# THE IMPLICATIONS OF GLOBAL WARMING FOR ENERGY PRODUCTION AND CONSUMPTION

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## Summary

To protect the biosphere for future generations, energy-related carbon emissions must be aggressively reduced. To achieve this, large changes will be required, not only in the technologies of global energy production and consumption, but also in the decision-making and planning criteria that shape our cities and institutions and thereby determine patterns of energy demand. This article considers five approaches to carbon abatement: energy efficiency, nuclear energy, natural gas substitution, carbon sequestration, and renewable energy. To determine their possible roles, the article compares their potential to reduce carbon dioxide ($CO_2$) emissions, their environmental and social implications, and their readiness for implementation. Transportation and urban planning are discussed separately because of their large and growing importance in the context of global urbanization.

While non-carbon energy technologies clearly have the potential to supply future human energy needs, a technological approach alone will not guarantee adequate implementation, nor does it guarantee that the least risky and most socially beneficial options will be pursued. Only comprehensive, integrated planning that makes sustainability a core criterion in all decision-making, from the production of goods to the planning of communities, will suffice. The emerging example of sustainable cities

offers a vision and starting point for such an integrated approach. If pursued globally, sustainable cities could greatly reduce energy demand while increasing quality of life.

While the human energy future cannot be predicted, a preferable path is clear and achievable through public policy (see *Energy Policy for $CO_2$ Emissions Reduction*). Greatly expanded use of nuclear energy poses unacceptable risks and is unnecessarily erosive of justice and democracy. The technological sequestration of carbon is highly speculative and risky, and therefore cannot be relied upon as a means to control climate change. However, further research and development, particularly on coal decarbonization, is probably warranted. Energy efficiency and renewables have the clear potential to meet human energy needs, and pursuing this path from a broad sustainability perspective is likely to leave humanity profoundly better off.

## 1. Introduction

Clearly, our global energy future cannot simply be predicted, as it will depend heavily on policy and investment decisions, which themselves may be influenced by unpredictable events. For example, the personalities of government leaders in key countries at critical times and the timing of conspicuous warming-related events, like the sudden collapse of large portions of the Antarctic ice shelves, could catalyze very different policy responses. If such catalytic events occur sooner, we can anticipate heavy investments in early, proven, low-carbon energy technologies and efficiency. Similarly, the timing of events related to key technologies, such as a catastrophic nuclear reactor accident, could affect decision-making at such critical times. Because early investments can lock in market advantages, these kinds of unpredictable events may be major determinants of which energy technologies are winners or losers. On the other hand, we can do better than simply leaving the future of humanity and the biosphere to fate. We can actively seek out and pursue an energy path that presents the least risks and the greatest benefits at the lowest cost. It is in this spirit that the following analysis proceeds.

The magnitude of change required in the multi-trillion dollar global energy infrastructure is profound. According to the assessment of the Intergovernmental Panel on Climate Change (IPCC), global $CO_2$ emissions must be reduced by 60–80% just to avoid a doubling of atmospheric $CO_2$ concentrations. But not even this level of abatement is guaranteed to avoid catastrophic consequences for the biosphere, especially in view of possible positive feedbacks to climate warming that are not currently included in the model. These include the warming-related release of methane hydrates from ocean sediments (discussed further below) and the release of large stores of carbon from tundra soils. Significantly, these large reductions in carbon emissions must be accomplished while accommodating a much larger human population, and ideally while substantially increasing the standard of living of, at minimum, the neediest third of humanity. Moreover, this must all be accomplished in a biosphere under increasing stress from multiple causes (intensification of land use, cumulative pollution loading, mass extinction of species, and ozone depletion, to name just a few). This makes imperative the maintenance of substantial safety buffers.

From these arguments it is clear, to be reasonable stewards of the welfare of future generations, we must virtually eliminate carbon emissions from fossil fuel combustion. Fossil fuels currently supply about 85% of global primary commercial energy use. Among anthropogenic sources, fossil fuel combustion is the single largest source of greenhouse gas emissions and constitutes 75% of $CO_2$ emissions, which are responsible for an estimated 60% of the total anthropogenic warming.

Currently, there are five major approaches being considered for carbon abatement: (1) greatly increasing electricity generation from nuclear fission (referred to henceforth simply as nuclear power), (2) substituting natural gas for coal, (3) increasing the efficiency of energy use, (4) using renewable energy sources, and (5) mitigating through carbon sequestration (which here includes the decarbonization of fossil fuels). Serious commitments must soon be made to some or all of these options. Yet, the different options have profoundly different implications for society's future. These options and their implications are discussed in the following sections. Because of its unique set of issues, transportation is discussed separately. Sustainable cities are then described as one important example of how broad, integrated planning can greatly reduce energy demand and impacts, while improving the quality of life. Finally, in the Conclusions, the different approaches are compared and broad energy policy recommendations are offered.

## 2. Energy Options for Carbon Abatement

### 2.1 The Role of Energy Efficiency

The most obvious approach to reduce carbon emissions is simply to reduce energy consumption. Improving the efficiency of energy-consuming products, like light bulbs, motors, and vehicles, has typically been the most popular approach because it requires little or no change in institutions, infrastructure, and behavior. Efficiency is the major component of the "no-regrets" approach to carbon abatement because saving energy with efficient technologies frequently costs less than supplying the same amount of energy. It is also one of the least-cost means to control air pollution. This section briefly summarizes the potential role of energy efficiency in carbon abatement (see *Energy Efficiency and the Switch to Renewable Energy Sources*).

The potential of efficiency to reduce energy demand and carbon emissions has been the topic of much research. The 1997 Energy Innovations report by the Alliance to Save Energy and others constitutes a comprehensive attempt to model the potential of key policy and technology innovations to stimulate US investments in efficiency and renewables, and to quantify the associated benefits. The results indicate that this "innovative path" would reduce energy demand in 2030 by more than 40%, compared to the demand anticipated if current energy trends continue, the "present path." The total technical potential for demand reduction through efficiency is larger, with efficiency improvements continuing well beyond 2030. Significantly, the report also finds that such investments would actually be beneficial, not only to the environment, but also to the economy, and they would create more jobs. It should be noted that the "innovative path" also constitutes an absolute reduction in energy consumption of almost 20% over the 40-year period modeled (from 80 to 65 exajoules from 1990 to 2030). Predicted $CO_2$

emissions reductions are larger, at 46%, primarily because of stimulated introduction of renewable energy sources and cogeneration. The latter eliminates large heating energy requirements by utilizing what would otherwise be waste heat from electricity generation.

While improved efficiency clearly has large potential and provides a cost-effective means to control carbon emissions, efficiency alone is not a solution to the global warming problem. The magnitude of the necessary carbon emissions reductions, increased per capita energy demand in the developing world, and the anticipated growth in human population preclude this. Projections of ultimate human population range from 8 to 12 billion, although the upper estimate is unlikely to be sustainable, given that the current human population already uses substantially more resources than the earth can sustainably supply. Taking 50% as a rough approximation of the potential of efficiency to reduce energy demand, population growth alone could cancel out efficiency improvements. Current increases in per capita energy consumption in highly populous Asia will make this challenge larger. Meeting the currently unmet heating and cooking energy needs of the poorest third of humanity, a minimum ethical requirement, will make this challenge larger still.

Of additional concern, our most abundant conventional energy source is coal, which has the highest $CO_2$ and air pollution emissions of any energy source. Lacking alternatives, the temptation will be to increase coal use as easily accessible stocks of oil and natural gas are depleted. Clearly, other options must be pursued in concert with efficiency. These options are examined in the following sections.

### 2.2 The Trade-offs of Nuclear Power

Nuclear advocates have been urging greatly expanded use of nuclear power (fission) to mitigate climate change. The argument is that nuclear power plants emit no $CO_2$ during normal operations. Critics have challenged this argument pointing out substantial indirect emissions inherent especially in uranium mining and processing. Recent analysis suggests that the total life-cycle emissions associated with today’s nuclear plants are less than those from conventional fossil-fuel generation, but more than those associated with renewable energy. Thus, substitution of fossil-fuel generation with nuclear power could reduce emissions substantially. The questions are: At what cost? And are preferable alternatives available?

Without substantial new investments, the nuclear power industry could be in trouble. Public opinion against nuclear power has virtually stalled the industry in most, if not all, of the countries with substantial nuclear capacity (Table 1). In the United States, the largest generator in the world, there have been no new orders for nuclear plants since 1978. Indeed, in the history of commercial nuclear power in the US there have been more total plant cancellations than installations. Moreover, much of the installed capacity is near (or in some cases beyond) the expected plant lifetime, raising concerns about possible safety risks arising from progressive radiation damage to critical components of the reactor core. Thus, without major new investments, nuclear generation can be expected to decline rapidly in the US in the next couple of decades. In fact, over the past decade, the Far East is the only region of the world that has been experiencing sustained increase in nuclear capacity (Figure 1), with the majority of new additions going into South Korea and Japan, in that order.

| **Region/Country** | **Nuclear generation per year (kWh, billions)**[a] | **Total electric generation per year (kWh, billions)** | **% of country's total generation** | **% of world generation** |
|---|---|---|---|---|
| United States | 628.6 | 3494.4 | 18 | 27.7 |
| France | 374.3 | 476.6 | 79 | 16.5 |
| Japan | 306.1 | 999.3 | 31 | 13.5 |
| Germany | 161.8 | 524.7 | 31 | 7.1 |
| Russia | 104.5 | 784.0 | 13 | 4.6 |
| United Kingdom | 89.3 | 325.9 | 27 | 3.9 |
| Canada | 77.9 | 562.2 | 14 | 3.4 |
| Ukraine | 75.4 | 168.6 | 45 | 3.3 |
| Korea, South | 73.2 | 230.3 | 32 | 3.2 |
| Sweden | 66.7 | 148.2 | 45 | 2.9 |
| Spain | 52.5 | 178.5 | 29 | 2.3 |
| Belgium | 45.0 | 74.9 | 60 | 2.0 |
| Taiwan | 34.8 | 124.0 | 28 | 1.5 |
| Switzerland | 24.0 | 60.8 | 39 | 1.1 |
| Finland | 19.0 | 72.8 | 26 | 0.8 |
| Bulgaria | 16.4 | 40.1 | 41 | 0.7 |
| Hungary | 13.3 | 33.4 | 40 | 0.6 |
| South Africa | 12.6 | 196.2 | 6 | 0.6 |
| Czech Republic | 12.5 | 61.7 | 20 | 0.6 |
| China | 11.4 | 1054.5 | 1 | 0.5 |
| Lithuania | 10.9 | 13.3 | 82 | 0.5 |
| Slovakia | 10.5 | 23.6 | 44 | 0.5 |
| India | 10.5 | 441.1 | 2 | 0.5 |
| Mexico | 9.9 | 166.1 | 6 | 0.4 |
| Argentina | 7.5 | 76.0 | 10 | 0.3 |
| Romania | 5.1 | 54.6 | 9 | 0.2 |
| Slovenia | 4.8 | 12.6 | 38 | 0.2 |
| Brazil | 3.0 | 303.5 | 1 | 0.1 |
| Netherlands | 2.3 | 84.7 | 3 | 0.1 |
| Armenia | 1.4 | 5.8 | 24 | 0.1 |
| Pakistan | 0.4 | 56.7 | 1 | 0.0 |
| Kazakhstan | 0.3 | 49.5 | 1 | 0.0 |

Source: Energy Information Administration (EIA). (2001, Dec. 26—last update). *World Net Nuclear Electric Power Generation, 1989 – 1998.* [Website of the Energy Information Administration, US Department of Energy], [Online]. Available: http://www.eia.doe.gov/pub/international/ieapdf/tf_07.pdf.

Table 1. Nuclear generators in 1997, with countries ranked by contribution to world nuclear generation

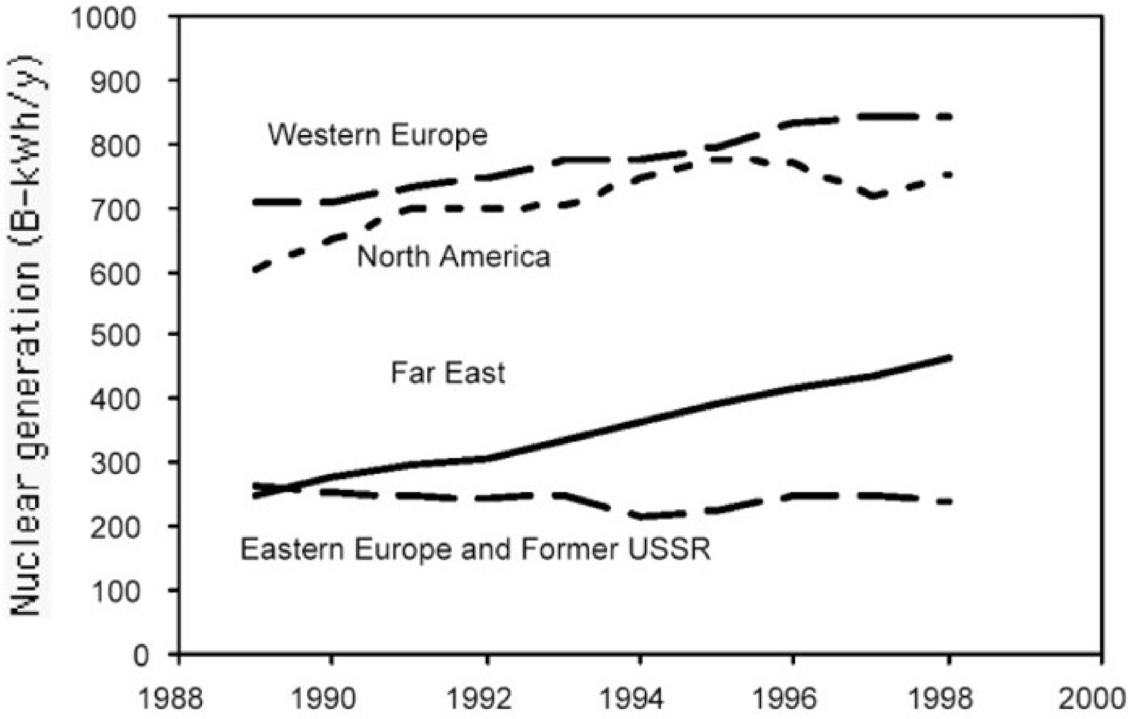

Figure 1. Nuclear electricity generation between 1989 and 1998 in different regions of the world

### 2.2.1 Security Risks of a Breeder Reactor Economy

As suggested earlier, proven technologies are likely to have an advantage in early carbon abatement decisions. Because nuclear fission currently supplies about 17% of the world’s electricity, and has been part of the power mix for almost half a century, nuclear power is frequently perceived as a proven, if perhaps risky, technology. Yet if nuclear power is to contribute substantially to long-term carbon mitigation, it will require the use of essentially unproven and considerably less safe technology.

The vast majority of today’s reactors burn uranium fuel in a “once through” process, after which the fuel rods become waste. Uranium is a scarce element. The fissile isotope of uranium (U-235) that allows the critical nuclear chain reaction to occur is scarcer still, constituting only 0.7% of all naturally occurring uranium. The remaining 99.3% is U-238, which, while radioactive, cannot sustain a chain reaction.

The scarcity of nuclear fuel would make nuclear power short-lived if future reactors used the once-through approach. The US uranium reserves demonstrate this problem.

US reserves would be depleted in a matter of decades if all US electricity were generated using U-235 in a "once-through" process. It has been proposed that ordinary reactors could operate six times longer if they used thorium fuels, which could postpone but not solve the finite resource problem.

The lure of breeder reactors is that they have the potential to convert the entire stock of uranium into a resource that could last many thousands of years. Breeder reactors produce energy and a new fuel (plutonium-239) simultaneously. Pu-239 is created when U-238, arranged in a blanket around the reactor core, absorbs neutrons. To be useable as the next generation of fuel, the Pu-239 must be separated out and fashioned into fuel rods. The separation process inescapably creates plutonium that is pure enough to be used in nuclear weapons. Indeed, breeder reactors are used for that very purpose.

A breeder reactor economy would, therefore, create vast quantities of plutonium that must be transported, processed, and stored (a nuclear weapon can be made with only 5 kg of plutonium). This would greatly expand opportunities for the clandestine diversion of fissile materials for weapons production and would proliferate weapons production capabilities into host countries. It was the concern of terrorist diversion and use of plutonium that convinced US President Carter, in 1977, to discontinue the US commercial breeder reactor program.

Breeder reactors are also inherently less safe than ordinary reactors. To produce enough neutrons to both sustain the core reaction and to breed more fuel than it is consuming, breeders must use Pu-239 as their fuel (fission of U-235 does not produce enough neutrons). It is the different fission-triggering requirements for Pu-239, versus U-235, that make plutonium reactors so much more dangerous. Pu-239 fission is triggered when it is intercepted by a fast-moving neutron, whereas U-235 fissions on slow neutrons. In ordinary reactors, slowing the neutrons takes time. The shorter time between fissions in a Pu-reactor means that the core reaction can go out of control much more rapidly. With the power output growing so rapidly, it is conceivable the reactor could explode like a nuclear bomb. By comparison, in the 1986 Chernobyl accident, the unit 4 reactor was destroyed when the runaway chain reaction super-heated the cooling water, causing a steam explosion.

The prospect of an accident far more serious than Chernobyl is sobering, given the 3.5 million people estimated by the Ukraine Health Ministry to have fallen ill as a result of the accident. It is even more troubling given that the Chernobyl toll will surely increase, because of the long latency period of many cancers and the passing of mutated genes to future generations. Still, many analysts consider proliferation of nuclear weapons technology, and the increased probability of the use of nuclear weapons by terrorists and "rogue" nations, a far greater risk because of the enormous toll that would result if those weapons were strategically delivered and detonated over a highly populated region.

The operations history of breeder reactors also calls into question their suitability as a major energy source. Only a handful of countries have operated breeder reactors and their operations history has been troubled, mainly because of sodium leaks. Breeder reactors cannot use water as the coolant because the compact core produces too much heat. Therefore, the typical design relies on liquid sodium metal (hence the name, liquid metal fast breeder reactor, or LMFBR). According to the US Department of Energy, only France, Japan, Kazakhstan, and Russia have operable LMFBRs. The UK, Germany, and the US have shut down, and, in the latter case, decommissioned, their reactors.

Given that nuclear reactor accidents have been the main catalyst for public opposition to nuclear power, the widespread use of far riskier breeder reactor technology would appear to be a political impossibility. While the public opinion problem does explain the industry's lobbying for a new generation of "inherently safe" reactors, it does not resolve the discrepancy in the dialogue. The proposed "passively stable" reactors are all uranium-fueled, essentially smaller, simpler cousins of the current generation of nuclear reactors. These will never supply large amounts of power for the long term, but will only serve to extend the lifetime of the struggling nuclear industry.

### 2.2.2 Other Problems Inherent in Nuclear Power

Nuclear waste disposal is another reason to be skeptical that the world will embrace a breeder reactor economy. Not a single country has yet resolved the waste problem. Based on public records, all countries plan to use geological disposal for high-level (highly radioactive) wastes; but none have approved sites. Many look to the US as a model, which has spent the last 25 years trying to identify, assess, and approve a long-term geological repository. The US Department of Energy (DOE) is mandated to base its assessment only on the site's merits. Yet, for years it has been considering only one site, Yucca Mountain in Nevada. This leaves no alternative if the scientific assessment were to conclude the site were inappropriate. Meanwhile, Nevada has passed legislation specifically outlawing the disposal of nuclear wastes within its borders. Of course, Nevada cannot override federal law, and it lacks the political power to persuade Congress to also consider sites in other states.

Despite many problems, it appears a virtual certainty that Yucca Mountain will be approved. The federal government is long overdue in providing a high-level waste repository. With all of the wastes generated during the history of US commercial nuclear power (>30 000 metric tons) having accumulated at power plants, in sites designed for short-term storage only, the nation's utilities are suing the DOE to take their wastes. Yet, outstanding questions remain about the site's long-term integrity, specifically evidence of geologically recent seismic activity in the region and of possible periodic intrusion of superheated groundwater into the disposal site. But what of the future?

Accommodating the wastes from nuclear generation expanded to 10 times its current level, as recently proposed by the industry, would require an entire repository like Yucca Mountain to be filled each year. Given the current controversy over opening even one such site, having to do so into perpetuity looks not only daunting but unacceptably politically divisive and socially disruptive. Persistent questions over the site's safety, despite decades of assessment, make this proposal yet more questionable.

The previous discussion highlights another problem of heavy reliance on nuclear power, its erosive effect on democratic societies. This type of high-tech, highly centralized technology forces minorities and other politically weak communities to bear the social and environmental brunt of power production and concentrates its benefits in the hands of the few (consider, for example, the enormous and largely uncompensated impacts of uranium mining on the Navaho community). It also inhibits effective public participation in decision-making about a critically important industry (energy supply). That is, decision-making tends to occur among a small group of industry experts, politicians and government officials vulnerable to industry lobbying.

Ultimately, though, it may be the monetary cost of nuclear power that eliminates it as a serious contender for carbon abatement. Despite an estimated US$150 billion in historic subsidies, far higher than for any other energy source, nuclear power is not competitive in the US electricity market. Nuclear power plants constitute the single largest share of noncompetitive assets stranded in the electricity industry deregulation process. While restructuring is not yet complete, the US Department of Energy has estimated that stranded assets will eventually run between US$10 billion and US$500 billion. Having now cost US$28 billion in California alone, clearly, the low-end estimate is wrong. While the nuclear industry is being “bailed-out” by ratepayers in essentially every state, it is clear that the nuclear industry would have been virtually shut down in a truly competitive market. In California, all other sources, including wind, biomass, geothermal, and solar thermal, but excluding photovoltaics (PV), are less costly than nuclear power. Moreover, historically, nuclear power costs have risen while PV costs have declined and continue to do so. Given viable alternatives, and after the costly bailout, it is unlikely that the public will tolerate the additional extensive subsidy that surely would be needed to develop either commercial breeder reactors or short-lived “inherently safe” once-through reactors.

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## Biographical Sketch

**Dr. Garbesi** is assistant professor of geography and environmental studies at the California State University at Hayward. She is also affiliated faculty of the Energy and Resources at the University of California at Berkeley, and a guest scientist of Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division. She received her bachelor's degree in physics with high honors, an MS and Ph.D. in Energy and Resources, all from the University of California at Berkeley. For her work on radon entry into houses she won the Alexander Hollaender Distinguished Postdoctoral Fellowship and an Associated Western Universities/Department of Energy Fellowship for Achievements in Science. That work explained large model underestimates of radon entry, and hence of indoor exposures, due to effects of scale in measurements on common heterogeneous soils.

As an assistant professor of environmental studies at San Jose State University (SJSU) she developed an undergraduate major and graduate studies in Energy Resource Management. She was graduate coordinator for environmental studies and chair of the University-wide Environmental Forum. While at SJSU she conducted a wind energy assessment for the Eritrean government as part of its sustainable development strategy. Dr. Garbesi is the current recipient of a Switzer Environmental Leadership Grant, through which she is a consultant to Golden Gate University's Environmental Law and Justice Clinic. In that work she is participating in the energy regulatory process as it affects the minority community of Southeast San Francisco and she is exploring alternative energy strategies for the city of San Francisco. Dr. Garbesi is a consultant to the Alameda Center for Environmental technologies on the development of green energy businesses to mitigate California's energy crisis. Her current research interests include sustainable cities, environmental justice, energy policy, and renewable energy assessment. She lives with her husband and 7-year-old daughter in Kensington, CA, in a house that generates its own electricity from the sun.