Energy Past, Present, and Future

Energy is the lifeblood of modern civilization. Energy consumption in U.S. and worldwide increased over ten-fold during the 20th century and per capita consumption more than tripled. When the National Academy of Engineering identified the "Greatest Engineering Achievements of the 20th Century" they included two energy technologies (electrification and petroleum) in their "top 20" achievements (Table 1). More importantly, these two technologies enabled all of the other 18 top engineering achievements. Modern civilization as we know it would not exist without electricity and petroleum fuels.

Table 1. Greatest Engineering Achievements of the 20th Century

1. **Electrification**
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. **Petroleum** and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

The U.S. and other developed countries accounted for most of this increase in global energy consumption. However, since 1980 per capita energy consumption in developed countries has leveled off. Nevertheless, their economies have continued to grow due to increasing energy efficiency. For example, from 1980 to 2010, U.S. per capita energy consumption decreased 8 percent while real per capita GDP (Gross Domestic Product) increased 67% percent. By improving energy efficiency, the U.S. can continue this trend and achieve robust economic growth for the foreseeable future without increasing per capita energy consumption.

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Developing countries are in a very different situation. They are rapidly increasing their energy consumption to catch up with the standard of living of developed countries. Global energy consumption (and production) will triple in the 21st century to twelve times current U.S. energy consumption if 1) the world's population increases to 10 billion and 2) global per capita energy consumption increases to 40% of current U.S. per capita consumption. (Note: This 40% value is roughly equal to current per capita energy consumption in Spain and Italy, slightly less than in Great Britain and Japan, and slightly higher than in Greece and Hong Kong. It is also consistent with tripling per capita energy consumption in developing countries, while per capita energy consumption remains flat in developed countries.)

Energy is big business. Since 1970, the cost of energy for the U.S. has averaged 9% of GDP, with a high of almost 14% in 1981 and a low of slightly less than 6% in 1999. In general, the economy has performed best when the cost of energy as a percent of GDP was low and decreasing (1990s) and worst when it was high and increasing (1974 to 1981 and 2008).

To understand energy, it is useful to consider how much energy (food) the human body requires to function. The average American consumes about 2,500 calories per day. This is the energy-equivalent of slightly less than one-tenth of a gallon of gasoline per day, or about 30 gallons per year. (The human body is an amazingly efficient biological machine!) The food consumed annually by the entire U.S. population contains roughly as much energy as 9 billion gallons of gasoline, or slightly over one quad of energy. Note: A quad is a unit of energy equal to one quadrillion (a million billion) British Thermal Units.

The U.S. consumes about 100 times more energy as fuel and electricity than as food. This is a key reason why our standard of living is so high: non-food energy powers the economy.

In 2010, the U.S. consumed 98 quad of energy. About 83% of this energy was supplied by fossil fuels: petroleum (37%), natural gas (25%) and coal (21%). The remaining 17% was provided by nuclear power (9%) and renewable energy sources (8%). Table 2 shows U.S. energy consumption by source.

Table 2. U.S. Energy Consumption by Source (2010)

Fossil Fuels:	
Petroleum	37%
Natural Gas	25%
Coal	21%
	83%
Other Sources:	
Nuclear Power	9%
Renewables	8%
	17%

(Data from EIA Annual Energy Review 2010)

About 40% of this energy is used to produce electricity. In 2010, most electricity was produced using coal (45%), natural gas (24%), nuclear power (20%), and renewables (11%). The other 60% is consumed mostly as liquid fuels (such as gasoline, diesel fuel, and jet fuel) and gaseous fuels (primarily natural gas), but a small fraction is used as feedstock for chemical and industrial products.

In 2010, the U.S. consumed 32% of its energy in industry and manufacturing, 28% in transportation, 22% in residential buildings, and the remaining 18% in commercial buildings, as shown in Table 3.

Table 3. U.S. Energy Consumption by Sector (2010)

Industry & Manufacturing	32%
Transportation	28%
Residential	22%
Commercial	18%
Total	100%

(Data from EIA Annual Energy Review 2010)

Will the U.S. deplete its oil and natural gas resources anytime soon? The simple answer is "no," but there are nevertheless good reasons (which will be discussed later) to develop alternative and renewable energy resources to supplement fossil fuels, and ultimately replace them. This process will probably require at least a century, and perhaps much longer.

Table 4 shows the current estimate of technically recoverable U.S. oil resources: 219 billion barrels (1,270 quad). About half of these resources are onshore in the lower 48 states. The other half are offshore and in Alaska. At the current rate of production of two billion barrels annually, these resources will not be depleted for about 100 years. In addition, as technology advances, technically recoverable resources are likely to increase. For example, current technology enables recovery of only about one-third of initial oil-in-place. If improved technology enables recovery of a larger fraction of this oil, then technically recoverable oil resources will increase. Also, the U.S. has very large oil shale resources, which are not considered recoverable with current technology. New technology could enable economic, environmentally sound production of this oil shale in the future. The net result is that the U.S. can probably continue producing oil at the current rate for well over a hundred years, and even increase production to reduce imports. However, this will require drilling on federal lands, offshore, and in Alaska. In addition to U.S. oil resources, Canada has huge oil sands deposits -- large enough so they could supply most U.S. oil import needs for at least a century, and probably much longer.

Table 4. U.S. Oil Resources -- Technically Recoverable (2010)

	Quad	Billion Barrels
Proven Reserves	122	21
Unproven Reserves	1148	198
Total	1270	219

(Data from EIA Annual Energy Review 2010)

Table 5 shows the current estimate of technically recoverable U.S. natural gas resources: 2,544 trillion cubic feet (2,484 quad). At the current production rate of 23 trillion cubic feet annually, these resources will not be depleted for about 100 years. Furthermore, just as with oil, new technology will probably expand the technically recoverable resource base. For example, in just the last five years, technically recoverable natural gas resources have increased 50% due to new technology (horizontal drilling and hydraulic fracturing) for production of shale gas. The U.S. has vast quantities of other unconventional natural gas resources that are not recoverable with current technology, such as methane hydrates. Improved technology will likely enable production of more unconventional natural gas resources in the future. The bottom line: the U.S. can probably continue producing natural gas at the current rate for over 100 years, and even increase production to replace coal and oil in some applications.

Table 5. US Natural Gas Resources -- Technically Recoverable (2010)

	Quad	Trillion Cubic Feet
Proven Reserves	239	245
Unproven Reserves	2245	2299
Total	2484	2544

(Data from EIA Annual Energy Review 2010)

The U.S. should nevertheless develop alternative and renewable energy resources, for three reasons: cost, energy security, and climate change.

Cost. As global energy consumption increases, and as the "easy to recover" fossil energy resources are depleted, the cost of fossil fuels could increase, stifling U.S. and global economic growth. One way to prevent this is by developing alternative and renewable technologies such as biomass, biofuels, wind, solar, geothermal, and nuclear power.

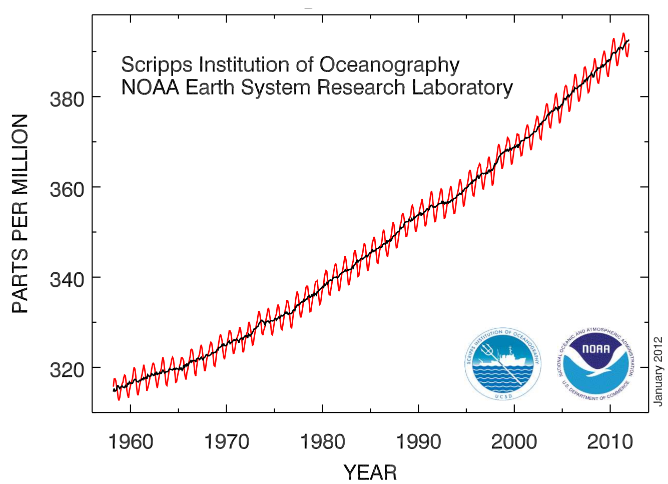
It is by no means certain that the cost of fossil fuels will increase in the future, as new technology could potentially reduce the cost of extracting unconventional resources. This is precisely what happened in the U.S. during the past five years when shale gas flooded the market and halved the price of natural gas. Nevertheless, it is prudent to diversify energy supplies to guard against future increases in the cost of fossil fuels.

Energy Security. The world is overly dependent on oil. A large fraction of the world's oil is produced by relatively few countries, many in the Middle East. As a result, the world economy is hostage to events that are largely unknowable and uncontrollable.

The U.S. imports nearly half of its liquid fuels (primarily as crude oil) at a cost of about $300 billion annually. Oil supply disruptions and price spikes have contributed to all major U.S. recessions and wars in the past 40 years. In the near term, the best way for the U.S. to reduce its dependence on oil imports from unreliable sources is by 1) improving the fuel economy of light vehicles, 2) increasing domestic oil production, and 3) increasing imports from Canada. Over the longer term, however, alternative fuels will be needed to supplement (and ultimately replace) oil. It is prudent to start developing them now, since the transition will probably require a very long time.

Climate Change. The concentration of carbon dioxide in the earth's atmosphere has increased from less than 300 parts per million (ppm) in 1900 to almost 400 ppm now. Figure 1 shows how carbon dioxide levels have increased in the past 50 years.

Figure 1. Atmospheric Carbon Dioxide Concentration from 1960 to 2010



The United Nations Intergovernmental Panel on Climate Change (IPCC) projects that the concentration of carbon dioxide in the earth's atmosphere could double or triple in the 21st century, to a level not experienced since the age of the dinosaurs. The IPCC also projects that average global temperatures could increase by several degrees (Fahrenheit) as a result. This projected global temperature rise is much faster than any

increase that has occurred in the last 400,000 years, when the earth's climate has fluctuated between ice ages and warmer interglacial periods.
A few scientists question whether global warming is real, and some people argue that warmer weather and increasing carbon dioxide concentrations may be good for humanity. However, most are convinced that global temperatures are rising, and that the resulting climate change will stress both human civilization and the world's ecosystems. While it is true that the science of global warming is uncertain, the effect could be either greater or less than currently estimated. This uncertainty may in fact be the best reason to act now, to prevent a low probability, worst case scenario from seriously damaging the earth's ecosystems.

Global warming poses a significant international security risk, because it has the potential to divide the world into antagonist blocks as climate change affects the most vulnerable countries first, and then progressively affects other nations. If populations are uprooted by climate change, where will they go? Who will make room for them? Will they demand compensation from those who caused global warming? The potential for environmental degradation, economic disruption, territorial conflicts, and global terrorism is real.

Much has been learned about climate change since the Rio Earth Summit highlighted the problem in 1992. Smart energy and climate policy will find a middle ground between those who deny that human activities are affecting the world's climate and those who believe that global warming is the most urgent problem facing humanity. Some policy options are as follows: 1) improve energy efficiency, 2) shift from high-carbon fuels such as coal and oil to low-carbon fuels such as natural gas, 3) expand renewable energy production, 4) increase nuclear power generation, 5) sequester carbon (for example, with improved farming and forestry practices and by using carbon dioxide to increase oil production), and 6) adapt to climate change. All of these measures will probably be necessary to some extent. The challenge is to develop and implement cost-effective policies that will equitably address the problem, without choking off global economic growth.

Finding sustainable, affordable solutions to the world's energy challenges will not be easy, and it will not be done quickly. But failure is not an option. Just as the U.S. and other developed countries found a way to expand energy production over ten-fold in the 20th century so their economies could grow, the world must now find a way to at least triple global energy production in the 21st century and dramatically improve energy efficiency so the global economy can continue to grow.

In 2100, when the National Academy of Engineering selects the "Greatest Engineering Achievements of the 21st Century," what technologies will they choose? No one knows. But it is likely that all or most will either be related to energy or dependent on energy. In fact, the quality and quantity of energy innovations in the 21st century may profoundly impact the future of human civilization.