alternative future technology options for increased penetration of diesel technology and potential use of hydrogen systems are described below.

Business as Usual Baseline

The baseline scenario used for these analyses, termed here the "Business as Usual" (BAU) scenario, is modeled on the IPCC SRES-B2 scenario.[19] The B2 world is one that emphasizes local solutions to economic, social and environmental issues. In this future, both global population and economic activity grow steadily, with incremental advances in a diverse portfolio of existing energy technologies. While the gap between rich and poor nations is reduced, development and technological progress occur at different rates across world regions.

Major drivers for the BAU projection of U.S. and global energy consumption and CO_2 emissions are the growth in population and GDP assumed over the course of the 21st century. In this scenario, U.S. population increases to approximately 450 million, while the global population reaches 9.5 billion by the end of the century. The GDP for the U.S. is nearly five-fold at the end of the century and grows at an average rate of 1.6 % per year. The global economy grows even more significantly to a ten-fold increase within the same time frame and at an average rate of 2.2 % per year.

The BAU scenario projects total U.S. CO_2 emissions to double from 1,407 metric tons of carbon (MTC) in 1990 to 2,883 MTC by 2095. CO_2 emissions from passenger transportation services contribute significantly to this total by the end of the century. In the base case, the lack of advanced vehicles and a viable non-petroleum based transport technology result in passenger transportation services alone contributing more than a third of the total U.S. CO_2 emissions in this timeframe.

---

[18] Edmonds JA, JF Clarke, JJ Dooley, SH Kim, and SJ Smith. 2003. "Modeling Greenhouse Gas Energy Technology Responses to Climate Change." *Energy Policy* 863-868. Dooley JJ, CA Geffen, and JA Edmonds. 2002. "Global Climate Change and the Unique Challenges Posed by the Transportation Sector." Published in the Proceedings of the 8th Diesel Engine Emissions Reduction Conference held in San Diego, CA August 26, 2002. (PNWD-SA-5860, Pacific Northwest National Laboratory). November 2002.
[19] Nakicenovic, N., et al. ***Special Report on Emissions Scenarios***. Cambridge University Press, Cambridge, United Kingdom, 2000.

In 1990, the energy intensity of passenger automobiles and light trucks was 6,183 and 7,774 Btu per vehicle mile, respectively, or approximately 18 and 14 miles per gallon (mpg) of gasoline, respectively.[20] An improvement in fuel intensity of 0.5% per year was assumed for both of these modes for the rest of the modeling time period. Historically, fuel intensities per vehicle mile for automobiles and light trucks have been falling at a faster rate, approximately 2% per year, in the last several decades, although they have leveled off in recent years. The lower levels of improvement in fuel intensity have been assumed for this analysis to explore the nearer term implications of greater penetration of diesel vehicles and their potential role in improving the overall fuel economy of passenger transportation service. The diesel penetration scenarios are described in the next section of this paper.

Two Scenarios of Diesel Penetration

Two scenarios were developed for this paper to explore the potential impact on CO_2 emissions of greater diesel vehicle penetration in the passenger vehicle segment of the U.S. market. In the first scenario, we assumed that diesel engines obtain and hold 50 percent of the market for passenger automobiles and light trucks (50% Diesel Penetration). The second scenario assumed that diesel engines obtain and hold 100 percent of the market (100% Diesel Penetration). We assume that this turnover occurs in one model time period or 15 years which corresponds to the average vehicle lifetime. No change was assumed in the freight transportation segment of the market, with continued dominance of diesel technology in heavy trucks. All other parameters of the BAU base case were held constant to allow determination of the direct impact of increased diesel penetration on CO_2 emissions.

Using the MiniCAM model, a single value each was used to represent the average fuel efficiencies of the automobile and light truck modes. To simulate diesel engine penetration for passenger automobile and light truck modes, we assumed higher overall fuel efficiencies for these modes. For the 50% Diesel Penetration case, an average of the baseline fuel economy and a 30% higher fuel economy was used. For the 100% Diesel Penetration Case, fuel efficiencies 30% higher than the base case were used.

We introduced the increased penetration of diesel technology after the 2005 model year with full 50% and 100% penetration by 2020. The specific mileage assumptions used in each of the diesel cases are shown in Figure 1. Average automobile fuel efficiencies in 2020 of 25 mpg and 29 mpg were assumed for the 50% and 100% Diesel Penetration cases for all automobiles. For light trucks, 20 mpg and 23 mpg were assumed in 2020 for the 50% and 100% Diesel Penetration cases. By 2095, assuming incremental improvements in fuel efficiency of 0.5% per year, automobile fuel efficiencies grow to 36 and 41 mpg; light truck fuel efficiencies reach 29 mpg and 33 mpg, as shown in Figure 1 below.

[20] Center for Transportation Analysis, Oak Ridge National Laboratory, Transportation Energy Data Book, Edition 18, September 1998.

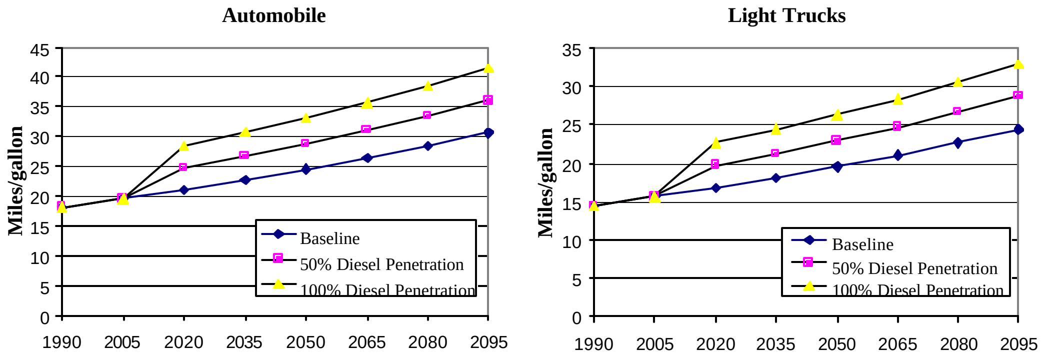

Figure 1. Assumed Passenger Auto and Light Truck Fuel Efficiencies

The higher fuel efficiencies simulated by the 50% and 100% diesel penetration result in reductions in passenger transport sector fuel consumption, and resultant decreases in CO_2 emissions as shown in Figure 2. The 50% Diesel Penetration case results in a reduction of passenger transportation fuel consumption of from 11 to 13 percent from the base case throughout the modeling time period; 100% penetration of diesel technology results in a reduction of fuel consumption of from 20 to 23 percent from the base case. Full penetration of diesel technology reduces petroleum requirements from those needed in the baseline scenario by about 6 Exajoules (EJ) per year of petroleum in the early part of the century to 12 EJ per year of petroleum by the end of the century. This is equivalent to a savings of from 2.7 to 5.4 million barrels of crude oil per day. In both these cases, demand for passenger transport services remains essentially unaffected, although slightly higher levels of demand due to higher fuel efficiencies and thus a lower cost of passenger transport are observed in the model (i.e., people drive more because these fuel efficiency improvements have made the cost of owning and operating a vehicle slightly lower).

The reductions in fuel consumption from the passenger transport sector directly affect the projected emissions of CO_2. Emission reductions are essentially the same in percentage terms as reductions in fuel consumption. In absolute terms, from 69 to 128 MTC per year are avoided in the 50% Diesel Penetration case and from 122 to 224 MTC per year are avoided in the 100% Diesel Penetration case.

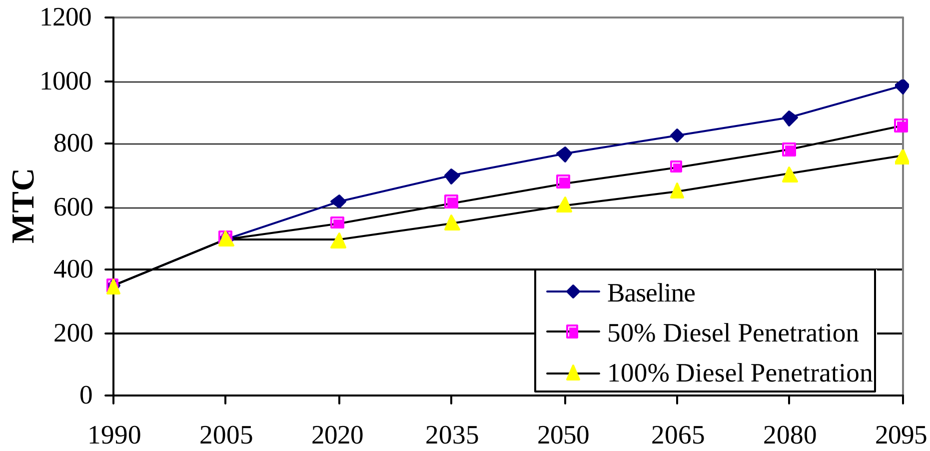

Figure 2. U.S. Passenger Vehicle CO_2 Emissions

Based on this analysis, it is clear that greater penetration of diesel technology in the passenger transportation sector can result in reduced emissions of CO_2 from this sector. It should be noted that this preliminary analysis did not, however, address the potential increase in other greenhouse gases and related constituents, including black carbon and particulates, that might be observed from greater use of diesel technology. A more detailed study accounting for all relevant greenhouse gases, as well as local and regional air quality impacts, is necessary.

It is also important to recognize that the reductions in emissions observed from greater penetration of diesel technology, while important from the perspective of a single end-use service and demand sector, represent only 3 to 10 percent of the total U.S. CO_2 emissions projected from all sectors. Achieving larger reductions in emissions profiles will require the development and deployment of a wide variety of technology options, including non-carbon emitting technologies and alternative fuels, across multiple sectors of the economy to have any significant impact on the long-term reduction of total U.S. CO_2 emissions.

Long-Term Scenarios: Hydrogen and Carbon Mitigation Policies

The analysis of the impact of increased penetration of diesel technology suggests that fuel efficiency improvements alone cannot dramatically alter the future CO_2 emissions trajectory from the transportation sector. Even with an average fuel efficiency for all passenger automobiles in excess of 40 mpg, CO_2 emissions from passenger transport more than double by the end of the century (see Figure 2). The great demand for passenger transport service driven by a multi-fold increase in population and income ultimately overwhelms the emissions mitigation from improvements to vehicle fuel efficiencies.

One scenario that could potentially reverse the trend of growing CO_2 emissions from the transportation sector over the course of the 21st century includes a future with advanced technologies that use hydrogen as an energy carrier. To achieve the goal of low to zero emissions from such a scenario, the life cycle of this energy option must be evaluated. Production of hydrogen, in this case, must occur without the emission of carbon, such as through nuclear or renewable energy or through capture and storage of carbon from fossil fuel conversion. To explore the impact of long-term use of hydrogen in the transportation sector, we include a preliminary analysis conducted for the Energy Modeling Forum (EMF19) at Stanford University.[21] In this study, the deployment of hydrogen fuel cell vehicles, along with hydrogen production with carbon capture and storage, under a carbon constraint policy was shown to dramatically change the future CO_2 emissions trajectory from the transportation sector. Assumptions made for this analysis include fuel cell vehicles available at a cost that is competitive with the traditional ICE technology and efficiencies reaching 100 mpg (equivalent) by the end of the century.

Based on the expected availability of hydrogen based systems and technologies (by the middle of this century), implementation of hydrogen based transportation systems begin to have an impact by mid-century, and begin to reverse the projected levels of carbon emissions, resulting in emissions being cut by half the current level by the end of the century, as shown in Figure 3. It is important to note, however, that this level of reduction can only be achieved through the concurrent development and application of other advanced technologies, including carbon capture and disposal technology, to ensure that carbon emissions are not simply displaced from the transportation sector to the new hydrogen production industry.

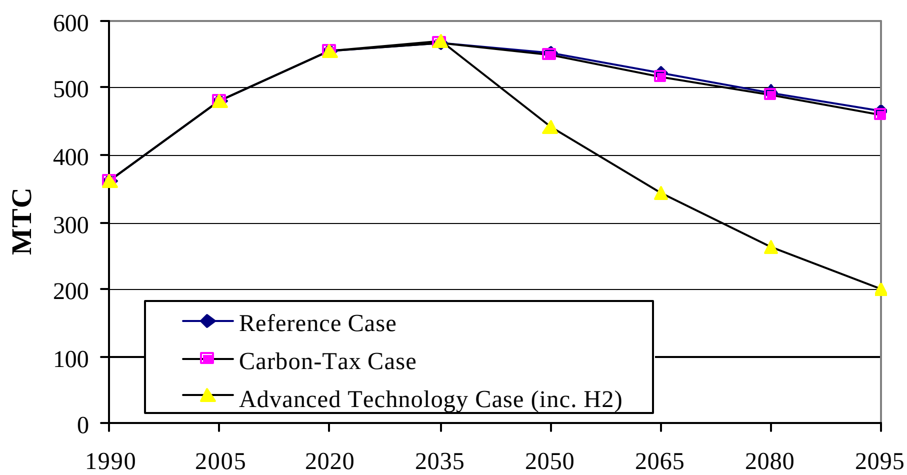

Figure 3. U.S. CO_2 Emissions from the Transportation Sector

[21] Edmonds JA, SH Kim, and SJ Smith. "PNNL MiniCAM EMF-19 Results-Part II." PNNL-SA-36622, Pacific Northwest National Laboratory, Richland, WA, 2002.

Conclusion

This analysis clearly demonstrates the value, from the perspective of carbon emissions, of moving to more fuel efficient technologies as they become available. The immediate reductions in CO_2 emissions observed from increased penetration of diesel technology can provide an important start to reducing the impact of the transportation sector as more advanced technologies, such as hydrogen systems, are being developed. The direct correlation of fuel intensity and CO_2 emissions suggests that in addition to diesel technology, greater use of hybrids would also have a positive near term impact on the emissions profile from this sector.

In the long-term, hydrogen provides new possibilities for serving the growing energy needs of the world through a wide diversity of energy sources. Depending on the production technique used, hydrogen also has the potential to meet these future needs without the direct environmental impacts observed with current energy technologies. In a world where energy security is of increasing importance and emissions of carbon are severely constrained, a hydrogen-powered economy may be an attractive alternative for meeting societal needs. Yet a transition from current energy sources to a hydrogen-based economy will require concurrent availability of appropriate fuel inputs, production techniques, end use technologies and related infrastructure, all at a cost that is competitive with existing energy technology systems. Furthermore, it is not the only alternative. Hydrogen systems, like every energy system, must compete for their market share.

Promoting greater use of more efficient technologies currently available across all sectors of the economy, as in the case of diesel in the transportation sector, is likely to provide an important interim contribution to CO_2 emissions mitigation as more advanced technologies are developed, tested and deployed. More aggressive improvements to fuel efficiencies will have even greater benefits to emissions reduction, particularly if such technologies are readily available and at low cost.

Significant diesel penetration could yield important emissions reductions and provide a step forward in the transition to a lower carbon-emitting transportation system. While penetration of diesel engines for passenger transport alone cannot solve the climate change problem, the more we can do in the near term to reduce greenhouse gas emissions at reasonable cost by promoting the use of available technologies is a worthwhile contribution. While hydrogen has the potential in the long term to help address climate change and energy security simultaneously, depending on how it is produced, the economic and technical feasibility of this technology, as well as the development of a production and fueling infrastructure to support such a fundamental transition, is likely several decades away.