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Nuclear Power: No Solution to Global Climate Change

Special combined issue of *Science for Democratic Action* and *Energy & Security*. See back page.

BY ARJUN MAKHIJANI

A popular refrain in recent debates on global climate change is that nuclear power must be a significant part of any strategy to reduce greenhouse gas emissions. Proponents argue that as a carbon-free technology nuclear power is one of the few ways that carbon dioxide emissions can be significantly reduced while meeting growing energy needs. This claim does not hold up to careful scrutiny, either on technical or economic grounds. Nuclear power and high levels of fossil fuel use each create a diverse set of problems. This article examines issues relating to nuclear power, while the accompanying articles on global warming (p. 3) and creating a sustainable energy supply (p.5) look at some fossil fuel-related questions.

Reactor Safety

There is no practical or reasonable way to eliminate the safety and proliferation threats arising from commercial nuclear power. All reactor types that have been developed or designed pose some level of risk of catastrophic accidents on scales similar to Chernobyl, though the specific accident mechanisms and probabilities depend on reactor design.[1] This is in part because commercial nuclear power was developed as an adjunct to the nuclear arms race and as a tool of Cold War propaganda.[2] In its rush to build new reactors, the industry, from its inception, put public safety, health, environmental protection and even economics behind weapons development and propaganda.

From the early days of reactor development, the Atomic Energy Commission

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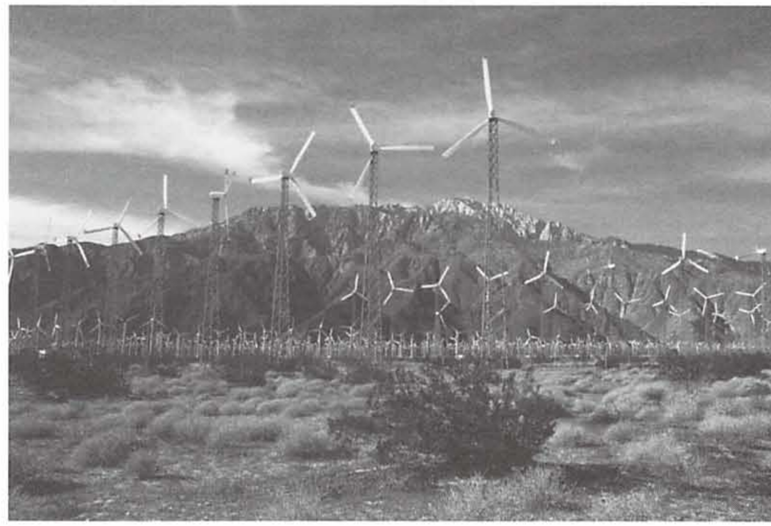

Wind power systems—one component of a sustainable energy future.

The Energy-Security Link

Many crucial security, economic, and environmental issues that will affect human survival and well-being for centuries to come are converging around a single word: *energy*. Will the twenty-first century see a revival of nuclear energy to counter the build-up of greenhouse gases that threatens to drastically alter the planet's climate? Will plutonium enter into commerce as an energy source on a large scale, posing greater proliferation threats? Will the flow of oil from the Persian Gulf (the West's "lifeline" that, curiously and problematically, runs outside the West), be disrupted by conflicts over issues related to nuclear weapons and other weapons of mass destruction?

Such questions are not entirely new. For instance, during the Cold War, some of the Pentagon's scenarios for nuclear war began with a crisis in the Persian Gulf-West Asia region that then spread to Europe. During World War II, much of the strategy revolved around control of oil resources, which were the lifeblood of the war machines of all sides. Indeed, the US-Japanese crisis that boiled over into the Japanese bombing of Pearl Harbor centered on the oil resources of Indonesia, then colonized by Holland.[1] A part of the Allied strategy during World War II centered on preventing German access to the rich uranium resources of the Congo, then colonized by Belgium.[2]

The environmental connections have also

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been drawn in the past. Widespread burning of coal in urban areas has given rise to terrible episodes of air pollution, for example in London (and at the present time, some cities in China). The devastating consequences of the spread of fission products like iodine-131 and cesium-137 from serious nuclear power plant accidents have been among the main concerns about nuclear energy. The mining of both coal and uranium has caused severe pollution in many areas of the world. Plutonium-239, which is created in large amounts in nuclear power plants, has been a principal source of concern regarding nuclear power not only because of its utility in making weapons, but due to its long half-life (24,000 years) and its high radiotoxicity.

These issues are now coming together at an unprecedented political, military, and environmental conjuncture. Here are some of its characteristics:

- The build-up of greenhouse gases (notably carbon dioxide, methane, nitrous oxide and halocarbons) has reached a point where it is likely that it is changing the global climate. Expanding the use of nuclear energy to avert catastrophic climate change is now supported not only by the nuclear industry but also by a number of governments, among them some of the richest and most powerful.
- The collapse of the Soviet Union and the subsequent economic crisis in the region has led to heightened fears that nuclear warheads or nuclear weapons-usable materials, of either military or commercial provenance, could wind up on the black market.
- The United States, Russia, and other nuclear states are proposing that surplus plutonium from military programs be used as a fuel in commercial reactors. Moreover, despite the poor economic, environmental and non-proliferation characteristics of plutonium, powerful bureaucracies in several countries support continued operation of reprocessing plants (France, Britain, Russia, Japan, India). At the same time, there is renewed interest in separation of plutonium from commercial spent fuel among politically and economically powerful advocates in the United States.
- Since the 1979 Iranian revolution, the Persian Gulf region has been in an intense long-term military crisis that includes the Iran-Iraq war during the 1980s, Iraq's 1990 invasion of Kuwait, the 1991 Gulf War, Iraq's programs to develop weapons of mass destruction, and the United Nations sanctions against Iraq.
- A significant portion of the world's natural gas resources, which could be used to alleviate the greenhouse gas crisis, lie in the Central Asian and Persian Gulf regions, and in land and offshore areas belonging to countries such as Azerbaijan, Kazakstan, Iran, Saudi Arabia, Iraq, and Qatar. These same countries also have among the world's largest oil reserves. Thus the security of natural gas transport, which could be vital to both energy supply and to reduction of greenhouse gas emissions, is added to the various other security crises in the area.

These issues are so intertwined that major decisions of powerful

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Science for Democratic Action

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Global Warming and the Greenhouse Effect

BY KEVIN GURNEY

The gases that make up the Earth's atmosphere and the way in which energy passes through or is absorbed by these gases play a crucial role in regulating the temperature of the planet. The atmosphere, made up mostly of molecular nitrogen (78 percent) and oxygen (21 percent), contains small amounts of particular gases referred to as **radiatively active gases**. Prominent among the radiatively active gases are water vapor (H_2O) and carbon dioxide (CO_2), both of which exist in relatively minute quantities. These gases allow most sunlight, primarily visible radiation, to pass through the atmosphere to the planet's surface, where about 70 percent of the energy is absorbed, raising the temperature of the Earth. The Earth then emits thermal (infrared) radiation to space, thereby maintaining an energy balance: the amount of energy entering the Earth/atmosphere system equals the amount leaving.

> Increasing temperatures could cause a sufficient melting of permafrost and frozen soil layers in the polar regions to release huge amounts of methane and carbon dioxide.

As this thermal radiation makes its way out of the atmosphere, it is intercepted by radiatively active trace gases. They absorb the outgoing radiation, increasing in temperature as they do so. This interplay between thermal radiation emission and absorption by the atmosphere raises the overall temperature of the Earth and the atmosphere system above what it would be if there were no atmosphere present. In fact, without the presence of radiatively active gases in the atmosphere, the Earth would only be 1.4 degrees Fahrenheit! (-17 degrees Celsius.) Because of the energy absorbed by the atmosphere, the global average temperature is instead a comfortable 59 degrees Fahrenheit (15 degrees Celsius). This insulating ability has come to be known as the "greenhouse effect" because the process is much like that in a greenhouse, where visible light passes through the panes of glass in the ceiling, but heat is retained within through absorption of infrared radiation by the glass.

Unfortunately, human activities such as the burning of fossil-fuels, large-scale fertilizer use, cattle production, and deforestation have begun to directly increase the amount of "greenhouse gas" in the atmosphere above natural levels. This rise in greenhouse gas concentration is expected to increase the global average temperature of the planet to levels that may disrupt atmospheric, oceanic, ecological, and ultimately human systems and well-being. It is this enhancement of the natural greenhouse effect that is referred to as "global warming."

The principal greenhouse gases, in order of their estimated contribution to global warming are: carbon dioxide, methane, halocarbons, and nitrous oxide. Measurements taken at remote locations around the globe reveal the unmistakable increase in concentration of these gases in the atmosphere. Some, like carbon dioxide, are both natural and anthropogenic gases. Others, like some halocarbons, are purely man-made.

The Principal Greenhouse Gases

Carbon Dioxide (CO_2): CO_2 is by far the greatest contributor to climate change, accounting for about 64 percent of estimated current global warming. The primary sources of carbon dioxide emissions to the atmosphere are the production, transportation, processing, and consumption of fossil fuels (86 percent), tropical deforestation and other biomass burning (12 percent), and miscellaneous sources (2 percent), such as cement manufacturing and oxidation of carbon monoxide. Once emitted, a specific molecule of carbon dioxide cycles through the atmosphere and the biota before being permanently removed by oceanic processes or long term increases in terrestrial biotic storage (i.e., uptake by plants). The amount of time in which about 63 percent of the emissions of a gas are removed from the atmosphere is called its **effective residence time**. There is often a considerable uncertainty in this crucial parameter, which is important for calculating the climatic effects of a greenhouse gas. When the rate of emission of a greenhouse gas is greater than the rate of removal, then its atmospheric concentrations increase. For carbon dioxide, this has been happening over the last century or more. The estimated range for effective residence time of carbon dioxide is 50 to 200 years.

Methane (CH_4): Methane has both natural and anthropogenic sources of which the latter is derived primarily from fuel production, enteric fermentation (e.g. cattle), rice cultivation, landfill emissions, and deforestation (mainly biomass burning and decay of excess organic matter). Accounting for an estimated 20 percent of current global warming, methane emissions are a significant source of greenhouse gases. Molecule for molecule, methane is about 21 times more effective a greenhouse gas than CO_2. Methane is principally removed from the atmosphere by reacting with the hydroxyl radical (OH).[2] Because many hydrocarbons

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and halocarbons (including many ozone-depleting compounds) also are removed from the atmosphere through reaction with OH, higher methane concentrations can have significant effects on the general ability of the atmosphere to remove greenhouse gases. There are some indications that methane and other pollutants have caused a reduction in OH concentrations. About 30 percent of the increase in methane concentration in the atmosphere is due to the reduced capacity of the atmosphere to absorb it.

Halocarbons: Halocarbons are a class of chemical compounds, both human-made and natural, containing carbon and one or more atoms belonging to the halogen group of elements, such as fluorine and chlorine.[3] The most abundant halocarbons in terms of their contribution to global warming are chlorofluorcarbons (CFCs, also known by the trade name, Freon); specifically CFC-11 and CFC-12. Though existing in relatively trace amounts in the atmosphere, these chemical compounds exhibit powerful radiative trapping abilities in addition to their well-known ozone depleting properties. Halocarbons account for about 10 percent of current global warming, but the atmospheric concentration of these compounds has begun to fall as a result of an international ban on their production and consumption. Measurements of similar chemicals used as substitutes for CFCs—hydrochlorofluorcarbons (HCFCs) and hydrofluorcarbons (HFCs)—are now showing concentration increases. Should concentrations continue to rise, these substitute chemicals may contribute significantly to global warming in the future.

Nitrous Oxide (N_2O): Like CO_2, nitrous oxide is present naturally in the atmosphere. However, the extensive use of artificial nitrogen fertilizer and fossil-fuel combustion account for the majority of anthropogenic emissions of nitrous oxide. N_2O levels account for about 6 percent of current global warming.

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TABLE 1. CHARACTERISTICS OF THE PRINCIPAL GREENHOUSE GASES

greenhouse gas	primary sources	present concentration in atmosphere (ppmv)	% annual increase	Atmospheric Increase*	effective residence time in atmosphere	sinks and reservoirs*
carbon dioxide	production of commercial energy; deforestation; other biomass burning.	360	0.4%	~7.1 billion metric tons/yr[4]	50-200 years	Atmospheric reservoir; ocean uptake; uptake by N. Hemisphere forest growth. (Occurs over a few years.) Transfer to soils and to the deep ocean (Occurs on century time scale)
methane	natural gas production and transmission; enteric fermentation (e.g., cattle); rice cultivation, landfill emissions, deforestation	1.7	0.5%	~37 million metric tons/yr.	12.5 years	Main removal process: tropospheric hydroxyl radical (OH)[5]; also: stratosphere; soils
halocarbons Most abundant are CFC-11 and CFC-12	solely of human origin: used in industrial processes and end-use products like air-conditioners and refrigerators (as coolants and insulation)	CFC-11 = 27 CFC-12 = 500	Falling due to ban on use. Substitutes (HCFCs, and HFCs) are showing increases.	CFCs: currently ~0 should decrease slowly due to Montreal Protrocol; HCFCs, HFCs: recently showing an increase	ranges from a few years to a few thousand years	Atmospheric reservoir; removed mainly through breakdown by sunlight (photolysis) in the stratosphere
nitrous oxide	mainly from use of fertilizer and fossil-fuel combustion	315	0.25%	3-8 million metric tons/yr.	120 years	Removed mainly through breakdown by sunlight (photolysis) in the stratosphere

* "Atmospheric increase" and "sinks and reservoirs" from Intergovernmental Panel on Climate Change, *Climate Change 1995* (Cambridge University Press, 1996), pp. 15–19.

CFCs = chlorofluorocarbons　　HFCs = hydrofluorocarbons

HCFCs = hydrochlorofluorocarbons　　ppmv = parts per million by volume

Reducing Greenhouse Gases and Creating a Sustainable Energy Supply

BY ARJUN MAKHIJANI

The global energy system poses severe threats to the world's well-being that derive from both large-scale fossil fuel use and nuclear energy, albeit in different ways. Human dependence on fossil fuels and other resources that produce greenhouse gases could lead to catastrophic climate change. Currently, the capacity of the biosphere to absorb carbon dioxide is considerably lower than present emission levels.[1] This is leading to an increase of CO_2 concentration in the atmosphere. Since CO_2 is the main greenhouse gas (see article on p. 3), fossil fuel use at anywhere near existing levels and with current technology poses grave risks of global climate change.

Proponents of nuclear energy suggest that the problem of greenhouse gases can be solved by nuclear power because nuclear reactors do not emit carbon dioxide into the atmosphere. However, the high costs and many risks that accompany nuclear power make it no less problematic than large-scale fossil fuel use (see article on p. 1).

Because governments and corporations have focused almost all of their resources and development on fossil fuels and nuclear energy, transforming the world's economy to a healthy, secure, and sustainable energy system will not be easy. This article will look at the technical aspects of some of the options for reducing greenhouse gas emissions in terms of energy supply—notably fuel for electricity generation—and lay out some basic criteria for creating a sustainable energy system.

Criteria for a Sustainable Energy System

To be viable and sustainable, a global energy system must be able to meet simultaneously the following basic criteria:

1. It must be reliable.
2. Its cost should be reasonable.
3. It should not produce routine severe pollution.
4. It should be possible to almost wholly confine the environmental and security costs of the energy system to the generations benefiting from it. In other words the system should be amenable to cost internalization.
5. It should be capable of sustaining reasonable levels of energy services[2] to eight to ten billion people (the projected population of the world in the next century).
6. Its core functions should be resilient to supply, transportation, transmission, and economic shocks.

Nuclear energy use cannot meet these criteria mainly because of (i) the risk of long-term and widespread damage from Chernobyl-scale accidents and (ii) the risks inherent in the production of vast amounts of nuclear-weapons-usable materials. Fossil fuel use in the present manner and scale cannot meet these criteria mainly because of the risk of catastrophic global climate change. Other problems exist also.

A sound strategy would work toward a vast increase in efficiency over the next several decades, and a mix of renewable energy sources supplemented by a modest amount of fossil fuels. Fossil fuels do not need to be completely phased out in order to mitigate global warming, since nature has some capacity to absorb anthropogenic carbon dioxide (in addition to natural CO_2 circulation between the atmosphere, water, soil, and biota). The long-term goal should be to keep emissions well below this natural absorption level of roughly three billion metric tons of anthropogenic carbon emissions. However, it should be noted that absorption of these emissions into the oceans, biota, and soil occur in ways that are still not well understood.

It may be possible to use fossil fuels at carbon emission levels greater than the natural absorption capacity of the atmosphere, if ways to prevent CO_2 emissions to the atmosphere can be found. Strategies to trap CO_2, which go by the generic term "sequestration," are varied, and include storing CO_2 in underground reservoirs or pumping it undersea. There are considerable environmental uncertainties associated with such proposals and their costs are high. Given that CO_2 emissions must be reduced greatly in the next few decades in a manner compatible with increasing energy services, investments in energy efficiency which accomplish both goals at once, and can do so more economically, are more desirable than sequestration strategies. The policies we discuss here, therefore, are not dependent on the use of sequestration as a measure to reduce CO_2 emissions.

Some Sustainable Options for Reducing Greenhouse Gases

A variety of technologies exist that can help achieve substantial reductions in global greenhouse gas emissions and at the same time promote economic well-being. Wind power, cogeneration, fuel cells, natural gas-assisted solar thermal power plants, and replacing

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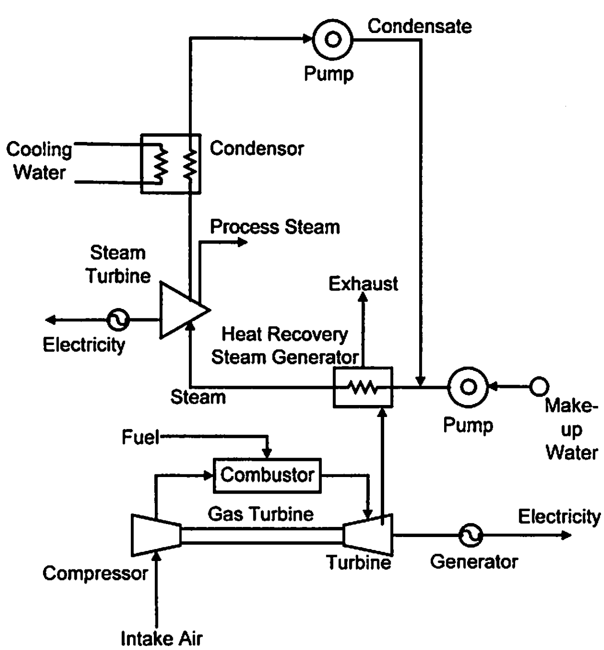
inefficient coal plants with renewable and/or natural gas plants are some of the technical options for maintaining the expanding electric power capability while reducing greenhouse gas emissions. Investments in combinations of these technologies would considerably *reduce* CO_2 emissions, rather than merely preventing CO_2 emissions, as would be the case with building new nuclear power plants. In fact, the expense of nuclear power would actually preempt investments in technologies more appropriate for achieving goals of reducing carbon dioxide emissions.

Table 1 shows that natural gas combined-cycle plants are more economical than nuclear power plants in all cases. Combined-cycle plants use a fuel such as natural gas in a two-step electricity generation system. First, the natural gas drives a gas turbine and a generator. Then the hot exhaust gases from the turbine are used to raise steam, which drives a steam turbine (see diagram below). The efficiency of such a system available commerically today is about 50 percent.

Note that China, the main prospective customer for new nuclear power plants, is unlikely to have the highest costs of combined cycle plants because it would use piped gas (from its own onshore and offshore fields as well as Central Asia) and not liquid natural gas (on which all three costs are based). This comparison

COMBINED-CYCLE PLANT



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excludes pessimistic scenarios for nuclear power plant costs, which would be substantially higher than the highest nuclear costs given in the table.[3]

Each cent per kWhe difference in costs works out to about $66 million per year in additional electricity costs for nuclear power plants (1,000 MW size). This works out to a present value over a 30 year period (at an annual discount rate of 4 percent) of $1.15 billion for every cent per kWhe difference in electricity costs. (Future costs are discounted, since a dollar saved at a future time is worth less than a dollar in hand today.) Using these figures, one can compare a strategy of using nuclear power plants to displace existing coal-fired power plants with one of using combined-cycle power plants. We have compared the various cases for combined-cycle versus nuclear: low cost versus low cost, medium versus medium, and high versus high. For a typical case, building combined-cycle plants would result in a reduction of about 40 percent more CO_2 than could be achieved with nuclear (comparison of Case 2 combined cycle with the corresponding nuclear power plant). This gain can be expected to increase since efficiencies of combined cycle plants are increasing.

One could also use the capital cost savings achieved by building combined-cycle plants instead of nuclear to develop and promote solar and wind technologies and to increase energy efficiency. The avoided CO_2 emissions in such cases would vary depending on the sites for the power plants or the specific technologies chosen to increase efficiency. If combined-cycle plants were used to retire half the coal-fired power stations in the world, an overall annual global carbon dioxide emissions reduction of about 15 percent could be achieved.

During the 1970s, there was concern that natural gas was a very scarce resource, but it was not well founded. Gas is a widely available resource, and does not carry the proliferation risks of nuclear power. Our approach is not premised on use of natural gas into the indefinite future, but only on its use in high efficiency applications over the next several decades. This use of natural gas as a transition fuel is a sound economic and environmental strategy. During that time we expect, with appropriate action on the part of governments, corporations, and consumers, that renewable energy sources will take over most of the energy supply in a vastly more efficient economy.

World reserves of natural gas have been steadily rising, and now stand at about 75 years of consumption at 1995 levels (corresponding to reserves of about $5.2*10^{21}$ joules in reserves, and an annual utilization of about $7*10^{19}$ joules). Global gas reserves have been steadily increasing, despite increasing consumption.[4]

Coal fired power stations are located in many parts of the world, including western Europe, the United

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TABLE 1. ESTIMATED COSTS: COMBINED CYCLE VS. NUCLEAR PLANTS

Power system	Capital cost $/kW	Int+dep ¢/kWhe[1]	Nat gas price $/million Btu[2]	Fuel cost ¢/kWhe	Non-fuel O&M ¢/kWhe[3]	Total cost ¢/kWhe	Tot. CO_2 reduction after 30 yrs kg C[4]	Carbon reduction ratio, Gas/nuc.
Combined cycle (CC)[5]								
Case 1 CC	500	0.76	150	1.02	0.48	2.26	9.97×10^{10}	1.37 (Case 1)
Case 2 CC	500	0.76	250	1.71	0.48	2.95	1.02×10^{11}	1.40 (Case 2)
Case 3 CC	500	0.76	400	2.73	0.48	3.97	1.09×10^{11}	1.50 (Case 3)
Nuclear[6]								
Case 1 Nuc	1500	2.28		0.6	1.7	4.58	7.29×10^{10}	
Case 2 Nuc	2500	3.81		0.6	1.7	6.11	7.29×10^{10}	
Case 3 Nuc[7]	4000	6.09		0.7	2.0	8.79	7.29×10^{10}	

Based on the following sources: For nuclear plant costs (cases 2 and 3): Steven M. Cohn, *Too Cheap to Meter: An Economic and Philosophical Analysis of the Nuclear Dream*, State University of New York Press, Albany, 1997, pp. 106 and 155; U.S. Nuclear Regulatory Commission, *Information Digest 1997*, Washington, DC, 1997, Tables 6 and 7. For gas costs: the US Energy Information Administration web page at: *www.eia.doe.gov/oiaf/ieo97/gas.html*. For combined-cycle power plant costs: D.M. Todd and H. Stoll, "Integrated Gasification Combined-cycle—The Preferred Power Technology for a Variety of Applications," GE Power Systems Schenectady, Paper presented at the Power-Gen Europe 97 Conference, Madrid, June 1997 and C. Komanoff, R. Brailove, and J. Wallach, *Good Money After Bad: An Economic Analysis of the Early Retirement of the Salem Nuclear Generating Station*, Pace University School of Law Center for Environmental Legal Studies, White Plains, NY, September 1997, page 39.

NOTES:

1. Interest and depreciation assumed to be 10 percent in all cases. Capacity factor assumed to be 75 percent in all cases.
2. Btu stands for British thermal unit. 1 Btu = about 1,055 joules. One kWhe (kilowatt-hour electrical) = 3.6 million joules = 3,413 Btu.
3. Non-fuel nuclear costs include 0.2 cents per kWhe for waste disposal and decommissioning, except in the worst case (case 3) where this cost is taken to be 0.5 cents per kWhe. See Cohn, p. 155.
4. The CO_2 emissions avoided are calculated on the assumption that both types of power plants would displace existing coal fired power plants emitting 0.37 kilograms (carbon basis) per kWhe. For nuclear the avoided emissions would therefore be 0.37 kg, to a first approximation. For combined-cycle with 50 percent efficiency, the figure is about 0.25 kg per kWhe (emissions from the coal-fired power plant less the emissions from the combined-cycle plant). The avoided CO_2 emissions figures for combined-cycle plants are likely to be increase for plants installed a few years hence, because the efficiency of these plants is increasing.
5. Efficiency of the combined cycle plant is assumed to be 50 percent. Higher efficiencies, approaching 60 percent, are expected in the next few years. We have assumed a natural gas fuel value of 1,000 Btu per cubic foot in these calculations. (Nuclear power plant thermal efficiency is about 33 percent. The exact figure does not affect power costs substantially, since fuel costs are a small fraction of total costs.)
6. Nuclear costs do not include any reprocessing and plutonium management costs..
7. The worst case capital cost of nuclear (case 3) was typical of US costs for plants coming on line after 1983, but with far higher capacity factor than was typical of the 1980s in the US. The best case nuclear capital cost (case 1) is that reported by the media for sales of Russian VVER-1000 reactors to China.

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States, the former Soviet Union, China, India, and eastern Europe. While it is unlikely to be economically feasible to immediately replace coal-fired plants with combined-cycle plants, it is possible to phase out coal-fired plants and replace them over time. In some areas, wind capacity would also provide an effective and economical offset for CO_2 emissions.

One drawback to increased use of natural gas is that natural gas pipelines add to methane emissions due to small leaks in the pipelines. One estimate of such leaks in the case of power plant use is 0.8 percent. Since methane is a far more powerful greenhouse gas than CO_2, it is necessary to offset these emissions in order to maximize the greenhouse gas reductions that can be obtained from natural gas use. Such offsets can be obtained by relatively simple measures, such as building biogas plants at feedlots, and recovery of methane gas emitted from landfills (now a significant pollutant in many areas) for use as a fuel. Landfill gas is used on a limited basis in many places to produce electricity or fuel for heating. For instance, landfill gas from the Fresh Kills landfill, where the municipal waste from New York City is dumped, provides heating fuel for 14,000 homes.[5]

Energy Efficiency and Renewable Energy Sources

How do we make the transition to an energy system that meets energy needs and is also sustainable and environmentally sound? It is not difficult to postulate some distant future when renewable sources of energy might be economical to meet basic energy needs. But how will we get to that future, especially when solar and wind energy have not yet made substantial contributions to global energy supply after many decades of effort, and when energy efficiency improvement has

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The Kyoto Protocol

From December 1–11, 1997 the Third Conference of the Parties ("COP-3") to the United Nations Framework Convention on Climate Change was held in Kyoto, Japan and included over 10,000 participants from governments, intergovernmental organizations, NGOs and the press. In the Kyoto Protocol, adopted by 171 countries at the conference, structures were put into place to reduce six major greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The Protocol must still be ratified by the legislative bodies of the signatory countries. Major provisions of the Kyoto Protocol are described below.

NOTE: "Annex I parties" are those countries included in Annex I to the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992. "Annex B parties" refers to those countries included in Annex B in the Kyoto Protocol. See table.

MAJOR PROVISIONS OF THE KYOTO PROTOCOL

1. **Greenhouse gas emissions reduced to 5 percent below 1990 levels:** *Article 3* of the Protocol reflects the parties' commitments to reduce overall emissions of greenhouse gases by 5 percent below 1990 levels between 2008 and 2012. The 5 percent target is not a global target but applies as an overall target to a list of countries in Annex B of the Protocol. Some countries, including the US, Canada, European Union countries and Japan, will have to ruduce emissions up to 8 percent. Some on this list including Australia and Iceland will be allowed to increase emissions by varying amounts up to 10 percent. There are no limits for "developing" countries including China, India, Brazil, Mexico, Indonesia, Nigeria, etc., whose per capita consuption of fossil fuels is still relatively low.

2. **Emissions trading:** *Article 16 bis* states that, "The Parties included in Annex B may participate in emissions trading for the purposes of fulfilling their commitments under Article 3 of this Protocol. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article." Article 16 bis was a late addition to the Kyoto Protocol, and a subject of contentious debate. It allows emissions trading in principle, but specific rules are to be worked out at the Fourth Conference of the Parties ("COP-4"), to be held November 2–13, 1998 in Buenos Aires, Argentina.

3. **"Clean Development Mechanism"** *Article 12* defines a clean development mechanism, the purpose of which is to assist developing countries to achieve "sustainable development." Annex I countries could count reductions in greenhouse gases achieved in this way against their own targets.

4. **Joint Implementation** *Article 6* states that, "for the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy" While similar to the "clean development mechanism," joint implementation refers to the trading of emissions reduction units *among* Annex I parties (generally, industrialized countries), while the clean development mechanism allows Annex I parties to benefit (i.e. gain emission reduction units) from emissions reduction projects performed by corporations in *non*-Annex I countries.

NOTE: "Science for the Critical Masses" replaces the traditional centerfold found in *Science for Democratic Action*.

ANNEX I AND ANNEX B PARTIES

(all are both Annex I and Annex B unless otherwise noted)

	Kyoto protocol emissions limit as percentage of base year (1990)
Australia	108
Austria	92
Belarus (Annex I only)	-
Belgium	92
Bulgaria	92
Canada	94
Croatia (Annex B only)	95
Czech Republic	92
Denmark	92
Estonia	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia	92
Liechtenstein	92
Lithuania	92
Luxembourg	92
Monaco (In Annex B only)	92
Netherlands	92
New Zealand	100
Norway	101
Poland	94
Portugal	92
Romania	92
Russian Federation	100
Slovakia	92
Slovenia (Annex B only)	92
Spain	92
Sweden	92
Switzerland	92
Turkey (Annex I only)	-
Ukraine	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

JOINT IMPLEMENTATION: NO PANACEA

Joint implementation, a key part of the provisions of the Kyoto Protocol, involves the trading of emissions between two parties. The idea is that if one party can reduce emissions more cheaply than another, or is already below allowable limits, then the party for whom it would be more expensive could simply purchase emissions reductions. This avoids the added expense involved when all polluters must reduce their own emissions. Thus, in theory, by relying on "market principles," society would achieve emission reduction targets at the lowest cost.

This theory has been tried out with some success in the United States for reducing sulfur dioxide (SO_2) emissions from industrial sources. These sources, such as many coal burning power plants, are large emitters of SO_2, and their emissions are relatively well known. It has enabled industries that might otherwise face a shutdown to prolong their timetables for achieving compliance.

The following conditions appear to be required for emissions trading to be successful:

- The implicit price of a unit of pollution should be high enough to provide a substantial incentive to all polluters to reduce emissions.
- There should be a progressive tightening of targets towards the desired levels, so that the desired reductions are actually achieved in a reasonable time.
- The sources of emissions should be well characterized, so that the progress in emissions reductions can be measured with confidence. This is a key requirement, since without it, enforcement would be impossible and questionable schemes would flourish.
- Price negotiations should be between parties of comparable economic power, so that trading is equitable.

These conditions were all met in the US experience with SO_2 trading, and generally hold in the case of emissions from large industries within countries. They may also be roughly fulfilled when large industries in different countries negotiate across borders, although factors such as differences in currency convertibility and inequitable exchange rates must be taken into account.

In the case of CO_2 emissions regulated under the Kyoto Protocol, the units of account are countries themselves, so that domestic trading is not at issue. (Each country may, of course opt to have CO_2 trading permits within its boundaries to achieve its Kyoto Protocol targets, but that is within the province of that country's government and not the Protocol itself.) Trading of emissions between large industries, such as power plants, located in most countries listed in Annex I (or Annex B) may be appropriate, provided the pricing arrangements are worked out. However, since there are many economically weak countries with weak currencies on the Annex I list (such as the former Soviet Union and eastern European countries), trading may become inequitable. Moreover, the pre-1990 records of emissions from large industrial plants in the FSU and eastern Europe are likely to be poor or incomplete in many cases. Finally, the relevance of these records for the next decade is highly questionable, given the huge changes that have taken place since 1990.

If trading between Annex I countries for the purposes of joint implementation appears to be problematic, it will be even more so between Annex I countries and developing countries. Besides the measurement and enforcement questions, the equity issue is particularly serious here. The CO_2 problem has been caused primarily by emissions from the industrialized countries. But emissions rights are being allocated on the basis of 1990 levels, giving the lion's share of the value of emissions credits that could be traded to those who created the problem. The countries with lowest fossil fuel consumption would hold the lowest emissions credits and hence derive the least benefit, though they have contributed least to the problem. This is a central reason that these countries did not agree to emission limits for themselves in the Kyoto Protocol. This keeps open until a later date (presumably the meeting in Argentina in November 1998), the question of what level of emissions trading rights developing countries will have.

If the emissions rights were on a per capita basis, as many people in the developing countries are demanding, then the feasibility of joint implementation would be considerably expanded, as would the economic benefits to be derived from it.

Proposals for joint implementation involving sectors other than industry involve additional problems. Examples include planting forests in developing

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JOINT IMPLEMENTATION

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countries, and using agricultural residues in power plants to offset CO_2 emissions in industrialized countries. Such proposals are ill-suited to joint implementation, as they do not meet several of the conditions set forth above. First, the inequality of the negotiating parties in such arrangements is evident, and is exacerbated by the fact that upper classes in highly class-divided societies do the negotiating on behalf of farmers and the poor.

The technical issues are equally daunting. In the simplest instance, a tree would contribute to CO_2 reductions only during the growth period. After that there may be a net increase or decrease in CO_2, depending on the specific circumstances. Further, emissions of greenhouse gases such as nitrous oxide and methane would need to be taken into consideration. Would replanting be required? How would one account for natural changes in the forest area over time? It is quite unclear how such complex processes would be factored into greenhouse gas accounting.

There is also the question of land. Most developing countries do not have much idle productive land. Common land and partly forested land is often used by the poor for grazing draft animals, as a source of fuelwood and construction wood, and for other uses. Monetizing this land by making it a part of joint implementation projects could deprive millions of poor people access to basic resources, even though they did not create the present greenhouse gas problem.

Even many projects that appear attractive on the surface do not stand up to scrutiny. For instance, a project that might use bagasse (left over organic matter after the juice is crushed out of sugarcane stalks) for generating electricity in India could have disastrous consequences of large numbers of people. Bagasse is already used for a variety of purposes, including electricity generation. The pressure to get more bagasse for such generating plants could wind up increasing sugarcane cultivation, displacing food crops. Further, many places in India use bagasse in traditional furnaces to make raw brown sugar, known as "gurdh." (It's quite delicious.) Joint implementation might kill such traditional industries, which employ large numbers of people, and create even more unemployment in already distressed rural areas.

In sum, there are limited prospects for joint implementation and these could perhaps be pursued with some economic benefit to the global community. However, they would have to be carefully thought through in a way that has not yet been done to ensure that they are equitable, that their results are measurable, and that the poorest populations of the world are not adversely affected.

—ARJUN MAKHIJANI

GREENHOUSE EFFECT

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Measuring and Modeling Global Warming

Temperature data collected over the last century show a statistically significant rise in global mean temperature of between 0.3 and 0.6 degrees Celsius since the late 19th century. While there are some uncertainties as to the extent this is attributable to increases in greenhouse gases, the temperature increases recorded so far are broadly consistent with global warming theory. This evidence, coupled with that of greater occurrences of extreme climatic events, has led the Intergovernmental Panel on Climate Change (IPCC) to conclude that "the balance of evidence suggests that there is a discernible human influence on the global climate."[6]

In order to estimate what future changes in climate might occur as a result of greenhouse gas increases, models of climate, called **general circulation models** have been developed with various assumptions about the workings of the physical climate. Though there are uncertainties with the projection, (mainly associated with the role of increased evaporation and cloud formation in redistributing radiation and thermal energy), the near-consensus estimate is that the average global temperature would increase 1.0 to 3.5 degrees Celsius with a doubling of pre-industrial carbon dioxide-equivalent. Under present trends, this is expected to occur near the year 2100. Regionally, temperatures could increase as much as 10 degrees Celsius in the polar regions and possibly not at all in equatorial areas.

Warming beyond this estimate is possible given further increases in greenhouse gas concentrations. Many researchers have suggested the possibility of catastrophic, sudden increases in methane and/or carbon dioxide. Increasing temperatures could cause a sufficient melting of permafrost and frozen soil layers in the polar regions to release huge amounts of methane and carbon dioxide now trapped in them. The quantities of greenhouse gases emitted could potentially be so large and their effects on atmospheric chemistry and composition so unpredictable that no model exists

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LIFETIMES, CONCENTRATIONS, AND GLOBAL WARMING POTENTIAL OF MAJOR GREENHOUSE GASES REGULATED UNDER THE KYOTO PROTOCOL[1]

Greenhouse Gas	Chemical Formula*	Atmospheric Lifetime* (years)	Pre-industrial Concentration	Concentration in 1994	Rate of concentration change[2]	Global Warming Potential[3] (time horizon) 20 yrs	100 yrs	500 yrs
carbon dioxide	CO_2	50-200[4]	~280 ppmv	358 ppmv	1.5 ppmv/yr (0.4%/yr)	1	1	1
methane[5]	CH_4	12±3[6]	~700 ppbv	1720 ppbv	10 ppbv/yr (0.6%/yr)	56	21	6.5
nitrous oxide	N_2O	120	~275 ppbv	312 ppbv[7]	0.8 ppbv/yr (0.25%/yr)	280	310	170
sulfur hexafluoride	SF_6	3,200	0	3.2 pptv	0.2 pptv/yr (6.3%/yr)	16,300	23,900	34,900
HFC-32	CH_2F_2	5.6	0	0 (1989 est.)	0	2,100	650	200
HFC-125	C_2HF_5	32.6	0	0 (1989 est.)	0	4,600	2,800	920
HFC-134a	CH_2FCF_3	14.6	0	0 (1989 est.)	0	3,400	1,300	420
HFC-143a	$C_2H_3F_3$	48.3	0	0 (1989 est.)	0	5,000	3,800	1,400
HFC-152a	$C_2H_4F_2$	1.5	0	0 (1989 est.)	0	460	140	42

Sources: Intergovernmental Panel on Climate Change, *Climate Change 1995*, (Cambridge University Press, 1996), pp. 15, 22; A. Makhijani and K. Gurney, *Mending the Ozone Hole*, (Cambridge, MIT Press, 1995), pp. 96, 103; M. Maiss, et al., "Sulfer Hexafluoride - a powerful new atmospheric tracer," *Atmospheric Environment*, Vol. 30, No. 10/11, (1996), pp. 1621-1629.

* Chemical formulas and estimates of atmospheric lifetimes may vary. These are from IPCC, 1996.

pptv = parts per trillion (million million) by volume
ppbv = parts per billion by volume
ppmv = parts per million by volume
CFC = chlorofluorocarbon
HFC = hydrofluorocarbon

1 CFCs, HCFCs, and other halocarbons regulated under the Montreal Protocol are not included in this table.

2 The growth rates of CO_2, CH_4 and N_2O are averaged over the decade beginning 1984.

3 Global warming potentials depend on a number of assumptions regarding the carbon cycle and CO_2 concentrations. The figures given here are calculated based on the Bern carbon cycle model and current CO_2 concentrations.

4 No single lifetime for CO_2 can be defined because of the different rates of uptake by different sink processes.

5 The global warming potential for methane includes indirect effects of tropospheric ozone production and stratospheric water vapor production.

6 This has been defined as an adjustment time which takes into account the indirect effect of methane on its own lifetime. In other words, methane can affect the ability of the atmosphere to cleanse itself of pollutants including methane itself. See *Mending the Ozone Hole*, pp. 262-63 and IPCC, 1995 pp. 18–19.

7 Estimated from 1992–93 data.

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that could even begin to estimate the effects with moderate confidence. We do not even know enough to calculate how likely or unlikely such catastrophic events might be. We know only that they are possible and that the resulting changes may be devastating far beyond anything projected by current models of global warming.

Aside from changes in global average temperature, a variety of other climate variables may change as a result of the increased absorption of outgoing radiation and the subsequent increase in temperature. While there are considerable uncertainties as to the specifics, the most important possible changes are:

- an increase in global precipitation, especially in mid- to high-latitude regions in winter
- a decrease in soil moisture over the mid-latitudes in summer
- diminishing global sea ice and snow cover
- an increase in tropical storm intensity

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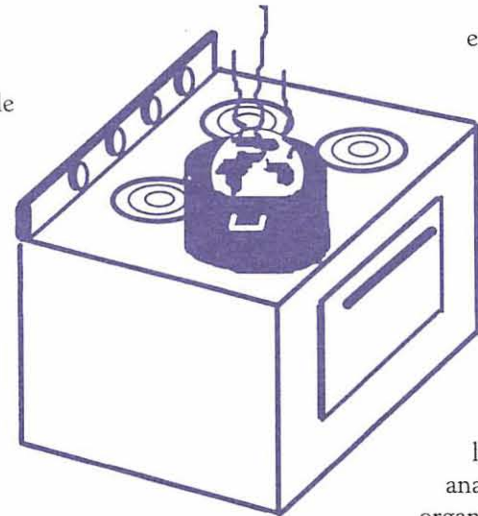
- a rise in global sea level of 50 cm (a little over 1.5 feet) by the year 2100



Global Warming

A host of alterations to ecological, biogeochemical, human, and animal systems could occur in response to these perturbations to the climate and hydrologic systems. They may be a result of the absolute magnitude of climate change, and/or the rapidity with which the projected changes occur. In fact, some researchers believe that the speed of temperature change and other changes is likely to be the main cause of any subsequent ecological and economic disruption since neither ecosystems nor populations will have enough time to adjust.[7]

What are the Options?

As the science has improved and uncertainties narrow, more options to mitigate global warming have emerged. Given that CO_2 emissions from fossils fuel use are the largest single source of greenhouse gases, changes in current energy production and consumption are being examined carefully. Because coal produces more CO_2 per unit energy delivered than natural gas, many proposals include shifts in electricity production towards natural gas (see below). Further reductions in CO_2 emissions can come from greater energy efficiency measures such as improved lighting, more efficient industrial processes, co-generation of electricity and heat (see "Dear Arjun," p. 17), better building insulation, and more efficient cars and trucks. Increased reliance on nuclear power has also been suggested, but it is not an environmentally or economically sound alternative (see main article).

Measurements taken at remote locations around the globe reveal an unmistakable increase in concentration of greenhouse gases.

Given the current trends in energy consumption and the expansion of electricity use in many parts of the world, a shift away from fossil-based energy appears necessary in the long-run to mitigate the projected rise in CO_2 to the extent many feel is necessary. To that end, renewable energy supplies such as solar photovoltaics, biomass, and wind energy are being considered. Natural gas could provide a good source of fuel during the transition to these energy supplies. However, it should be noted that natural gas production, transmission, and use involves small amounts of methane emissions whose greenhouse effect is greatly magnified since methane is a more powerful greenhouse gas than carbon dioxide. Increased use of natural gas must therefore be accompanied by measures to reduce anthropogenic methane emissions. This can be done in a variety of ways, such as capturing and using methane emitted from landfills (emissions due to anaerobic decomposition of organic matter, such as food waste), reducing transmission losses, and converting animal manure into usable methane through anaerobic digestion.

There is also the possibility of direct removal of CO_2 from the atmosphere through net growth of plants and trees; a mitigation option referred to as **carbon sequestration**. Through reforestation of areas that had been converted to agriculture in the past (for example, New England) some of the rising CO_2 in the atmosphere can be permanently stored in soils or in the tissue of living things. Other sequestration schemes, such as pumping CO_2 into underground and undersea reservoirs, have also been proposed.

Limiting the emission of other greenhouse gases, such as halocarbons, N_2O (nitrous oxide), and CH_4 (methane) can also help mitigate global warming. As noted above, gains have been made through the regulation of the well-known CFCs, but compounds such as hydrofluorocarbons and hydrochlorofluorocarbons are either unregulated or are slated to be phased out decades from now.

The build-up of greenhouse gases due to human activities over the last century is an incontrovertible, established fact. The general radiative characteristics of these gases are also well known. These facts, coupled with many other laboratory experiments, observations

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ERRATA

In *SDA* Vol. 5 No. 3, p. 7:

The correct range for uranium releases to the air given in the RAC study estimates is 590,000 lbs. to 790,000 lbs., with a best estimate of 680,000 lbs.

In addition, the figure for RAC 1996 in the The Summary of Estimates of Uranium Releases table should also read 680,000 lbs.

SUSTAINABLE ENERGY

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been halting and far below its potential?

The first thing to note is that neither energy efficiency nor renewable energy sources have had anywhere near the level of research and development effort and investment as fossil fuels or nuclear energy. The failed plutonium breeder reactor technology alone, which is just one part of nuclear fission energy, has had far more resources poured into it than wind and solar energy combined.

Secondly, crucial problems in energy efficiency are not even recognized by policy-makers, much less are they objects of substantial research and development. For instance, developing heat exchangers that are highly efficient, compact, and economical for low temperature heat sources would open up vast new possibilities in energy efficiency. But government funds for the needed basic research are meager and private sector research is generally focused on short-term pay-off technologies.

Third, energy statistics are seriously deficient. For example, large sources of energy, notably biomass for draft animals that provide power for agriculture in much of the world, are not included in compilations of energy data. Also not counted in energy data are the large amounts of natural gas that are considered a waste by-product of oil extraction and are flared or vented. For instance, Shell oil company flares the natural gas associated with its oil production in Nigeria.[6]

Transforming the world's energy system will be a huge and difficult task. A large part of the problem arises from the fact that large corporations that have profit as their primary purpose and have made huge investments in fossil fuels and nuclear energy control most energy production, conversion, and distribution. As with the Montreal Protocol that resulted in action to protect the ozone layer, governments will now have to use the Kyoto Protocol to create the regulatory structure and the financial incentives and penalties so as to elicit the desired reductions in greenhouse gas emissions from the marketplace. Firm action at the local, national, regional, and global levels is essential and urgent so as to achieve a change from the present energy system fraught with dangers to an environmentally sustainable one.

1 Most estimates put the amount of excess carbon that can be absorbed by the biosphere at about 3.3 gigatons (3.3 billion metric tons) per year while emissions are in the range of seven to eight gigatons per year. Annual emissions due to fossil fuel burning are about 5.5 gigatons. All figures are expressed as weights of carbon present in carbon dioxide. *Source*: Intergovernmental Panel on Climate Change, *Climate Change 1995*, (Cambridge: Cambridge University Press, 1996), p. 17.

2 We speak of energy services rather than energy use or energy supply because people do not need fuels as such but the services that energy use provides, like lighting heating and transportation. As the discussion on the second law of thermodynamics in this newsletter shows (see p. 17), the energy supply needed for a given level of energy services can vary a great deal.

3 See Steven M. Cohn, *Too Cheap to Meter: An Economic and Philosophical Analysis of the Nuclear Dream*, State University of New York Press, Albany, 1997, p. 155, "pessimist projection."

4 US Energy Information Administration web page: *www.eia.doe.gov/oiaf/ieo97/gas.html.*

5 Vivian Toy, "Sealing Mount Garbage: Closing Staten Island's Fresh Kills Dump Is an Operation of Staggering Complexity," *The New York Times*, December 21, 1997.

6 Flaring of natural gas will end by 2008. Telephone interview with Don Cannon, General Manager, External Affairs/Investor Relations, Shell Oil Company, New York Office, February 19, 1998.

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of the Earth's temperature, and biogeochemical characteristics, have led to the general conclusion accepted by most scientists in the field that increasing greenhouse gases have already affected the climate and are likely to affect it far more if we do not act to curb them. The means to curb them are known—the largest uncertainties revolve not around technical facts, but cost.

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1 From Arjun Makhijani and Kevin Gurney, *Mending the Ozone Hole: Science, Technology and Policy*, (Cambridge: MIT Press), 1995, p. 4.

2 There are four primary removal mechanisms, or "sinks" are at work in the atmosphere which help remove ozone-depleting compounds: chemical alteration by reaction with another compound; chemical alteration through interaction with solar radiation; dissolution into rainwater or seawater; and absorption onto surfaces. It is through reaction with the hydroxyl radical that many ozone-depleting compounds are removed. This occurs mainly in the troposphere, where the hydroxyl radical is most abundant. See *Mending the Ozone Hole*, pp. 257–264 for more details about the role of the hydroxyl radical in atmospheric chemistry.

3 Halocarbons are derived from a larger class of chemicals called hydrocarbons, which are compounds that contain both carbon and hydrogen. A halocarbon is a hydrocarbon in which one or more hydrogen atoms have been replaced by one or more halogen atoms.

4 For comparison, emissions in 1994 were 6.1 GtC/yr.

5 Greater methane concentrations in the atmosphere reduces the concentration of the hydroxyl radical, which can in turn reduce the rate of methane removal.

6 From World Meteorlogical Organization/United Nations Environment Program, (WMO/UNEP), *Climate Change 1995: The Science of Climate Change*, (Cambridge, UK: Cambridge University Press, 1996), p. 5. The Intergovernmental Panel on Climate Change was established in 1988 jointly by the World Meteorological Organization and the United Nations Environment Programme.

7 WMO/UNEP, *Climate Change 1995: Impacts, Adaptation, and Mitigation of Climate Change*, (Cambridge, UK: Cambridge University Press, 1996), pp. 3–12.

NO SOLUTION

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(AEC) was aware of the possibility for catastrophic accidents. In 1957, Brookhaven National Laboratory published an assessment, known as WASH-740, which outlined the potential health and property damages that could result from a severe reactor accident. Several months after the release of the report, Congress passed the Price-Anderson Act, limiting liability of utilities to $500 million—just ten percent of the property damage costs estimated in WASH-740.[3] This amount was increased to $7 billion in 1988, still far below the likely damages of such an accident.

The nuclear industry continues to downplay the potential for catastrophic reactor accidents, despite the evidence presented by the Chernobyl disaster in April, 1986. The explosion and fire at Chernobyl deposited fallout on every country in the northern hemisphere and forced the evacuation of over 100,000 people in a 30 kilometer zone around the plant, and the abandonment of 250,000 to 375,000 acres of agricultural land. But the nuclear industry as well as the International Atomic Energy Agency (IAEA), citing misleading official Soviet data and ignoring the lack of accurate data on health effects, have tended to minimize the significance of the accident. Official estimates of the radioactivity released in the first ten days were 80 million curies. But in an independent assessment, Soviet scientist Zhores Medvedev estimated that the releases of radioiodine and radiocesium were about three times higher than officially stated.[4] The overall costs of Chernobyl are difficult to calculate, but even official estimates of about ten to fifteen billion dollars surpass the $7 billion liability limit of the Price-Anderson Act.

Nuclear power is irrelevant to the needs of a great majority of countries, since nuclear power plants are too large and expensive to fit into their electricity grids.

The most important and tragic lesson of Chernobyl is that the most severe kind of nuclear power accident can actually happen. Moreover, the problems created by such severe accidents will persist for many generations. While claims have been made for a new generation of "inherently safe reactors," they are exaggerated and highly misleading.[5] It would take many decades to test various designs to determine whether creating a practical reactor that is economical and invulnerable to catastrophic accidents is achievable at all.[6] Consequently, nuclear power cannot safely help the world reduce carbon dioxide emissions—a pressing need that must be addressed with policies in place in the next few years.

Economics

As demonstrated in the table on page 7, nuclear power is a far more expensive and risky way of generating electricity than highly efficient combined cycle natural gas plants. Even in France, which is highly dependent on nuclear power, officials have admitted that combined cycle electricity plants using natural gas are more economical than nuclear power plants.[7] Each nuclear plant built can typically be expected to cost from about $1 billion to several billion dollars in excess lifetime costs.[8] To make a substantial reduction in CO_2 emissions, nuclear power plants would not only have to supply much of the world's electricity growth but also replace many coal-fired plants as they are retired. This would require the construction of on the order of 2,000 nuclear power plants (1,000 megawatts each) in the next several decades. The total cost penalty of using nuclear would amount to several trillion dollars. This vast sum of money would have to come in the form of subsidies from governments and/or electricity ratepayers (in the form of higher prices). It could be much more efficiently used to make investments in energy efficiency, cogeneration, renewables, combined-cycle power plants, fuel cells and the like.

Thus, investments in nuclear power will detract from efforts to reduce carbon dioxide emissions by preempting more appropriate investments.

Non-Proliferation and Disarmament[9]

The challenges of non-proliferation and disarmament issues are even more daunting than safety and economic issues, because they are not only technological, but also military, political, and institutional in nature.

Plutonium is made in all commercial reactors.[10] Once separated by reprocessing, the plutonium in this spent fuel can be used to make nuclear weapons. Stocks of separated commercial plutonium have been growing very rapidly since the early 1980s and are set to surpass military stocks in the next few years. There are now five countries that have commercial reprocessing policies: France, Russia, Britain, Japan, and India. Six other countries also own commercially separated plutonium: Germany, the Netherlands, Belgium, Switzerland, Italy, and the United States (from a commercial reprocessing plant that operated from 1966 to 1972).[11]

If nuclear power were used as a means of reducing greenhouse gas emissions, the inventories of plutonium would rise dramatically. If 2,000 new nuclear power plants are built over the next several decades (in addition to replacing the present 350,000 MW of

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nuclear capacity), the global inventory of commercial plutonium would rise to about 20,000 metric tons by the middle of the next century, dwarfing present stocks. This inventory, the pressure on uranium resources, and the popular opposition to nuclear waste repositories would greatly intensify pressures for commercial plutonium separation and the use of such plutonium in nuclear reactors. This would further exacerbate economic, environmental, and proliferation problems associated with nuclear power.

Nuclear technology has been glamorized as "high technology" for decades, and its promotion is part of the Nuclear Non-Proliferation Treaty.[12] Western propaganda dates back at least to President Eisenhower's December 1953 "Atoms for Peace" speech, in which he connected renunciation of nuclear weapons to the promotion of nuclear energy. The result of these Cold War policies is huge governmental or subsidized private establishments in key countries with a vested interest in plutonium economies. These bureaucracies continue to be politically and financially powerful despite the environmental, non-proliferation, and economic failures of key technologies such as breeder reactors and reprocessing.[13]

Suitability of Nuclear Technology

Nuclear power is irrelevant to the needs of the people in a great majority of countries of the world, since nuclear power plants are too large and too expensive to fit into their electricity grids. In those countries where it might conceivably be applied, such as India and China, the economic and technological arguments are by far in favor of other technologies, such as combined cycle natural gas fired power plants, and of greatly increasing electricity grid efficiency and coal-fired power plant efficiency. Investments in these technologies can produce far more electricity than money put into nuclear power plants. After over four decades of development, only 3 percent of India's electric capacity is nuclear.

> Investments in nuclear power will detract from efforts to reduce carbon dioxide emissions by preempting more appropriate investments

Only a few countries have a substantial reliance on nuclear power plants, and these are already heavily industrialized. In these countries, as in others, there is much potential to increase energy efficiency. This is especially true in the United States which has the largest number of nuclear power plants licensed to operate (106 at latest count). Furthermore, some of these countries are reducing reliance on nuclear power, not increasing it. Even in France and Japan, the heavy commitment to nuclear energy is coming under increasing governmental and public scrutiny.

Radioactive Waste

As discussed above, for nuclear power to contribute significantly to the reduction of greenhouse gases, thousands of new nuclear power plants would be needed. This would result in the creation of hundreds of thousands of metric tons of spent fuel in addition to existing wastes. There is no viable policy for the management of spent fuel at the present time. Nuclear power advocates see the "solution" of building a geologic repository as an essential element in the revival of nuclear power, at least in the United States. This has evoked the counter response of opposition to repositories until the issue of long-term management can be separated from promotion of nuclear power. Proposals to manage the waste through transmutation (changing long-lived radioactive elements into short-lived ones), are not viable for several reasons. Transmutation will not only require nuclear reactors of one sort or another; it will require implementation of reprocessing technologies that can also be modified for production of weapons-usable materials. Transmutation and reprocessing technologies will also create their own waste management problems by generating large new volumes of radioactive waste. Thus, what appears at first to be a technical answer to the problem of proliferation and waste management is likely to exacerbate proliferation problems without really solving waste management problems. Besides failing to eliminate the need for repositories or other disposal strategies, these technologies remain very expensive, and would greatly increase the cost of nuclear power, which is already uncompetitive.[14]

Phasing Out Nuclear Power

In addition to the safety, proliferation, and economic drawbacks cited above, there are a number of reasons why a nuclear phase-out is necessary to a sustainable, peaceful and healthy energy future, including:

- The presence of large stocks of separated plutonium as well as plutonium in spent fuel can make reversion to a nuclear armed state in times of tension and war more likely.

- The bureaucracies that are most eager to promote nuclear power are also the ones that tend to promote nuclear weapons in many countries, including the present nuclear weapons states. These nuclear bureaucracies continue to harbor hopes of a plutonium economy despite the technological, environ-

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mental, and economic failures of nuclear power. This is a continuing incitement to proliferation, declaratory policy notwithstanding.

- Nuclear power plants can become targets in conventional wars, greatly increasing environmental and health devastation.
- Promotion of nuclear power aggravates conflicts, instabilities, and uncertainties in the Central and West Asian regions (including the Persian Gulf). The conflict between the United States and the European Community, Russia, Malaysia, and Iran over French-Gazprom-Malaysian investments in Iranian gas is an important example.

Unless the West, which first glamorized nuclear power, renounces it and begins to phase it out, others are unlikely to give it up. Nor will the West have a basis to deny this technology to others. For example, although Iran is in compliance with IAEA inspections and safeguards, the US has expressed a great deal of concern about the possible proliferation consequences of its purchase of Russian reactors. This is because the US government suspects Iran of having a covert nuclear weapons program. It is ironic and instructive that it was the United States which first encouraged Iran's nuclear ambitions in the 1970s before the 1979 revolution. While a phase-out of nuclear power in the West does not guarantee progress on other issues or, for that matter, a phase out in all other countries, it is an essential condition for making problems associated with oil, natural gas, and greenhouse gas build-up more manageable. As illustrated above, the problem of long-term management of spent fuel also cannot be addressed satisfactorily without a phase-out of nuclear power.

Nuclear power cannot be phased out immediately or without careful planning. Indeed, in a few countries, if all the nuclear power plants were shut off at once, it would cause severe disruption or even breakdown of all or portions of the electricity grids. France, Germany, Japan, some parts of the former Soviet Union and eastern Europe, and portions of the United States are in this position. It will be necessary while advocating the phase-out of nuclear power to also put forward and implement clear energy polices that will address the problem of greenhouse gas emissions and the energy needs of a majority of the world's population. Many viable policies, technologies and suggestions have been put forward (see article p. 5 for one detailed example).

1 See table of reactor accidents in IEER's 1996 report, *The Nuclear Power Deception*, by Arjun Makhijani and Scott Saleska, p. 121. It can also be found on IEER's web page, *www.ieer.org/reports/accident.html.*

2 This is discussed in detail in *The Nuclear Power Deception*. Key portions of the report are available on the web at *www.ieer.org/reports/npd.html.*

3 Atomic Energy Commission, *Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants: A Study of Possible Consequences if Certain Assumed Accidents, Theoretically Possible but Highly Improbable, Were to Occur in Large Nuclear Power Plants*, WASH-740, U.S. Atomic Energy Commission, Washington D.C., March 1957.

4 Zhores A. Medvedev, *The Legecy of Chernobyl*, (New York: W. W. Norton, 1990), p. 78. (Dr. Medvedev was also the first scientist in the Soviet Union to report openly on the the explosion of a high-level waste tank in 1957 at Chelyabinsk-65.) It is important to note that official (Soviet) Chernobyl release estimates are decay corrected to 10 days after the accident, which is one component of the underestimates.

5 *Nuclear Power Deception*, pp. 118–120.

6 *Nuclear Power Deception*, Chapters 3 and 4.

7 Edouard Launet, "Nuclear Power's Future in Question as Relative Costs Rise," *Paris Libération*, April 17, 1997.

8 This is a discounted cost, that is, it is the present value of the future extra costs of electriciy incurred if a nuclear plant is built instead of a combined-cycle plant. It takes into account the higher fuel costs of the combined cycle plant and the fact that these fuel costs are incurred over the life of the plant. Present value of a future cost or revenue is derived by discounting it because money in the future is worth less than cash in hand.

9 More on the proliferation consequences of nuclear power can be found in *Energy & Security*, (IEER's international newsletter), issues #1–3. Available from IEER in hard copy and on our website at: *www.ieer.org/ensec/index.html.*

10 Many naval nuclear reactors do not make significant amounts of plutonium as they use highly enriched uranium as a fuel, but in this case the highly enriched uranium itself can be used to make nuclear weapons. Reactors that use uranium-233 as a fuel and therefore would produce no plutonium have also been proposed. Uranium-233 does not occur naturally, but must be made from thorium-232. No reactors of this type have been commercialized. A fuel type that combines uranium-235 and thorium-232, which would breed uranium-233, has been proposed for existing light water reactors. (See: Alex Galperin, Paul Reichert, and Alvin Radkowsky, "Thorium Fuel for Light Water Reactors—Reducing Proliferation Potential of Nuclear Power Fuel Cycle," *Science & Global Security* Vol. 6 (1996) pp. 267–292.) However, the advertised claim that this fuel type can almost eliminate proliferation concerns does not hold up to careful scrutiny, since U-233, like plutonium-239, could be used in weapons.

11 For figures on stocks of commercial separated plutonium, see David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*, (Oxford: Oxford University Press, 1997), p. 230. World-wide, stocks are increasing by about 20 metric tons per year. See also *Energy & Security* #1.

12 Article IV of the NPT states that ". . .All of the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing. . .to the further development of the applications of nuclear energy for peaceful purposes. . ."

13 Electricité de France has been putting a zero value on plutonium since 1992. However, the value of French commercial plutonium is actually negative since it costs roughly $100,000 per kilogram (of plutonium) to extract it from spent fuel.

14 National Research Council, *Nuclear Wastes: Technologies for Separations and Transmutation*, (Washington DC: National Academy Press, 1996).

Dear Arjun

Dear Arjun,

What is the second law of thermodynamics and why is it important?

—Hot in Havasu

Dear Hot,

It was a very hot and humid day when King John signed the Magna Carta on 15 June 1215. To console himself for the loss of royal prerogative to wantonly tax barons, he decreed the Second Law of Thermodynamics. It states that you can move heat from a hotter place to a colder place without doing work, but you need to work to move heat from a colder place to a hotter place.[1] King J. thought that with the second law in place he wouldn't have to worry about taking any heat from the Vikings up north, since the north was a colder place.

King John decrees the 2nd law of thermodynamics.

Surprisingly, the second law of thermodynamics has stood the test of time and scientific scrutiny and, unlike the Magna Carta, the British Parliament cannot now repeal it. Application of the second law of thermodynamics helps explain the various ways in which engines transform heat into mechanical work, as for instance in the gasoline engine of a car or in a steam turbine.

Efficiency measures based on the second law of thermodynamics take into account the *quality* of energy—unlike efficiencies based on the first law of thermodynamics which take into account only the *amount* of energy. The first law of thermodynamics states that energy is conserved even when its form is changed, as for instance from mechanical energy to heat. By contrast, the second law of thermodynamics allows us to know how well an energy system performs in terms of the quality of the energy. In 1824, a French physicist, Nicholas Léonard Sadi Carnot, described the most efficient (ideal) engine for converting heat to mechanical work. This maximum theoretical efficiency, called the **Carnot efficiency**, allows us to compare how well any particular real-world energy-using system is performing relative to the maximum theoretical performance.

The temperature at which energy is available is a good measure of its quality—the higher the temperature of the energy, the more mechanical work we can theoretically get out of it. Thus a kilogram of steam at 1,000 degrees Celsius will produce more mechanical energy than steam at 500 degrees Celsius other things (such as pressure) being equal. Energy at 20 degrees Celsius provides a comfortable living environment, but is essentially useless for producing mechanical work in everyday situations.

Let us consider the case of a natural gas heating system that provides warm air for heating a building. (This example could also apply to systems that provide hot water for heat.) A typical natural gas heating system degrades the heat of natural gas from possible temperatures over 1,000 degrees Celsius to about 50 degrees Celsius. Thus, while most of the quantity of energy in the natural gas is transferred to the air that is used to heat the building, the capacity of the natural gas to do work has been almost entirely wasted. Hence a typical natural gas home heating furnace has a high first law efficiency, often around 85 or 90 percent, but a low second law efficiency of only a few percent (depending on outside temperature). Measuring this system using the second law of thermodynamics allows us to see that the initial natural gas input could be used more efficiently and to greater benefit if its heat were not wasted.

For example, one could use natural gas as a hydrogen source for fuel cells to generate electricity at 60 percent efficiency (second law). The electricity could then be used to "pump" the heat from the cold air outside up to the desired room temperature. (A heat pump uses electrical energy to pump up the energy present in outside air or soil to room temperature and transfer it into a building.[2]) Another way of describing it is as an air-conditioner in reverse that blows warm air into a building rather than out of it. In moderate climates this could improve efficiency of natural gas use by four times or more. In colder climates, heat from the earth, which is warmer than the air, could be pumped up to the desired room temperature, with similar efficiency improvements.

Use of gas engines to generate electricity and waste heat for heating and cooling (called a cogeneration system) can provide similar increases in efficiency. Higher efficiencies could also be achieved with heat exchangers (devices that take energy from a warmer medium to heat a cooler medium, such as a boiler that transfers energy from hot gas to cool water) that are more efficient than those available today. Theoretically, the efficiency of fuel use in space heating applications could be increased ten to fifteen fold relative to typical present-day systems in the United States.

There are, of course, practical problems associated with using cogeneration systems, so that they are not

SEE **DEAR ARJUN** ON PAGE 18

It pays to increase your jargon power with Dr. Egghead

1. **effective residence time**:

a) The amount of time a child continues to live at home before going off to college.

b) The amount of time a medical intern puts in before becoming a doctor.

c) The amount of time one has to live in a state to obtain residency.

d) The amount of time it takes for about 63 percent of the molecules of a chemical to be removed from the atmosphere.

2. **general circulation model**:

a) A diagram of the human circulatory system.

b) A map used by librarians to track the routing of books that are checked out.

c) The Department of Defense plan for moving high-ranking officers from post to post.

d) A model of climate that uses certain assumptions about the workings of the atmospheric, terrestrial, and aquatic environments to explain changes greenhouse gas concentrations and estimate the climatic changes that might result.

3. **combined-cycle plants**:

a) House plants that thrive best when placed near multi-cycle washing machines.

b) A genetically engineered cross between a bicycle and a plant.

c) Factories that produce both mountain bikes and road bikes.

d) Natural gas-fired plants that use internal combustion engines combined with steam turbines to generate electricity. The natural gas is burned in a gas turbine or reciprocating gas engine and the hot exhaust gases are used to produce steam which drives a steam turbine.

4. **insolation**:

a) The practice of applying an extra strip of material inside a shoe for protection and comfort.

b) A kind of transcendental meditation.

c) The art of being regularly rude and insolent.

d) The amount of sunlight reaching an area, usually expressed in watts per square meter per day.

5. **solar constant**:

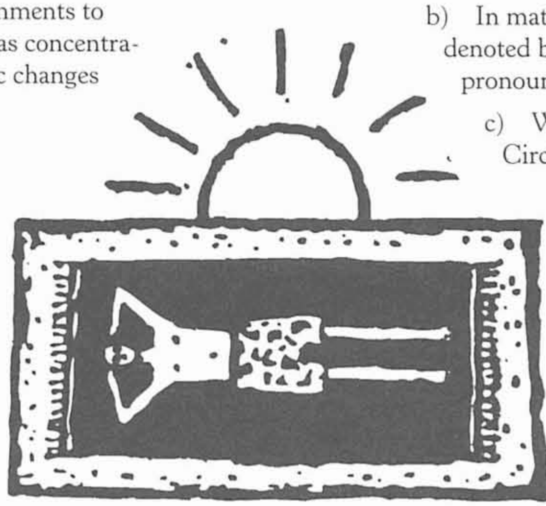
a) A sun bather who never leaves the beach.

b) In math, a fixed value in an equation denoted by the symbol: and pronounced "Ra."

c) What you experience in the Arctic Circle during the height of summer

d) A new brand name for fancy sunglasses.

e) The rate at which energy is received from the sun just outside the earth's atmosphere on a surface perpendicular to the sun's rays. Approximately equal to 1.36 kW per square meter.



A solar constant.

DEAR ARJUN

FROM PAGE 18

always economical. For instance, practical applications would depend on factors such as the amount of heat, hot water, air-conditioning and electricity needed, whether the electric generation system can be connected to a grid, and the cost of small-scale generators. However, over the last two decades, new technologies have evolved to enable far more widespread economical use of cogeneration than the level of current use of this system.

Claims that increases in energy use—meaning use of primary fuels—are the only way to increase the services that energy provides are not based on a careful consideration of the vast potential for increases in energy efficiency even in the so-called "advanced" industrialized countries. By the yardstick of the second law of thermodynamics, the world's energy system is very inefficient. Therefore, great increases in the services that energy provides, such as heating, cooling, or

SEE **DEAR ARJUN** ON PAGE 20

Sharpen your technical skills with Dr. Egghead's Atomic Puzzler

Gamma, Dr. Egghead's trusty dog, recently overheard a group of high-powered energy planners talking about how to reduce carbon emissions to the atmosphere while meeting energy needs. After some discussion, the planners agreed that despite the added costs of nuclear power, it was the best solution to address climate change concerns because it was a carbon-free technology. But Gamma saw a problem with this line of thought and burst into the room to address the startled group. Unfortunately, Gamma has no opposable thumbs and couldn't write his ideas on the board, so he's asked if you could finish the calculations for him and mail them to Dr. Egghead (details below). Here's what he told the group:

1. Assume a typical coal-fired power plant is rated at 1,000 Megawatts of electrical power (1,000 MWe). If it operates for 6,600 hours out of the year, it would produce _______ Megawatt-hours of electric energy (MWhe) over one year.
   If this coal plant emits 0.37 metric tons of carbon per Megawatt-hour of electricity generated, the total annual carbon emissions would be ________ metric tons.

2. A typical natural gas combined-cycle plant operating at the same capacity for the same number of hours per year emits 0.12 metric tons of carbon per Megawatt-hour, for a total of _________ metric tons of carbon emissions per year.

3. Suppose that two natural gas plants could be built for the same overall cost as building one nuclear plant.* How many metric tons of carbon emissions are avoided in each scenario?

* Note from Gamma: The actual number of combined-cycled natural gas plants that could be built for the same cost as nuclear depends both on the fuel price of natural gas and the capital costs for nuclear power. Since these two factors can vary widely, actual carbon reductions can also vary. See Table 1, p. 7.

a) One nuclear plant with zero carbon emissions replaces 1 coal plant for a total reduction in carbon emissions of: _______metric tons/year.

b) Two natural gas plants, with combined carbon emissions of _______ metric tons/year, replace two coal plants with combined carbon emissions of _______ metric tons/year.

c) For each scenario, the net annual reduction in carbon emissions is the total avoided emissions from displaced coal plants minus the total new emissions. The net annual reduction for each scenario is therefore:

   i. (nuclear scenario) _______ metric tons of carbon/year

   ii. (natural gas scenario) _______metric tons of carbon/year

   Carbon reductions in scenario ____ are greater than those in scenario _____ by ________%.

NOTE: Gamma ignored carbon emissions other than at the power plant itself for these calculations. He also ignored greenhouse impact of slightly increased methane emissions from use of natural gas, which would need to be offset by relatively minor investments (see p. 7).

Attention *Energy & Security* Readers

Answer to *Energy & Security* #4 Puzzle: A worker at the Deep Canyon uranium mine would receive a dose of 0.59 rad over one month, and 7.072 rad over one year.

Send us your answers via fax (301-270-3029), e-mail (ieer@ieer.org), or regular mail (IEER 6935 Laurel Ave., Suite 204, Takoma Park, MD 20912), postmarked by **April 24, 1998.** IEER will award 25 prizes of $10 each to people who send in a solution to the puzzle (by the deadline), right or wrong. There is one $25 prize for a correct entry, to be drawn at random if more than one correct answer is submitted. International readers submitting answers will receive a copy of *Climate Change and Transnational Corporations*, a report prepared by IEER staff for the United Nations.

WHY ENERGY

FROM PAGE 2

governments and corporations in any one area are likely to have long-lasting and profound effects on all of them. Our review of the global situation leads us to conclude that we cannot provide sound information and analysis on the security, health, and environmental consequences surrounding nuclear development unless we integrate consideration of broader energy issues into them.

IEER staff have significant experience on energy and climate change issues (including ozone layer protection), though this is less familiar to many than our nuclear-weapons-related work. Most of my work in the 1970s and a considerable amount of work in the 1980s and 1990s has been on these subjects. IEER has produced a number of reports on ozone layer protection, beginning with *Saving Our Skins*, a basic analysis on the chemistry of ozone depletion prepared in 1987, to *Mending the Ozone Hole*, published in 1995 by MIT Press. In the coming year, IEER will integrate more of this work with the nuclear-weapons-related environmental and security issues that have been the main focus of *Science for Democratic Action* in the past.

—ARJUN MAKHIJANI

1 Daniel Yergin, *The Prize*, New York: Simon and Schuster, 1991, pp. 314–6.

2 Leslie R. Groves, *Now It Can Be Told: The Story of the Manhattan Project*, (New York: Harper & Brothers: 1962), pp. 33–35 and pp. 218–220.

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Special Combined Issue

IEER is joining *Science for Democratic Action* (until now a vehicle for discussion of US issues) with the English edition of our global newsletter, *Energy and Security* on an experimental basis. For several issues (at least), we will publish a single newsletter in English to present a unified view of the problems related to nuclear armaments and nuclear energy, the build-up of greenhouse gases in so far it related to energy use, and related environmental and security questions. As has been our policy in the past, we hope not only to shed light on the problems, but to also make a contribution to the public policy debate on their solution.

In this first joint issue, our main articles will attempt to (i) provide an overview of the technical options for an energy system that does not use nuclear energy or contribute to greenhouse gas build up, and (ii) critique the use nuclear energy as a "solution" to global warming, and the issues surrounding nuclear energy in general.

DEAR ARJUN

FROM PAGE 18

lighting, are possible even while final use is kept constant or even reduced.

1 The second law of thermodynamics can also be stated in terms of entropy. Entropy is a measure of disorder in a system. Since it takes work to increase the orderliness inside a closed system, an increase in order corresponds to a decrease of entropy. Hence, a decrease in the entropy of a system requires an input of work into that system.

2 In practice, all materials contain some amount of thermal energy. Even frigid air or ice have a considerable amount of thermal energy in them. Zero thermal energy—that is no random motion of atoms or molecules—is achieved only at a temperature known as absolute zero, which is equal to about -273 degrees Celsius (about -460 degrees F). An absolute zero temperature cannot actually be reached by any practical device.

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