



ASME GENERAL POSITION STATEMENT ON

TECHNOLOGY AND POLICY RECOMMENDATIONS AND GOALS FOR
**REDUCING CARBON
DIOXIDE EMISSIONS**
IN THE ENERGY SECTOR



APRIL 2009

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EXECUTIVE SUMMARY

Atmospheric levels of carbon dioxide (CO₂) have increased steadily since the beginning of the industrial revolution and these levels are projected to increase even more rapidly as the global economy grows. Significant climate changes are very likely associated with increased atmospheric concentrations of certain gases, most significantly CO₂. The human and ecological cost of climate changes forecast in the absence of mitigation measures is sufficiently large, and the time scales of both intervention and resultant climate change response are sufficiently long, that prudent action is warranted now.

The ASME, founded in 1880 as the American Society of Mechanical Engineers, recommends that CO₂ emissions be reduced to achieve a sustainable atmospheric concentration. This paper provides a technology and engineering perspective, with policy and technology goals. Given the complexity of a carbon-constrained energy portfolio and its associated economic issues, integrated governmental, industrial, technological, and societal approaches are required to control and reduce CO₂ emissions. The technical and economic means for significantly reducing CO₂ emissions are within reach. Substantial additional research, development, and deployment investments are required to demonstrate technology viability, ensure enabling infrastructures, and minimize cost. Given the time constants for technology deployment and associated climate responses, prudent action addressing CO₂ emissions in the near term will have less negative economic impact than deferring action, which necessitates more draconian emissions reductions in the future.

Additionally, ASME acknowledges that adaptation to climate change will be an important and necessary climate response strategy. We therefore recommend that the likely consequences of climate change be determined with more clarity, and that effective measures to adapt to such consequences be identified, prioritized, and incorporated into governmental policies as soon as reasonably practicable.

Policy Recommendations

ASME recommends that a policy framework to address CO₂ emissions include:

- *Mandatory, progressive targets to reduce emissions associated with all major energy sectors including power generation, transportation, manufacturing, and commercial and residential buildings, focusing on near-, mid-, and long-term timeframes.*
- *Flexible approaches to motivate achieving CO₂ emission limits that may vary by economic sector, and could include, depending on the sector, market-based incentives; governmental loan guarantees; investment tax credits; performance standards; tax reform; incentives for technology research, development and deployment; and other appropriate policy tools.*
- *Approaches that account for the global dimensions of achieving and maintaining sustainable levels of atmospheric CO₂ and encourage cooperative action by all countries, including the U.S. and large emitting nations in the developing world, to implement CO₂ emission reduction strategies.*
- *Investments in research to develop cost-effective renewable and efficient energy technologies, improve the performance of carbon energy systems, and support the research for new, clean energy systems and processes.*
- *Increased emphasis and investment in education and training of the workforce in all advanced energy technologies and their deployment.*
- *Enhanced development of infrastructures that are required to implement technologies that reduce CO₂ emissions.*

Technology Goals

Timely development and implementation of cost-effective technologies to reduce CO₂ emissions will be required. We therefore recommend the following technology goals:

- **Revolutionize** the carbon footprint of electricity production by:

- Increasing generation efficiency, demonstrating environmentally sound carbon capture and storage (CCS) from coal and natural gas fired generation, and exploring revolutionary improvements in carbon-based fuel cycles.
- Accelerating the development and deployment of renewable electricity generation, including enabling storage and electrical infrastructures.
- Resolving nuclear waste management, closing the nuclear fuel cycle, and streamlining regulatory approval of safe, secure, next-generation nuclear power plants.
- Enhancing electric transmission and distribution, and developing and deploying the smart grid.

- **Reinvent** transportation by:

- Accelerating the development of electric vehicles as well as an advanced electric grid capable of energy storage in order better to accommodate this technology with renewable electricity.
- Accelerating development of alternative propulsion technologies including more efficient engine and power trains concepts and systems, including those employing renewable fuels.
- Developing environmentally sustainable transportation fuels such as cellulosic ethanol, hydrogen fuel cells, algae-generated, and other alternative fuels.
- Adopting sustainable lifecycle design changes to minimize energy and environmental footprint.
- Facilitating development and deployment of transportation infrastructures and operational approaches that minimize GHG emissions while enabling growth of freight and human transport.

- **Transform** the buildings sector by:

- Mandating development, demonstration, and deployment of codes and standards encouraging building construction and retrofit to enable the use of sustainable materials and highly energy-efficient architectural, equipment, and operating systems.
- Increase research, development, and demonstration of methods to increase energy efficiency in building operations and integration of building equipment (including on-site generation) into the local energy infrastructure (particularly the electric grid).
- Resolving technical, regulatory and business practice barriers for broad implementation of on-site combined heat and power and renewable energy systems for building applications.

- **Promote** more sustainable industry by:

- Creating incentives for adopting energy-efficiency measures in industry.
- Promoting increased levels of recycling and remanufacturing to recover the energy invested through virgin material processing and reducing the embedded energy content of materials.

- **Empower** innovation by:

- Increasing the breadth and collaboration of participants in R&D.
- Additional economic incentives for private sector R&D for possible breakthrough technologies.
- Increasing the quantity of R&D for low carbon technologies.

Terms of Measurement

Bcf	109 cubic feet (at standard temperature and pressure)
Bcfd	Bcf per day
GDP	Gross Domestic Product, a measure of national economic output
Gg	gigagrams (10 ⁹ grams)
Gigatons	10 ⁹ tons (1 ton = 2000 pounds)
GW	gigawatts (10 ⁹ watts)
kW	kilowatts (10 ³ watts)
Mt	megatons (10 ⁶ tons)
MW	megawatts (10 ⁶ watts)
PJ	petajoules (10 ¹⁵ joules)
ppb	parts per billion (typically volumetric)
ppm	parts per million (typically volumetric)
Tcf	10 ¹² cubic feet at standard temperature and pressure)
Tg	teragrams (10 ¹² grams or 10 ⁹ kilograms, or 10 ⁶ metric tons)
tonnes	1000 kilograms, also termed <i>metric ton</i> (1 kilo gram = 1000 grams)



1.0 INTRODUCTION

Founded in 1880 as the American Society of Mechanical Engineers, ASME has monitored the progression of interest and activity related to climate change for more than a decade. ASME members are deeply involved in technology, especially those technologies that are most affected by, and most responsive to, the climate change challenge. Climate change has the potential to profoundly impact how civilization interacts with nature. In this position paper, ASME focuses on technologies for reducing carbon dioxide (CO₂) emissions associated with energy generation, conversion, and utilization, which are the largest anthropogenic sources of such emissions. Other gases affecting climate change (e.g., methane, nitrous oxide, ozone, and sulfur hexafluoride) are not addressed because they are less concentrated in the atmosphere and believed to have less impact on climate.

In December 1998, ASME issued a general position paper entitled, *Technology Implications for the U.S. of the Kyoto Protocol Carbon Emission Goals*. This paper highlighted the substantial challenge for the U.S. to meet the then proposed Kyoto agreement goals. ASME asserted that the U.S. would be unable to meet these goals under the proposed time constraints of the Kyoto agreement. Rather, a four-pronged approach was advocated as a reasonable approach, summarized as:

- *Accelerate the introduction of environmentally sound available technology, while government and industry develop advanced technologies that reduce carbon emissions.*
- *In the near term, shift primary fuel use away from coal to natural gas and accelerate the development and implementation of nuclear, renewable, and sustainable biomass energy for electric power production.*
- *Maximize implementation of advanced technologies, while recognizing that schedules and approaches should accommodate long lifetime of existing capital equipment and potential need for industrially specific metrics.*
- *Consider strategies that are more global and political (though such strategies as reforestation, carbon sequestration, permit trading, tax policy, and government grants were not discussed).*

In the intervening years, scientists worldwide continued to monitor and assess the physical, chemical, and biological factors relevant to climate change. Governments and industry have followed the scientific progress made thus far in understanding and predicting climate change. As a result, government and industry are now poised to begin making broad national and international policy decisions focused on reducing greenhouse gas (GHG) emissions.

ASME reconvened a Climate Change Task Force to review progress and update the insights and recommendations of this earlier study, particularly for use by decision makers in government and industry. In this paper, ASME presents the perspectives gained in the deliberations of that Task Force, refined through discussions within ASME, and approved by the ASME Board of Governors.



2.0 CLIMATE CHANGE AND IMPLICATIONS

In 2007, the Intergovernmental Panel on Climate Change (IPCC) issued its Fourth Assessment Report (Solomon 2007; Parry 2007; Metz 2007). Based on physical, chemical, and biological measurements and observations, the IPCC concluded that global warming is unequivocal.

The IPCC also concluded that atmospheric concentrations of gases with significant influence on earth's solar radiative processes have increased substantially. The most significant of these gases is CO₂, which has risen from a pre-industrial level of about 280 ppm to more than 380 ppm, a level substantially higher than any level during the last 650,000 years. Similarly, methane (CH₄) and nitrous oxide (NO_x) concentrations have risen substantially from pre-industrial levels (from 715 ppb to 1730 ppb, and 270 ppb to 319 ppb, respectively). For these gases, most of the concentration increases have occurred during the last 100 years. Other gases such as ozone and sulfur hexafluoride also contribute to climate change, but their impact is less.

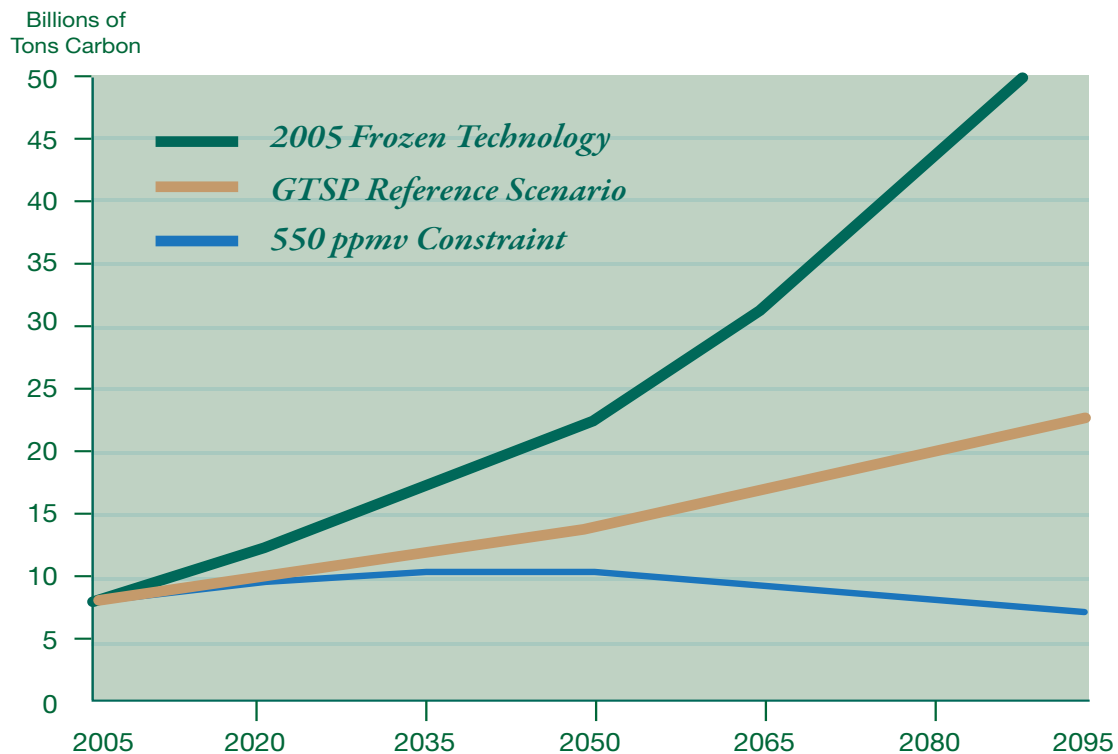


Figure 1. Illustration of Carbon Emission Reductions Estimated to be Needed to Limit CO₂ Concentration to 550 ppm. (GTSP Reference Case assumes implementation of best available technology)(Edmonds et al. 2007).

Furthermore, the IPCC has asserted that increases in these GHGs are likely due to human activity. This assertion marks an increased confidence by the IPCC, relative to earlier IPCC reports, that anthropogenic GHG emissions are a significant driver in global warming. With continued research, gaps in our current knowledge will diminish permitting improvement in future predictions of climate change and its consequences, and resolution of the role of anthropogenic emissions in climate change. Such research is essential because decisions ultimately rest on this body of knowledge.

Typically, the time scales of global change are measured in centuries or longer. Carbon dioxide emissions have an estimated atmospheric half-life of 27 years, which means almost one-third of today's emissions will remain in the atmosphere for 100 years. *Figure 1* illustrates the magnitude of emission reduction estimated to be required to limit atmospheric CO₂ concentration to approximately twice the preindustrial level (Edmunds et al. 2007). Action taken now to reduce emissions can limit the maximum concentration (and consequent impacts) or delay the point at which higher concentrations are realized.

The consequences of climate change are predicted to include substantial changes in local and regional ecology due to changes in rainfall, sea level and chemistry, and temperatures. Depending on their severity, these physical and ecological changes could affect the majority of earth's population, due to such impacts as global dislocation of coastal communities, major geo-agricultural and marine productivity changes, changing pest-predator-prey relationships, and increased storm severity and frequency.

Although only a limited number of economic studies have been conducted, one of the most thorough studies estimates that the economic impact associated with climate change will be 5 percent of the global gross domestic product (GDP) if no actions are taken (Stern 2007). Additionally, if higher ranges of risk and impact are assumed, the impact could be as high as 20 percent of global GDP.

The scientific progress in monitoring and analyzing climate change, combined with increasing appreciation of the consequences, has inspired calls for action by the leading governmental science academies,¹ scientific societies (AGU Council 2003), and industrial/corporate partnerships.²

2.1 HUMAN CLIMATE CHANGE CHALLENGE –ADAPTATION & MITIGATION

Two courses of action are available to address the challenges associated with climate change: 1) adapting to the consequences of climate change and 2) mitigating climate change through reduction of GHG concentrations.

Adaptation focuses on implementing measures that enable people to alter their lifestyles in ways that minimize impact of climate change on their lives. Such measures are driven by the nature and degree of climate change and the subsequent influence of those changes on mankind. Examples of adaptation measures include promoting efficient use of water resources; developing low-cost technologies for desalinating seawater; improving

¹ Joint science academies' statement on growth and responsibility: sustainability, energy efficiency and climate protection. May 2007. Accessed October 13, 2008 at www.nationalacademies.org/includes/G8Statement_Energy_07_May.pdf.

² U.S. Climate Action Partnership. 2007. A Call for Action. Accessed October 13, 2008 at <http://www.uscap.org/USCAPCallForAction.pdf>.

health care and pest control; developing and using drought-resistant crops; and constructing disaster-resistant buildings and infrastructures. Although policies to implement adaptation measures may be established at a global, national, or regional level, the consequences of climate change and the necessary adaptation to it must be undertaken locally, with the burden of adaptation borne by those literally in harm's way.

Infrastructure and societal changes that might be required to suitably and economically limit the consequences of climate change will require long implementation times. Therefore, early identification of likely climate change effects and the potential responses to minimize the impacts is essential. These measures include technological, institutional, financial, and regulatory approaches. The need, means, and will to adapt vary greatly around the world. Consequently, the efforts to adapt to climate change will require the same degree of cooperation and coordination that will be needed to mitigate climate change. It is unlikely that costs of both mitigation and adaptation will be borne equitably (i.e., those who contribute to mitigation may or may not see proportionate reduction in costs for adaptation). Although attention to mitigation may diminish the scope of adaptation, these fundamentally different endeavors require different approaches.

Enabling Actions

- 1. Refine the tools to project climate change impacts and employ those tools to assess measures that will reduce the magnitude and cost of managing those impacts.*
- 2. Enact appropriate international, national, regional, and local approaches to minimize the long-term cost and magnitude of action needed to respond to climate change through well-designed adaptation measures.*

This position paper focuses on mitigation measures, primarily in the energy sector. Mitigating climate change by reducing GHG concentrations has many dimensions ranging from reducing emissions to increasing natural processes for GHG removal and long-term sequestration. Examples of measures to reduce emissions include improving combustion efficiency in engines, reducing use of fossil fuels for power production, improving energy efficiency in buildings, increasing the use of recycled materials, and shifting from fossil fuels to low carbon energy sources. Examples of measures to increase natural GHG capture and long-term sequestration include increasing forestation (and reducing deforestation), increased use of vegetation with high biomass productivity and carbon sequestration, improved crop and grazing land management, reclamation of peaty soils, reduced nitrogen fertilizer use, and improved rice cultivation practices.

Similar to adaptation, the potential societal impacts of implementing mitigation measures are enormous. However, those most affected by implementation of mitigation measures are rarely those most affected by climate change. This, and other inequities, creates a staggering challenge to those seeking to mitigate climate change, necessitating highly-cooperative, coordinated approaches that span public and private institutions, require dramatic acceleration of technology development, and transformational change in financial and regulatory structures. Historically, only in times of world war has meeting a common challenge demanded the depth and degree of global collaboration that is required in this case.

Meeting this challenge, while daunting, offers enormous opportunity to develop and implement new technologies. Developing and deploying these new technologies may have unparalleled economic rewards, that complement societal and environmental benefits.

ASME has chosen to focus its attention on reducing anthropogenic emissions of CO₂. This choice is based on an assumption that governments and industry will make decisions regarding the reduction in anthropogenic CO₂ emissions. It is also based on the knowledge that ASME is particularly well suited to address the energy sector because of the strong role its members play in all aspects of the energy sector (source of most CO₂ emissions). This paper also provides insight regarding the technical options available for reducing CO₂ and associated actions required to enable those options.



3.0 REDUCING GREENHOUSE GAS EMISSIONS

Between now and 2050, the global economy is expected to grow by a factor of four and as much as a factor of 10 in developing countries like China and India (OECD/IEA 2008). Such growth will inevitably require increased energy use. The International Energy Agency forecasts a 70 percent increase in oil demand and a 130 percent increase in CO₂ emissions by 2050.

Approximately 65 percent of global anthropogenic GHG comes from energy-related activities and the remaining 35 percent comes primarily from agricultural and land-use practices. For most industrial countries, the most significant anthropogenic GHG is CO₂. Most CO₂ is emitted as a result of using fossil fuels. Globally, 89 percent of primary energy consumed comes from fossil fuels (85 percent in the U.S.). *Figure 2* shows a flow chart of CO₂ emissions from primary energy use in the U.S.³ Electric power production accounts for the most CO₂ emissions, followed by the transportation sector, industrial sector, and natural gas in buildings. However,

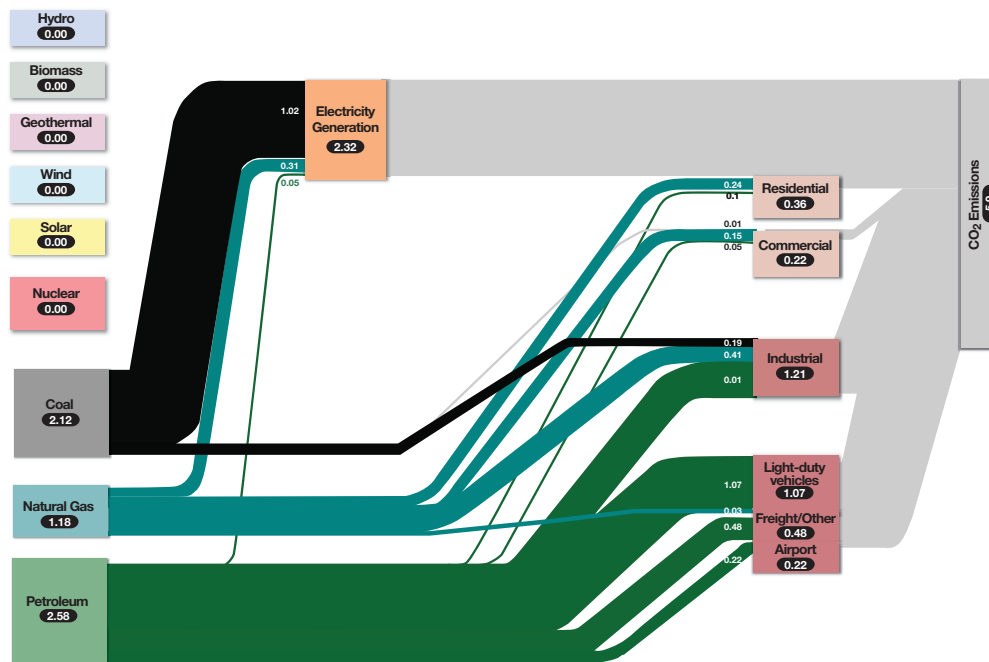


Figure 2. CO₂ Emission for U.S. Energy Utilization – Gigaton

³ President's Council of Advisors on Science and Technology. 2006. The Energy Imperative – Technology and the Role of Emerging Companies; Report of the President's Council of Advisors on Science and Technology. Accessed October 13, 2008 at http://www.ostp.gov/pcast/PCAST-EnergyImperative_FINAL.pdf.

buildings are responsible for more than 70 percent of electricity use; therefore, reducing electricity use in buildings directly affects carbon emissions in electricity production.

Developing global, national, and local strategies to address CO₂ emissions through technology policy inevitably requires that careful attention be paid to the entire lifecycle of energy resources and subsequent usage. The production, conversion, transport, and use of energy can involve many processes that affect GHG emission. Therefore, it is vital that life-cycle analyses, which include all GHG-related facets, be adopted as a standard analytic approach in development⁴ of technology policies for carbon reductions.

Enabling Actions

1. *Adopt systems-level, life-cycle analyses for characterization and comparison of technologies and policies to potentially reduce GHG emissions.*
2. *Develop GHG emission impact metrics to support analytic methods at all system levels.*

3.1 ELECTRICITY FOR A CARBON-CONSTRAINED WORLD

Reducing GHG emissions requires assertive action in all energy sectors. For electricity production, there essentially are three methods to reduce CO₂ emissions: 1) use fuels with lower or no CO₂ emission per unit of electricity produced, 2) increase the efficiency of both electricity production and end-use, and 3) capture and permanently store CO₂ emissions. These methods are applied in electricity generation by increasing the use of renewable energy sources, increasing the use of nuclear power, and reducing the carbon footprint of fossil power. End-use of electricity is addressed in Sections 3.6 and 3.7.

3.2 REVOLUTIONIZING THE CARBON FOOTPRINT OF FOSSIL POWER

Fossil fuels generate two-thirds of the world's electricity, and in doing so, produce one-third of global CO₂ emissions. This sector also accounts for emissions of minor amounts of other GHGs, notably methane during the production and transport of coal, natural gas, and oil. Coal fuels more than 40 percent of global electricity generation and 50 percent of U.S. electricity. Natural gas provides about 20 percent of electricity—both globally and in the U.S.. Oil is a relatively minor player in the electricity sector and provides 7 and about 2 percent of global and U.S. electricity, respectively.

Coal use is projected to increase under foreseeable scenarios because it is inexpensive and abundant (EIA 2007a). Abundant coal resources are distributed in many regions of the world. In particular, the U.S., China, and India have large coal reserves. Even under high carbon-emission cost scenarios, coal use is projected to increase (MIT 2007).

⁴ ISO 14041. 1998. Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis. International Organization for Standardization. Geneva, Switzerland.

Advancement of three technology options will enable reduced CO₂ emission from use of fossil fuels for power generation: fuel substitution, efficiency improvement, and carbon capture and sequestration.

Fuel Substitution

Using natural gas to produce electricity instead of coal can reduce the CO₂ emissions per kilowatt-hour (kWh) of electricity generated by one-half. This reduction assumes that the natural gas is produced in North America. The life-cycle GHG emissions for electricity produced using liquefied natural gas (LNG) can be as much as 35 percent higher than using coal because of increased emissions associated with liquefying, transporting, and regasifying the LNG (Jaramillo et al. 2007).

Traditionally, bio-derived fuels (e.g., forest and agricultural waste) are considered renewable with zero net-carbon emissions and therefore, when co-fired with coal, reduce the net CO₂ emissions by the fraction of bio-derived fuel employed. However, a recent study indicates that the biomass production method is a significant factor in determining net emissions (Fargione et al. 2008). Converting grassland to a biofuel farm can incur a carbon debt; however, growing perennial biofuels on abandoned agricultural land can offer a sustained GHG advantage. Hence, CO₂ emission accounting associated with fuel substitution must be done on a life-cycle basis.

Efficiency Improvement

Increased generating efficiency translates directly into lower CO₂ emissions per kWh of electricity produced. Currently, pulverized coal (PC) combustion is the primary technology used to generate electricity. For new plants, significant efficiency gains for PC technology are realized by increasing the peak temperatures and pressures of the steam cycle, albeit at higher capital cost for the advanced materials these systems require. Supercritical plants are commercial technology and have an efficiency of approximately 39 percent (relative to 30-35 percent for most existing PC plants). Ultra-supercritical PC power plants have an efficiency of approximately 43 percent with the potential to increase to approximately 48 percent with improved, high-temperature materials. While no ultra-supercritical plants have been built in the U.S., higher fuel costs have led to the construction of almost a dozen plants in Europe and Japan. Compared with subcritical plants, supercritical plants have 10 percent lower CO₂ emissions and ultra-supercritical plants have 25 percent lower CO₂ emissions (MIT 2007).

Integrated Gasification Combined Cycle (IGCC) plants, a relatively new option for power generation, have efficiencies of 38 to 42 percent. With technology advancements such as membrane-based oxygen separation, advanced steam and gas turbine designs, and integrated solid oxide fuel cells, IGCC plant efficiencies could approach 50 percent. Four coal-based IGCC demonstration plants have been built in the U.S. and Europe—all with government support.

Sequestration

Carbon capture and storage (CCS) involves capturing CO₂ streams in power plants and injecting them at high pressures into deep geologic formations, for permanent storage. Natural analogues from oil and gas fields indicate that CO₂ can remain trapped for millions of years (Metz 2005). CCS can be feasibly integrated into all new, large, CO₂-producing power plant systems to reduce carbon emissions by 90 percent or more.

Implementing CCS inevitably increases the cost of coal-fueled electricity. Currently, supercritical PC plants without CCS are the least cost option. The cost of electricity (COE) of an IGCC plant without CCS is 20 percent higher than the comparable supercritical plant without CCS. However, if CCS is incorporated, the COE is 65 percent higher in an IGCC plant and rises to 80 percent higher in a supercritical PC plant relative to the comparable supercritical plant (NETL 2007). Technologies under development have the potential to reduce the incremental increase in COE for CCS applied to either PC or IGCC plants to 25 percent above the base

case without capture (EPRI ETAC 2007). Since neither IGCC nor PC plants have demonstrated CCS, further development of these technologies is warranted.

If, as expected, coal maintains a major role in U.S. electric power production, applying CCS technologies to nearly all new coal-based power plants entering service after 2020⁵ would make the largest single contribution towards reducing future U.S. electric sector CO₂ emissions.

Enabling Actions

1. *Build multiple, commercial-scale, coal-based demonstration plants operating with 90 percent CO₂ capture and with the associated infrastructures to transport and store the captured CO₂ by 2015. This demonstration schedule would enable commercial deployment of CCS by 2020.*
2. *Resolve the legal, public acceptance, and regulatory issues that arise from the many phases of a Carbon Capture and Sequestration project.*
3. *Increase efficiency, reduce capital cost, and improve reliability of the Pulverized Coal and Integrated Gasification Combined Cycle technologies.*
4. *Increase domestic natural gas supply by reducing technological and regulatory barriers to producing gas from unconventional resources such as coal bed methane, landfill gas, and sand formations that require stimulation.*

3.3 REALIZING THE POTENTIAL OF RENEWABLE ELECTRIC POWER

Renewable energy technologies generate far lower or near-zero emissions of GHGs compared with fossil fuels. Renewable electric technologies include hydropower, wind, solar (concentrating solar thermal power and photovoltaics), geothermal, waste-to-energy and combustion of renewables and waste (biomass).⁶ According to the Energy Information Agency, conventional hydroelectric power is the largest source of renewable electricity in the U.S., generating 7.1 percent of electricity produced in 2006 by the electric power sector (EIA 2008). Wind, solar, geothermal, biomass, and nontraditional hydrokinetic (wave/tidal/currents) account for only a small fraction of the electricity produced worldwide despite the availability of technologically advanced systems. Adaptation of non-hydropower renewables has been slow for complex reasons including the cost relative to conventional fossil fuel energy, the uncertainty of deploying new technologies, and the technical challenges of storage and distribution. At present, worldwide efforts to encourage growth in installed renewable capacity are driven by government policies and incentives.⁷

⁵ Future of Coal: Hearing on S. HRG 110-69 Before the Committee on Energy and Natural Resources, 110th Congress (2007) (testimony of Bryan Hannegan, Vice President, Environment, Electric Power Research Institute)

⁶ Combustible renewables and waste as defined by the International Energy Agency includes biomass, animal products, and municipal waste. Note that the IEA lists hydropower separately. The U.S. Energy Information Administration includes conventional hydroelectric power in their statistics for renewable electricity. Hydropower is not included in this section of the paper.

⁷ REN21-Renewable Energy Policy Network for the 21st Century. 2006. Renewables – Global Status Report, 2006 Update. Accessed October 13, 2008 at http://www.ren21.net/pdf/RE_GSR_2006_Update.pdf

A study by the American Solar Energy Society reports that for an aggressive but achievable climate-change-driven scenario, it is feasible to achieve 50 percent renewable electricity (excluding traditional hydropower) in the U.S. by 2030. For this scenario, the American Solar Energy Society study projects about one-third of the renewable electricity in 2030 will be wind power and the remaining two-thirds will be divided equally among concentrating solar thermal power, photovoltaics, biomass, and geothermal electricity. In contrast, the U.S. Department of Energy's (DOE's) reference case projects a modest worldwide growth in renewable electricity (including hydroelectric) of 1.7 percent from 2004 to 2030. The actual growth in renewables will depend in large part on future policy and economic drivers. Solar and wind technologies are ready for deployment with favorable incentives. Conventional hydroelectric and geothermal powers are generally accepted to be near their maximum utilization in the U.S. although the Electric Power Research Institute estimates a potential increase of 10 GW in conventional hydropower. The greatest utilization of biomass for energy likely will focus on transportation fuel rather than electricity production.

Hydropower

Hydropower includes conventional run-of-river and storage reservoirs, pumped storage reservoirs, and the new emerging technologies of ocean, wave, tidal, and hydrokinetic energy. The Electric Power Research Institute estimates the potential increase in U.S. generation capacity by 23 GW by 2025, including 10 GW from conventional hydropower, 3 GW from new hydrokinetic technologies, and 10 GW from ocean wave energy devices. If implemented, this growth in hydropower would represent a 25 percent increase over the existing U.S. hydropower generation capacity of 96 GW. Pumped storage hydropower may provide critical storage capacity for intermittent and non-peak renewable generation from wind, solar, and ocean technologies. Key challenges for hydropower include continued development of new technologies to harness ocean, wave, tidal, and hydrokinetic energy, and mitigate environmental impacts associated with larger-scale conventional hydropower generation.

Biomass

The greatest use of biomass for power today is direct firing of post consumer residues of the forest industry. Outside the pulp and paper industries, only a small amount of biomass is used to produce electricity. Commercially available technologies for converting biomass to heat and electricity include fixed-bed combustion, fluidized beds, dust combustion, biomass and coal co-firing, and several types of gasification systems. At present, interest in biomass energy is focused primarily on the production of liquid fuels for transportation. The most significant challenge to expand biomass use beyond combustion is developing the technologies to process lignocellulosic (non-food crop) biomass and efficient use of arable land which is needed for food crops.

Wind

Wind power is the fastest growing source of renewable electricity. In 2006, the installed capacity worldwide was 75 GW and wind power supplied more than 25,000 GWh of electricity (GWEC 2008). Wind power capacity grew by 50 percent in the U.S. in 2008 to 25,170 megawatts of installed capacity, enough electricity to power nearly 7 million households (GWEC 2009). Most modern installed turbines have 84 m hub heights and a rotor diameter of 67 m. Modern Type 3 turbines have advanced mechanical-to-electrical conversion characteristics to handle grid interface issues. The evolution of controls has eased the integration of wind power plants with the utility system. As wind energy approaches penetration levels of 20 percent, grid dispatch ability may limit growth unless improved electric grid management techniques and cost-effective storage technologies are available (DOE 2008b; Zavadil et al. 2007.)⁸ Investments in transmission capacity and improvements in transmission are needed to handle intermittency and transmission over large distances.

⁸ A number of studies are found on the Utility Integration (UWIG) Website at <http://www.uwig.org>.

Concentrating Solar Power

Concentrating Solar Power (CSP) comprises multiple technologies including parabolic troughs, dish-engine systems, and heliostat-based power towers. One of the advantages of CSP is its suitability for hybridization with conventional natural gas combined cycle or coal plants, and the use of heat storage or auxiliary fuel firing to achieve full power and remove intermittency from operation with insufficient sunlight. Today, 7 GW of CSP are installed worldwide. Recently installed and planned facilities in the U.S., Mexico, Europe, Middle East, Asia, and Africa are 4.56 GW. With sufficient direct solar radiation, it is possible that CSP could become the lowest-cost utility for the southwestern U.S. and other areas of the world. A study for the U.S. Western Governors Association⁹ estimates that CSP could provide 7000 GW of electrical capacity and identifies 200 GW at optimal locations for transmission.

Photovoltaics

Photovoltaic (PV) modules can be used for utility-scale electricity generation; however, they are used more commonly as a distributed power source on buildings. Individual PV cells have a solar-to-electric conversion efficiency of 15 to 20 percent; however, the efficiency of modules combining many cells is 10 to 15 percent for crystalline silicon and 5 to 10 percent for thin-films. The grid-connected solar PV capacity grew on average more than 60 percent per year but total installed capacity remains low, only 3.1 GW at the end of 2005.¹⁰ Japan, Germany, and the U.S. account for more than 90 percent of installed PV capacity in the Organization for Economic Cooperation and Development countries.¹¹ The challenge for greater implementation of PV is achieving lower cost systems.

Geothermal

Generally, geothermal electricity production is practical only where underground steam or water exists at temperatures greater than 100°C. Global geothermal electric-generating capacity is approximately 9 GW with most of it concentrated in Italy, Japan, New Zealand, and the U.S.. According to the Energy Information Administration, the U.S. design capacity is 3 GW and geothermal electric generation in 2006 was 14,842 GWh.¹² Most U.S. geothermal plants are located in California and Nevada. Existing plants operate 90 to 98 percent of the time and can provide base load electricity. Today, geothermal electricity is produced using the hydrothermal resources (nominally hot water and steam) accessible within 3 km of the earth's surface. Growth of conventional geothermal energy is expected to be modest, and the resource base can only be expanded by drilling to greater depth, and development of technologies for extraction of the thermal energy stored in dry rock. This resource is vast, but it is currently not economical to tap because of its depth, low permeability, and lack of water as a carrier fluid.

Transmission

Solar and wind power technologies are constrained to the temporal and spatial variation of the resource. Consequently, significant expansion of these technologies in the U.S. electric power sector may require special consideration of transmission. Modern grid systems are designed to handle loss of the largest power plant without disruption and ramp up and ramp down to meet changing demand. As long as intermittent renewable

9 Western Governors Association, Solar Task Force. 2006. Clean and Diversified Energy Initiative Solar Task Force Report. Accessed October 14, 2008 at <http://www.westgov.org/wga/initiatives/cdeac/Solar-full.pdf>.

10 REN21-Renewable Energy Policy Network for the 21st Century. 2006. Renewables – Global Status Report, 2006 Update. Accessed October 13, 2008 at http://www.ren21.net/pdf/RE_GSR_2006_Update.pdf

11 BP. 2007. BP Statistical Review of World Energy June 2007. Accessed October 14, 2008 at http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2007/STAG-ING/local_assets/downloads/pdf/statistical_review_of_world_energy_full_report_2007.pdf

12 Energy Information Administration. http://www.eia.doe.gov/cneaf/solar.renewables/page/prelim_trends/rea_prereport.html, Table ES3

power increases and decreases within the capability of the system, renewables can be integrated without additional generation or storage. Although estimates vary, it is generally thought that at renewable penetrations greater than 10-20 percent of electricity production, improvements to the electric grid will become necessary to reduce cost and storage requirements. Increased grid capacity and use of *Smart Grid* controls are needed to operate the grid reliably, to manage the temporal and geographical mismatches of renewable power production and use.

Enabling Actions

1. *Expand renewable incentives in order to drive down costs of renewable electric technologies through learning curve technology maturation and achievement of economies of scale and mass production.*
2. *Expand research and development (R&D) to increase performance, reduce cost, and establish cost-effective energy storage methods.*
3. *Improve transmission infrastructure, especially for transmission of intermittent sources far from load centers, enabling renewable sources to play a greater role in supplying electricity.*

3.4 EXPANDING UTILIZATION OF NUCLEAR POWER

Nuclear energy is an established *low emissions* and *low climate impact* technology (each modern 1000 kWe nuclear plant, displaces about 3Mt CO₂ /yr compared to natural gas-fired power generation and more for coal). Nuclear fission power already is a mature technology that provides about 16 percent of the world's electricity. In addition to the roughly 400 nuclear power plants currently located throughout the world more than 100 additional reactors are expected to be built within the next 20 years.

The cost of energy worldwide from the advanced Generation III and Generation III+ reactors is cheaper than gas and comparable with coal, depending on the plant's location and size (NETL 2007; OPA 2005; EIA 2006a; EPRI 2006). After 2021, Generation IV reactors should be demonstrated and cost less than Generation III reactors (DOE 2008c). In the absence of efforts to accelerate deployment, the U.S. will experience, at most, a doubling of capacity over the next 30 years. This would only replace the aging existing nuclear capacity and hence would not contribute to future emissions reduction.

Objections to expanding nuclear power have impeded deployment in the U.S. at the political level. Concerns focus on 1) disposal of spent nuclear fuel (although the technology of geologic disposal has been widely demonstrated (CORWM 2006; NWMO 2005;¹³) and 2) adequate safeguards to prevent weapons proliferation. In the U.S., this objection to waste disposal is often manifested as political opposition to both high-level waste and to low-level waste sites at the State level. At the Federal level, political opposition has resulted in long delays and cost increases of the Yucca Mountain high-level waste facility, which has not opened but will be at design capacity if all current spent fuel is shipped and stored there. It is the predominant view that the technical issues have been solved. The approach taken in Finland, including site characterization, facility design,

13 Agence Nationale pour la Gestion des Déchets Radioactifs Radioactive Materials and Waste Planning Act of 28 June 2006. Andra Publication Reference Series. Accessed October 14, 2008 at <http://www.andra.fr/publication/produit/loi-VA-12122006.pdf>.

and then final disposal, provides a logical, consistent, measured technical approach. However, in the U.S., opening and licensing the Yucca Mountain facility has been repeatedly deferred. If opened today, and in the absence of fuel recycling, reprocessing or re-use, the Yucca Mountain facility would be immediately filled with spent fuel from existing plants. (Miller and Marcos 2007).

Advanced fuel cycles can greatly reduce the ultimate waste stream volumes, if spent fuel is recycled and used as an energy resource, as is the case in France, Japan, Russia, the United Kingdom, and India. In addition, consolidating interim storage of spent fuel is technically feasible and demonstrated, as shown by the Zwileg facility in Switzerland.

3.4.1 A New Vision

New reactor system design concepts are possible beyond 2021 (so-called Generation IV). These are expected to be safer, more efficient, lower cost, and adaptable for nuclear-hydrogen systems (DOE 2008c, 2002). Massive deployment of these technologies in response to GHG emission reduction challenges will require a marked departure from the present course.¹⁴ In addition to assertive deployment of advanced reactor designs, extension of the nuclear fuel resource by a factor of six is possible through a combination of recycling uranium through existing nuclear power plants and through exploiting thorium-based fuel. This fuel switch postpones any constraint imposed by uranium supply allowing ample time for the development of breeder and other types of advanced reactors. The development of such reactors also is the subject of the U.S. Global Nuclear Energy Partnership (GNEP) initiative, which envisions recycling spent fuel and actinide burning in modified fast *burner* reactors (DOE 2008c). This development is intended to dramatically reduce the storage capacity needed beyond the existing capacity at the Yucca Mountain high-level waste facility. Interim spent fuel storage should also be implemented as a means to enable safe nuclear waste management until a terminal repository is available. Finally, international programs, similar to those incorporated in GNEP, are vital to progressive, safe, and secure adoption of nuclear power in many parts of the world.

Enabling Actions

- 1. Establish technical and engineering expertise and industrial capability to support nuclear power growth, through expanded funding of nuclear engineering education and rapid authorization of new nuclear power plant construction.*
- 2. Implement known spent-fuel interim storage and disposal technologies.*
- 3. Reduce waste streams by closing the fuel cycle while reducing the risk of weapons proliferation.*
- 4. Establish plant licensing processes that ensure speedy decisions and reduce risk of compliance uncertainties.*
- 5. Enhance R&D in advancing new reactor technologies including those enabling hydrogen production, transport, and utilization.*

¹⁴ Using one IPCC scenario (B2), an expansion by a factor of 16 is required to achieve desired GHG concentration reductions over the actual worldwide nuclear generation in 2000.

3.5 REINVENTING TRANSPORTATION

Globally, petroleum accounts for the greatest fraction of fossil fuel consumption (39 percent of total primary energy). Fuel use by light duty vehicles accounted for 11 percent of global petroleum consumption. In the U.S., transportation accounts for 29 percent of all energy consumption, and of that amount 62 percent is for light-duty vehicles.

Transportation sources accounted for approximately 29 percent of total U.S. GHG emissions in 2006. Transportation is the fastest-growing source of U.S. GHGs, accounting for 47 percent of the net increase in total U.S. emissions since 1990 (see *Figure 3*). Transportation is also the largest end-use source of carbon dioxide, which is the most prevalent GHG, producing over 30 percent of the nation's total in 2003. The U.S. transportation sector derived all but 2 percent of its energy from fossil fuels in 2003, 97 percent of which was petroleum. These estimates of transportation GHGs do not include emissions from additional lifecycle processes, such as the extraction and refining of fuel and the manufacture of vehicles, which are also a significant source of domestic and international GHG emissions.

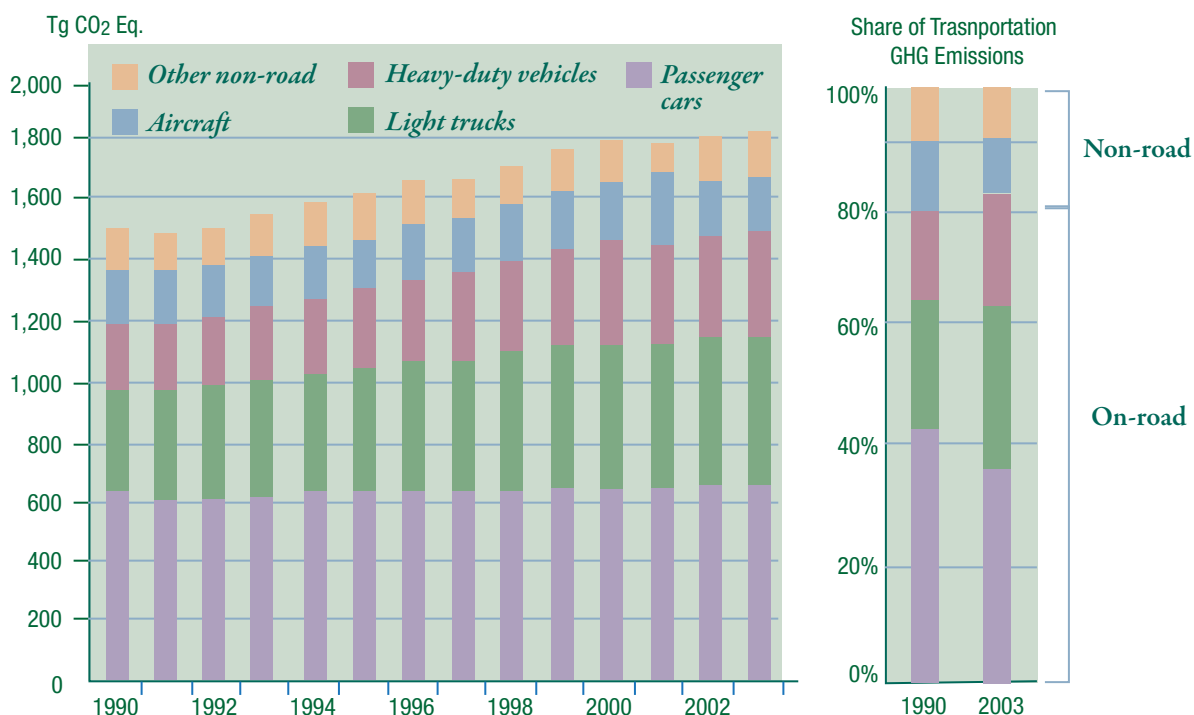


Figure 3. GHG Emissions by Mode of Transportation, 1990-2003 (source data from U.S. EPA, 2005), [Other Non-Road includes boats, ships, rail, pipelines and lubricants; emissions from refrigerated transport and mobile air conditioning are not included in this chart]

Reduction in GHG emissions revolves around the following three strategic objectives:

- Increasing diversity of energy resources supplying transportation.
- Displacing petroleum consumption through increased system efficiency and use of lower carbon fuel alternatives.
- Reducing life-cycle emissions associated with the electrification of the transportation industry.

Achieving these strategic objectives requires resolution of a number of key technology challenges, including:

- *Develop and deploy advanced battery and/or other energy storage-power systems for the adoption of plug-in and electric vehicle technologies.*
- *Use current and next generation biofuels in a cost effective and environmentally responsible manner.*
- *Leverage, in parallel, multiple potential energy carriers (e.g., liquid and gaseous fuels, and electricity).*
- *Utilize lower carbon fuels and propulsion alternatives across multiple modes of transport.*
- *Optimize conventional propulsion systems while developing advanced propulsion technologies.*

Managing GHG emissions across the transportation industry also will require managing issues concerning balance between personal and freight transport and public and/or mass transport. The World Business Council for Sustainable Development's Sustainable Mobility 2030 Project focused on many elements for designing in a balanced transportation infrastructure across the dimensions of personal, public, mass, and non-vehicle transport. This study projects there will continue to be a struggle for balance across personal, public, and mass transport that projects a global increase in personal transport (person miles) and freight transport (freight miles—especially road miles). Freight transport accounts for approximately 43 percent of transport energy. Meanwhile, global public and mass transport modes continue to decline. Technology and infrastructure development policies must recognize and reconcile the growing competition between freight and passenger vehicles for access to existing infrastructure resources (WBCSD 2004). Reinventing transportation will further require pursuit of sustainable mobility today and tomorrow by effectively designing capacity and efficiency parameters of the existing road and public transport infrastructure and developing land use and transportation strategies that optimize spatial location and public transport policies.

3.5.1 Meeting the Technology Challenge

Specific to personal transportation, many of the propulsion challenges will need to address optimizing internal combustion engines. The key will be developing engine technologies in coordination with the burgeoning bio-fuels market. Further development in the areas of other alternative fuels, such as cellulosic ethanol and biodiesel, is required, as they become effective options supporting energy diversity in the transportation sector. However, development of renewable fuel infrastructures and systems is very complex. Therefore, comprehensive analyses are required to ensure that implementation accomplishes the desired goals, with few unintended consequences. Experience with implementation of alternative fuels production policies suggest that tradeoffs will be inevitable, reinforcing the merit of comprehensive multi-dimensional analyses, for guiding governmental and industry policies and practices. Hydrogen, as a vehicle energy carrier, requires a comprehensive systems approach in order to effectively design, develop, and implement the infrastructure required for production, delivery, and station and/or on-board storage. The prudence of widespread adoption of hydrogen for vehicular use has been analyzed a number of times, under various *well-to-wheel* scenarios. R&D for hydrogen vehicular systems should continue as determined by comprehensive life-cycle analysis for realistic scenarios.

Due to its flexibility, electrification with accompanying plug-in technologies is the most viable option for all forms of transportation. However, plug-in technology requires advanced battery and/or other energy storage-power systems. Studies are being conducted on the infrastructural system designs that will enable two-way power flow (grid to vehicle and vehicle to grid), in order to determine the types and scale of benefit to the grid and consumers. Such systems make it possible for all vehicles to supply electricity back to the grid thereby reinforcing grid functions and adding additional economic value to vehicle battery systems. To date, the advanced battery focus has been on *power* for hybrids, not *energy* for plug-ins and pure electric vehicles.

Advanced battery technologies and systems will also benefit from the development and deployment of a *smart* distribution grid and the associated communications infrastructure aligned with the deployment of plug-in hybrid electric vehicles to fully realize the energy efficiency and reduction in GHG emissions (EPRI 2007). A smart grid is essential if vehicle electric storage is to be utilized for support of grid markets or operations.

Enabling Actions

1. *Accelerate the development and deployment of advanced battery/energy storage and vehicular electric power technology.*
2. *Accelerate the development and deployment of an electricity infrastructure employing smart distribution and enhanced transmission infrastructure.*
3. *Accelerate development of coordinated policy and technology strategies for adoption of biofuels for transportation based on comprehensive life-cycle analyses.*
4. *Accelerate development of alternative propulsion technologies including more efficient engine and power trains concepts and systems, including those employing renewable fuels.*
5. *Adopt sustainable design methods to minimize energy and environmental footprint, and enable upstream resource use to produce materials and fuels that reduce the vehicle's life-cycle emissions footprint.*
6. *Facilitate development and deployment of transportation infrastructures and operational approaches that minimize GHG emissions while enabling growth of freight and human transport.*

3.6 MANUFACTURING FOR A GREEN FUTURE

Manufacturing accounts for about 84 percent of energy-related CO₂ emissions and 90 percent of the energy consumption of industrial end-uses (Schipper, 2006). The predominant sectors within manufacturing include petroleum and coal products, chemicals, primary metals (steel, aluminum, etc.), paper, food, and non-metallic mineral product (cement, glass, etc.) (NAICS 2002). The large amount of energy used by manufacturing industries is largely associated with raw material separation, reaction, and processing; for this reason, they are often termed *energy-intensive* industries. Energy intensity in this case may be defined as the energy consumed per dollar of output produced.

Manufacturing industries emit CO₂ directly via in-plant fossil fuel combustion, use of carbon-based materials (e.g., natural gas) as feed streams, and calcinations of calcium carbonate in cement production. Indirect emissions are associated with electricity consumption for industrial purposes. For the industrial sector, approximately half of the CO₂ emissions are direct emissions while the remainder is associated with electricity consumption. The direct industrial CO₂ emissions are provided in *Figure 4* (EPA 2008).

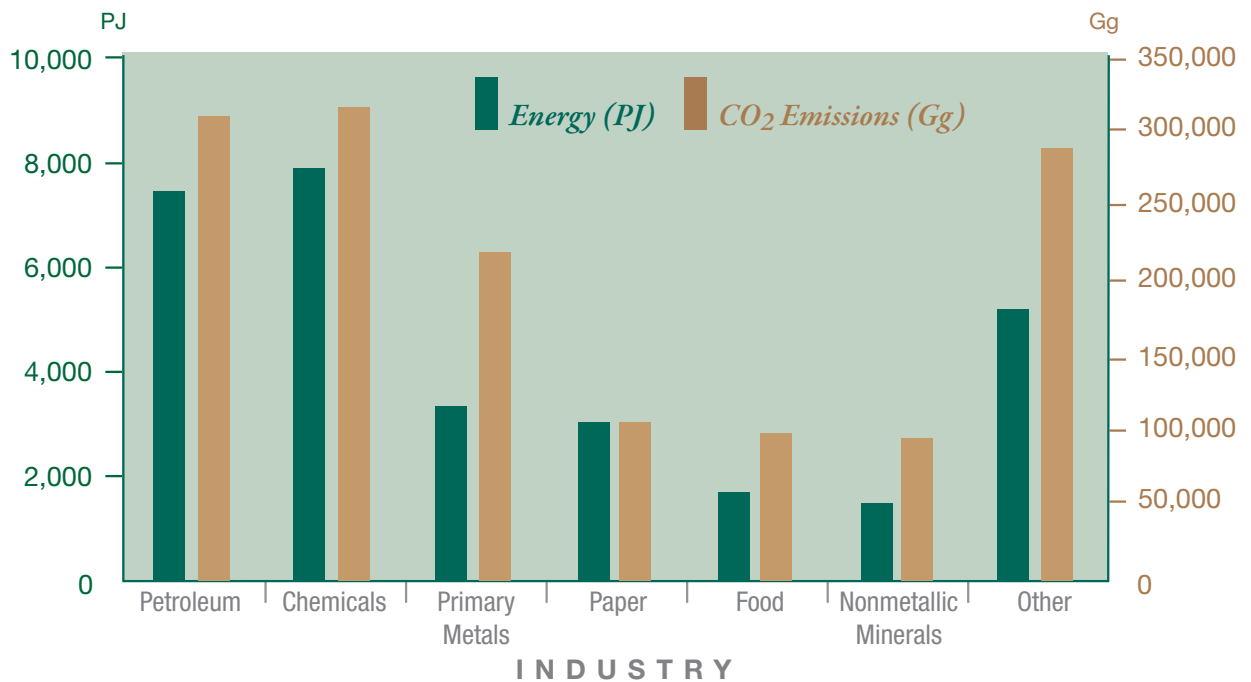


Figure 4. Energy Consumption and CO₂ Emissions for Manufacturing Industries ¹⁵

3.6.1 Energy Efficiency in Manufacturing

Energy-intensive industries generally have low levels of R&D spending relative to other industries such as semiconductors and pharmaceuticals. The commoditized nature of the products generated by energy-intensive industries makes such R&D investments difficult. In spite of this challenge, modest improvements in energy efficiency within these industries continue to occur; in 2001, the energy intensity of the U.S. industrial sector was at its lowest level in history. Many opportunities exist for additional energy-efficiency improvements. Examples of some industry specific measures are described below.

Energy consumption in steelmaking is largely associated with process heating requirements. High-efficiency heating systems are under development, providing the potential for reduction of energy consumption by 63,000,000 GJ, reducing GHG production by 17,000 Gg CO₂, and reducing NO_x by 9.49 Gg over the next 10 years (Thekdi 2006).

Cement production consumes about 4 GJ per tonne of cement produced (Khurana et al. 2002). A significant fraction (35 percent in one study; EPA 2008) of the input energy is lost as waste heat. Methods exist to recover and utilize this waste heat reducing the plant's electricity requirements by 30 percent and improving primary energy efficiency of the plant by 10 percent.

The petroleum and chemical industries both rely heavily upon large quantities of heat as part of production processes. A new generation of highly efficient and low emission process heaters has been developed and commercialized through government/industry partnerships. Improved process heating has the potential to reduce energy consumption by 88,000,000 GJ annually, producing an associated reduction of emissions: 136 Gg of NO_x and 4,000 Gg of CO₂ annually (Mason 2003).

¹⁵ U.S. Department of Energy (DOE). 2001. Current Situation: Energy Profile of the Industrial Sector.

Drying processes within the paper products industry are extremely energy intensive. The Institute of Paper Science and Technology has developed a new method of impulse drying that has the potential to reduce energy consumption by 13,000,000 GJ annually and reduce 1,000 Gg of CO₂ emissions by 2020 (DOE 1999).

In aluminum production, the smelting of alumina using the Hall-Heroult process consumes large amounts of energy in addition to emitting considerable quantities of GHGs and perfluorocarbons. Using dynamic inert metal anodes in conjunction with wetted cathode technology offer the potential for annual reductions of 1,000,000 GJ and 7,000 Gg in GHGs (DOE 2001).

In the absence of collective efforts to develop and implement energy-efficient technologies, growth in CO₂ emissions will accompany the growth in energy demands.

3.6.2 Sustainable Consumption

Additional strategies exist for fundamental systemic reduction of energy intensity, primarily reducing energy consumption via changes to material, product, and energy usage paradigms.¹⁶

Materials are integral to modern society. The extraction, processing, and manufacturing of materials requires significant energy, and in particular, the processing of virgin materials. Material selection during product design plays an important role in energy consumption associated with materials processing and manufacturing (Ashby and Johnson 2002). Disposing of used products results in the loss of all functional value and embodied energy created through materials processing and manufacturing. Significant energy benefits can therefore be achieved through reuse, remanufacturing, and recycling. While many examples of these strategies currently are employed, a more pervasive use of these approaches is needed, which will require that technological barriers be surmounted and, in some cases, sociological challenges as well.

Though increasing the use of recycled materials is an important step towards reducing energy consumption, dematerialization can decouple economic activity from the consumption of raw materials and energy (Reiskin et al. 1999). Dematerialization seeks to employ less total material through such methods as more efficient product designs, better materials, and transitioning from a tangible or material-based product to a service or an intangible product.

Changes in the materials usage paradigm represent one method for decoupling energy consumption from economic activity. Additional strategies for reducing the energy intensity are as follows:

- *Increase attention by designers to product energy efficiency and the complete energy chain from generation to the delivery of useful work.*
- *Increase useful product life, and encourage life extension and modularity of product components that enable replacement of failed components for products with significant levels of energy-intensive materials and manufacturing (e.g., computers; Williams 2004).*

¹⁶ Kaya, Y. 1990. "Impact of carbon dioxide emission control on GNP growth : interpretation of proposed scenarios," presented at the IPCC Energy and Industry Subgroup, Response Strategies. Working Group, Paris, France.

Enabling Actions

1. *Create incentives for adopting energy-efficiency measures in industry that accommodate changing market conditions and pressures, energy prices, and business concerns that affect the ability and willingness of industry to pursue energy efficiency opportunities.*
2. *Enhance R&D to identify, develop, and demonstrate cost-effective measures that contribute to GHG emission reduction for energy-intensive industries.*
3. *Increase attention to dematerialization and material selection during design, focusing on reducing the embedded energy content of materials*
4. *Promote increased levels of recycling and remanufacturing to recover the energy invested through virgin material processing*
5. *Increase the understanding of energy consumption across product life-cycle stages to enable prioritization of development of low-energy content products.*

3.7 BUILDINGS FOR THE 22ND CENTURY

Residential, commercial, and institutional buildings account for about one-third of the primary global energy demand. They represent a major source of energy-related GHG emissions. In the U.S., emissions from buildings, including those emissions from both fuel combustion and use of electricity derived from CO₂ emitting sources, account for nearly 37 percent of total U.S. CO₂ emissions (electricity accounts for about 45 percent of energy use in U.S. buildings and about 70 percent of the electricity generated is consumed in buildings). Since 1990, these emissions have been increasing at almost 2 percent a year primarily due to sector growth. Because buildings are one of the longest-lived assets, their initial design and construction practices can long impact future energy consumption and efficiency options.

There were 83 million buildings having a total floor space of almost 15 billion m² in the U.S. in 2000. Annual new construction is about 1-3 percent. The relatively slow growth in new construction means that much of the opportunity in the U.S. (and likely all industrialized nations) for energy efficiency comes through retrofits. This is not true of other countries. Economic growth in the developing nations will drive dramatic increases in their building construction. It is estimated that fully 50% of all new buildings will be constructed in China and India (WBCSD 2008). China alone is adding over 2 billion m² per year. At this rate, in the next decade China will construct new buildings having a floor space equivalent to all of the current U.S. building stock.

The reduction in future GHG emissions due to buildings focuses primarily on advances in energy efficiency and employment of sustainable technologies. Typically, over 80% of the life cycle energy use is associated with operation of the building rather than construction or renovation (including material manufacturing and transport). Efforts to stimulate more sustainable practices in building design and construction (including retrofits) have gained considerable momentum. An example is The U.S. Green Buildings Council, which spearheads its

implementation of sustainable technologies through its Leadership in Energy and Environmental Design (LEED) program. The U.S. Green Buildings Council, has determined that the increased capital cost of achieving LEED certification is between 0 and 3 percent, while achieving the highest level (Platinum) results in a capital cost increase of less than 10 percent (Morris, 2004). These up front costs are more than recouped through down stream savings (Kats, 2003). Similarly, studies in Germany suggest that energy use can be reduced by 50% for no increase in construction cost.

The U.S. Department of Energy has estimated that by 2050, with advances in building envelopes, equipment, and systems integration, it may be possible to achieve up to a 70 percent reduction in a building's energy use, compared with the average energy use in an equivalent building today. If augmented by on-site energy technologies (e.g., photovoltaics, solar thermal systems for hot water and air conditioning, or distributed sources of renewably-fueled combined heat and power), buildings could become net-zero GHG emitters.

3.7.1 Building Envelope

DOE's research on the building envelope—the interface between the interior of the building and the outdoor environment—focuses on systems that determine or provide control over the flow of heat, air, moisture, and light in and out of the building. It also focuses on materials that can affect energy use, including insulation, optical control of coatings for windows and roofs, thermal storage, and related controls.

3.7.2 Building Equipment

Research on building equipment focuses on significant improvements to efficiency of heating, cooling, ventilating, thermal distribution, lighting, home and office appliances, and on-site energy and power devices. This area includes advanced refrigerants and cycles, solid-state lighting, smart sensors and controls, small power supplies, fuel cells with combined heat and power capability, and other areas, include integrating renewable energy systems and storage devices.

Future research directions include advances in on-site power production (e.g., fuel cells, micro-turbines, and advanced reciprocating engines), ultra-efficient heating, ventilation, and air-conditioning systems (e.g., magnetic or solid-state cooling systems, advanced desiccants, and absorption chilling systems), solid-state lighting technology, and low-power ubiquitous sensors with wireless communication for advanced heating/cooling controls.

3.7.3 Combined Heat and Power in Buildings

Due to the capture of useful energy both as electricity and thermal output, combined heat and power (CHP) systems can offer exceptional total fuel efficiency. Typically, CHP systems will achieve total energy-use efficiencies that exceed 60 percent, and may exceed 80 percent where conditions of thermal load and site permit. CHP typically uses natural gas as a fuel, which emits less CO₂ than other fossil fuels. Other fuels, like municipal waste and biomass, also can be used, although siting can be more limited. Incorporating CHP in buildings is site-specific and some existing buildings are not capable of hosting on-site generation. Additionally, timely resolution of technical, regulatory, and business practice barriers related to local grid interconnections are needed for broader use of CHP.

3.7.4 Whole Building Integration

Advanced tools and technologies for systems integration in buildings are needed, with a particular focus on sensors and controls for supply and end-use system integration, and development of pre-engineered, optimized buildings.

3.7.5 Codes and Standards

The buildings industry, including design, construction, and equipment development and manufacturing, is highly diffuse technically and financially, and generally lacks the resources and vertical integration necessary to drive holistic technology development. For this reason, codes and standards, and specifically energy codes and standards, provide a vital means of ensuring that advances in building energy efficiency are employed in new and retrofit structures. Combined with voluntary incentive efforts such as provided in the U.S. by the U.S. Green Buildings Council and their LEED certifications, aggressive building codes and standards are a key method for reducing GHG emissions. Implementation of advanced buildings will necessitate broad stakeholder adoption through national and local building electrical codes, fire codes, and local zoning.

Enabling Actions

1. *Mandate development, demonstration, and deployment of codes and standards encouraging building construction and retrofit in a manner enabling use of sustainable materials and highly energy-efficient architectural, equipment, and operating systems.*
2. *Increase research, development, and demonstration of methods to increase energy efficiency in building operations and integration of building equipment (including on-site generation) into the local energy infrastructure (particularly the electric grid).*
3. *Use building complexes (particularly government owned) as early adopters of advanced buildings technology, operations, and integration into local energy systems.*
4. *Resolve technical, regulatory, and business practice barriers for broad implementation of on-site CHP and renewable power systems for building applications.*

3.8 INFRASTRUCTURE ENABLING GREENHOUSE GAS REDUCTIONS

Effective and efficient electric grids, pipelines, rail, and road infrastructures are essential to implement technologies that will ensure economic growth and enable GHG emissions reduction.

Advanced Electric Grid

In the U.S., electrical consumption is expected to grow by 41 percent between 2005 and 2030 (EIA 2007b). While electric generation capacity is continuing to grow, reserve margins (excess generation capacity relative to load) are expected to continue their decline. This means that generation capacity growth is not keeping pace with actual growth in electric demand.¹⁷ Similarly, construction of new transmission systems is lagging behind demand growth.¹⁸ The lack of adequate electric transmission capacity, combined with limitations at the distribution level due to aging infrastructure, will degrade the ability of the electric system to absorb and manage distributed generation, particularly from renewable sources. Development of advanced grid operations technologies, and grid-connected electric storage are also essential to enabling future GHG management options. Increased electrification of transportation would dramatically affect the electric grid. While plug hybrid vehicles and electric vehicles can serve as an asset in grid management and can improve grid utilization, the prospect of transmitting large amounts of electricity over an already constrained electric grid is of concern. The current electric grid can provide about 70 percent of the vehicle energy use during off-peak periods (Kintner-Meyer et al. 2007; Scott et al. 2007). Increases above this level would require additional power generation capacity and potentially additional transmission capacity. Reductions in CO₂ emission would only occur if electricity came from low/no- CO₂ emission power generation.

Natural Gas

Natural gas use is projected to increase during the next two decades (EIA 2006b). During the last decade, pipeline capacity additions have averaged about 10 Bcfd/yr, or about 7 percent of current capacity (i.e., 150 Bcfd) and more than 75 Bcfd is possible over the next several years. Increased pipeline capacity is forecast due in part to the increased import of LNG. More than 50 new LNG import facilities were proposed between 2006 and 2010 with each having capacities of about 1 to 2.5 Bcfd. Additional development of new gas reserves in the Western U.S. contribute to that potential. In the long term, gas hydrates, estimated to be 2-4 times as large as current natural gas reserves, may be developed as a viable resource.¹⁹

Pipelines

The prospect of carbon sequestration raises the challenge of whether CO₂ will be transported to sequestration sites. If the CO₂ from current U.S. coal combustion for electric power were captured, it would total 2.1 billion tons of CO₂ (EIA 2006c). If the CO₂ were transported as a gas, it would equal 37 Tcf, or more than 1.5 times the total natural gas consumption in the U.S.. Use of biofuels will require additional consideration. For instance, existing hydrocarbon fuel pipelines cannot tolerate E-85 ethanol because its higher water content causes corrosion. Similarly, the widespread use of hydrogen will have many infrastructure challenges including efficient, safe transport.

3.8.1 Technology Timescales

U.S. infrastructures, such as the 300,000 miles of transmission and 1.1 million miles of distribution for natural gas, 130,000 miles of oil pipelines, 165,000 miles of high voltage lines, 110,000 miles of freight rail system, 46,000 miles of interstate highways, and 115,000 miles in the National Highway System, have taken various amounts of a century to develop (DOT 2007). Even individual technologies, like fuel injection and front wheel drive, will often take two decades from invention to widespread adoption. Commercializing new technology in the oil and gas market takes an average of 16 years from concept to widespread commercial adoption (NPC 2007).

¹⁷ North American Electric Reliability Council (NERC). 2006. 2006 Long-Term Reliability Assessment.

¹⁸ President's Council of Advisors on Science and Technology. 2006. The Energy Imperative-Technology and the Role of Emerging Companies, Executive Office of the President, Washington, D.C., http://www.ostp.gov/galleries/PCAST/pcast_energyimperative_final.pdf

¹⁹ U.S. Geological Survey, USGS Geological Research Activities with U.S. Minerals Management Service.

Clearly, CO₂ reduction technologies that are dependent upon replacing existing infrastructures, will likely see their penetration, and consequent impact on CO₂ emissions slowed where existing infrastructures have long lifetimes or low turnover rates.

Enabling Actions

- 1. Review and document infrastructure dependencies of CO₂ emission reduction strategies.*
- 2. Prepare and implement roadmaps for enhanced development of infrastructures that are required to implement technologies that reduce CO₂ emissions along with retrofitting existing structures to accomplish similar reductions.*

3.9 EMPOWERING INNOVATION

New technology can be categorized as sustaining or disruptive (Christensen 1997). Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology is highly prized for its power to overcome established technology, create markets and reveal wholly new solutions to mankind's challenges, but is not tried and proven. The challenge today is how to stimulate the discovery and maturation of these disruptive technologies, so we can realize their benefits in a timely manner.

Certainly many of the current methods to stimulate discovery and maturation of technology will be needed, including continued investment in science and engineering at our universities and national laboratories, increased focus on translation of scientific discovery into technology, and incubation through venture investment. However, innovation will also come through the development and implementation of a new process that can uncover and discover the disruptors to accelerate technology deployment. Increasingly, solutions are coming from diverse scientific and engineering disciplines. To be most effective this *new* process will be open, facilitated by the Worldwide Web, and contributed to from all areas of expertise and interest groups.

Enabling Actions

- 1. Increase the breadth of collaboration of participants in R&D*
- 2. Additional economic incentives for private sector R&D for possible breakthrough technologies.*
- 3. Increase the quantity of R&D for CO₂ emission reduction technologies.*
- 4. Simplify transmission of technology from government laboratories to private industry*



4.0 POLICY CONSIDERATIONS

Public policy is vital to successfully reduce CO₂ emissions. Appropriate policies must be developed that 1) seek to minimize or disallow any barriers which otherwise could preclude action; and 2) empower avenues of discovery, innovation and commerce to enable real, measurable progress.

There is no single solution for reducing CO₂ emissions. Developing and implementing policies that realize lower carbon life-cycle emissions require strategies that address lifecycle attributes of energy resources (including coal, natural gas, and renewable sources), the conversion to energy carriers (liquid and gaseous fuels, electricity and hydrogen), and development of low carbon propulsion systems (all mobility systems), and manufactured products. Such policies are currently not in place at the federal level, though they are being established in various states and some foreign countries. Policies and their accompanying strategies will be required to uncover the market potentials for creating the aforementioned technological portfolio of solutions (WBCSD 2004).

ASME recommends that a policy framework to address CO₂ emissions include:

- *Mandatory, progressive targets to reduce emissions associated with all major energy sectors including power generation, transportation, manufacturing, and commercial and residential buildings, focusing on near-, mid-, and long-term timeframes.*
- *Flexible approaches to motivate achieving CO₂ emission limits that may vary by economic sector, and could include, depending on the sector, market-based incentives; governmental loan guarantees; investment tax credits; performance standards; tax reform; incentives for technology research, development and deployment; and other appropriate policy tools.*
- *Approaches that account for the global dimensions of achieving and maintaining sustainable levels of atmospheric CO₂ and encourage cooperative action by all countries, including the U.S. and large emitting nations in the developing world, to implement CO₂ emission reduction strategies.*
- *Investments in research to develop cost-effective renewable and efficient energy technologies, improve the performance of carbon energy systems, and support the research for new, clean energy systems and processes.*
- *Increased emphasis and investment in education and training of the workforce in all advanced energy technologies and their deployment.*
- *Enhanced development of infrastructures that are required to implement technologies that reduce CO₂ emissions.*



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