Sustainable and Unsustainable Developments in the U.S. Energy System

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Editor's Summary

The U.S. energy system achieved mixed success in its quest toward sustainability from 2000-2006. On one hand, carbon emissions as a fraction of GDP declined, end-use efficiency increased, and energy-related air quality improved. On the other hand, high levels of fossil fuel combustion continued, and U.S. energy use and emissions relative to other industrialized nations remained high. To continue successes while combating deficiencies, the federal government should increase energy efficiency through applied standards and improved technology, support research and development of energy-efficient commercial buildings, implement a tax or cap-and-trade system, support biofuel research, and set emissions targets for industry.

Over the course of the 19th and 20th centuries, the United States developed a wealthy society on the basis of cheap and abundant fossil fuel energy. As fossil fuels have become ecologically and economically expensive in the 21st century, America has shown mixed progress in transitioning to a more sustainable energy system. From 2000 to 2006, energy and carbon intensity of GDP continued favorable long-term trends of decline. Energy end-use efficiency also continued to improve; for example, per capita electricity use was 12.76MWh per person per year in 2000 and again in 2006, despite 16 percent GDP growth over that period. Environmental costs of U.S. energy production and consumption have also been reduced, as illustrated in air quality improvements. However, increased fossil fuel consumption, stagnant efficiency standards, and expanding corn-based ethanol production have moved the energy system in the opposite direction, toward a less sustainable energy system.

This Article reviews energy system developments between 2000 and 2006 and presents policy recommendations to move the United States toward a more sustainable energy system.

I. Sustainable Development

To paraphrase the Brundtland Commission, sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their needs.[1] Regarding energy production and consumption, sustainability primarily addresses issues of the environment, economics, and the political system. The criteria for measuring sustainable energy usage constantly shift in response to resource availability, costs, and new technologies. Likewise, the meaning of sustainable energy varies by geographic area: What is sustainable for the United States through its energy imports is unsustainable for the rest of the planet. Aside from moral and ethical questions of resource distribution, increased energy sustainability in the United States assumes adoption of global-scale definitions.

Governments can play a central role in the development of sustainable energy by guiding market forces and acting as a bulwark against human avarice. Policies can encourage increased use of renewables on the supply side and improved efficiency and conservation on the demand side. The European Union, Japan, and China have articulated national and international targets for sustainable energy. In June 2006, the European Council adopted a Sustainable Development Strategy for all EU countries. In Asia, Japan has adopted its 3R Initiative for Building a Sound Material-Cycle Society, and China has developed its Circular Economy Development Strategy. However, the issue of sustainability has not yet risen to such a level in energy discussions in the United States.

1. World Comm'n on Env't & Dev. (Brundtland Comm'n), Our Common Future 43 (1987).

II. Sustainability of the U.S. Energy System: 2000-2006

From 2000 to 2006, the U.S. energy system moved both toward and away from sustainability. Positive developments include diminishing the carbon and energy intensity of GDP, increased energy end-use efficiency, and improved air quality. Trends away from sustainability include increased combustion of fossil fuel, particularly coal, failure to implement improved energy efficiency standards (especially stagnant standards for appliances and vehicles), and increased production of corn-based ethanol.

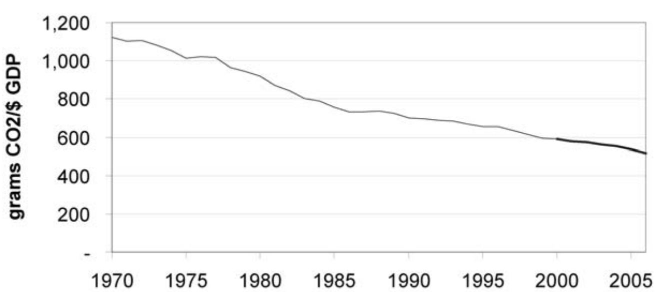
Following is a discussion of three trends in U.S. energy sustainability: declining carbon emissions as a fraction of GDP; increased energy enduse efficiency/declining energy intensity; and improved energy-related air quality. In the absence of other quantitative metrics, these trends serve as indicators of U.S. energy system sustainability.

A. Declining Carbon Emissions as a Fraction of GDP

In order to measure the sustainability of economic growth in the United States, annual energy-related carbon emissions are divided by GDP to calculate carbon intensity. While carbon intensity does not portray changes in absolute carbon emissions levels or sources of emissions, it does provide a useful indicator of economic and environmental sustainability.

As illustrated in Figure 1, the carbon intensity of U.S. GDP has declined intermittently since 1970. While the economy continued to expand, carbon intensity was reduced through economic restructuring (i.e., the shift of economic growth from industrial production to the service sector) and improved energy end-use efficiency (including reduced electricity requirements for home appliances). The trend during the past five years has been similar to the long-term trend in which the carbon intensity of the United States economy declined by 54 percent between 1970 and 2006.

Figure 1
Carbon Intensity of U.S. GDP, 1970-2006



Source: EIA, AER 2006; IEA, Carbon Emissions From Fossil Fuel Combustion.

The decline in carbon intensity has been 2.0 percent per year over the last six years, comparable to the long-term trend since 1970. This decline in U.S. carbon intensity needs to be seen in the context of global carbon dioxide (CO_2) emissions. Acceptable levels of CO_2 concentrations correspond to a very wide variety of emissions profiles and distribution of emissions between industrialized and developing countries.[2] Almost all scenarios of CO_2 emissions worldwide predict a much higher contribution from developing than from industrialized nations. As a result, a slope of -3 to -4 percent per year on Figure 1 is more likely to be a number that, when combined with comparable actions by other industrialized countries and energy efficiency policies in developing countries, could result in a more sustainable energy future.

Table 1 shows the absolute value of CO_2 emissions in the United States. Partially as a result of declining industrial-sector energy use, emissions have grown at a slower pace—0.2 percent annually—than occurred over the preceding eight years or in the 20 years after the oil embargo of the 1970s.

Table 1
U.S. CO_2 Emissions From Fossil Fuel Combustion by Sector (Mt CO_2), 1972–2006

	1972	1992	2000	2006	AAGR 1972–1992	AAGR 1992–2000	AAGR 2000–2006
Residential	891.37	970.60	1,171.90	1,197.00	0.4%	2.4%	0.4%
Commercial	575.30	783.30	1,006.40	1,046.00	1.6%	3.2%	0.6%
Industry	1,237.13	1,720.80	1,778.00	1,669.00	1.7%	0.4%	-1.0%
Transportation	1,783.10	1,566.30	1,854.00	1,965.00	-0.6%	2.1%	1.0%
Total	**4,486.90**	**5,041.00**	**5,810.20**	**5,877.00**	**0.6%**	**1.8%**	**0.2%**

Source: EIA, AER 2006.
Note: 2006 data are preliminary; AAGR=Average Annual Growth Rate (%).

Table 2 presents the same information for energy use. A comparison between Tables 1 and 2 illustrates how closely CO_2 emissions and energy track one another.

Table 2

	1972	1992	2000	2006	AAGR 1972–1992	AAGR 1992–2000	AAGR 2000–2006
Residential	15.7	18.4	21.6	22.2	0.8%	2.0%	0.5%
Commercial	9.6	14.2	18.1	19.0	1.9%	3.1%	0.8%
Transportation	18.7	23.6	28.0	30.0	1.2%	2.1%	1.1%
Industry	32.7	34.5	36.7	34.2	0.3%	0.8%	-1.2%
Total Energy	**76.7**	**90.7**	**104.4**	**105.4**	**0.8%**	**1.8%**	**0.2%**

Source: EIA, AER 2006.
Note: Final energy use; 2006 data are preliminary; AAGR=Average Annual Growth Rate (%).

2. Intergovernmental Panel on Climate Change (IPCC), Working Group I (2007).

B. Increased Energy End-Use Efficiency and Declining Energy Intensity

Between 2000 and 2006, energy use in the United States grew at historically low rates in both absolute terms and in relation to the economy and population. There are various aggregate indicators that can be used to describe improving energy efficiency and declining energy intensity:

- *Annual energy consumption per capita* (in units of primary energy per year) declined from 371 GJ/capita in 2000 to 352 GJ/capita (giga-joules per person per year) in 2006. This occurred while per capita GDP grew from $34,883 in 2000 to $38,122 in 2006 (in deflated year 2000 dollars).
- During the same period, *per capita electricity consumption*, which usually rises faster than overall energy use because electricity is the energy form of choice for expanding energy uses in developed countries, remained constant (12,765 kWh/capita in 2000 compared to 12,758 kWh/capita in 2006).
- Decline in *energy intensity of GDP* of 2.0 percent per year (equal to that of the decline in CO_2 emissions, as previously noted).

C. Improved Energy-Related Air Quality

A large portion of air pollution is caused by combustion of fuel; as such, it is useful to note trends in local emissions to the air and air quality throughout the United States. Overall, air quality in the United States improved in the period 2000-2005. This trend was seen at local air quality and emissions monitoring stations throughout the nation. During 1999-2001, monitoring stations showed 4.5 percent of air quality readings to be in excess of standards for ozone. This percentage dropped to 2.1 percent for 2003-2005. Similarly, measurements showing small particulate ($PM_{2.5}$) violations of air quality standards declined from 2.1 percent in 1999-2001 to 1.4 percent in 2003-2005.

Below, we describe total emissions trends in the United States. In some cases, data are only available through 2002; in others, they are available to 2005. The data summarized here are either for 2000-2002 or 2003-2005, and are compared to the data from the 1990s.[3]

Emissions of carbon monoxide (CO), of which more than 90 percent comes from vehicles, declined 33 percent from 1990 to 2002; the decline from 2000 to 2002 was at roughly the same rate.

All nitrogen oxide (NO_x) emissions are caused by the combustion of fuels. NO_x emissions declined about 10 percent from 1996 to 2000 and roughly another 10 percent from 2000 to 2002. Ambient concentrations throughout the country declined through 2004. All regions of the country are in compliance with NO_x standards.

Emissions of anthropogenic volatile organic compounds (VOCs), which along with NO_x are an important input to ozone concentrations, have declined steadily on the order of 2 to 3 percent per year since 1990 and at a higher rate from 2000 to 2002. Fifty percent of anthropogenic VOCs come from fuel combustion; the remainder is from industrial processes.

Emissions of particulate matter with mass median diameter less than 2.5 micrometers ($PM_{2.5}$), 60 percent of which are from vehicles or stationary fuel combustion, showed no decline from 2000 to 2002.

Sulfur dioxide (SO_2) emissions declined 34 percent from 1990 to 2002. The major source of SO_2 emissions is coal-fired power plants (two-thirds of the total); such plants showed the greatest reduction. As a result of the decrease in ambient levels of SO_2, considerable progress has been made since 1990 in reducing acid rain deposition, especially in the mid-Appalachian region and the Ohio River Valley, where its impacts have been most serious.

Mercury levels from municipal and medical wastes and incinerators have been reduced substantially. Mercury from coal-fired power plants, however, has declined little, and it increased as a portion of total mercury emissions from 25 percent in 1990-1993 to more than 40 percent in 2002 because of the decline in emissions from other sources.

D. Continued High Levels of Fossil Fuel Combustion

Since 1992, coal has retained a steady 23 percent share of total primary energy consumption (see Table 3). Over the past six years, noncarbon energy sources have not significantly increased in the energy mix. In 2006, fossil fuels provided 85 percent of the U.S. energy supply; in 2000, the fraction was 86 percent. In contrast to the past six years, from 1972 to 1992 the United States did diversify its energy sources away from an even stronger reliance on fossil energy. During the same period renewables showed significant relative increases in wind and biofuels. Still, the share of renewables and of nuclear energy—the two nonfossil fuel energy sources—remained virtually unchanged from 1992 to 2006.

The trend of reduced carbon intensity of energy use from 1970 to 2000 reversed in 2000.

Figure 2 shows that since 2000 emissions of CO_2 per unit of energy consumed have exceeded the 36-year trend line, as well as the absolute value of carbon intensity over the previous 10 years. If the United States had maintained the earlier trend for this indicator, CO_2 emissions would have declined more rapidly than energy use. Increased coal use partially explains why carbon intensity of energy consumption in 2000-2006 was above the 36-year trend.

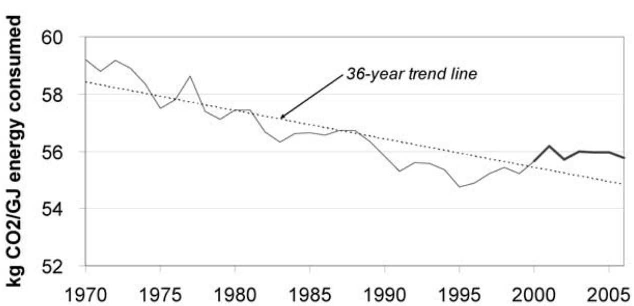
3. All data in this section are from the U.S. EPA Science Advisory Board Draft Report on the Environment (2007), Chapter 2. The original source of the information was in most cases the National Emissions Inventory, maintained by EPA.

Table 3
U.S. Fossil, Nuclear, and Renewable Energy Consumption, 1972–2006

	Energy Consumption (EJ)				Share of Total			
	1972	1992	2000	2006	1972	1992	2000	2006
Hydroelectric	3.02	2.76	2.97	3.05	4%	3%	3%	3%
Biomass	1.59	3.09	3.18	3.46	2%	3%	3%	3%
Wood	1.58	2.44	2.39	2.23	2%	3%	2%	2%
Waste	0.00	0.50	0.54	0.43	0%	1%	1%	0%
Biofuels	-	0.15	0.25	0.80	0%	0%	0%	1%
Geothermal	0.03	0.37	0.33	0.37	0%	0%	0%	0%
Solar/PV	-	0.07	0.07	0.07	0%	0%	0%	0%
Wind	-	0.03	0.06	0.27	0%	0%	0%	0%
Total Renewables	4.64	6.32	6.61	7.17	6%	7%	6%	7%
Nuclear	0.62	6.84	8.29	8.66	1%	8%	8%	8%
Fossil Fuels	71.42	77.43	89.39	89.42	93%	85%	86%	85%
Coal	12.74	20.17	23.82	23.75	17%	22%	23%	23%
Total	**76.70**	**90.68**	**104.42**	**105.37**	**100%**	**100%**	**100%**	**100%**

Source: EIA, AER 2006.
Note: Total final energy use; 2006 data are preliminary; wood, waste, and biofuels are components of biomass.

Figure 2
Carbon Intensity of U.S. Energy Consumption, 1970-2006

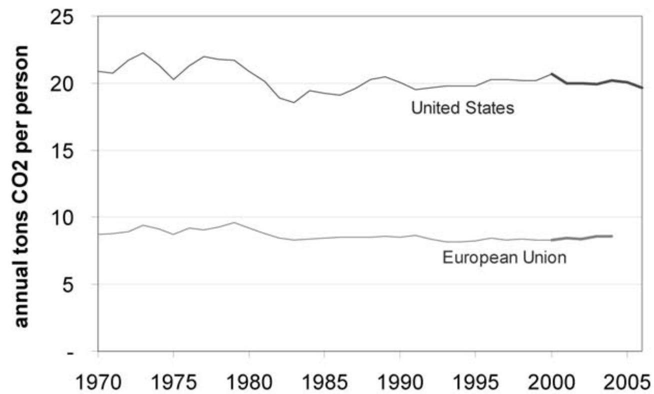


Source: EIA, AER 2006; IEA, Carbon Emissions From Fossil Fuel Combustion.
Note: Total final energy use; 2006 energy data are preliminary.

E. High Energy Use and CO_2 Emissions Relative to Other Industrialized Nations

It is important to recognize how far outside the norm of energy use and carbon emissions per capita the United States is in comparison with other industrialized countries. Figure 3 shows that the United States is responsible for 2.5 times the per capita CO_2 emissions of the major European Union nations. The ratio has changed little over the past 35 years. Recent data are not available to make comparisons for all of the past six years.

Figure 3
Annual Energy-Related Per Capita CO_2 Emissions in the EU and the United States, 1970-2006



Source: IEA and U.S. EIA.
Note: EU data cover the EU 15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

III. Lack of Federal Engagement in Energy Efficiency Policy

The two major federal policies to increase energy efficiency in the United States are appliance standards and the corporate auto fuel economy (CAFE) standards. However, only recently has the federal government begun to address new standards for appliance efficiency and to update the 1975 corporate automobile fuel standards.

The Energy Policy and Conservation Act (EPCA), as amended,[4] required the U.S. Department of Energy (DOE) to undertake rulemakings for appliance standards on specified schedules. On September 7, 2005, the Natural Resources Defense Council, 15 states, and the city of New York filed a lawsuit against DOE in the U.S. District Court for the Southern District of New York, alleging that DOE failed to comply with deadlines and other requirements for publishing final rules concerning energy efficiency standards for 22 categories of products. On January 31, 2006, DOE published a report to Congress containing a five-year schedule, to be completed by June 2011, to issue the final rules required by EPCA. In November 2006, the district court issued a consent decree, which the parties had agreed to, stating that "[f]or each product covered by the Complaints, DOE shall publish a final rule by the deadlines set forth," with the last due in June 2011. The DOE completed five *Federal Register* notices in this area in 2006, and two final rules in 2007, and other rulemakings are in process.

Because light trucks have become a large portion of the U.S. vehicle fleet, their fuel economy is significant. In 2007, a standard was set for light trucks at 22.2 mpg in 2008, increasing to 23.5 mpg in 2010. However, the Ninth Circuit

4. 42 U.S.C. §§6291-6317.

found these new light-truck rules to be arbitrary and capricious, and directed NHTSA to prepare a new standard as quickly as possible.

The standards for automobiles remained at the level of 27.5 mpg as mandated in 1975 (and achieved by 1985) until 2007. In December of that year, Congress passed the Energy Independence and Security Act,[5] which requires increases in fuel efficiency during the model years 2011 to 2020, reaching at least 35 mpg in 2020 for the total fleet of passenger and non-passenger automobiles. For the years 2021 to 2030, the standards require mpg to be the "maximum feasible" fuel economy.

In comparison, Japan and the European Union have set voluntary standards in the range of 50 mpg by 2020. It remains to be seen whether the voluntary approach will be effective in these countries; however, it is virtually certain that fuel economy in new vehicles in the United States will lag behind many or most other industrialized countries. China recently adopted standards that are tighter than U.S. standards.

IV. Burgeoning Biofuels

Biomass plays a growing role in the U.S. transition from reliance on fossil fuel to a more diversified energy system. Between 2000 and 2006, biomass consumption grew at an average annual rate of 1 percent. Within biomass energy usage, wood diminished by 7 percent and biofuel consumption more than tripled.

Biomass and particularly biofuel consumption only have the potential, at best, to marginally increase the sustainability of the U.S. energy system. However, the current American production of biofuels through corn-based ethanol is unsustainable for four reasons:

- low energy return on energy investment;
- low energy density;
- inflationary impact on food and energy prices;
- ecological limitations on the feasible scale of U.S. and global corn production.

Whereas petroleum production generates an energy return of approximately 15:1 on energy investment (i.e., 15 units of energy returned for each unit of required energy input), the ratio for corn-based ethanol varies between only 1.2:1 and 1.6:1.[6] Corn-based ethanol's low energy return on investment means that vastly more energy is required to produce the same given amount of liquid transport fuel.

This low energy return is compounded by the low energy density (unit of energy per unit volume) of ethanol. On a volumetric basis, ethanol contains only 65 percent of the energy of an equivalent amount of gasoline. Despite these limitations of corn-based ethanol production, the U.S. government has provided a generous production subsidy in the form of a $0.51 tax credit per gallon of ethanol used as motor fuel.

Further, growth of biofuel demand has had a negative effect on food and oil prices. Although U.S. maize production increased to historic levels over the past three years, maize prices rose from $78/ton in December 2000 to $142/ton in December 2006.[7]

Finally, the capacity of the United States for biofuel production is limited. Dedication of all U.S. corn and soybean production to biofuels would meet only 12 percent of gasoline demand and 6 percent of diesel demand.[8] While domestic biofuel production presents an attractive political alternative to fossil fuel imports, current production technologies are not sustainable.

Increased biofuel production, particularly from palm oil, corn, and sugarcane, further demonstrates that renewable energy sources are not necessarily sustainable. Given the scale of biofuel production necessary to offset liquid transport fuel demand, current programs for renewable cultivation are detrimental to sustainable energy production. Soil nutrient depletion, fertilizer consumption, water consumption, carbon-intensive land use change, and high primary energy requirements for ethanol production all undermine the sustainability of existing renewable fuel initiatives.[9]

V. Policy Recommendations for More Sustainable U.S. Energy

In response to developments in the U.S. energy system between 2000 and 2006, this article presents five federal-level policy recommendations to improve sustainability:

1. *Increase energy end-use efficiency through applied standards and improved technology.* This can be achieved by substantially tighter appliance efficiency standards for many products and an aggressive policy to require more efficient automobiles, light-duty vehicles, and heavy-duty vehicles.

2. *Support research, development, and demonstration of energy-efficient commercial buildings to prepare the way for net zero-energy buildings.* This area of research and demonstration has been underemphasized for years and offers large energy savings opportunities.

3. *Implement taxation on energy production and consumption of carbon or a cap-and-trade system of carbon emissions.* Taxation or a cap-and-trade system would internalize costs and align private incentives with social costs.

5. Pub. L. No. 110-140, 121 Stat. 1492 (2007).
6. Alexander E. Farrell et al., *Ethanol Can Contribute to Energy and Environmental Goals*, 311 Science 506-08 (2006).
7. Kenneth G. Cassman & Adam J. Liska, *Food and Fuel for All: Realistic or Foolish?*, 1 Biofuels Bioproduction, Biorefining 18-23 (2007).
8. Jason Hill et al., *Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Fuels*, Proceedings of the Nat'l Acad. of Sciences 103(30): 11206-10 (2006).
9. Timothy Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions From Land-Use Change*, 319 Science 1238-40 (2008).

4. *Support biofuel research to supplant inefficient and inflationary corn-based ethanol production.* Biomass will play an important role in the transition to a modern solar energy system. However, it is important to make the transition from corn to more sustainable energy sources (e.g., woody crops).

5. *Set targets for industrial-sector CO_2 emissions in advance of establishing a carbon tax or cap and trade system.* Despite the absolute decline in industrial energy use over the past six years, U.S. industry remains less energy efficient, in many cases by a substantial margin, than industry in other developed countries.