INSTITUTE FOR ENERGY AND
ENVIRONMENTAL RESEARCH

6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912

Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
http://www.ieer.org

Low-Carbon Diet without Nukes in France

An Energy Technology and Policy Case Study on Simultaneous Reduction of Climate Change and Proliferation Risks

Annie Makhijani
Arjun Makhijani, Ph.D.

Institute for Energy and Environmental Research

May 4, 2006

Table of Contents

Preface

As concerns about the possibility of global warming have mounted, the nuclear industry has increasingly presented itself as the champion that could help save the planet from climate catastrophe. Unlike the previous boast that nuclear energy would one day be "too cheap to meter," which was known to be wrong at the time it was made,[1] this claim has technical merit. An energy system based entirely on nuclear power and renewables would not have any carbon dioxide emissions.

Yet, the world does not lack sources of energy that can be used to create a zero-CO_2 global economy. Solar, wind, and hydropower could be readily used to solve the problem of eliminating CO_2 emissions. In order to achieve a reliable energy system, however, their use would have to be combined with the use of hydrogen or some other method or medium of energy storage. The problem then is not a lack of carbon-free energy. Rather the problem is defined by other parameters. First, the amount of money available to convert from the existing fossil fuel system to a zero-CO_2 system is necessarily limited. So society must decide how best to use the available financial resources to address the transition. Second, there is the matter of problems other than global warming. Do the sources of energy that do not emit CO_2 create other severe liabilities, especially for generations far into the future that will not benefit from the energy use in the generations that will live in the twenty-first century?

Nuclear energy poses the well known risk of proliferation and of catastrophic accidents of the scale of Chernobyl whose consequences would last far into the future, afflicting generations who will not have experienced the benefit of the energy. Hence four criteria must be considered in proceeding to a low or zero-CO_2 future:

- Cost
- The speed with which the transition can be made (since the climate change problem is now widely recognized to be urgent)
- Potential new severe burdens or risks on future generations not deriving from CO_2 emissions
- The problems of security associated with a re-organized energy system.

Since France gets about four-fifths of its electricity from nuclear power plants and also uses plutonium extracted from spent fuel as a source of fuel, it has lower CO_2 emissions per unit of GDP than comparable European economies. We have chosen to study the possibility of greatly reducing CO_2 emissions while phasing out nuclear power in France precisely for these reasons. The vulnerabilities that nuclear energy presents are different than those of fossil fuels, but they are nonetheless serious. The study of a course by which CO_2 emissions can be reduced or even eliminated while phasing out nuclear power is therefore incumbent on those who would seek to address all four of the criteria laid out above.

[1] Makhijani and Saleska 1999, Part 1.

Our choice of France as the geographic-political entity for study here is not without its downsides. The electricity sector in France is far less diverse than in other countries, thus policy choices are more constrained when one considers France alone. For that same reason, it is not realistic or economically feasible to create a very accelerated shut down of nuclear power in France while still meeting economic criteria.

We also recognize that an energy policy report that covers a single major country in Europe must necessarily suffer from the deficiency that it does not address the reality of European integration that has been occurring at all levels, including in the energy sector. France is an importer of oil and an exporter of nuclear electricity. Its nationalized utility is set to be partially privatized.[2] There will be more cross border flows of electricity, in all likelihood. At the same time, local generation is also likely to increase. Hence some of the technical aspects of the mix of energy sources in the scenarios in this report should be viewed as illustrative rather than prescriptive.

For the reasons stated, we focus on a phase out of nuclear power and on technologies where new investments can reconcile economic realities with environmental and security goals. Nuclear power and high fossil fuel use in transportation for instance, each impose large risks in the interim because high-consumption society has dug itself into a deep hole, not so much because of high consumption but the specific constituents that compose it. The path out of it will not be free of either the risk of catastrophic climate change, nuclear accidents, terrorist attacks on nuclear power plants, or civilian nuclear materials diverted for nuclear weapons use. Considerable investment in technologies that could lead to more rapid transitions to non-CO_2-emitting and non-nuclear-fission technology is surely desirable and justifiable in this context.

The vulnerabilities of the U.S. and French energy systems have many similarities. Hence, much of this report is adapted from IEER's report, *Securing the Energy Future of the United States: Oil, Nuclear, and Electricity Vulnerabilities and a post-September 11, 2001, Roadmap for Action,*[3] to the French situation.

IEER's energy scenario for the United States is contrasted with the Bush-Cheney energy plan. In this report, IEER's energy scenario for France is contrasted with the scenario S1 described in *Energie 2010-2020*. In our report we refer to it as the "Business-as-Usual" (BAU) scenario because in it energy supply and demand respond to market forces under present day laws and regulations. This is the most energy intensive with the highest increase in carbon dioxide emissions. We chose this scenario to show that for the same amount of energy services rendered, it is possible, over a period of 40 years, to drastically reduce energy consumption as well as carbon dioxide emissions while at the same time phase out nuclear power.

The IEER Existing Technology (ET) scenario is also briefly compared with the *Scénario Vert pour la France* produced by the organization Détente. The Scénario Vert demonstrates that it is possible, over a period of 20 years, to practically phase out nuclear power (and completely in 25-30 years) while at the same time adhere to the Kyoto Protocol, that is, to maintain a zero increase in carbon dioxide emissions in the case of France. While Détente and IEER

[2] Bezat 2005.
[3] Makhijani 2001a.

share the same goal of phasing out nuclear power, IEER believes that the potentially disastrous effects of climate change are so serious that going well beyond the Kyoto Protocol is necessary if these effects are to be mitigated. In order to achieve this goal, the phasing out of nuclear power in the IEER ET scenario covers a period twice as long.

Atmospheric CO_2 concentration is headed towards 500 or 600 ppm (parts per million) or more in this century.[4] If emissions are to be reduced below the three billion metric tons of carbon absorption level[5] (say two billion metric tons) by the end of the century, then *the per person allotment of CO_2 will be 250 kg of carbon per year, assuming a population* of 8 billion.[6] Current French emissions of 1,800 kg of carbon per person are therefore clearly unsustainable.[7] These approximate figures demonstrate the well-known understanding that for climate stabilization and prevention of catastrophe, the Kyoto Protocol is only a start in the right direction. We believe that for an 85 percent (or greater) reduction in carbon dioxide emissions to be achieved in France within the twenty-first century, substantial reductions must be achieved within the next couple of decades and a 40 reduction – about half of what is needed, should be achieved by mid-century. This is not only desirable, but also economically and technically possible without assuming any lifestyle changes. Such a reduction would require sustained effort not only for deployment of existing technology (the IEER ET scenario) but also for more advanced technologies (IEER AT scenario).

Of course, if current global norms of what is considered the good life were to change in the direction of reduced stresses on the global environment and greater simplicity combined with greater technological and ecological sophistication, it may be possible to do a great deal more. We will not cover such possibilities in this report, which will remain within a rather conventional framework of accepting greater material consumption and show that this is possible without nuclear power and greatly reduced greenhouse gas (GHG) emissions, even in France.

Only technologies that have been shown to be feasible are considered in this report. For the IEER Existing Technology (ET)Scenario, only technologies already proven in the marketplace or close to it are included. For the IEER Advanced Technology (AT) scenario only technologies that are close to commercialization or those that have been demonstrated are included. We have sketched out some concepts for zero-CO_2 approaches. Only a qualitative discussion for zero-CO_2 approach is presented based on approaches that have been shown to be feasible, at least in principle. We have not considered nuclear fusion in this report because the scientific feasibility of this technology has yet to be established. The term "nuclear power" in this report refers only to power derived from nuclear fission. We note in passing here that some nuclear fusion approaches, such as the proton-lithium reaction and the proton-boron reaction, would likely meet the essential security and environmental goals of a sound energy system, if they could be shown to be technically feasible and cost-effective.

A note on units: We have expressed energy in units of million metric tons of equivalent petroleum (Mtep), which is the unit conventionally used in Europe and electricity in terawatt hours. The suffixes "e" and "th" are used to denote "electrical" and thermal" energy when

---

[4] The pre-industrial level was about 280 ppm.
[5] The carbon absorption level is the annual amount of carbon that is taken up by the oceans and the biosphere.
[6] In 2002, worldwide carbon emissions were about 6.7 billion metric tons. (EIA 2005b)
[7] CEA 2001.

necessary to avoid ambiguity. Emissions of carbon dioxide are expressed in terms of metric tons of carbon, unless explicitly mentioned. We have expressed automobile efficiency both in terms of liters per 100 kilometers and miles per gallon. For the purpose of this report we have taken nuclear, wind, solar, and biomass energy all to have zero-CO_2 emissions as a first approximation. We recognize that some energy inputs are required for all of these energy sources to be able to be put into forms that are usable. However, they are distinguished from fossil fuels in that the source of energy itself is, in principle, free of CO2 emissions. Hence if an economy is run entirely on that source of energy or on a mix of these sources of energy there would be no CO2 emissions.

We would like to thank Benjamin Dessus, Yves Marignac, Bernard Chabot, and Michel Frémont for their comments on various drafts of this report. Of course, as usual, the authors alone are responsible for the contents of this report, including its conclusions and recommendations and any errors that may remain.

This study is part of IEER's global outreach project. We gratefully acknowledge the generous support of the program by the John D. and Catherine T. MacArthur Foundation and the W. Alton Jones Foundation. We would also like to thank IEER's individual donors, as well as Rockefeller Financial Services, Colombe Foundation, Ford Foundation, The New-Land Foundation, Turner Foundation, HKH Foundation, Ploughshares Fund, Simons Foundation, Stewart R. Mott Charitable Trust and Town Creek Foundation for their financial support to IEER's.

Annie Makhijani
Arjun Makhijani
Takoma Park, Maryland
April 2006

Chapter I: Summary and Recommendations

France is at a crossroads in energy and security policies. Its reliance on nuclear power for the generation of more than three-fourths of its electricity has, like in the United States, revealed, more than ever, the vulnerabilities after the attacks of September 11, 2001. And with the rest of Europe and the world, it is also at a crossroads in deciding how far it is willing to go to reduce greenhouse gas emissions so as to reduce the severity of human-induced global climate change.

These questions have a special poignancy in France, which decided to lean heavily on nuclear power in the wake of the 1973 oil crisis. The Arab oil embargo against the United States demonstrated the vulnerability of France to disruption in oil supplies. But the events of September 11 have now pointed up the vulnerabilities of France's heavy dependence on nuclear energy and also its decision to use plutonium as an energy source. France's plutonium energy sector is also a source of global proliferation vulnerability. France is the most important country in perpetuating the use of this nuclear-weapons usable material in the commercial sector.

Nuclear energy has allowed France to diversify its energy supply, but it has not greatly reduced France's oil-related vulnerability since oil is the principal fuel for France's transportation sector, and the country would literally come to a standstill without it.

Besides its security implications, oil is also at the center of the global climate change problem. About 40 percent of fossil-fuel-related carbon dioxide emissions in the world are attributable to the burning of oil.[8] Most urban air pollution comes from motor vehicles.[9] Much of the pollution of the oceans comes from oil spills, both routine and accidental.[10] Major disruption of the global climate is not only likely to produce adverse health and economic consequences but also will have serious security implications whose impact is difficult to anticipate.

For these reasons, the twin foci of the report are reducing CO_2 emissions, especially through lower use of oil, and phasing out of nuclear power, both within the framework of conventionally accepted economic goals.

A. Main findings

1. France has achieved a greater diversity of energy supply since 1973. However, while imported uranium is relatively secure in terms of supply, France now has two kinds of serious vulnerabilities in place of one. In 1973 only oil imports were a serious vulnerability. That vulnerability remains. The vulnerability associated with a great reliance on nuclear power has been added. Nuclear vulnerabilities are relatively great in France since it has the largest commercial reprocessing plant in the world (at La

[8] EIA 2004.
[9] GEO 2000.
[10] Smithsonian 1995.

Hague on the Normandy peninsula) where liquid and solid radioactive wastes and some eighty metric tons of separated plutonium are stored.

2. If oil and nuclear fuels continue to be at the center of France's transportation and electricity systems, as currently envisioned in official projections, these vulnerabilities will increase because (i) nuclear targets will become more plentiful for terrorism, in particular in the nuclear electricity system (ii) oil imports will rise and (iii) proliferation risks will increase as a result of continued use and export of plutonium fuel.

3. France has not significantly reduced its energy imports as a result of reliance on nuclear energy. Since France imports all of its uranium and only about seven percent of nuclear electricity comes from the use of plutonium (mixed oxide) fuel, French dependence on energy imports is greater than it was three decades ago (see Table IV.5). Despite this, French energy security in terms of supply has improved because its energy sources have been diversified.

4. France has reduced its greenhouse gas emissions relative to other countries in Europe of comparable economic size (per person) as a result of its use of nuclear energy, but only at the expense of creating serious new vulnerabilities and at high cost.

5. It is technically and economically possible for France to phase out nuclear power over the next four decades while at the same time reduce carbon dioxide emissions by about 20 percent with existing technologies and by 40 percent with advanced technologies that are close to commercialization. However, the effort it will take to do that in France will be much greater than in the United States, because (i) the efficiency of energy use in France is higher, (ii) France gets most of its electricity from nuclear power plants and (iii) land-based French sources of wind energy are far smaller relative to electricity generation requirements than in the United States. Policies that produce a 40 plus percent reduction in CO_2 emissions in the United States would produce roughly a 20 percent reduction in CO_2 emissions in France.

6. The transport sector dominates carbon dioxide emissions in France. Large carbon dioxide emission reductions in this sector are essential, whatever level of nuclear power generation is achieved for non-transportation applications.

7. The technologies to achieve the goal of simultaneously reducing carbon dioxide emissions and vulnerabilities to attack already exist. Some, such as wind energy and cogeneration, are already economical. Others will need suitable government procurement policies to make them economical. All of the needed technologies are advanced enough that they can be commercialized within the next five to ten years. Combined cycle power plants fueled by natural gas, fuel cells, cogeneration of various types, wind power, and highly efficient heating and cooling systems are the key technologies to achieving a substantial growth in the services that energy provides and reducing greenhouse gas emissions at the same time.

8. France's trade balance would be favorably affected by a reduction in oil imports. Under the IEER ET scenario compared to the business-as-usual, the savings in oil imports would be roughly 25 billion euros in 2040 (this is assuming a price of US

$40 a barrel and US$1=1 euro). Some of this would be spent in importing more natural gas, which under the IEER scenario would amount to about 8 billion euros in 2040.

9. Moving in the direction of a distributed grid will pose significant challenges for France whose electricity structure is now highly centralized due to the concentration of 58 nuclear power plants at 19 sites. However, distributed grids can provide for greater reliability and reduced transmission and distribution losses.

10. The French electricity law of 2000, that transcribes the European Electricity Directive of 1996 to allow competition in the electricity market, may result in long-term inequities for small consumers if France does not stop reprocessing and distributes decommissioning costs equitably among electricity consumers.

11. It is possible to go to an economy that has zero-CO_2 emissions and zero nuclear power within the twenty-first century with technologies that have been shown to be feasible, but some of which are still in the development phase.

B. Scenario comparison summary

Figures 1 and 2 summarize the Business-as-Usual (BAU) and IEER energy scenarios respectively. Figures 3 and 4 compare the oil imports of the BAU scenario versus the IEER scenario for all sectors and for the transport sector. Figures 5 and 6 compare the CO_2 emissions of the BAU scenario versus the IEER scenario for all sectors and for the transport sector.

1. Business-as-Usual (BAU) Energy Scenario Summary – Base Case
2. IEER Energy Scenario Summary
3. Total oil projections BAU versus IEER
4. Oil projections in the transport sector BAU versus IEER
5. Carbon dioxide emissions (carbon basis) BAU versus IEER
6. Carbon dioxide emissions (carbon basis) in the transport sector BAU versus IEER

Figure 1: BAU Energy Consumption Projection for 2040

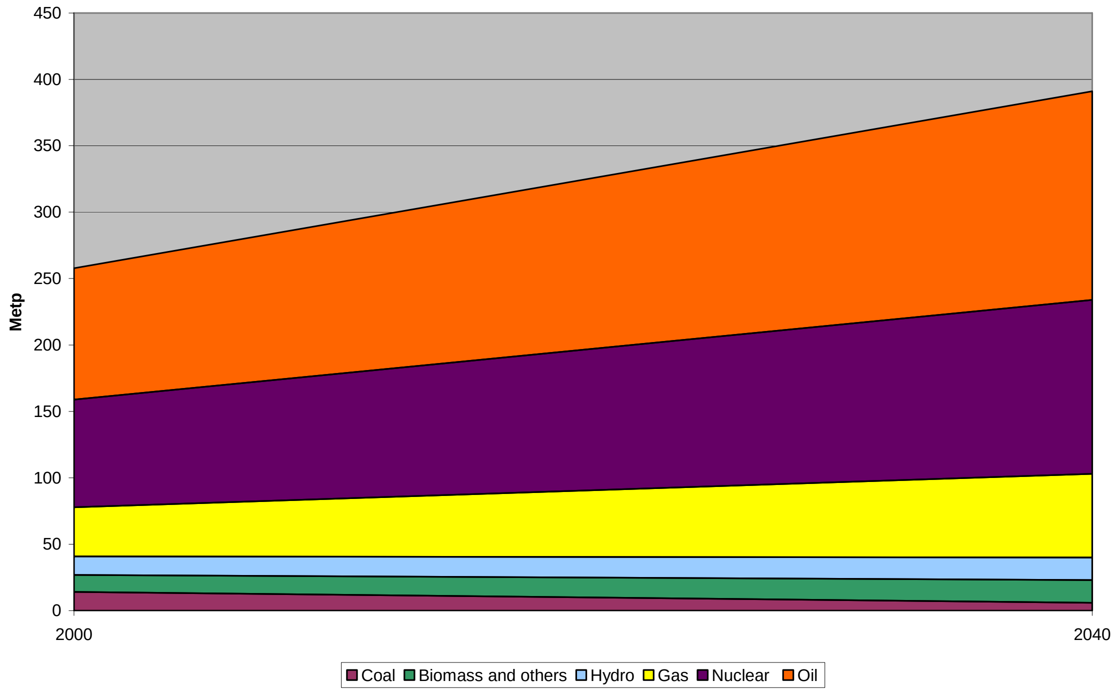


Figure 2: IEER ET Scenario Energy Consumption Projection for 2040

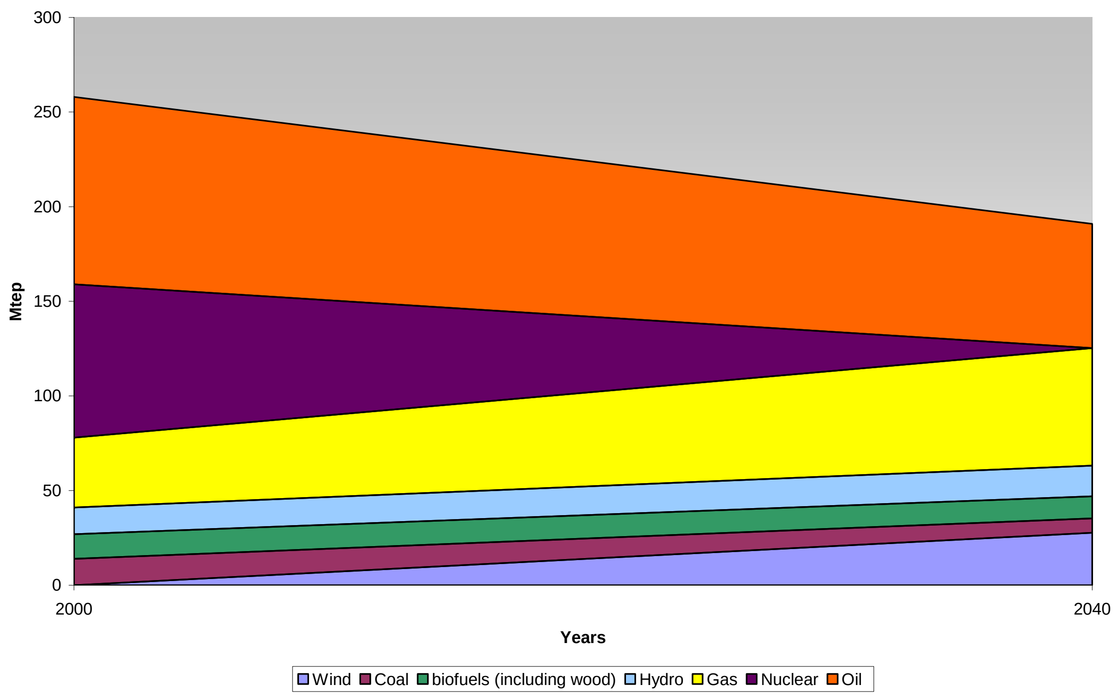


Figure 3: Comparison of Total Oil Projections
BAU versus IEER ET Scenario for the year 2040

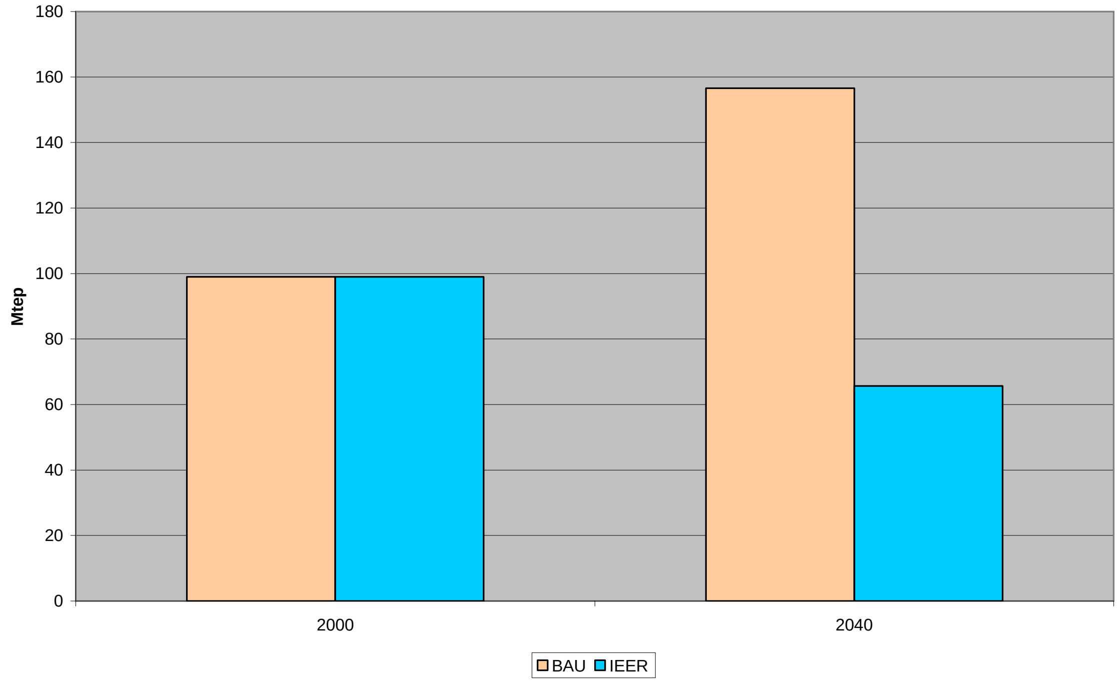


Figure 4: Comparison of Oil Projections in the Transport Sector
BAU versus IEER ET Scenario for 2040

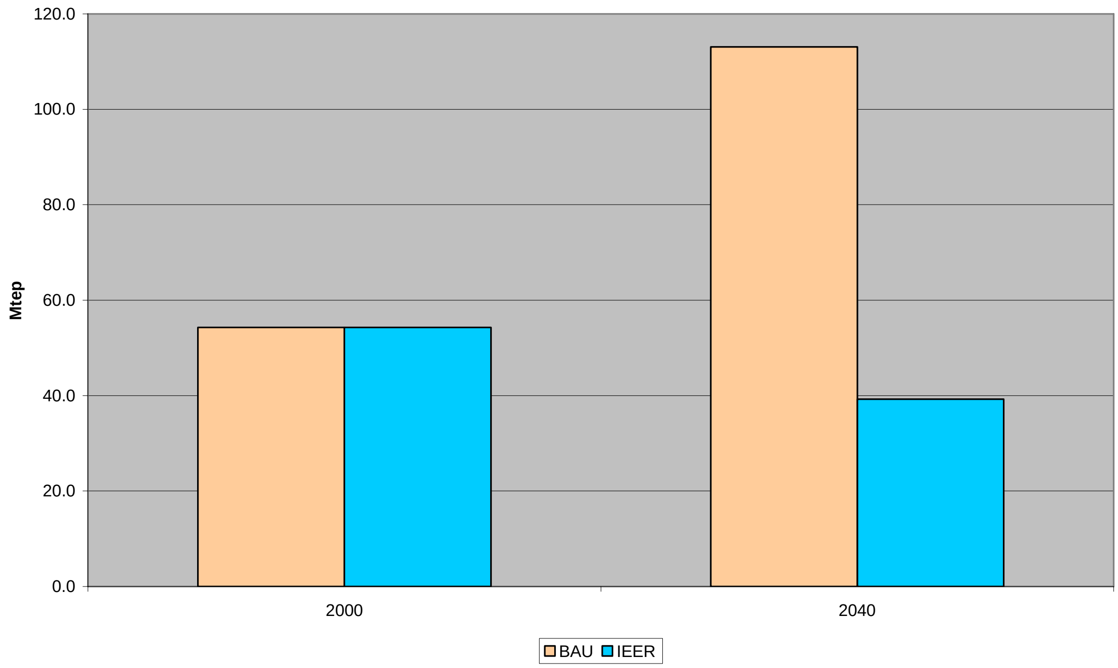


**Figure 5: Comparison of Carbon Emission Projections in all Sectors
BAU versus IEER ET Scenario for 2040**

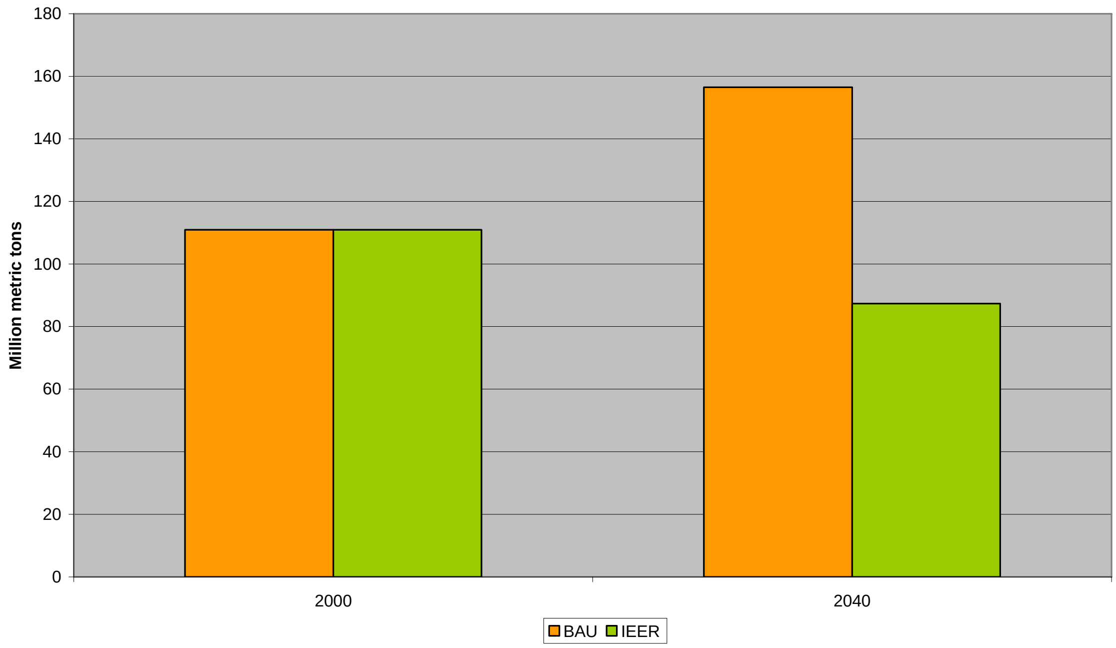
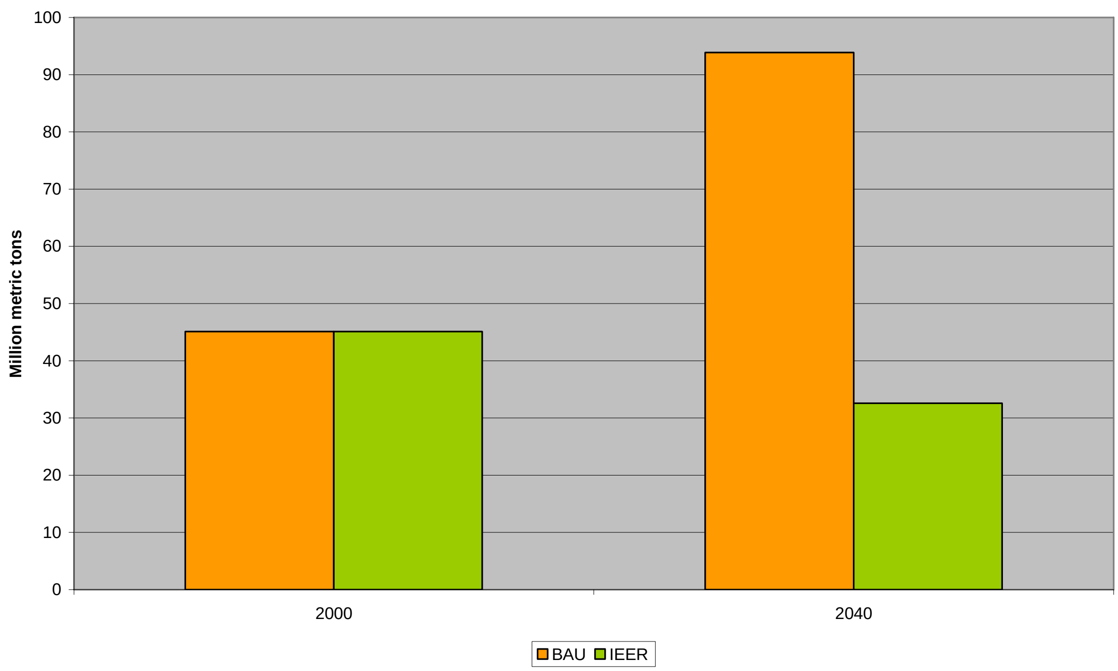


**Figure 6: Comparison of Carbon Emission Projections in the Transport Sector
BAU versus IEER ET Scenario for 2040**



C. Main recommendations

1. France should adopt an energy plan that would set goals for the long-term – a four-decade period. During this period, it must seek to essentially eliminate the most severe vulnerabilities to attack and reduce carbon dioxide emissions by about 40 percent by mid-century.

2. A goal of an average efficiency of 100 miles per gallon (2.4 liters per 100 kilometers) for new passenger vehicles should be set for the year 2020. The efficiency goal should be accompanied by improved safety and emissions standards, so that all three issues can be coherently and simultaneously addressed. The technologies to achieve safe, efficient, and relatively non-polluting cars already exist.

3. Given the great centralization of the present electricity grid and its structure around existing nuclear power plant sites as the source of electricity supply, a special study should be undertaken to assess the cost and practicality of a transition to a distributed grid.

4. Nuclear power should be phased out as a matter of national policy. In general, the power plants can be decommissioned as they reach the end of their original license lifetimes. Some might need to be retired earlier if they have particular vulnerabilities.

5. The French government should commit about 2.5 billion euros per year for at least ten years to purchase renewable energy, earth source heat pumps, efficient automobiles, and other leading edge technologies at efficiencies that are higher than those available on the open market in order to promote the commercialization of progressively more efficient technologies and renewable energy. Another 2.5 billion euros per year should be given to the regions for the same purposes. All subsidies other than those implicit in this procurement program should be eliminated. The program should operate consistently and reliably for at least a decade, and preferably for 20 years. Tax breaks, under the assumption that they will be available, for plants already built or under construction, can continue.

6. France should create a task force to address the fiscal implications of greatly reducing the use of gasoline, which is heavily taxed, over the long-term. One revenue option would be to tax new cars and other motor vehicles that have efficiency below certain levels, which would increase with the years.

7. France should close out plutonium fuel use and create a mechanism for paying for decommissioning costs that is equitable, before the effects of deregulation take effect, so that its small consumers, notably French households, will not be left to shoulder these costs.

8. France should enact rules for existing and new residential and communal buildings that will result in drastically increased building envelope efficiency and through increased use of technologies such as earth source heat pumps and cogeneration.

Chapter II: Introduction

The link between global climate change and anthropogenic releases of greenhouse gases (GHGs) from the burning of fossil fuels is now clear and widely accepted. For instance, in 2001 the Intergovernmental Panel on Climate Change (IPCC) concluded:

> …there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.[11]

Because the effects of global climate change may be so rapid that plants, animals, or even humans may not be able to adapt to them, it is arguably the most serious environmental problem in the world. As a French wine grower expresses it:

> I need to know if, twenty years from now, global climate change will have shifted the Champagne wines to Belgium. [12]

In July 2003, John Houghton, who was co-chair of the IPCC, compared the effects of global climate change to those of weapons of mass destruction:

> As a climate scientist who has worked on this issue for several decades, first as head of the Met Office, and then as co-chair of scientific assessment for the UN intergovernmental panel on climate change, the impacts of global warming are such that I have no hesitation in describing it as a 'weapon of mass destruction.'[13]

This prescient declaration came just a few weeks before the deaths in France of more than 14,000, mostly old, people during the worst ever recorded heat wave in that country during August 2003.[14]

In light of the growing evidence of serious climate disruption during the 1990s, 148 countries have ratified the Kyoto Protocol,[15] which is aimed at reducing emissions of greenhouse gases. It came into force in February 2005, despite the fact that the United States, the world's largest source of greenhouse gas emissions refused to ratify it. The Kyoto Protocol was the first practical, specific step pursuant to the United Nations Framework Convention on Climate Change, which went into force in 1992 as the treaty instrument that would provide the umbrella for future international agreements on reducing GHG emissions. Since it is a first step, its greenhouse gas emissions reduction goals are modest.[16] The industrialized countries that signed it (which are listed in Annex B of the treaty) agreed to reduce their GHG emissions by 5 percent below their 1990 levels sometime in the period 2008 to 2012. It is now widely recognized, even in official circles, in most industrialized countries that far larger reductions will be needed in the coming decades if global society is to have a reasonable chance of ameliorating the severe effects of climate change. For instance, a 2004

[11] IPCC 2002, Preface.
[12] Galus 2003. Translated by Annie Makhijani.
[13] Houghton 2003. The Met Office is Britain's Meteorological Office.
[14] Nau 2003.
[15] Kyoto Status 2005, as of April 6, 2005.
[16] Under the Kyoto Protocol the European Community as a whole will have to reduce its greenhouse emissions to 8 percent below its 1990 level between 2008 and 2012 and after redistribution among the member states France is committed to just keep its GHG emissions to the 1990 levels. (Deneux 2002, page 171).

official French report advocates that the industrialized countries lower their emissions by 75 percent by 2050.[17] This larger reduction in the industrialized countries will be required since it is expected that the total as well as per person emissions in the developing countries would increase even if they did take steps to considerably reduce the emissions per unit of economic output.

The nuclear power industry has advocated in recent debates on global climate change that nuclear power can be a principal part of any strategy to reduce greenhouse gas emissions:

> We are calling for the near-term deployment of new nuclear power plants to help the United States achieve energy security and to combat the effects of global climate changes.
> …
> Failure to build new nuclear power plants would mean a significant increase in the emission of greenhouse gases and harmful particulates…"
>
> -- Dr. Gail H. Marcus, President of the American Nuclear Society[18]

This view has gathered momentum as the prognosis regarding the effects of climate change have become more grim. A major international conference was held in Paris on March 21 and 22, 2005. It was "attended by Ministers, high-ranking officials and experts from 74 States and 10 international organizations." Air pollution and greenhouse gas emissions were at the top of the list of reasons that the conference declaration advocated for the consideration of nuclear energy.

> ….[A] vast majority of participants affirmed that nuclear power can make a major contribution to meeting energy needs and sustaining the world's development in the 21st century, for a large number of both developed and developing countries, taking into account the following:
>
> - Nuclear power does not generate air pollution or greenhouse gas emissions…[19]

Its 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. However, even advocates of maintaining or expanding the role of nuclear power admit that it is an expensive means of reducing carbon dioxide emissions. A 2003 estimate made by an interdisciplinary team at the Massachusetts Institute of Technology headed by former Undersecretaries of the U.S. Department of Energy, John Deutch and Ernest Moniz, estimated that the nuclear option reduces emissions at a cost between $100 and $120 per ton of CO_2 saved when compared to coal.[20]

The fact that nuclear power plants do not emit carbon dioxide is a major advantage of nuclear energy. However, they pose a different set of environmental, health, and security problems, which are for the most part incommensurate with those of fossil fuels (Table II.1).

---

[17] Lepeltier 2004, page 2.
[18] ANS 2002.
[19] IAEA 2005.
[20] MIT 2003, page 42.

Table II.1: Risks: Comparison of Fossil Fuels and Nuclear Power

Risks	Nuclear power	Fossil fuels
Incremental climate change risk	None	Potentially catastrophic if sustained carbon dioxide emissions above 3 billion metric tons per year
Potential consequences of catastrophic accidents	Severe: long lasting effect over large regions	No consequences for large regions but may be locally severe; effects generally short term
Air pollution, routine operations	Relatively low	Severe to moderate depending on control technology
Water pollution, routine operations	Often serious at mines, mills, and uranium processing sites (includes non-radioactive and radioactive pollutants); potentially serious at waste disposal sites. Moderate damage from thermal pollution at reactors using once-through cooling systems. Some tritiated water discharges.	Often serious at coal mines; serious at some oil fields (includes non-radioactive and radioactive pollutants, notably radium-226 near many oil wells)
Risk of nuclear proliferation	Yes	No

Source: Adapted from Makhijani 1996, pp. 8-9. The comments assumed the plants and facilities are built and operated with due regard to regulations and to keeping emissions and discharges low, using modern pollution control technology.

Climate change is the most important global environmental issue facing the world; nuclear proliferation is, in many ways, the most crucial security issue facing the world. Therefore, the issue before us is whether greenhouse gas emissions can be greatly reduced while phasing out nuclear power in the country that is now most dependent on it and has one of the lowest per capita carbon dioxide emissions in the EU.[21]

Any analysis of the issues of meeting energy requirements must be within a broad framework that has the economic implications of energy policy at its center. That is the framework of the analysis in this report.

In Chapter III, we will summarize the data on French energy supply and demand.
In Chapter IV, we will present the historical background of France's energy system from World War II until now, with a particular emphasis on the development of the nuclear electricity sector. We will also discuss the present vulnerabilities of the energy system.

[21] The carbon dioxide emissions for France were 1.6 metric tons of carbon per person for the year 2000. Sweden and Switzerland were slightly lower with 1.5. For comparison, the per capita emission of carbon for the United. States was 5.7, higher than the worst EU emitter (Débat National 2003b, citing OECD's International Energy Agency).

In Chapter V, we present an official energy scenario which we call the "Business as Usual" or "BAU" scenario and two IEER energy scenarios (existing technology (ET) and advanced technology (AT)). We 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. We have also done a comparison of oil use and CO_2 emissions in these scenarios. Chapter V also contains a very brief sketch of a zero-CO_2 energy system based on technologies whose feasibility has been demonstrated. Finally, in Chapter VI we will describe the policy recommendations for the implementation for a low CO_2 economy in France.

Chapter III: French Energy Demand and Supply: Overview

A. Energy demand

Oil and uranium are the two most important fuels that France consumes – oil in the transport sector and uranium in the electricity sector. Natural gas (homes and industry) comes next while renewable energies (mostly wood and hydropower) and coal make modest contributions. Table III.1 details the contribution of each energy source.

Table III.1: Consumption by source in 2000, in million metric tons of petroleum equivalent (Mtep) and percent

	Coal	**Oil**	**Gas**	**Nuclear + hydro**	**Other**	**Total**
Mtep	14.1	98.5	37.3	94.9	12.7	257.6
%	5.5	38.2	14.5	36.9	4.9	100

Source: Adapted from ODE 2001, p.20. One Mtep is equivalent to $42x10^{12}$ joules The contributions of nuclear and hydroelectricity are 81 and 14 percent Mtep respectivily, or 31 and 6 percent of the total consumption. Hydroelectric energy is converted into thermal equivalent: 1MWh electrical = 0.222tep thermal.

Practically all of the electricity consumption is in the residential, commercial, and industrial sectors. Yet, while electricity use in the transport sector is small, it is very important to the sector and in the overall transportation infrastructure in France. Most French trains run on electricity; France's high-speed train (TGV) is electric. Of course, the rest of the transport sector runs almost exclusively on oil: cars, trucks, buses, planes, and boats run on it, though there is some propane use in motor vehicles also. Table III. 2 below shows energy consumption by sector.

Table III.2: Energy Consumption by Sector in 2000

Sector	**Total,** in Mtep
Residential and commercial	101
Industry	58
Feedstock	17
Transport	54
Agriculture	3
Energy sector use	25
Total	**258**

Source: Adapted from ODE 2001, page 20. Rounded to the nearest Mtep.

B. Energy production and imports

France relies heavily on imports for its energy needs. The domestic production of fossil fuels is negligible and fossil fuel reserves are small.[22] On the other hand, the domestic energy contribution from hydropower and wood, although small overall, is far from negligible.[23] The

[22] ODE 2001a, pages 11, 15, and 18.

[23] Hydropower is exploited at its full potential. The modernization of the actual hydroelectric park and the construction of new small and medium hydroelectric plants would only add an additional 6 TWh/year (UFE et al. 2003). The contribution of wood is 9 Mtep. A better valorization of the exploitation of wood could provide an additional 4 to 9 Mtep (FNB 2003).

domestic production and import of energy, as well as the countries from which energy is imported, are given in Table III.3.

Table III.3: Production and imports of fuels in Mtep for 2000

Fuel	**Domestic Production, Mtep**	**Imports, Mtep**	**Total**	**% imports**	**Comments**
Petroleum	1.9	115	117	98	Main suppliers: Norway 25%, Saudi Arabia, 18%, Great Britain 12%, Iraq 7% (Middle East total = 30%)
Natural gas	1.6	36	38	95	Norway 30%, Ex USSR 29%, Algeria 25%, Netherlands 12%
Nuclear	7.7 [1]	84[2]	92	91	Main uranium suppliers: Australia, Niger, Canada, Gabon
Hydropower	16	0	16	0	
Coal	2.3	13	15	87	Main suppliers: Australia, South Africa and United States
Renewables	12	0	12	0	Mainly wood
Total	42	248	290	86	Rounded

[1]Plutonium recovered from spent fuel and used to manufacture MOX fuel for French reactors is counted as domestic energy production. France is an electricity exporter. We discuss only the domestic French electricity sector in this report, net of exports.
[2]Uranium. France imports all of its uranium. (Areva 2005).
Sources: The numbers for domestic production and imports are from ODE 2001, page 20.The countries from which France imports fuel are from ODE 2001, page 4 for petroleum; DGEMP Gaz for natural gas, DGEMP 1999, page 35, for uranium and DGEMP Charbon for coal. For coal the Mtep value has been converted from million metric tons.

Nuclear power has contributed to a diversification of fuels and of sources of fuel imports. However, it has not significantly decreased the proportion of imported fuels in France's energy mix, since France imports all of its uranium supply (see Chapter IV, section E below). Therefore, nuclear power has not increased France's energy independence as defined by proportion of imported fuel, though the diversification has increased its energy security in terms of a reduced risk of disruption of fuel supply. As the Commission of European Communities with respect to energy risks noted:

> Security of supply does not seek to maximise energy self-sufficiency or to minimise dependence, but aims to reduce the risks linked to such dependence. Among the objectives to be pursued are those balancing between and diversifying of the various sources of supply (by product and by geographical region).[24]

[24] CEC 2000, page 2.

France has to a large extent already implemented this risk reduction strategy in its energy system because of the diversification of sources of its energy supply. However, the diversification has been achieved by a heavy reliance on nuclear energy for electricity generation. This has created new risks of its own (see Chapter IV Section G).

Chapter IV: The French Energy System, its evolution and its vulnerabilities

A. Introduction

France's lack of control of its main sources of oil during World War I led to "the birth of an obsession: energy independence."[25] This is because, like the other major military powers, France recognized that powerful military machines of the future would be run on oil. Coal-powered ships could not match oil-powered ones. Tanks and other motorized vehicles were becoming central to land warfare; air warfare was emerging as an area of major military competition and power. All of that required oil.

Senator Bérenger of France was very dramatic when, in 1918, he spoke of the role of oil in World War I. Oil was, he said,

> the blood of victory… Germany had boasted too much of its superiority in iron and coal, but it had not taken sufficient account of our superiority of oil…. As oil had been the blood of war, so it would be the blood of the peace. At this hour, at the beginning of the peace, our civilian populations, our industries, our commerce, our farmers are all calling for more oil, always more oil, for more gasoline, always more gasoline. *More oil, ever more oil!*[26]

"More oil" did not necessarily mean domestic oil production. France had essentially no domestic oil sources. The issue had a colonial aspect from the start:

> After World War I, the ruling establishment understood that in order to guarantee the independence and development of France, acquiring and controlling foreign underground resources was essential…[27]
> – Henri Revol (Senator)

It was the same for Britain. (Imports were not a factor for the United States until after World War II.) Hence, the evolution of military technology was, in a curious way, a principal factor in the British and French governmental authorities coming to see *control of foreign oil* sources as a central factor in their own *"independence."* Between the two world wars, France and Britain competed for influence in the Middle East, an area that was seen to have immense potential as an oil exporting region.

In 1924, the Compagnie française des pétroles (CFP, the forerunner of Total) was created by the French government with the mandate to manage the German share of the Turkish Petroleum Company it acquired after WWI.[28] Although a private company, it had relationship with the French government, which provided 36 percent of its capital.[29] The mission of this new private company was to protect French interests in matters of energy.[30] In 1960, the French government created a new nationalized structure, the Union Générale des

[25] Ortoli 1996. Translation by Annie Makhijiani.
[26] As quoted in Yergin 1991, page 183. Translated from the French in Yergin, with the exception of "More oil, ever more oil" (Emphasis added)
[27] Revol 1997-1998, Titre Premier, Ch. III.I.B.1. Translation by Annie Makhijiani.
[28] Roche 2003, pages 24 and 25.
[29] Revol 1997-1998, Titre Premier, Ch. III.I.B.1.
[30] Roche 2003, page 27.

Pétroles (UGP, the forerunner of ELF, which was created in 1976) to compete with the CFP, which was viewed by some as too close to the American and British companies.[31]

After World War II, the French government took control of all aspects of the domestic energy system by nationalizing the remaining energy sectors -- electricity, coal, and natural gas.[32] This nationalization was central to the French approach to energy independence. Of course, this could not overcome the limitation that France had (and still has) almost no indigenous petroleum resources.[33] But it allowed the French government to make large investments in domestic coal production, which allowed a reduction of imports of coal and even oil (which was then used in electricity generation), although the foreign sources of both fuels were cheaper. Most large-scale domestic hydropower resources were also developed after World War II. A part of the nationalization scheme was a nationalized electric utility, Electricité de France (EDF), to generate, transmit, distribute, and sell electricity.[34]

Hydropower and coal became the two main sources of energy used for the production of electricity, while the contribution from oil was just 7 percent in 1960. That was the peak year for hydropower in terms of its proportion in the mix: 56 percent of the total electricity supply.[35]

This strategy began to unravel in the 1960s. France was running low on coal resources and the remaining coal resources were of low quality and increasingly expensive in relation to oil.[36] Cheap oil, notably from the Persian Gulf region, was available to meet the rapidly growing demand, in large measure because the cost of production in that region was very low.[37]

As a result, oil began to be used increasingly in the electricity sector, at a time when its use in the transportation sector was also growing rapidly. By 1973, oil was fueling 39 percent of France's electricity.[38] The 1973 oil price increases and the insecurity resulting from the Arab oil embargo against the United States created a new crisis that was partly due to the rapid rise of the use of oil to generate electricity during the 1960s and early 1970s. This was a basic factor in the decision to revamp the electricity sector in favor of nuclear power. This situation is summarized in the *Rapport sur l'aval du cycle nucléaire*[39]*:*

---

[31] Roche 2003, pages 40 and 42.
[32] Charbonnages 2003 for coal and Loi N° 46-628 du 8 avril 1946 for electricity and natural gas.
[33] The proven domestic resources in 1998 amounted to 14.6 Mtep (Revol 1997-1998, Titre premier, Ch. III.I.A.1).
[34] Prior to deregulation, which is the opening up of the electricity sector to competition, EDF had a total monopoly in the transmission of electricity. As regards the generation of electricity, the Société Nationale d'Electricité Thermique (production of electricity from coal), the Compagnie Nationale du Rhône (production of electricity from hydropower); and the Société Hydroélectrique du Midi (a subsidiary of the nationalized trains system) generated a small share of the total electricity produced (Finon 2001, page 5). However they were obliged to sell to EDF.
[35] EDF 2002a.
[36] In 1993, the domestic reserve of coal amounted to about 100 Mtep (Revol 1997-1998, Titre premier, Ch. III.I.A.1).
[37] For example, the cost of pumping a barrel of oil in Saudi Arabia is between US$1 and US$2. (Energy Bloomberg 2004).
[38] EDF 2002a.
[39] Bataille and Galley 1999. Quotes translated by Annie Makhijani.

…during the 50s coal's dominance was being eroded by the significant decrease of the price of the fuel oil ....[It] decreased by 50 % in francs between 1964 and 1969. Consequently EDF built oil-fired power plants and converted some coal power plants into oil-fired power plants.

Although the report states that:

Thus it was not during the first oil crisis that France opted for nuclear power. This choice was already made during the 50s owing to a particular situation affecting our country, that is a dearth of competitive fossil fuel in its sub-soil.

It also states that:

As early as 1973, that is after the first oil crisis, the Messmer plan greatly hastened the construction of nuclear power plants.

Table IV.1: Percentage of electricity generated from various sources from the end of 1960 to 2001

	1960	**1973**	**1996**	**2001**
Coal	~35	16	5	6
Hydro	56	27	14	14
Oil	7	39	Included in "other thermal"	2
Other thermal	Small	10 mostly natural gas	3.6 mostly natural gas and oil	1.4 natural gas
Nuclear fuels	Negligible[1]	8	77	76

[1] The initial sources of nuclear electricity in France were the plutonium production reactors in the nuclear weapons sector.[40]
Sources: EDF 2002a and Ngô 1999 for 1960, 1973 and 1996, and DGEMP 2003b for 2001. We do not have exact data for coal and natural gas electricity generation for 1960.

Table IV.2 shows the evolution of the share of primary energy sources for the overall energy sector from 1960 to 2000.

Table IV.2: Percentage contribution of different fuels to the entire energy sector, 1960 to 2000.

	1960	**1973**	**2000**
Coal	55	17	3
Oil	31	66	36
Natural gas	4	9	15
Hydropower	10	6	5
Nuclear fuels	Negligible	2	35
Others			5

Source for 1960 and 1973: Galley and Bataille 1998, Tome I, Section.I.A.1.a, citing "Rapport de la commission d'enquête de l'"Assemblée nationale sur la situation l'énergie en France, 5 novembre 1974 (no 1275)."
Source for 2000: ODE 2001, pages 15 and 20

[40] Charpin, Dessus and Pellat 2000, page 28.

Since the 1990s, parts of the energy sector have been undergoing privatization and consolidation. The oil sector was first, with the merger in 1999 of two companies, Totalfina and Elf into one TotalFinaElf.[41] The European Electricity Directive of 1996 mandated that each country pass a law to allow competition in the electricity market.[42] The French law deregulating electricity production is known as the Law of February 10, 2000.[43] For the first years, the implementation of competition and choice in the electricity sector was restricted to large users only. Beginning in 2000, industrial and commercial users that consumed more than 16 GWh annually could choose a supplier other than EDF. About 1600 customers fit into this category. While the number of consumers was small, they accounted for 30 percent of the total electricity used. The threshold was lowered to 7 GWh in February 2003. In July 2004, 2.3 millions clients from small businesses, professionals and local government were able to choose their supplier. In July 2007, the market will be totally open, in that all consumers will have the right to choose among suppliers.[44] The Law of February 10, 2000, article 10, also obligates EDF and other electricity providers to buy electricity produced from cogeneration and renewables. Two subsequent decrees fixed the *maximum* size of the facilities to 12 MW if the producer was to be granted a guaranteed price above the market rate.[45] This, in effect, stifled the growth of large wind farms, since they could not avail themselves of the guaranteed price. Subsequently, in June 2005, the 12 MW ceiling for wind energy was lifted. The size of a wind farm is now left to the decision of the local authorities.[46] A European Directive of 2001 mandates that the share of renewable energies, including hydropower, in the production of electricity in France be increased from 15 percent to 21 percent by 2010.[47]

The availability of choice for large consumers ahead of small ones could create inequities in the long-term, since it may leave small consumers saddled with the cost of paying for high cost nuclear facilities, while large industry flees to cheaper sources. This inequity is likely to be particularly glaring in the case of plutonium fuel use that is acknowledged to be a significant additional cost.[48] If France does not close out plutonium fuel use before the consequence of deregulation takes effect, its small consumers, notably French households and small businesses will be left with most of the bill of $1 billion per year, plus decommissioning costs.[49]

B. Nuclear energy until 1973-74

Parallel to the intense exploitation and use of coal, and keeping with the idea of energy independence, the Commissariat à l'énergie atomique (CEA), created in 1945 to build the French atomic bomb, slowly developed in the fifties a UNGG (Uranium Naturel Graphite

[41] Roche 2003, page13.
[42] Directive 96/92/EC.
[43] Loi No 2000-108.
[44] EDF 2003b, page 7.
[45] Décret no 2000-1196 and Arrêté du 8 juin 2001. The guaranteed price was set at 8.38 c€/kWh for the first 5 years of operation and between 3.05 and 8.35 c€/kWh varying with the number of operating hours per year for the following 10 years. These higher prices were set to encourage development of less windy sites.
[46] EED 2005.
[47] Directive 2001/77/CE, Annex.
[48] The cost difference calculated from the table on page 221 of Charpin, Dessus and Pellat (2000) between S7 (a hypothetical scenario with no reprocessing) and S4 (a scenario corresponding to the actual MOX use and a 45 year lifetime of the nuclear power plants), is 0.64 cF/kWh (0.1 US cents/kWh).
[49] Makhijani 2001, page 28.

Gas) infrastructure (graphite gas reactors fueled with natural uranium) with the dual purpose to produce military plutonium and electricity. In all, nine reactors of this type were built and connected to the grid between 1956 and 1972.[50] The first three (G1, G2, and G3) were run by the CEA.[51] Their main purpose was to produce military plutonium, but they also produced modest quantities of electricity. Between 1958 and 1966 EDF built six reactors of this type, three at Chinon (Chinon A1, A2, and A3), two at Saint-Laurent-des-Eaux (A1 and A2) and one at Bugey (Bugey 1).[52] Although these plants were built by EDF to produce electricity, they also secretly produced plutonium for the military.[53] At the end of the sixties EDF decided to switch to pressurized light water reactors (PWRs) and by 1970 it had specific plans for the construction of two such reactors.[54] Before the oil crisis, the decision to build a total of six PWRs had been made.[55] Framatome, the French nuclear power plant manufacturing company, now part of Areva, a largely government-owned multinational corporation, licensed France's pressurized water reactor design from the U.S. company, Westinghouse, in 1959.[56] Thus, France already had a nuclear infrastructure in place before the 1973 oil crisis, though the actual construction plans were rather modest. As Robert Galley and Christian Bataille, a French parliamentarian author of numerous parliament reports on civilian nuclear energy related matters, have noted:

> Thus it was not during the first oil crisis that France opted for nuclear power. This choice was already made during the 50s owing to a particular situation affecting our country, that is a dearth of competitive fossil fuel in its sub-soil.[57]

But the degree to which and the speed with which reliance on nuclear power increased was affected by the oil crisis. In 1973, about three-fourths of France's energy requirements were met by fossil fuel imports. The large role of oil, *including a significant role in the electricity sector*, resulted in a more than threefold increase in France's oil import bill between 1972 and 1974.[58] The 1973-74 rise in petroleum prices gave the nuclear industry a large opening and justification to argue for a vast acceleration in France's nuclear energy program. A significant part of this program was to phase out the use of oil for generating electricity.

In 1974, an ambitious energy program with two components was launched with the dual purpose of helping to ease the energy bill and making the energy supply more secure. The first component of this energy policy was the creation of a large-scale nuclear program; the second was the creation of the Agence pour les économies d'énergie (AEE - Agency for energy conservation).[59] That year the slogan "France does not have oil, but it has ideas" was coined.[60]

---

[50] Charpin, Dessus and Pellat 2000, page 28.
[51] Charpin, Dessus and Pellat 2000, page 28.
[52] ASN 2004a.
[53] Barrillot 1999, pages 57 and 59.
[54] EDF 2002b.
[55] Bataille and Galley 1999, Ch I.I.B.3.
[56] Bataille and Galley 1999. Ch.I.II.C.
[57] Bataille and Galley 1999, Ch.I.II.A.1. Translation by Annie Makhijani.
[58] EDF 2002b.
[59] In 1982, the AEE became the Agence française de maîtrise de l'énergie (AFME – French Agency for Energy Managment) and then, in 1991, the Agence de l'environnment et de la maîtrise de l'énergie (ADEME – the Agency for the Environment and Energy Management) (Revol 1997-1998).
[60] "En France, on n'a pas de pétrole, mais on a des idées" (DGEMP 2001b, page 22).

C. The nuclear electricity sector: 1974 to 2004

Between 1974 and 1975, the decision was made to build 28 reactors of 900 MW each in addition to the six already planned.[61] Later, 24 more, larger, reactors were also planned and built. Today, the French nuclear power system consists of 58 reactors at nineteen sites with a combined capacity of 62,000 MW. The nuclear electricity production in 2001 was 401 TWh, which was 76 percent of the total French generation.[62] Table IV.3 below summarizes the capability of the French nuclear power system.

Table IV.3: Commercial LWRs in operation, number, and size in 1999

Number of reactors	**Reactor size, MW**	**Installed capacity, MW**
34	900	30,600
20	1,300	26,000
4	1,450	5,800
Total: 58		**Total: 62,400**

Source: EDF 2003a

Note: France had two breeder reactors that used MOX fuel (mixed oxide fuel, a mixture of plutonium dioxide and depleted uranium dioxide), but neither is part of the commercial electricity sector (see below). (Davis 2001 pp. 290 and 200). They are not included in this table.

France's reactors use two types of fuel.[63] Thirty-eight of them use only uranium dioxide (low enriched uranium) fuel, the typical fuel for such reactors worldwide. The other twenty use uranium dioxide for 70 percent of the reactor core and a plutonium fuel, consisting of a mixture of plutonium dioxide and depleted uranium dioxide, called mixed oxide (MOX) fuel, in 30 percent of the core.[64] These 20 reactors are among the thirty-four 900 MW reactors that were the first nuclear units of PWRs to be built in France.[65]

D. The failed plutonium economy

As the worldwide construction of nuclear power plants increased rapidly in the 1970s, many in the industry believed that uranium would become scarce and that, consequently, its price would soar. The use of plutonium produced during the irradiation of uranium fuel was thought to be the solution to that problem. As it turned out, uranium prices did increase for a short time in the period after 1973 but this was mainly in reaction to the rising oil prices rather than any underlying shortage of uranium resources. Prices fell again in the 1980s and 1990s.[66] They have risen from a low of about \$20 to \$30 per kilogram of U_3O_8 a few years ago to the range of \$70 in mid-September 2005.[67] That is still considerably lower than the more than \$100 per kilogram prevailing in 1960.[68]

---

[61] Bataille and Galley 1999, Ch.I.B.3.
[62] ODE 2002a.
[63] Charpin, Dessus and Pellat 2000, page 32.
[64] Bataille and Galley 1999.
[65] Bataille and Galley 1999.
[66] Makhijani 2001, page18.
[67] Uranium spot prices can be found on the Web for example at http://www.uxc.com/review/uxc_prices.html. Viewed on 21 September 2005.
[68] Makhijani 2001, Table 2, gives the 1960 price of uranium as \$100 per kilogram in 1995 dollars, which would be about \$120 per kilogram in 2004 dollars.

The use of plutonium as a fuel has been advocated most vigorously by those who have wanted nuclear power as a very long-term energy source. They point to the fact that uranium-238 constitutes 99.3 percent of natural uranium, but it is non-fissile – that is, it cannot sustain a chain reaction with slow neutrons. But uranium-238 can be converted to plutonium-239, which is fissile. The plutonium produced from the non-fissile uranium-238 during the irradiation of low enriched uranium oxide fuel in a reactor has therefore been (and in some circles is still) looked at as the solution, or one of the main solutions, to the long-term problem of nuclear fuel supply and, more broadly, energy supply.

Plutonium is made in reactors by irradiation of uranium-238 with neutrons. In order to fabricate it into a fuel, it must first be separated from the irradiated fuel. It is then processed and manufactured into fuel. It can be used in a fast breeder reactor, whose goal is to produce more fissile plutonium from non-fissile uranium-238 than the fissile material it consumes as a fuel.[69] The plutonium breeding program was at the core of France's concept for the nuclear energy sector. This program, it was believed, would make France truly energy independent as far as electricity production was concerned. In theory, a fast breeder reactor system can increase fissile material supply from a given uranium resource base by a factor of more than one hundred compared to light water reactors that use uranium in a once-through mode.[70]

Like other major powers, France had been interested in developing a plutonium economy even before the oil crisis. France first began to develop fast breeder reactors that would run on plutonium fuel in 1959. In order to pursue this course, the CEA had developed two small research reactors and one experimental reactor (Rapsodie); the latter went critical in 1967.[71]

The construction of Phénix, (a demonstration reactor of 250 MW connected to the grid in 1973), and Superphénix, (a commercial reactor of 1,200 MW[72] connected to the grid in 1986) were attempts to go to the next stage of electricity production by creating a commercial infrastructure of fast breeder reactors. It should be noted that the decision to go forward with the construction of Phénix was taken in 1969, four years prior to the oil crisis. Similarly, although the authorization to build Superphénix was given after the oil crisis, the PEON commission[73] was proposing the creation of such a reactor as early as 1971. The oil crisis simply gave more impetus to this enterprise.

To provide the plutonium necessary to fuel Phénix and Superphénix, the La Hague reprocessing facility UP2 (UP stands for Usine de Plutonium, that is, Plutonium factory), situated in Normandy on the English Channel, was modified so that it could extract

[69] See Makhijani 2001, Chapters 1 and 2.
[70] Some of the uranium-238 in light water reactors is converted into plutonium-239 in the course of reactor operation. A part of this, in turn, is fissioned, and provides some of the energy generated in a once-through cycle. Thus there is some plutonium use as a fuel even in once-through cycles.
[71] Galley and Bataille 1998, Tome.I, Section I.A.1.b.
[72] Galley and Bataille, 1998, Tome.I, Section I.A.1.b.
[73] The PEON commission (Commission consultative pour la production d'électricité d'origine nucléaire) was established in 1955. (Charpin, Dessus and Pellat 2000, page 30). In 1970 it recommended to the government that "most of its research and development effort should be devoted for breeder reactors." This recommendation was heeded by the government's sixth plan (1971-1975) when EDF dedicated two-thirds of its R&D resources to the development of breeder reactors (Galley and Bataillle 1998, Tome I, Sections I.A.1.b and I.B.1). Translated by Annie Makhijani.

plutonium from uranium oxide fuel from the light water reactors. UP2 was built in 1966 to extract plutonium from natural uranium metal fuel of the EDF gas-graphite reactors.[74]

By the early 1990s it became evident that this path was not to be the solution for two reasons. First, the cost of uranium declined in the 1980s and continued to decline during the 1990s. At the same time, the cost of reprocessing remained high. As a consequence, plutonium simply became uneconomical as a fuel.[75] Second, the breeder reactor program has been crippled with technical problems and huge cost overruns. The failure of Superphénix was at the center of these problems. Over its twelve years of operation, Superphénix produced only 8.2 TWh of electricity, yielding a lifetime capacity factor of about six percent.[76] It became evident that breeder reactor technology would be difficult and costly to master, since there were troubles and premature shutdowns at several reactors around the world.[77] While some breeder reactors operated reasonably well, others did not. Two breeder reactors (the Fermi I reactor at Lagoona Beach, near Detroit in the United States, and the Monju reactor in Fukui prefecture, Japan) suffered serious accidents in 1966 and 1995, respectively. Superphénix stopped producing electricity in 1997 and was permanently shut down in 1998.[78]

Instead of recognizing the fundamental problems facing a plutonium economy and developing a large-scale program of alternative energy sources accompanied by a great increase in efficiency, the French government continued the implementation of a plutonium fuel program that was put into place in the mid-1980s. At that time EDF had made an agreement with COGEMA, the government-owned reprocessing company, to use mixed oxide fuel (MOX), consisting of a mixture of plutonium dioxide and depleted uranium dioxide, in some of its reactors on the assumption that it would be economically "interesting." However, by 1989 EDF had calculated that using MOX would not be economical. It calculated that the additional cost of using MOX fuel rather than uranium fuel over the next ten years would amount to 2.3 billion francs (in 1990 francs), about $330 million. But since the reprocessing contracts with COGEMA were already signed, EDF decided to go ahead because, in its view, keeping the reprocessing option open would also keep options open for the next generation of reactors. It also opined in a secret memorandum that abandoning MOX would have "detrimental consequences for the nuclear option as a whole."[79]

Estimates of the relative economics between MOX and the once-through uranium fuel cycle depend on assumptions about the costs of uranium, uranium processing and enrichment, MOX fuel fabrication, and final waste disposal. But MOX fuel can be expected to remain uneconomical in the foreseeable future.

Currently, Japan is one of the strongest remaining supporters of the plutonium economy. In addition to developing indigenous facilities, Japanese nuclear utilities have negotiated significant contracts for the reprocessing of their spent fuel and MOX fuel fabrication in Europe. However, a 1997 study by Baku Nishio, co-director of Citizens' Nuclear Information

---

[74] Davis 2001, page 111.
[75] Makhijani 2001.
[76] Davis 2001, page 290. The capacity factor is the average power output of an energy plant relative to its rated capacity.
[77] For a summary of large breeder reactor years of operation and costs, see Makhijani 2001, Table 3.
[78] Makhijani and Saleska, 1999, page 152; ASN 2004.
[79] EDF 1989, Sections 3 and 4. Translated by Annie Makhijani.

Center in Tokyo, estimated that the use of MOX fuel in Japan was nearly two and a half to three times as expensive as the use of the once-though uranium fuel cycle.[80]

Even more stark than the conclusions of the Japanese study are the results from a 2003 report written by a faculty group at the Massachusetts Institute of Technology on the future of nuclear power.[81] The authors' analysis shows that with reasonable assumptions for the fuel cycle costs, MOX is more than four times as expensive as uranium fuel. The MIT model predicts that the cost of plutonium fuel is 2.24 ¢/kWh (kilowatt-hour) versus 0.515 ¢/kWh for uranium. Even for the most economically optimal distribution of fuels considered in this study (16 percent MOX and 84 percent fresh uranium, this difference in fuel prices would add an additional 0.28 ¢/kWh to the total cost of electricity generated by nuclear power. In examining the sensitivity of these results to changes in the assumed input prices, the MIT report finds that even if the cost of disposing of the high level waste from reprocessing spent fuel were to go to zero, MOX would still be more than three times as expensive as fresh uranium fuel.

In order for uranium fuel costs to rise by about 1.7 cents per kWh, uranium prices would have to increase by about an order of magnitude from the September 2005 spot market price of $70 per kilogram. Such a price is not within the range forecast for the foreseeable future.

While it is true that compared to oil, coal, or natural gas, the cost of fuel makes up a much smaller portion of the overall cost of the electricity generated in nuclear power, the added costs from the use of MOX fuel are still significant. The increased costs have now been officially acknowledged in France. An official report to the Prime Minister, published in the year 2000, admits that plutonium fuel is more expensive than uranium fuel.[82]

The report presents six scenarios, S1 to S6, for which it estimates the cost of the kWh produced by nuclear power over the lifetime of the existing plants. Two lifetimes, one of 41 years, the other of 45, are chosen and for each lifetime three reprocessing strategies are considered, as shown in the table below.

Table IV.4: Reprocessing scenarios and their associated electricity costs

	Average lifetime 41 years	Average kWh in French cents[1]	Average lifetime 45 years	Average kWh in French cents
End of reprocessing in 2010	S1	15.13	S4	14.27
Partial reprocessing, MOX used in 20 reactors[2]	S2	15.20	S5	14.38
Full reprocessing, MOX used in 28 reactors	S3	15.28	S6	14.46
No reprocessing			S7	13.65

Source: compiled from Charpin, Dessus & Pellat 2000, page 51
[1] One French cent is equal to 0.0015 Euro
[2] Only 28 reactors out a total of 58 can use MOX. Partial reprocessing means that only 20 of the 28 reactors are being utilized.

[80] CNIC 1997, Table 4-1.
[81] MIT 2003, pages 146 to 148.
[82] Charpin, Dessus and Pellat 2000, pages 56 and 57.

The cost of electricity is cheapest for the scenarios in which reprocessing is phased out by 2010. This conclusion is independent of the assumed operating lifetime of the nuclear power plants. In the additional hypothetical scenario, S7, with no reprocessing past, present, or future, the estimate for the cost of electricity is by far the cheapest. The added costs from continuing the current level of reprocessing and use of MOX fuel (30 percent MOX in 20 out of 58 pressurized water reactors), as compared to using just the once through fuel cycle, amounts to an increase of more than five percent in the cumulative cost of electricity. Even this rather small percentage increase in the overall cost still results in an additional 22 billion euros ($22 billion) that would have to be spent over the lifetime of the reactors. Based on the report, IEER has calculated that, over a 45 year period, the cost difference between full reprocessing and no reprocessing is about $50 million per year per reactor using MOX.[83] It should be kept in mind that since each such reactor only uses MOX for 30 percent of its core, the added cost of electricity produced from MOX (that is from that 30 percent of the core) is about 2 cents per kWh. This is approximately the same as the economic penalty for MOX estimated by the MIT study.

In its 2001 report, *Plutonium End Game,* IEER has calculated that "France… has spent a total of almost $20 billion so far on its plutonium program since about 1960, not including several important cost elements or future liabilities from the past program."[84] France continues to spend on the order of $1 billion (about 1 billion euros) per year on its MOX fuel program."[85] In comparison, the French government's 2001 budget for energy efficiency and renewables was 152 million euros (about $152 million),[86] while in 1999 it was only 76 million euros (about $76 million).[87]

E. Evaluation of energy independence

France's dependence on imported energy sources has varied a great deal since World War II despite the decision at that time to create a high level of energy independence. The decision at the end of World War II to focus on coal and hydropower, coupled with the relatively small number of motor vehicles in use for the first decade after the War, led to a relatively high degree of independence in the early years as shown in Table IV.5. This independence eroded rapidly in the 15 years that followed.

France produced 60 percent of the energy it used in 1950, with domestic production consisting of coal and hydropower. By 1973, domestic production had dropped to 22 percent of energy use, due to the drop in domestic coal production and the increase in the imports of oil both for transport and electricity production.[88]

Today, France's total energy independence is officially claimed to be about 50 percent. This is only because the French official view includes the entire nuclear energy sector as domestically produced energy. However, if the term "independence" is understood to be synonymous to domestic production of fuels only, then the official claim does not hold up,

[83] Makhijani, Annie, 2001, page 10. We have used the approximate purchasing power parity 6.55 francs = 1 euro = 1 dollar as the basis for the calculations in this report.
[84] Makhijani 2001, page 29.
[85] Makhijani 2001, page 10.
[86] Plan Etat-ADEME 2001.
[87] Demarcq 2000, page20.
[88] Bataille and Galley 1999.

since *France imports all of its uranium supply*. It is no more reasonable to include electricity based on imported uranium as "domestic" than it is to include electricity generated from imported oil as "domestic." Since the latter is ruled out, the former should also be excluded. However, it is reasonable to consider the plutonium that is extracted from the spent fuel fabricated into MOX and put back in some reactors as domestic supply, since this fuel is produced by the processes of irradiation and reprocessing both of which take place in France. But MOX fuel produces only about seven percent of French nuclear electricity, or about 30 TWh, per year,[89] which amounts to about three percent of total energy use from all sources. Hence, in contrast to the official view that France produces half of its energy domestically, a more realistic accounting based on the amount of imported fuel is that France only produced about 15 percent of its energy requirements. Thus, it is at a historically low point in energy independence when measured by fuel imports.[90]

The historical evolution of energy independence according to these two different criteria for accounting for uranium imports is summarized in Table IV.5.

Table IV.5: Official and IEER estimates of the evolution of domestic energy production as a measure of energy independence in percent: 1950-2000

	1950	**1970**	**1973**	**2000**
Official view	60	29	22	50
IEER view	60	29	22	15

Sources: The numbers for 1950, 1970 and 1973 are from Bataille and Galley, 1999. The official number of 50 percent for 2000 is from ODE 2001, page 22. Official estimates consider nuclear energy to be domestically produced even though the entire French uranium supply is now imported. France ceased to produce uranium in 2001. The IEER estimate is the sum of the contribution from hydroelectricity (6 percent from note of Table III.1), other renewables (5 percent from Table III.1), the 3 percent from MOX fuel cited above, and the small amount of oil and gas produced in France.

F. Vulnerabilities versus energy independence

The concept of energy independence is often equated with the idea of energy self-sufficiency. Estimating the proportion of energy use that is domestically produced assesses the degree of "independence." While this has been a traditional goal in energy policy, reinforced by the uncertainties in oil supply and prices during the 1970s, it is remarkable that the ideas of energy independence have not been formally re-evaluated and restated in the context of European integration and a globalized economy in which countries are not self-sufficient in most of the areas that are vital to a prosperous economy.

In the context of globalization and European integration, the idea of energy independence should be reframed as the secure supply of energy, at reasonable prices, rather than zero imports. No country with a complex economy can cut itself off from trade, including trade in essential commodities. Economic security is therefore a far more complex matter than the simplistic view provided by a notion of energy independence. For instance, an energy system must function in such a way as to not harm the environment. This also should include the environment of the importing country. Diversification of import sources is also important. This means, as already quoted above, that for the importing countries:

---

[89] ASN 2001b.
[90] The issue of energy security and diversity of energy supplies is somewhat different as is next discussed.

> Security of supply does not seek to maximise energy self-sufficiency or to minimise dependence, but aims to reduce the risks linked to such dependence. Among the objectives to be pursued are those balancing between and diversifying the various sources of supply (by product and by geographical region). [91]

Today, many exporting countries depend on fuel exports for their own economic survival. So, in an integrated world economy, transitions to new energy arrangements have to be made cooperatively so common goals are achieved and security, economic well-being, and environmental protection are enhanced for everyone.

For France the import of oil is large; but compared to the 1970s the vulnerabilities for oil with respect to supply have decreased in part because of the diversification of sources. In 1973, 80 percent of its oil was imported from the Persian Gulf, while the rest came from Algeria and Libya. But since the 1973 oil embargo, France has increased the number of countries and diversified the regions from which it imports oil; hence it has succeeded in increasing its security of supply. In 2000 the imports from the Persian Gulf had dropped to about 30 percent, while Norway had become the main supplier. See Table III.3. Similarly the import of uranium is large, but sources are mainly from Australia and the West. Supplies are plentiful so that additional supplies can be procured from new sources in relatively short periods of time in case of unanticipated need. Hence, the diversification of fuels has increased France's energy security despite the increased import dependence.

While France has improved its energy security since 1973 in terms of diversity of energy supply, its reliance on nuclear power has created new vulnerabilities.

G. Vulnerabilities of the French energy system

The vulnerabilities of the French energy system are not so much associated with the lack of domestic resources – as discussed in the previous section – but rather with the risks inherent to the nuclear sector and to burning oil.

- Nuclear vulnerabilities

France has virtually eliminated its dependence on oil as far as its electricity system is concerned[92] but the creation of an electricity system that relies on nuclear power has created its own set of vulnerabilities:

- The construction of large centralized nuclear power plants in the event of a shutdown would make the loss of electricity production hard to replace.

- The isolation from the environment of nuclear waste whose toxicity will last for tens of thousands of years is a challenge that has yet to be met.

- Even the small risk of an accident in a nuclear reactor or in a spent fuel pool that could cause large releases of radioactivity is rendered more serious in a country like France

[91] CEC 2000, page 2.
[92] France's nuclear program for the electricity sector has helped to curtail the imports of oil -- for example, in 1998 the avoided oil import was 82 Mtep, as cited in DGEMP 1999, page14.

because of its dense population and the crucial role that food and agriculture play in its economy and culture.

- The French government's credibility on the matter of radiation releases from nuclear accidents is already low due to the misleading and wrong statements it made in the wake of the Chernobyl accident. Specifically, an expert report published in 2005 revealed that the French government did not take the necessary precautions to protect the population from the 1986 Chernobyl radioactive cloud.[93] The report is based on information obtained during searches at several ministries requested by the judge in charge of a lawsuit brought by thyroid cancer victims. The victims believe that their cancers are the result of the fallout from the Chernobyl accident. The report reveals that the government knowingly played down the importance of the contamination. For example, measurements taken by the Commissariat à l'énergie atomique at its Marcoule plant registered a level of cesium-137 20,000 times above background and levels of more than 10,000 Becquerels per liter of iodine-131 were detected in sheep's milk (200 times above the limit at which dumping is required). However the SCPRI (Service central de protection contre les rayonnements ionisants) announced "no significant rise in radioactivity" and that "[t]here was no reason to put in place special measures for health protection."[94] At the same time some European countries were dumping milk and vegetables.[95] This incident has raised questions about the degree of commitment of the French government regarding the protection of public health in circumstances that may call into question the future of nuclear power in France.

- The plutonium in spent fuel that can be used for the production of nuclear bombs increases the proliferation risk. This is not a theoretical construct. In the year 2002, the head of the Japanese Labor Party, Ichiro Ozawa, suggested in 2002 that if China got too powerful, Japan might make thousands of nuclear bombs from plutonium in its civilian nuclear sector.[96] Most of Japan's plutonium stock was reprocessed in France. While much of it is stored in France, Japan had enough separated plutonium on its territory to make roughly 1,000 nuclear bombs.[97]

Some of these vulnerabilities have been heightened by the terrorist attacks of September 11. The reader will find a discussion of these vulnerabilities in IEER's report *Securing the Energy Future of the United States*.[98]

- Oil vulnerabilities

Despite the fact that oil has essentially ceased to play a role in electricity production in France, it not only remains, by far, the main fuel for the transport sector, but its consumption has steadily increased in that sector since 1973 and is expected to continue to do so in the

---

[93] de Pracontal 2005.
[94] As cited in de Pracontal 2005. Translated by Annie Makhijani.
[95] Medvedev 1990, Ch. 6.
[96] Reuters 2002-04-06. On the basis of 7 kilograms per bomb.
[97] CNIC 2004.
[98] Makhijani 2001a.

future.[99] The emission of greenhouse gases from the transport sector represents its main vulnerability. Under the Kyoto Protocol, France is only required to keep its carbon dioxide emissions at their 1990 level. However this requirement will be hard to meet in the future if the current trend in the use of petroleum in the transport sector continues. In the year 2000 the consumption of oil in all sectors remained about 28 Mtep below the 1973 consumption, mainly due to the elimination of oil from the electricity sector in the prior decades.[100]

[99] Under the business-as-usual scenario the oil consumption in the transport sector is expected to increase to almost 45 percent by 2020.
[100] ODE 2001d, page 3.

Chapter V: Energy Scenarios

Most conventional thinking in France, as well as in much of Europe, is that without nuclear power, the obligations of the Kyoto Protocol will not be met. This is clearly expressed in the opinion of Loyola de Palacio, the Vice President of the European Commission in charge of Transport and Energy:

> If we walk away from nuclear power we will not be able to respect the Kyoto Protocol, but if we do not we will fulfill the Kyoto Protocol. It is that simple and the message has to be blunt so that people understand.
>
> --Loyola de Palacio (Vice President of the European Commission in charge of Transport and Energy)[101]

This sentiment that nuclear power is part of the answer to the climate change crisis has intensified considerably in the last two or three years. The other view is represented by Germany, which has decided to phase out nuclear power and meet its Kyoto Protocol commitments at the same time.

As noted already, France is not obligated to reduce its greenhouse gas emissions under the Kyoto Protocol relative to 1990 because French emissions per unit of output are already lower than other EU countries, mainly because of its high reliance on nuclear power. Its Kyoto Protocol obligation is to keep its greenhouse gas emissions constant at the level of 1990. France expects to meet its Kyoto Protocol obligations with less difficulty than other countries. The rest of the European Union must reduce greenhouse gas emissions (GHG) by 8 percent below 1990 emissions between 2008-2012.

France's challenge in reducing GHG emissions back to the 1990 level arises mainly in the oil-dependent transport sector. If current trends continue, France's overall GHG emissions are projected to increase 9.6 percent by 2010 relative to 1990.[102] This projection has reinforced the official commitment to nuclear power. The business-as-usual electricity sector presented below gives official backup for the belief that nuclear energy is indispensable.

There is some technical validity to the official view that nuclear power plants do not emit greenhouse gases. Therefore, it is true that the difficulties of reducing carbon dioxide emissions are more complex if phasing out nuclear power is a simultaneous goal. The challenges are even greater when we take into account the fact that the Kyoto Protocol is only a beginning for the GHG emissions reductions that are needed. Many European countries, including France, now recognize that cuts in GHG emissions on the order of 75 percent will be needed in the coming decades in the West to reduce climate change risks.[103] However, the main factor to keep in mind is that reducing GHG emissions is not limited by the availability of zero-CO_2 energy sources but by the total availability of capital. The difficulties in France do not arise from any limitations of technical possibilities that exist in theory, but from the deep entrenchment of nuclear power in the French energy sector. The analysis here shows

[101] AFP 2002. Translated by Annie Makhijani.
[102] Lepeltier 2004, page 20. The projected GHG emissions increase from 1990 to 2010 for the transport sector is 44.1 percent.
[103] Lepeltier 2004, page 1.

that these difficulties are not as great as might appear at first sight. France saw three enormous transitions in electricity in 50 years: coal to a mix of coal and hydro, then to oil and hydro, and from there to nuclear and hydro. A large transition to low CO_2 without nuclear in 50 years is not only possible, it has historical precedent.

IEER has shown in the case of the United States that carbon dioxide emissions can be cut by 40 over the next three to four decades with current or near current technology while phasing out nuclear power. The calculations presented in this chapter show that similar policies and technologies would result in smaller reductions in France (about 20 percent reduction in carbon dioxide emissions). This is mainly because, unlike the U.S. electricity sector which depends on coal for roughly half of the total output, the French electricity sector has very low greenhouse gas emissions due to the very high percentage of nuclear energy, with most of the rest coming from hydropower, which also has essentially zero greenhouse gas emissions. In other words, the simultaneous large reduction of GHG emissions by 40 and a nuclear power phase out will require more careful policies and planning than in the United States.

We examine two scenarios in this chapter. The first shows a 20 percent reduction in carbon dioxide emissions, using an approach similar to the one that IEER analyzed for the United States. The second illustrates an example of the technological and policy choices needed for a 40 reduction in carbon dioxide emissions without any changes in social or economic assumptions. These two scenarios are called the IEER ET scenario (ET stands for Existing Technology) and the IEER AT scenario (AT stands for Advanced Technology).

There is also a brief qualitative description of possible approaches to a zero-CO_2 emissions economy in France in the 21st century

We begin by laying out the economic and energy assumptions that provide the baseline starting point for our case study. We also briefly examine the "Scénario Vert" which has set forth an approach to phasing out nuclear power in France, but that does not have a simultaneous technology-policy framework for significant reductions in carbon dioxide emissions.[104]

A. The Business-as-Usual Scenario

Projections to the year 2020 for the entire energy sector are presented in a 1998 report published by the Commissariat Général du Plan, entitled *Energie 2010-2020*.[105] This report presents three scenarios, S1, S2, and S3 that share the same assumptions for population growth, international prices of energy, and economic growth.[106] The annual economic growth rate is 2.3 percent. Table V.1, below, shows the projections for the population and the international energy prices until 2020.

---

[104] Scénario Vert.
[105] Moisan 1998.
[106] S1 corresponds to a free market oriented scenario, in S2 the state retains its control over the energy sector and assures that it remains competitive, and in S3 the state is given the role of protector of the environment. (Compiled from Moisan 1998, Tables S1.3, S1.4, and S1.10 for 2010 and 2020. The values for 2000 are extrapolated from the 2010 and 2020 values)

Table V.1: Official projections for population and energy prices

	1995	2000	2005	2010	2020
Population (million)		59.4	*60.6*	61.7	63.5
Energy prices					
• Oil ($ per barrel)	17.0	*20.5*	24.0	24.0	24.0
• Natural gas ($ per million Btu)	2.5	*2.9*	3.3	3.3	3.3

Source: Compiled from Moisan 1998, page 96. The numbers in italics are extrapolated.

These prices are clearly obsolete at the time of publication of this report (May 2006). However, their relevance in the present analysis is only to provide a base case for economic assumptions. Increases in prices will tend to drive technology and consumption in the direction of greater efficiency and lower energy use per unit of economic output, so that it does not affect the overall, broad analysis presented here. However, the mix of what price and regulation might be expected to achieve would change somewhat.

We have chosen to present and discuss the scenario S1 (referred to hereafter as "the business-as-usual," or BAU scenario) in which the energy requirements are the highest (accompanied by high carbon dioxide emissions) since we have used its economic data to construct our own scenario.

The main projections in the business-as-usual scenario in terms of passenger miles, number of houses in the residential sector, and heated space in the commercial sector is given in Table V.2.

Table V.2: Demographic projections relevant to energy use for the year 2020 used in the BAU scenario

	2000	2010	2020
Transport			
Billion car-km	286	462	521
Billion delivery truck-km	90	120	160
Billion metric ton-km (trucks)	230	300	380
Residential			
Apartments (million)	10.1	10.8	11.2
Individual houses (million)	13.5	14.8	15.9
Commercial (millions m^2 heated surface)	767	875	1000

.

The business-as-usual scenario is characterized by

- Market forces dictate the evolution of the energy sector.
- Energy efficiency is not a priority. For example, in the transport sector, the annual efficiency increase is 0.1 percent for cars and 0.2 percent for trucks. In the residential and commercial sector there is little or no efficiency increase for heat and only modest efficiency increases for lighting and appliances.
- Public amenities such as public transport are developed only if profitable.

- A mix of fuels and their respective share of the overall energy demand remain essentially the same.

Table V.3 shows that under the business-as-usual scenario, the mix of fuels as well as the share of each fuel to the total consumption remains unchanged 20 years from today. However, over the same period of time, the carbon dioxide emissions increase by 12 percent.

Table V.3: Evolution of the mix of and share of fuels from 2000 to 2020 for the business-as-usual scenario.

Fuels	**2000**		**2020**	
	Mtep	**% of total energy**	**Mtep**	**% of total energy**
Oil	99	38	118	39
Uranium	79	31	100	33
Gas	37	14	47	16
Hydro	16	6	15	5
Coal	14	5	7	2
Others	13	5	14	5
Total	258	100[1]	301	100

[1] The figures in this column do not add up 100 because of rounding.
Source: For the Year 2000, data are from ODE 2001, page 20. The 2020 projections are from Moisan 1998, page 144. In the projection in this table, carbon dioxide emissions, oil imports, and energy consumption would all increase considerably. This scenario does not represent official policy, which is to meet the goals of the Kyoto Protocol. This scenario is the basis for the economic assumptions used for official policy, as well as for the scenario that IEER has constructed in this report.

The detailed official policy for energy goes out to the year 2020, which is not long enough for the accomplishment of the large carbon reductions that this study seeks to model with a concurrent phase out of nuclear power. Projections to the year 2050 for the electricity sector alone are given in an official report entitled *Etude économique prospective de la filière électrique nucléaire*.[107] We have used these projections, which are essentially similar to those made by the Commissariat Général du Plan, until 2020. The high nuclear power case for electricity through the year 2050 is shown in Table V.4.

[107] Charpin, Dessus and Pellat 2000.

Table V.4: Projections to the year 2050 of the mix of fuels and their contribution to the electricity sector, in TWhe

Fuels	**1995**	**2020**	**2030**	**2040**	**2050**
Hydro	76	73	74	74	74
Nuclear	359	377	437	497	556
Coal	22	4	-	-	-
Oil	2	10	10	10	10
Gas	2	-	-	-	-
CCNG*	-	28	26	28	25
Cogeneration	11	40	60	80	100
Wind	-	7	8	9	10
Others	-	12	14	17	20
Total	**471**	**551**	**629**	**715**	**795**

*CCNG (Combined cycle natural gas)
Source: Adapted from Charpin, Dessus & Pellat 2000, p.132.
Note: This official scenario includes about 70 TWhe in exports of electricity. IEER's scenarios are for French electricity consumption only. That is, it does not include electricity exports.

Projections to 2020-2030 for the entire energy sector were also presented in a May 1999 report produced for the Green Party by the organization Détente, based on work previously done by INESTENE (Institut d'Evaluation des Stratégies sur l'Energie et l'Environnement) entitled *Scénario Vert pour la France*. The Scénario Vert assumes the same economic growth and evolution of services as those of the scenario S1. We have chosen these assumptions in order to keep constant the services provided by the energy sector to society, such as vehicle miles or square meters of living and office space. That way the effect of different energy technologies and policies can be compared on purely technical merits in a straightforward way.

B. Scénario Vert

The main feature of the Scénario Vert is that it shows that, contrary to the nuclear industry's claim, adherence to the Kyoto Protocol is compatible with a nuclear phase out. France is not required to reduce GHG emissions under the Kyoto Protocol.

The table below shows the carbon dioxide emissions for the entire energy sector under the Scénario Vert.[108]

Table V.5: Total CO_2 emissions, 1989-2030 for entire energy sector, in million metric tons of carbon dioxide and corresponding carbon.

	1989	1992	2000	2010	2020	2030
CO_2	365	377	365	354	371	389
C	100	103	100	96	101	106

[108] We have not verified the estimates in the Scénario Vert. We simply present the results here as a point of information and comparison. We have not relied on any estimates done in this scenario or in the business-as-usual scenario for our energy calculations.

Note: The figures are estimated from T.35 (Figure 35) of the Scénario Vert. The figures for carbon are calculated. Figures for 2000 and later years were projections assuming Scénario Vert policies. T.35 has no figure for 2030. The value for that year was extrapolated using the data from 2010 and 2020.

The Scénario Vert proposes broad changes in the energy system compared to both the business-as-usual approach and the official scenario S3 for complying with the Kyoto Protocol. But the biggest change, by far, occurs in the electricity sector as described in the next section. More modest changes in the transport sector, as well as in the residential, commercial, and industrial sectors, contribute to maintain the 2020 overall carbon dioxide emissions to their 1990 level. Overall the estimates of the Scénario Vert are based on technology that is already commercialized. It assumes that the fuel cell technology will not significantly enter the market before 2020.

1. The electricity sector in Scénario Vert

The phasing out of nuclear power over a period of 25 years, starting in 2005 is achieved mainly by a combination of:

- Energy savings: These savings are obtained with higher efficiencies for lighting and appliances as well as a mix of measures for heating and hot water that range from stricter building standards to replacement of electricity with gas, solar energy, and wood. A phase out of electricity is also included in this category. Overall, this results in the reduction of electricity requirements from 500 TWh to 350 TWh over a period of thirty years. See Table V.6 below.

- Partial substitution of nuclear power with cogeneration and combined cycle natural gas plants. This corresponds to the generation of 150 TWh.

- Increase in the production of electricity from renewable energy sources, mainly wind. The production of hydroelectricity remains at its current level. This adds 175 TWh to the production of electricity.

Table V.6 gives the details of the production of electricity from the various fuels and Table V.7 gives the evolution of carbon dioxide emissions.

Table V.6: Electricity production in 2030 and the mix of fuels under the Scénario Vert

Fuels	**TWh**
Renewables	
• Hydro • Wind • Wood	81 75 19
Cogeneration	
• Residential and Commercial • Industry	41 47
Combined cycle, natural gas	63
Other	6
Coal and Oil	19
Total	350

Note: The figures are estimated from T.5 (Figure 5) in Scénario Vert .

Table V.7: Carbon dioxide emissions and corresponding carbon emissions of the electricity sector from 1989 to 2030 in million metric tons under the Scenario Vert

	1989	**1992**	**2000**	**2010**	**2020**	**2030**
CO_2	46	57	40	46	71	110
C	13	16	11	13	20	30

Note: The figures for carbon dioxide are estimated from T.35 (Figure 35) in Scénario Vert. The figures for carbon are calculated. Figures for 2000 and later years were projections assuming Scénario Vert policies. T.35 has no figure for 2030. The value for that year was extrapolated using the data from 2010 and 2020.

2. The transport sector

The Scénario Vert states that the goal of keeping carbon dioxide emissions at their 1990 level will be difficult to meet. It proposes more stringent measures focused mainly on the private vehicle than any official scenario because that sector is the main contributor to CO_2 emissions in France. But the private vehicle sector is the only transport sector for which carbon dioxide emissions decrease. All the other transport sectors – aircraft and commercial transport –register an increase in carbon dioxide emissions. Table V.8 gives the overall carbon dioxide emissions in the transport sector in the Scénario Vert. In the section below we briefly present the measures suggested in that scenario to reduce carbon dioxide emissions from private cars.

In 1992, 26 percent of the 24 million private cars ran on diesel and 74 percent ran on gasoline. In the Scénario Vert, priority is given to curbing urban pollution through a system of increased taxation of diesel compared to gasoline. Hence, it is proposed to reduce the percentage of new diesel cars from 20 percent in 1996 to 17.5 percent in 2030. Concurrently, diesel cars would be partially replaced by cars running on liquid petroleum gas and methyl ester while gasoline cars would be partially replaced by cars running on natural gas and ethanol. The rest of the fleet would still run on gasoline and diesel with increasing efficiency. New cars with an efficiency of close to 5 liters per 100 kms (47 miles per gallon) would have started to be introduced in 2005. By 2020, all cars in France running on gasoline and diesel are assumed to reach 5 liters per 100 kms (47 miles per gallon).

Table V.8: CO_2 and corresponding carbon emissions in the transport sector, 1989 – 2030 in million metric tons under the Scénario Vert

	1989	1992	2000	2010	2020	2030
CO_2	131	130	136	133	140	152
C	36	33	37	36	38	42

Source: Scénario Vert. page 40
Note: the figure for 2000 is estimated from T. 31 (Figure 31) in Scénario Vert. The values from 2000 onwards are projections

3. Other sectors: heat and hot water

The production of energy for heat and hot water is achieved by the partial substitution of carbon rich fuels, coal and oil, with gas, cogeneration and renewable energies (geothermal, solar and biogas).

For new construction, steps are taken to improve efficiency through the institution of efficiency standards for single family homes and apartment buildings. For old buildings, a policy of retrofitting is advocated.

The Scénario Vert is very important for the reason that it reduces the vulnerabilities associated with the production of electricity from nuclear power with no increase in carbon dioxide emissions for the entire energy sector. However, as stated previously, the cuts needed for carbon dioxide emissions reduction have to be much deeper and faster than mandated by the Kyoto Protocol. In the next section we discuss approaches and policies that could accomplish that.

C. The IEER scenarios

We have taken a two-step approach to developing the IEER scenarios for nuclear power phase out and carbon dioxide emissions reductions in France. The first step and set of measures relate to technologies that are available today and are economical or can be made economical with appropriate policies in ten to fifteen years. This is the IEER ET (Existing Technologies) scenario. The second relies on more advanced technologies that are still being developed and are not too far from commercialization but with somewhat uncertain economics at present. This is the IEER AT (Advanced Technologies) scenario.

The overall technological thrust of the approach is as follows:

- Vastly increased heating and cooling efficiency in existing buildings and in new construction through the general use of more efficient building design and construction methods and technologies such as earth source heat pumps and cogeneration.

- Very stringent efficiency standards for new passenger vehicles, becoming more and more stringent with time.

- Stringent standards for appliances.

- Reliance on natural gas as a transition fuel.

- Renewable energy sources, including large scale use of wind energy and in the IEER AT scenario use of solar photovoltaic cells.

- Cogeneration and increases in efficiency in industry.

- Increased use of biofuels as feedstock.

1. IEER Exiting Technology scenario

Over three-quarters of the electricity generation in France is nuclear in origin. The task of phasing out nuclear power while substantially reducing carbon dioxide emissions below the level of about 111 million metric tons of carbon per year in the year 2000 and, at the same time keeping a comfortable standard of living, is a challenging one. This task is rendered even more difficult since oil consumption in the transport sector alone is expected to rise substantially in the business-as-usual scenario, due to a sharp increase in passenger-miles.

In spite of these difficulties, the achievement of a nuclear power phase out, while reducing carbon dioxide emissions by about 20 percent below their year 2000 level, is possible with existing and near-term technologies with incremental improvements over the decades. For instance, earth-source heat pumps with coefficients of performance (COP)[109] of about 4.5 are currently available commercially. [110] The IEER ET scenario assumes an average COP of 5 will be achieved in France by the year 2040. The IEER ET scenario assumes a 60 percent average efficiency in 2040 for combined cycle natural gas power plants; this is only marginally higher than the over 58 percent efficiency that can be achieved today. [111] It needs to be carried out in the context of an overhaul of the entire energy system, with the simultaneous adoption of sound energy and economic policies that will be needed to accomplish that transition.

The basic approach to achieving significant carbon dioxide emissions reductions and a nuclear power phase out consists of the following elements:

- a much more efficient energy sector in all the major areas of energy use – residential, commercial, industrial, and transportation.

- a transition from an energy supply system based mainly on oil and nuclear to a mix of natural gas, oil, and renewable energies.

As we have noted, the current carbon dioxide emissions in France are lower than comparable Western countries because of the high use of nuclear power in the electricity sector. Our

---

[109] COP stands for coefficient of performance. It is a measure of how efficiently a heat pump works. COP is expressed as the work done by a system divided by the energy provided to the system.
[110] COPs of 4 are currently available in the United States for residential as well as commercial geothermal heating and cooling systems (ClimateMaster 2005).
[111] Engelbert et al. 2004, page 4.

energy plan would use more natural gas in the electricity sector, which would increase carbon dioxide emissions in that sector (in common with the Scénario Vert). We view natural gas as an important transition fuel, for the coming decades, in the energy sector. We achieve carbon dioxide emission reductions through efficiency standards in the transport sector that are far more stringent than those assumed in the Scénario Vert. Since this sector currently dominates carbon dioxide emissions in France, it is not going to be possible to achieve large carbon dioxide emission reductions without significant action in this sector, whatever level of nuclear power generation is achieved for non-transportation applications.

IEER's calculations presented in this section show that an implementation of the IEER ET scenario could, by 2040, reduce carbon dioxide emissions by about 20 percent without any change in socio-economic parameters. This is a significant reduction, but roughly only half of the reduction achievable (in percentage terms) using a similar approach in the United States.[112]

The IEER ET scenario proposes the implementation of a program in which:

- A nuclear phase out would be achieved by about 2040, the approximate date when the expected 40-year lifetime of the most recently completed nuclear power plant will end.[113] The first plant closures would start around 2017. This is a sufficiently long preparatory period and phase out schedule to allow for a non-disruptive transition to a non-nuclear electricity system with low carbon emissions. This approach also preserves the low carbon emissions of the existing electricity system while the replacement low-carbon emissions system is being phased in. It is consistent with the idea that the limited capital available for investment in a low CO_2 future should be directed where it is most effective, while reducing nuclear-related vulnerabilities.

- A reduction of oil consumption in the transport sector would be implemented by enactment of efficiency standards that become progressively more stringent for personal vehicles, with a more gradual improvement in other transport sectors. In 2000, transportation was responsible for about 45 million metric tons of the total carbon emissions of 111 million metric tons. However, because of increasing air traffic and truck and delivery vehicle transport, the incremental improvements and the combination of measures result in reductions in carbon dioxide emissions in this sector of about 28 percent to 33 million metric tons (expressed in terms of carbon emissions).

- The efficiency of the energy system in the remaining sectors (residential, commercial, and industrial) would be greatly improved. The approaches include the use of high-efficiency natural gas generation, cogeneration, and more efficient technologies to deliver heat, hot water, lighting, etc, to the residential, commercial, and industrial sectors. Efficiency and electricity generation are combined when cogeneration is used.

[112] Makhijani 2001a, page 19.
[113] The Civeau nuclear power plant was the last nuclear power plant to come online in France. It was brought into full scale operation in 2002. France's nuclear power plants are expected to have an operating lifetime of about 40 years, with evaluations being done every ten years regarding operability. Bataille and Birraux 2003, pages 18, 23 and 239.

1. The heating, cooling, and water heating, which account for about 65 percent of the energy used in the residential and commercial sectors, would be provided by earth-source heat pumps with a high coefficient of performance and/or heat recovery from natural gas fuel cells. This is the reference technology for the calculations. We do not assume that every house and building will have this technology, but that the efficiency of other systems, such as cogeneration in housing developments and commercial buildings, will be comparable.
2. The amount of electricity for lighting, running of appliances and motors is reduced by more than half relative to the business-as-usual scenario. In 2000 the residential and commercial sectors were responsible for carbon dioxide emissions of about 27 million metric tons (expressed in terms of carbon emissions).[114] This reduction would be achieved by standards that require a transition to the best available commercial technologies, in appropriate economic circumstances, with incremental improvements (see policy section below).
3. The heating and some of the electricity in the industrial sector would be provided by natural gas cogeneration, while some natural gas, oil, and coal would be used for feedstock – that is as raw materials, for instance for making plastics, rather than as energy sources. Total feedstock uses are unchanged from the business-as-usual scenario. Gradual efficiency improvements are also introduced in industry.[115]

Table V.9 below summarizes the fuels that would be used for the end use in each sector and the new features.

[114] ODE 2001c, page 1.
[115] ODE 2001c, page 1.

Table V.9: Assumptions for energy end-use sectors for the year 2040 in the IEER ET Scenario for France

Sector	End use	Fuel	Main new features
Residential and Commercial	Heating and cooling (including water heating)	Electricity generated from natural gas, hydropower, and wind. Mix of central and local stations	High COP[1] systems, with local heat recovery and/or earth source heat pumps. Average heating COP = 5 in 2040 (heat output to electricity input)
Residential and Commercial	Other (lighting, motors)	Electricity generated from natural gas, hydropower, and wind	Significant improvements in appliance efficiency based on present technology (40%, relative to the business-as-usual scenario), based mainly on presently available technology for lighting and motors
Transportation	Road vehicles	Oil	100 mpg (2.4 liters /100 km) for new cars by 2020. The average for all passenger vehicles will be 2 liters per 100 km by 2040. Assumes incremental improvements in freight transport efficiency of 2% annually.
Transportation	Aircraft	Oil	Two percent improvement in efficiency per year
Industrial		Natural gas, oil, coal (feedstock). Central station electricity	Cogeneration, gradual efficiency improvements, notably for electric motors

[1] COP stands for coefficient of performance. It is a measure of how efficiently a heat pump works. COP is expressed as the work done by a system divided by the energy provided to the system.

The official projections of energy supply are dominated by oil and nuclear, with the former being responsible for most carbon dioxide emissions. Even though carbon dioxide emissions in France are relatively low compared to most other EU countries, they are high compared to the levels that are needed to keep GHG accumulations in check globally. If carbon dioxide emissions from fossil fuels are allocated on a per person basis for the far future (several decades hence) and the total emissions reduced by 50 percent globally to 3 billion metric tons per year, the per person allowance would be about 330 kilograms for a global population of 9 billion people. This is about one-fifth the present level of per person emission in France.

We note that officially projected emissions are high, despite high use of nuclear power, because there is no operational plan to drastically improve the efficiency of the transport sector. The IEER ET scenario relates only to the energy sector itself and maintains all the broad economic and demographic assumptions of the official scenarios. But it would change the details of the energy sector in major ways described below by the year 2040. We have chosen a forty-year time frame from the year 2000 forward (the base year for energy data used here) for this transition because it would be very difficult and costly to achieve a transition in a much shorter time.

The results that would arise from the implementation of the IEER plan are presented in Table V.10 below. The main features of the IEER ET scenario in 2040 are the following:

- The total energy consumption would be reduced by about 26 percent compared to 2000.
- The carbon dioxide emissions would be reduced by about 20 percent compared to 2000.
- The share of natural gas in the energy system would more than double from about 14 percent to about 32 percent.
- Nuclear power would be phased out by about 2040.
- Renewable energy (wind, hydro, and biomass) would rise from 10 percent (hydro and biomass) to almost 30 percent (hydro, biomass, and wind) of France's energy supply by 2040.

A comparison between the IEER ET scenario and the business-as-usual plan shows that in 2040 the energy consumption in the business-as-usual plan is about 2 times higher than the consumption for the IEER ET scenario for the same energy services. The carbon dioxide emissions would be 2.2 times higher than the carbon dioxide emissions for the IEER plan.

Table V.10: IEER ET scenario in 2040 by fuel in Mtep

Source	**2000**	**%**	**2040**	**%**
Wind	0	0	28	15
Coal	14	5	7	4
Biofuels (including wood)	13	5	12	6
Hydro	14	5	16	9
Gas	37	14	62	32
Nuclear	81	31	0	0
Oil	99	38	66	34
Total	**258**	**100**	**191**	**100**

Note: Biomass, mainly wood, is not considered to have any net CO_2 emissions since it assumed to be produced on a renewable basis. Wind, hydro, and nuclear electricity generation is converted to thermal equivalent at 33 percent efficiency.

a. Electricity sector details of the IEER ET Scenario

In the *Etude économique prospective de la filière électrique nucléaire* report, the high electricity scenarios, H1, H2, and H3 project a consumption of about 645 TWh (after taking out 70 TWh for exports) for 2040.[116] IEER assumes the same level of energy services, but its electricity sector structure is considerably different. First of all, the direct use of fuels for heating in the residential and commercial sector has been eliminated and replaced by electricity. Therefore, IEER's scenario envisages essentially all-electric homes and commercial buildings. This electricity could be generated locally (with net metering, which allows for purchase and sales to the grid for the purpose of optimization), notably in the case of natural gas cogeneration systems in large buildings and in new housing developments. Combined cycle central station generation using natural gas and wind-generated electricity would provide the bulk of the large-scale electricity generation, supplemented by hydroelectric power.

Heating and cooling systems would be electricity-driven devices with coefficients typical of very efficient earth source heat pumps or equivalent systems available today. The average coefficient of performance of these systems based on electricity input by the year 2040 is projected to be 5. If electricity generation has an efficiency of 60 percent (as is assumed for the year 2040), the net coefficient of performance estimated as heat output relative to fuel energy input would be 3.

We also assume that France would have no net exports of electricity. This is done for convenience of calculations rather than for advocacy of self-sufficiency in the electricity sector. The objective of our study is to examine the potential for a simultaneous phase out of nuclear power and reduction of carbon dioxide emissions in the most nuclear-intensive country in the world. The assumption of no-net-exports allows a focus on the policies and technologies that are needed in France to achieve that goal. In practice, we realize the electricity sector in Europe is likely to be much more integrated in 2040 than it is today.

We also envisage effective policies to greatly increase the efficiency of electricity use. Outside of heating and cooling, the major uses of electricity are for lighting and in motors. We estimate that existing technologies, thoroughly applied, could reduce the electricity consumption outside of the heating and cooling sector by 40 percent relative to official projections. Larger reductions are possible with emerging technologies. We consider these more briefly in the IEER Advanced Technology scenario (IEER AT scenario).

The creation of a distributed grid would contribute additional energy savings of a few percent due to reduction of energy losses during transmission and distribution. A transition to a distributed grid from a system that relies almost entirely on large-scale power plants is likely to be more complex in France than in some other countries. The backbone of France's transmission system is a 400-kilovolt high-voltage network that is interconnected and centered on its nuclear power plants. These plants supply 75 to 80 percent of the total annual generation, and therefore at some periods, they supply nearly all of the generation. The structure of the high-voltage network, including redundancies and other means to achieve reliable and high quality electricity supply (in terms of constancy of voltage and frequency), is built around the 19 sites where the nuclear plants are located.

[116] Charpin, Dessus and Pellat 2000, page 132.

This is a geographic particularity that must be carefully addressed in the transition to a new system, so that reliability can be maintained. Siting policies such as putting combined cycle plants (though of smaller size) where the nuclear power plants are located may be one option to consider. Much of the electricity in the IEER ET scenario will be generated over a more dispersed area. The combination of a smaller central station capacity with a larger wind energy sector will need to be carefully evaluated. This is not a short-term issue (for the next decade or so) but it can be accommodated within the 40-year timeframe of the IEER ET scenario.

Whatever the specifics, the cost and schedule for a transition to a distributed grid and the specific mix of generation used to achieve it will need to be carefully assessed and phased in. Note that the overall energy inputs into the French electricity system would not change if some of the natural gas generation that has been shown as decentralized were actually in the form of larger central station plants, since the efficiency assumed for both types of plants is about the same. Therefore the assumption of a distributed grid is not essential to the IEER ET scenario. It is presented here as desirable from the point of view of efficiency and potential increase in reliability.

Under the assumptions described above, we have calculated that a production of almost 450 TWh of electricity will be required to provide for the assumed level of energy services. The table below shows the fuels and the distribution of electricity generation among them.

Table V.11: IEER ET scenario electricity sector structure, TWHe per year and percent

Source	**1995**	**%**	**2040**	**%**
Wind	0	0	126	28
Coal	22	5	0	0
Biomass	0	0	40	9
Hydro	76	16	74	17
Gas	13	3	204	46
Nuclear	359	76	0	0
Oil	2	0	0	0
Total	**472**	**100**	**444**	**100**

b. Transportation sector details of the IEER ET Scenario

France's oil consumption in the year 2000 was about two million barrels per day and is expected to go up to slightly over three millions barrels per day in 2040, according to BAU projections.[117] Currently about half the oil is consumed in the transport sector, the rest is used in the residential, commercial, and industrial sectors (and a comparatively small amount in agriculture) mainly as a source of heat and hot water, and also as feedstock in the industrial sector. Under the IEER scenario the consumption of oil will be totally eliminated in the residential and commercial sectors and drastically reduced in the industrial sector where it will be only used as a feedstock.

[117] IEER calculated these numbers from data found in Moisan 1998.

In 2000, the oil consumption in the transport sector amounted to a little over one million barrels per day.[118] In the BAU scenario cited above, there is essentially no gas mileage improvement. Under this scenario, the oil consumption would approximately double in forty years resulting in carbon dioxide emissions of about 94 million metric tons (in terms of carbon).

A central feature of the IEER ET scenario is a very large increase in motor vehicle efficiency. Cars would average 100 miles per gallon (2.4 liters per 100 kms) in 2030 compared to about an average of 35 miles per gallon (6.5 liters per 100 kms) at present for diesel and petrol cars combined.[119] The technology to achieve this is available today, though about ten years would be required to achieve the cost reductions needed to put such cars into mass production. Aircraft efficiency would also increase faster than officially projected to 2 percent compared to about 1 percent.

An efficiency increase of this magnitude would cut transport sector emissions of carbon by about 65 percent compared to the BAU scenario, to 33 million tons of carbon. This is about 30 percent less than transport sector CO_2 emissions in the year 2000.

c. Carbon dioxide emission details of the IEER ET Scenario

In the 1970s nuclear power was developed with the aim of reducing the dependence on imported oil. Among the official electricity scenarios, the ones that have the least carbon dioxide emissions are the ones that have the most nuclear development. However, these official scenarios that address the whole energy sector present few options for the transport sector. Hence, even a total reliance on nuclear in the electricity sector would still result in an approximately a 50 percent increase in carbon dioxide emissions. High nuclear dependence may also mean continued reprocessing and MOX fuel use. As noted above, the cost of the MOX fuel program in France's commercial reactors is $1 billion per year, in net additional costs.

The energy use in the business-as-usual scenario (a projection without serious extra effort to limit CO_2 emissions and increase efficiency) would be 390 Mtep in 2040. The energy use in the IEER ET scenario is cut by more than half to 191 Mtep, relative to business-as-usual reference case. The reduction in CO_2 is not as great as the reduction in energy use. The CO_2 reduction of the IEER ET scenario compared to the BAU scenario is about 44 percent compared to nearly 50 percent reduction for energy use. This is because much of the nuclear electricity generation has been replaced by natural gas generation. However, the latter is highly efficient (much more so than nuclear) and also the CO_2 emissions from natural gas use are only half of those of coal per Mtep burned.

When compared to CO_2 emissions in the year 2000, the reduction is just over 20 percent. This is significant, especially given that nuclear power is also phased out. However, it is rather modest compared to the need to reduce CO_2 emissions by ~80 percent in order to achieve goals related to minimizing the risk of severe climate change.

[118] IEER calculated these numbers from data found in Moisan 1998.
[119] ACEA 2003. page 2. In 2002 the average fuel consumption a car running on gasoline was 6.6l/100km while for diesel cars it was 5.7l/100km.

Table V.12 shows a comparison of the CO_2 emissions.

Table V.12: Comparison of CO_2 emissions, Business-as-Usual scenario versus IEER ET Scenario in metric tons of carbon

Source	**2000**	**2040**	**2040**
		BAU	**IEER ET**
Coal	16	7	8
Biomass	0	0	0
Hydro	0	0	0
Gas	24	41	40
Nuclear	0	0	0
Oil	71	109	38
Total	111	156	87

Note: Biomass is assumed to be used renewably at present and in the future. This is obviously a simplification. It does not significantly alter the overall, broad conclusions.

A larger reduction in CO_2 would require the vigorous implementation of more advanced technologies (see below).

d. Energy supply in the IEER ET Scenario

In this section we will examine the availability of resources, domestic and foreign, that will be needed for the year 2040. Electricity would be generated from a mix of natural gas, wind, and hydropower, while oil would remain the fuel for the transport sector.

Oil

Under the IEER scenario, the consumption of oil is eliminated from the residential and commercial sectors and remains only as a feedstock in the industrial sector. Oil remains the fuel for the transport sector. However its consumption in that sector is drastically reduced due to the implementation of strict fuel standards. Oil consumption in the year 2000 was 99 Mtep, including feedstock uses amounting to about 14 percent of the total. Under the IEER scenario the oil consumption in 2040 is reduced by a third from its 2000 level to 66 Mtep. Under the BAU scenario the oil consumption in 2040 is 157 Mtep.

The reduction of oil consumption under the IEER scenario would give the energy system more security in terms of possible disruption of supply and price increases; even more if France continues to diversify the countries from which it imports.

Natural Gas

Under the IEER scenario, natural gas will be the main fuel for the electricity sector. As a result, gas consumption amounts to 37 Mtep in the year 2000 compared to 62 Mtep in 2040. The IEER ET scenario natural gas consumption is close to the official business-as-usual estimate of 63 Mtep. Natural gas is almost all imported, and is likely to remain so since France has practically no domestic reserves. About ninety percent of the imported gas comes from the North Sea, the former Soviet Union, and Algeria.

Global proven reserves of natural gas are larger relative to usage compared to oil.[120] About 70 percent of the reserves are in the Middle East, Central Asia, and Russia. But since natural gas reserves are larger in terms of years of consumption, and since they are found in all continents, the possibilities for diversification of supply are great as well as for finding a new supply in the event of one being cut off.[121] However, it should be noted that the greater transport difficulties of natural gas restrict this flexibility, unless liquefied natural gas terminals are built and unless the facilities for LNG exports expand considerably in exporting countries. Rising prices of natural gas have been providing considerable incentive in this direction.

Natural-gas-based electricity generation would provide about 46 percent of the electricity generated in France by the year 2040 in various combinations of cogeneration and central station combined cycle plants (and a small component of single stage gas turbines to stabilize wind-generated electricity supply). This is not expected to impose a cost penalty on the French economy relative to generating electricity from new nuclear power plants, given that LNG costs are on the order of $4 to $5 per million Btu.[122]

A 2003 study done at the Massachusetts Institute of Technology estimates the base case costs of electricity generated from new nuclear power plants in the United States to be 6.7 cents per kWh. [123] The study assumed that there would be an interest rate penalty associated with the financial uncertainties of nuclear power in the United States. If we assume that there will be no extra financial risk for nuclear power in France, even after deregulation when utilities will have to borrow on the open market and face higher risks, the cost of nuclear electricity would still be in the range of 5.5 to 6 cents per kWh. This estimate does not take into account the cost penalties associated with French reprocessing policy.[124] Electricity from natural-gas-fired combined cycle power plants operating at 50 percent efficiency would have a comparable cost at a natural gas price of about $6.50 per million Btu, which is significantly higher than the cost of LNG.[125]

Wind

Although France's wind energy potential is the second largest in Europe it has done very little to develop that potential until after the turn of the century.[126] Most of the modest total capacity of 757 MW in 2005[127] has been installed since the year 2000, indicating a rising interest in this resource. The onshore wind potential is estimated at 70 TWh while the offshore potential is estimated to be 97 TWh at 10 km from the coast and a water depth of 10 meters. At 33 kilometers from the shore and 40-meter water depth the potential more than quadruples to 450 TWh.[128]

---

[120] EIA 2005.
[121] DGEMP 2001, page 5.
[122] EIA 2005d page 3 and 97, EIA 2003 page 35, Zaidi 2005, and Jensen 2003 pages 20 and 27.
[123] MIT 2003, page 42. Table 5.1. See also Appendix 5 for costing methodology and details.
[124] See Makhijani 2001, for discussion of reprocessing-associated electricity costs.
[125] Calculated from Makhijani 1998, Table 1 page 7.
[126] ADEME Basse-Normadie.
[127] EWEA 2006 Map.
[128] Eole 2005, pages 12-14.

In the IEER ET scenario the electricity production from wind energy is 126 TWh in the year 2040. We expect that most of this would come from offshore wind since public acceptability constraints appear to be significant in France, at least at the time of this writing (early 2006).

Wind power would supply about 30 percent the total electricity in France in the IEER ET scenario. This could cause reliability problems, especially at peak times, without some compensating measures. IEER has studied issues surrounding the marketing of wind energy in terms of committing wind energy on a day-ahead basis and the economic penalties that are associated with it.[129] The value and marketability of wind energy, as well as its contribution to reliability, can be enhanced if some source of readily available electricity is in place to compensate for the lack of precision in wind forecasts on a seasonal, day-ahead, and hour-ahead basis. We assume in this study (for simplicity) that the reliability of wind energy would be shored up by adding standby single stage gas turbine capacity equivalent to between one-fourth to one-half of the wind capacity but that this would be very sparingly used. The increase in capital cost of wind energy would be from about 6 to 12 percent.[130] The electricity output of the single stage natural gas turbines would be 5 percent of the wind output. These figures are very tentative and would need to be studied further to correspond to the detailed evaluation of the specific site at which wind is tapped and their relation to the nature of demand. The entire arrangement would cost less than 1 cent per kilowatt hour of electricity. Some of this cost would be offset by the more efficient use of the transmission infrastructure that the combination of wind-generated electricity and natural-gas-single-stage-standby-turbines would enable. We have not taken this cost reduction or any other cost advantage of wind power, such as no cooling water requirements, into account. It would also be possible to reduce the use of single stage gas turbine use by using wind in conjunction with pumped hydro, since France has an extensive hydropower network.

The total cost of wind-generated electricity with standby gas turbines would of course depend on the wind characteristics, the size of the wind farms, etc. Direct costs of wind-generated electricity (without any standby or storage capacity supplement) are in the range of 4 to 5 cents per kWh at favorable sites. Hence, with a maximum added cost of 1 cent per kWh for making wind energy reliability comparable to other sources of electricity by using a large standby single stage gas turbine capacity, the cost of wind energy can be projected to be about 5 to 6 cents per kWh. Over a two to three decade period, these costs can be expected to decline because of the steady improvement in wind turbine technology and the economies of scale that are being achieved with larger wind turbines. The projected cost of reliable wind energy of 5 to 6 cents per kWh (or less in the long term) compares favorably to the cost of nuclear energy.

Hydropower, wood, and other

The contribution of hydropower remains the same, about 74 TWh, since it is already exploited to its maximum. Wood is currently used for the production of heat. There is also regional use of geothermal energy for heating in France. In the IEER scenario, we assume that wood, other biomass, and possibly some geothermal sources will make a modest

[129] Makhijani et al. 2004, page 62.
[130] This assumes a capital cost of wind power at $1,000 per kW and of single stage natural gas turbines at $250 per kW.

contribution of about 40 TWh of electricity (or less than 10 percent) to the overall electricity supply.

In the IEER ET scenario we assume that the potential contribution of solar energy to electricity will be modest. This is because of the present relatively high cost of solar energy relative to wind and to average electricity prices. Solar energy does have the potential in various forms and some regions to make important contributions, but because projections of cost reduction would be speculative at this time, we have not assumed a significant role for this in our scenario. New developments at the time of this writing (early 2006) could change this dramatically. This has been taken into account in the IEER AT scenario.

2. IEER Advanced Technology Scenario

In order to reduce CO_2 emissions by 40 percent relative to the year 2000, more advanced technologies than those currently commercial would have to be employed. However, this is entirely feasible since there are many technologies, available and ready to be commercialized with the right policies, that could become significant factors in two to three decades. We consider a schematic scenario that would employ such technologies and result in about 40 percent reduction in CO_2 emissions in about 50 years. There are many options and some element of speculation involved in such a scenario, since it is obviously impossible to estimate with precision which of the technologies that are currently not commercial will make a large impact in the marketplace. In order to keep the scenario as realistic as possible, however, only technologies that have been demonstrated are considered in the IEER Advanced Technology (IEER AT) scenario.

Among them are:

1. Plug-in hybrid vehicles for the delivery vehicle sector and the personal automobile sector, with the latter having sufficient battery capacity to eliminate liquid fuel use in urban driving. We have assumed that 50 percent of the fuel-equivalent requirement for passenger cars will be met by electricity and that the figure for delivery vehicles will be 30 percent.

2. Solar photovoltaic rooftop electric generating capacity that is connected to a distributed grid. A generation of 2,500 kWhe per home for 8 million homes and 15 TWhe in the commercial/electric utility sector is assumed for this scenario. Until recently, this would have seemed rather high, in view of persistent high solar photovoltaic cell costs. However, developments in South Africa made public in early 2006 indicate that solar PV cells could be produced at a cost of less than one euro per peak watt.[131] This is dramatically lower (about five times lower) than silicon cells. At one euro per peak watt, solar PV is nearly commercial, especially on a decentralized level, which avoids many of the high voltage transmission costs that are associated with large-scale wind energy. This solar energy cost is much lower than small scale wind turbines, which are still several dollars per watt.

[131] Steenkamp 2006. The research was done at the University of Johannesburg under the direction of Professor Vivian Alberts. According to the announcement, the factory commercial-scale production of the first solar cells is set to begin in 2006.

3. Increase in offshore wind energy to depths of 20 to 30 meters.

4. Decrease in building heat requirements by 50 percent due to more efficient envelope. No change in building envelope efficiency was assumed in the IEER ET scenario compared to the business-as-usual scenario.

These assumptions do not require any change in lifestyle but will require stringent regulations for vehicles, homes, and commercial buildings, and even aircraft. However, with sufficient lead time and investment in research, there is no technical reason why such changes cannot be implemented over a period of four to five decades. The resultant energy supply would be as shown in Table V.13.

Table V.13: IEER AT scenario energy supply in Mtep

Source	2000	%	2040	%
Wind	0	0	41	22
Coal	14	5	7	4
Biomass	13	5	20	11
Hydro	14	5	16	9
Gas	37	14	44	24
Nuclear	81	31	0	0
Oil	99	38	48	26
Solar	0	0	8	4
Total	**258**	**100**	**184**	**100**

The carbon dioxide emissions from such a system are shown in Table V.14:

Table V.14: IEER AT Scenario CO_2 emissions in metric tons of carbon

Source	2000	2040	2040
		BAU	**IEER AT**
Wind	0	0	0
Coal	16	7	8
Biomass	0	0	0
Hydro	0	0	0
Gas	24	41	29
Nuclear	0	0	0
Oil	71	109	31
Solar	0	0	0
Total	**111**	**156**	**69**

The carbon dioxide emissions would be over 55 percent less than the business-as-usual scenario and almost 40 percent less than the CO_2 emissions in the year 2000, despite a complete phase out of nuclear power. That phase out is assumed to be accomplished as the reactors reach the end of their 40- or 45-year expected lifetime.

3. IEER Super Advanced Technology Scenario

Since large scale wind energy is already commercial on a large scale and solar PV appears to be nearly so, it should be possible to construct an all-electric economy with renewable energy sources. This could lead to a zero-CO_2 emission economy within the foreseeable future (less than a century). It is difficult to project the technical details and cost details of how that might be achieved, but the broad outlines and possibilities can be outlined because the main supply and energy conversion technologies and choices are already in view. While new and more attractive possibilities may arise in the course of technical research, the choices that are now feasible are broad enough that such a future can be envisioned. It can be said with some confidence that there are no insurmountable technical constraints to making it happen. The main difficulties would likely arise in the aircraft sector. In principle, ethanol can replace petroleum in aircraft. The technology has already been demonstrated as feasible. However, ethanol derived from crops presents some difficult issues in terms of the priorities for the use of land. In contrast to wind power, where the actual land footprint of the power plant is small, ethanol from crops requires the entire area over which the crops are grown. Ethanol from agricultural residues holds more promise. Overall, the questions of net nitrogen balance and the use of natural-gas-based nitrogen fertilizers need to be addressed. Ethanol from crop residues or even weed-plants such as water hyacinths grown in waste water could play a large role in liquid fuel supply. Zero-CO_2 ethanol would require zero-CO_2 industrial feedstock as well as zero-CO_2 energy inputs into the conversion of residues or weeds to liquid-fuels, but this can, in principle, be done with the right choice of efficient weeds or crop residues.

Issues of efficiency and adaptation of aircraft engines remain. Much aircraft travel can also be replaced by fast trains (~500 kilometers per hour), which would make aircraft travel less convenient for distances of 1,000 to 1,500 km. In such a case, the use of liquid fueled aircraft could be eliminated for intra-France and most intra-Europe travel

Other technologies that are somewhat available today or have been researched and demonstrated, such as passive solar building design, strong ultra-light weight materials that would make motor vehicles much more efficient without sacrificing safety,[132] daytime illumination using light pipes, spot lighting, general adoption of photo-electric devices and motion detectors for exterior and interior lighting together have the potential to drastically reduce the energy requirements per unit of GDP, far beyond those considered in either of the scenarios discussed in more detail here. Modest changes in lifestyle that could make urban life more pleasant by, for example, the use of small personal vehicles, mixed-use zoning, development of urban agriculture, use of local sources of food and drink that are more secure, could also make significant contributions to a changed energy landscape and a zero-CO_2-emissions economy.

The main ones are political. There may be some economic choices to make, but the costs of the catastrophic climate changes that are already in view is so much higher that the economic rationale is not much in question.

For France and Europe, the broad choices may revolve around the following:

[132] Jacoby 2004.

1. Development of solar PV for residential and commercial applications as well as offshore wind energy.

2. Development of large-scale solar and wind energy in portions of the Sahara as an important component of energy supply. Whether this might be converted to hydrogen in the Sahara for use in Africa and Europe or whether it would be used as electricity in Europe would depend on technological choices and developments in the next few decades.

3. Existing water reservoirs would be used and managed intensively for pumped storage of wind and solar energy.

4. It is possible of course that advanced flywheels, a long-sought technology could also serve as storage media for periods of hours or days, alleviating the most acute fluctuation problems associated with solar and wind energy systems. The level of technical and financial investment in this would have to be much greater than it has been to make this happen.

5. Much airplane travel as well as intra-urban travel using liquid fuels could be eliminated in the latter part of the century by widespread installment of magnetically levitated (maglev) trains. Lawrence Livermore National Laboratory, for instance, has a promising design.[133]

6. Recycling and reuse of materials and substitution of ethanol from crop residues or efficient weeds, such as water hyacinths, and other biofuels as feedstocks could essentially eliminate the need for fossil fuels.

7. Reduction of building energy use by passive solar construction and other methods of advanced design of building envelopes.

8. Reduction of transport vehicle weight for a given level of safety by 50 to 80 percent, which would drastically reduce the requirements for transportation fuels.

[133] LLNL 2003.

Chapter VI: Energy Policy Considerations

The IEER energy scenarios are explicitly designed to address certain vulnerabilities of the French energy sector. These vulnerabilities are excessive reliance on oil, climate change from burning fossil fuels, and disruption of the energy system, particularly the electricity sector, from accidents or terrorist attacks on nuclear-power-related installations.

Since the beginning of the twentieth century the supply of reliable and affordable energy has always been a problem for France, even before the 1973 oil crisis. The oil crisis revealed the dangers of excessive reliance on the Persian Gulf oil imports, so in 1974 France adopted an energy program with the double objective of easing the cost of energy and securing its supply. The implementation of this program rested on the development of electricity production from nuclear power and the creation of the Agence pour les économies d'énergie (Agency for Energy Conservation). Priority was given to the development of nuclear energy with strong and continuous support from the government. The conservation program was put in place more as an instrument to ease high energy costs than as a dedicated effort to reduce energy consumption. When oil prices dropped in the mid-1980s, so did the investment credits and aid dedicated to the efforts of energy saving. [134] Overall, the gains were impressive. Between 1973 and 1986 the level of consumption stayed about the same despite substantial economic growth.[135]

With the mounting awareness of the potentially disastrous consequences of climate change and the adoption of the Kyoto Protocol in 1997, France has conceived several programs to curb GHG emissions. The first one, Programme national de lutte contre le changement climatique (PNLCC), adopted in January 2000, had as its objective to keep the country's GHG emissions at their 1990 level in accordance with France's obligations under the Kyoto Protocol.[136] The second one, Programme national d'amélioration de l'efficacité énergétique (PNAEE), adopted in December 2000, had the same goal as the PNLCC but aimed at making improvements to promote energy efficiency and renewables.[137] However, it was found that the implementation of these two programs was insufficient to maintain the GHG emissions at their 1990 level.[138]

In 2003 the Prime Minister charged the MIES (mission interministérielle de l'effet de serre) to elaborate a plan known as the Plan Climat 2003 to reinforce the PNLCC
The objectives of the Plan Climat 2003 were to:

- stabilize the greenhouse gas emissions to the 1990 level as directed by the Kyoto Protocol
- reduce by 75 percent the GHG emissions by 2050
- enable tangible progress in the transport, residential and commercial sectors in which GHG emissions are increasing.

[134] ADEME 2004.
[135] DGEMP 2003a.
[136] PNLCC 2000, page 1.
[137] IEA 2002, page187.
[138] Lepeltier 2004, page 16.

Due to several delays, the Plan Climat 2003 became the Plan Climat 2004[139] with a goal for 2010 to go slightly beyond the requirement of the Kyoto Protocol.

Although the goal of a 75 percent reduction in GHGs by 2050 is an acknowledgment of the seriousness of climate change, the measures proposed will fall far short of achieving that goal. The main features proposed are:

- *Energy labeling:* it already exists for appliances and would be extended to air conditioning, cars, heaters, windows, isolating materials and even dwellings and offices.
- *Buildings*: (1) a diagnostic of performance would be mandatory before the sale or the rent of a building based on a kWh/m^2 energy consumption, (2) a reduction of property taxes for a few years would be possible for those owners that undertake to improve their energy label, (3) the construction or renovation of public housing will have to meet precise environmental requirements, (4) thermal norms will be instituted for the retrofitting of old buildings (5) tax credit between 25 and 40 percent on efficient and environmentally friendly equipment (40 percent for solar heaters).
- *Transport*: (1) the share of biofuels will be 5.75 percent by 2010, (2) a system of bonus/surcharge based on the energy label (in grams of CO_2 per km) is proposed to reward the purchase of an efficient vehicle and to penalize the purchase of a less efficient vehicle and (3) a modulation of airport taxes will be proposed at the European level along with a proposition on taxation of kerosene.
- *Energy norms for new buildings* such as insulating materials and installation of solar water heaters.
- *Industry, energy and wastes:* development of renewable energies.
- *Energy*: fulfillment of its commitment to produce 21 percent of electricity from renewable energies: biomass, solar, geothermal and in particular wind.

The main reason that these steps are unlikely to suffice is that no tough policy investment and regulatory requirements are specified. The technologies needed for developing an efficient energy system already exist and are economical. What is missing is the political and policy framework. For example, in the chemical industry,

> Chemists and chemical engineers developing photovoltaic films, fuel cells, or biomass energy systems know that these technologies have tremendous potential in industrial and consumer use and could save the nation many billions of dollars. But energy experts say that it doesn't matter how great the innovation is. In order for it to have an impact, it has to be deployed …even the best of the energy-efficient technologies will have no impact if they are not widely accepted and used.[140]

The failure of available technologies to be in more widespread use in the market place has several broad causes:

1. Institutional (whether governmental or corporate or both) roadblocks to the use of efficient technology, despite the fact that it is economical. This is the case for wind energy that has now become economical and is even cheaper than the use of plutonium as

[139] Lepeltier 2004.
[140] Johnson 2001.

fuel. [141] Yet, unlike Denmark and Germany, France did almost nothing in this sector until the year 2000. There has been some change since then and the installed capacity at the end of 2005 was 757 MW.[142] It is likely that wind power will continue to grow rapidly and make a significant contribution to the 21 percent of electricity from renewable energies by 2010.[143]

2. Failure of the government to implement more stringent long-term standards to improve the efficiency of motor vehicles. We believe that it is better to set very stringent standards for the long term. A non-binding agreement between the European Commission and the ACEA (Association of European Car Manufacturers) sets a weak goal of an average of 140g of carbon per km (the equivalent of 43 miles per gallon, or 5.5 liters per 100 kms) for new cars sold in the European Union by 2010. The Plan Climat 2004 states that it will support upgrading this goal to 120g of carbon per km by the year 2012 or just under 5 liters per 100 kilometers.

3. The lack of stringent standards for new appliances, lighting and motors used in the residential and commercial sectors.

4. The weak policies that perpetuate inefficient appliances and heating and ventilation systems in older housing and commercial building stock.

5. The lingering of nearly commercial technologies at the margins of implementation by the lack of a steady market and the inertia of vast and powerful vested interests in present inefficient technology.

6. The lack of adequate governmental standards and policies that would combine security, environmental, safety, and economic criteria.

One of the most important problems in the lack of rapid integration of new technologies into the market place is the lack of a predictable market that would allow a new technology to become established. The traditional method for attempting to overcome this market barrier has been to provide assured purchasing prices superior to the market price. We view this approach as inferior to the provision of a steady market by the government for desirable technologies that are already technically feasible. This market for provision of energy supply and efficient technologies should be made competitive so that a steady cost reduction in these technologies can be achieved. At the point that they are economical without a steady government-assured market, the government can shift the investment to sectors that are still not economical, but that are required to meet environmental and security goals.

[141] See Fioravanti 1999.
[142] EWEA 2005.
[143] The 2001 European Directive has set an EU goal of 22 percent for the share of electricity produced from renewable energies. See Directive 2001/77/CE. For France it is 21 percent. To realize that objective the share of electricity from wind would need to be between 20 and 35 TWh corresponding to an installed capacity of 7 000 to 14 000 MW. See PPI 2002.

The most straightforward approach to the use of government funds to promote renewables and efficiency is to eliminate all price subsidies and to focus government expenditure on encouraging investment in the targeted sectors. The government should dedicate a fixed sum each year to an open-bid, performance-based purchase of energy from designated renewable sources generated in specified areas, new electricity generation technologies for its buildings, efficiency improvements for its buildings, and highly efficient new vehicles that are beyond what is available in the marketplace. An expenditure of 5 billion euros per year for a ten-year period combined with a firm policy of continued expenditures for another ten-year period would provide wind energy, fuel cell vehicles, efficient on-site generation using fuel cells, combined microturbine fuel cell plants, and other similar cutting edge technologies, with a reliable market. The savings obtained in the phasing out of MOX would be about 1 billion euros per year. This money could be used to cover part of the expenditure. Further, a great part of the investment in the earlier years would be recovered through lower energy costs for government or through re-sales of renewable energy purchased by the government. Hence the net cost of a properly designed procurement program in France may be on the order of 2 billion euros a year over ten years.

About 30 years ago, guided by strong government back up and public finances, France embarked on an ambitious nuclear power program which became a technological success in a relatively short time. Today France is regarded as a world leader in nuclear power matters, if not *the* world leader in most nuclear power-related issues. There is no reason that a similar effort could not be marshaled to create a highly efficient energy system.

We provide here the broad outlines of policy action powered by renewables, cogeneration, natural gas and hydro that are needed in order to transition to a far more secure energy system that will also result in a substantial reduction of carbon dioxide emissions over the four decades. Since the reduction of oil use and nuclear vulnerabilities is central to the IEER ET and AT scenarios, we will first discuss these issues in some detail before listing the broad policy actions needed at the central and regional levels.

A. Oil

In France, the government's strategy proposed to reduce carbon dioxide emissions in the transport sector combines various approaches. Some of them are:

- a modest improvement in mileage
- a partial introduction of alternative fuels (such as natural gas)
- measures to reduce the use of private cars
- a partial switch from trucks to rail (that is almost all electrified) for the transportation of goods
- tax breaks for the purchase of more efficient cars

Under the best official scenario all these measures would not even keep carbon dioxide emissions constant by 2020, although they would be close to the 2000 emission level. In contrast to these many approaches, IEER proposes one central approach: a stringent efficiency standard for passenger vehicles, delivery vehicles, trucks and planes. This is not to say that other components such as increased and improved public transport, for example, are not important. However, given the central role of personal passenger vehicles and trucks, other large improvements in their efficiency are essential to have significant CO_2 reductions.

This conclusion is reinforced with the reality that people's attachment to the mobility that personal cars offer is very strong and is unlikely to diminish in the foreseeable future as a choice.

1. Personal passenger vehicles

Some have argued for higher oil taxes in order to reduce oil consumption. We argue against such a move because the ability to pay for an efficient car is lost. The table below illustrates the savings realized in fuel cost at various efficiencies:

Table VI.1: Annual fuel cost savings for various efficiencies

Distance traveled per year in kilometers	Fuel consumption in Miles per Gallon	Fuel consumption in Liters per 100 kilometers	Cost of fuel in euros	Savings per year relative to 35 mpg (6.8 l/100km)
24,000	35	6.8	1,600	
24,000	60	4	960	640
24,000	100	2.4	560	1,040

Note: we have taken the price of gasoline to be 1 euro per liter (inclusive of taxes)

If one assumes the life of the car to be ten years and the discount rate to be 4 percent (in real terms), then the present value of the savings in fuel over the life of the car for a 100 mpg (2.4 l/100 kms) car relative to a 35 mpg (6.8 l/100 kms) car amounts to 8,500 euros. This is the approximate amount that can be invested in a car for increasing the efficiency from 35 mpg (6.8 l/100 kms) to 100 mpg (2.4 l/100 kms). An increase in the discount rate to 10 percent would reduce this estimate to about 6,400 euros. In 2003, the cost of a hybrid car with an efficiency of about 50 miles per gallon (4.7 l/100 kms), available commercially in the United States where gasoline is much cheaper, is about $4,000 more than an equivalent conventional car getting 30 to 35 miles per gallon (6.8 to 7.9 l/100 kms). Herein, the use of standards appears justifiable on economic grounds especially as it offers a route to achieving efficiency improvements without the severe regressive effects of a gasoline tax.

The need to address the transport sector with the introduction of a stringent efficiency standard for cars will have two opposite effects. One effect will be a reduction of payments for imported oil; the other will be a loss of revenue that the government derives from taxes on gasoline because the consumption of gasoline and diesel in France (as with the rest of Europe) is heavily taxed. The share of taxes on a liter of gasoline at the pump amounts to 70 percent or more of the total price. Overall, taxes on oil amount to about 13 percent of the government budget.[144]

Imposing a tax on low mileage cars that would increase each year could rectify the loss of revenue in the short and medium term. In the long run (ten to twenty years) some other modes of taxation will have to be found to offset the reduction in taxes because of reduced gasoline consumption. This would amount to several percent of the French government's budget. But a vehicular tax on relatively low efficiency new vehicles that gets steeper over time might suffice.

[144] Calculated from Budget 2000 and Documentation française 2003.

France's trade balance would be favorably affected by a reduction in oil imports. Under the IEER ET scenario compared to BAU scenario, the savings in oil imports would be 25 billion euros per year in 2040 assuming a crude oil price of 40 euros a barrel. Some of this would be spent in importing more natural gas, which, under the IEER ET scenario would amount to 8.3 billion euros per year in 2040, an increase of 2.4 billions euros from 2000. The natural gas imports would be about the same in the IEER and the BAU scenarios. In the BAU scenario the annual cost of gas in 2040 is 8.3 billions euros. For these calculations we have assumed a price of 24 euros per barrel of oil and 3.3 euros per million BTUs of natural gas (We have taken 1 euro = $1).

The current state of technology in relation to automobile efficiency is far in advance of the current average performance for passenger cars. The average performance for new cars is about 36 miles per gallon (6.5 l/100km for diesel and petrol cars combined). A voluntary agreement has been reached between the European Union and the European Automobile Manufacturers Association for the combined average between new petrol cars and new diesel cars to be 41 miles per gallon (5.7 l/100 kms) in 2008.[145] However, cars that offer better mileage are already offered on the market:

- The Honda Insight (2-passenger) gasoline powered hybrid engine gives about 60 mpg (4 l/100 kms)
- The Toyota Prius, 4-passenger gasoline powered car with a hybrid engine gives almost 50 mpg (4.7 l/100 kms).
- The Audi A2 1.2 TDI diesel according to company data gives 78 miles per equivalent gallon of gasoline (3 l/100 kms).[146]

GM has made a prototype fuel cell car that gives 100 miles per gallon of gasoline equivalent (2.4 l/100 kms), which it believes, can be commercialized by about 2010. It goes from zero to sixty in about 9 seconds.[147] Honda and Toyota have manufactured fuel cell cars and put a few of them on American and Japanese roads.[148,149] A number of other manufacturers also can make cars of 75 miles per gallon (3.2 l/100 kms) or more. Volkswagen sells a car that averages almost 80 mpg (3 l/100 kms).[150] What is needed is a steady, significant market to bring these into general use rapidly. Volkswagen has built a 235 miles per gallon (1 l/100 kms) concept/prototype car that even averaged 264 miles per gallon (0.9 l/100 kms) on a test drive.[151]

Automobile manufacturers are resisting rapid change in part because higher initial costs create market uncertainties and potential for losses. An appropriate purchasing policy for central and regional government fleets would remedy this problem and provide the incentive to build vastly more efficient cars as a matter of routine. If governments set the efficiency pace in the procurement of their own vehicles as a matter of policy, automobile manufacturers can expect a steady market

---

145 ACEA 2003.
146 Audi 2001.
147 Evanoff 2000.
148 Toyota 2002. Viewed on April 2006.
149 Sullivan 2002. Viewed on April 2006.
150 VW 2003.
151 Popular Science 2004. For information on efficient cars, safety, and latest technical developments see, for instance, the web site of the Rocky Mountain Institute, http://www.rmi.org.

A mileage goal for all new cars and light trucks by 2020 of 100 miles per gallon (2.4 l/100 kms) is feasible and should be set now. This goal should be buttressed by a sound government purchasing policy. This is admittedly a stringent goal and goes far beyond what has been advocated so far. But if energy vulnerabilities relating to oil imports are taken seriously, a stringent goal that would rapidly reduce dependence on imports is required. Given that society in France, in spite of adequate public transport in many big cities, depends and will continue to depend on private vehicles, it is essential that very stringent standards be set for passenger vehicles.

Such a goal would result in the average fuel efficiency performance of the passenger vehicle fleet of about 100 miles per gallon (2.4 l/100 kms) by the year 2030. Oil use would decline from the present 1 million barrels a day to about half a million barrels a day, given the same assumptions about use of cars. Current trends of rising oil consumption would put use at about 2.3 million barrels a day by that date.

The policy for stringent standards would relieve long-term upward pressure on oil prices due to rising consumption in the developing countries and also create opportunities for export of technology that would reverse or reduce the rate of oil consumption increases there.

There has been great resistance to stringent efficiency standards among motor vehicle manufacturers. Historical experience shows that car makers seem to remember safety when the issue of mileage standards is raised and seem to remember mileage when the issue of reducing emissions of noxious gases, like nitrogen oxides or hydrocarbons, is raised. In practice they have needed government action to set standards for all three -- emissions (other than carbon), mileage, and safety. All three can and should be simultaneously mandated by the government. Setting achievable, stringent standards well in advance also encourages research and development on new technologies, such as new strong materials to reduce the weight of cars and increase safety at the same time.[152]

High efficiency standards can achieve a collateral benefit in terms of security relating to oil pipelines, refineries and storage facilities. A 10-gallon equivalent tank in a vehicle getting 100 mpg (2.4 l/100km) would give it a theoretical range of 1,000 miles, or more than two to three times the present range. The length of time cars could be driven in case oil supply would be disrupted would be lengthened, in a typical case, to several weeks, allowing time for alternative supplies. This means that high efficiency standards would considerably increase the resilience of the system in case of some kinds of disruption. That resilience can be additionally increased if parts of fleets of governments and corporations are dual-fuel capable. This means that they could switch from gasoline to, say, propane. This technology is already commercial.

2. Public transportation policy

In France public transport in large cities is viewed more as a public utility, in the same manner as electricity, water, sewage, and telephones. A policy of improving and expanding such a system would contribute to reduction of carbon dioxide emissions.

- *Tramways for big and medium-sized cities*

Many big cities in France have a relatively efficient public transport system. Paris is a global model in regard to the density and efficiency of its Metro. To make systems more efficient

[152] See www.rmi.org

(and less polluting) buses can gradually be replaced by tramways that run on electricity. Already several big French cities have introduced tramway lines that complement bus lines and, in some town, metro lines. Further, Daimler Chrysler has sold 36 fuel cell buses that are in operation in Europe, Australia and China.[153]

- *Electric trains for inter-city travel*

Travel between big and most medium-sized cities is well provided by frequent and fast trains that run on electricity while buses and trains that run on diesel provide transportation between smaller sized cities. In the latter case, the service is often of mediocre quality and the use of car becomes the preferred option. A more comprehensive network of trains that run on electricity to serve medium-sized cities would discourage the use of cars and make France's intercity train transport, which is already among the world's best, even more efficient.

3. Trucks

The carbon dioxide emissions from trucks can be reduced in two ways. First, electric trains should increase their share of the transport of goods and merchandise. Second, as with cars and light trucks, a mileage goal for all new trucks should be 73 miles per gallon (3.2 l/100km) by 2020. This goal would be not as hard to achieve in France as in some other countries, since there are still many enterprises that are owned or partly owned by the government. These enterprises can help implement governmental policy by purchasing more efficient trucks than they might otherwise. However, there would be resistance to this given the loss of profitability that it might entail. In this regard, and in some other cases of policies discussed here, pan-European policies that cover the entire EU would be less disruptive.

B. Nuclear power, spent fuel, and reprocessing

The damage from a single severe accident or attack on a nuclear power plant would be so catastrophic that it must be avoided. A contamination on the scale of Chernobyl in France would mean that a large fraction of the land would be polluted for hundreds of years not to mention the large potential loss of life.

Spent fuel storage vulnerabilities are in some ways lower and in other ways greater than reactor vulnerabilities. Before being sent to La Hague for reprocessing, spent fuel is stored outside the secondary containment, so that there is no substantial buffer against an attack. Given that fresh spent fuel must be stored underwater for a few years in order to cool down enough, the option of dry, subsurface storage for all spent fuel cannot be easily realized unless existing nuclear power plants are phased out or entirely new pools are built. It may be possible to add barriers to spent fuel pools to make them less vulnerable, but this would not likely be of a magnitude comparable to the reactor core itself, which is itself vulnerable at least in some degree. Phasing out nuclear power in a manner compatible with electric grid stability is imperative if nuclear vulnerabilities, especially from spent fuel storage are to be reduced to a point where the entire installation becomes unattractive to an attack.

In the context of such a program, spent fuel storage vulnerabilities can be greatly reduced. Spent fuel can be transferred to dry storage within a few years of discharge from the reactor. Such casks can be put into subsurface facilities that are similar to the way in which vitrified high level radioactive waste is stored at La Hague. In our judgment, an attack comparable to

[153] DaimlerChrysler 2005.

September 11 on these subsurface facilities could cause serious harm to the site and many people working on it, but it would not cause the kind of catastrophe that would result from a comparable attack on a spent fuel storage pool, or even above-ground storage in dry casks.

The reprocessing of spent fuel at the La Hague plant increases the nuclear vulnerabilities in France. The damage from a single attack on that plant could be very severe due to the large amounts of highly radioactive liquids on site and other factors. Not only the vulnerabilities from the spent fuel awaiting reprocessing in pools at La Hague are similar to the ones of a nuclear power plant but the amount of spent fuel (from all the French reactors and from many foreign reactors) stored at that facility is enormous. An attack on that plant would be far more damaging than an attack on a single nuclear power plant. In addition, once the spent fuel is reprocessed, the high level waste is stored in tanks that are also vulnerable to an attack. The end to reprocessing the spent fuel stored at la Hague, followed by the recommendations given above, would immediately mitigate the risks from accidents or attacks.

C. Plutonium

More than eighty metric tons of separated plutonium (French and foreign) in the form of plutonium dioxide powder are stored at La Hague. To minimize damage from an attack it is necessary to put the plutonium into a different physical form that would (i) limit the damage to as small an area as possible, (ii) resist fire, and (iii) enable easier clean-up and recovery of plutonium with less danger to workers and the public.

Immobilization is an approach that mixes plutonium with a non-radioactive material and puts the mixture into a ceramic form that is highly resistant to fire and dispersal in the form of fine particles. The ceramic storage form resembling a hockey-puck is put into a steel cylinder and molten glass is then poured around it. The resulting steel canisters with glass logs containing the plutonium-laced ceramics pucks can then be stored underground on-site at one or more large nuclear weapons plants in silos a few tens feet deep. With carefully thought out technical specifications, the offsite consequences could be minimized even in case of an attack on the scale of September 11. Minimizing the potential for severe offsite impacts would also be the best preventive measure against attack, since it would make plutonium storage sites unattractive as targets. The risk of theft or illicit sale would also be greatly reduced.[154]

Plutonium immobilization uses technology that is reasonably well understood and is similar to that now used for high-level radioactive liquid waste, which is, in some ways, more difficult to process than plutonium. For instance, glass logs containing high-level waste are produced and stored at the La Hague reprocessing plant.

---

[154] The National Academy of Sciences has recommended a “spent fuel standard” for immobilizing plutonium to reduce the risk of theft or re-use in nuclear weapons (NAS 1994). While this level of diversion resistance is desirable, it would take far longer to implement. It is more urgent to put the plutonium into a non-dispersible, not-easily-usable form and obtain more proliferation resistance through joint monitoring and verification programs.

D. Electricity system restructuring

Currently almost all electricity is generated in large-scale centralized plants connected to a centralized grid. It would be far better to build a mix of small-scale plants that are close to the consumer or are on the consumer's premises and interconnect them to regional grids, which also have large-scale plants on them. Such a system of regional distributed grids can be joined with regional renewable energy sources on a large scale. In particular, the wind energy resources of the Atlantic region can be fed into existing transmission corridors. Given the fuels used for space and water heating in households and commercial establishments, as well as offshore wind power availability in coastal areas, it should be possible to have an interconnected electricity grid that relies on a combination of central station power plants, local consumer-based small-scale generation systems, and medium-scale local or regional generation. Regulatory changes on both the generation and consumption side would be required to make such an outcome possible. Were it done, the share of renewables in the electricity supply could be increased to about 40 percent in the next 40 years. In the long term, research and development of hydrogen derived from renewable sources is important to continued reduction of greenhouse gas emissions. This technology needs considerable development and although it is not necessary to the achievement of short and medium term security and environmental goals, it should be part of the government’s procurement policies.

E. Some Specific Policy recommendations

1. Purchase of renewable energy, efficient on-site electricity generation, highly efficient motor vehicles, highly efficient heating and air-conditioning technology to the tune of 2.5 billion euros per year by the government, with a commitment to continue the program for at least ten years. The procurement program should be carried out annually on a performance-based bidding process similar to that used for leasing out tracts for oil and gas drilling.
2. Government allocation of $2.5 billion euros per year to the regions for their own procurement programs.
3. Promulgation of a standard of 100 miles per gallon (2.4 l/100 kms) for all new passenger vehicles (including light trucks) by 2020, with simultaneous safety and emissions standards and progressively smaller increases after that time.
4. Enactment of progressively more stringent carbon emission limits per unit of electrical power generation.
5. Rules that encourage investment in cogeneration in residential and commercial buildings, both new and existing. For instance, an energy efficiency report could be required at the time of sale of a house or commercial building. Capital charges for energy supply could be levied on new residential and commercial developments that do not meet progressively stringent efficiency standards.
6. Phase out of nuclear power, with plants being shut down as their original licenses expire, or sooner in those cases where special vulnerabilities exist.
7. Abandon plans for new nuclear power plants and for use of plutonium as a fuel in nuclear reactors.
8. Transfer of spent fuel out of pools into dry storage when it is safe to do so.

9. Storage of dry casks containing spent fuel in hardened on-site storage at operating nuclear power plants.
10. Transfer control of spent fuel to the government at closed plants
11. Adoption of policies to encourage distributed grids.
12. Reinforced commitment to the Kyoto Protocol process, with the starting point being a commitment to reduce carbon dioxide emissions by 40 percent over the next four decades (without international trading).

References

ACEA 2003 European Automobile Manufacturers Association and European Commission. *Monitoring of ACEA's Commitment on CO_2 Emission Reductions from Passenger Cars (2002): Final Report: Joint Report of the European Automobile Manufacturers Association and the Commission Services*. Brussels: ACEA, September 5, 2003. Alternate title: Monitoring of ACEA Commitment on CO_2 Emission Reductions from Passenger Cars. On the Web at http://www.acea.be/ASB20/axidownloads20s.nsf/Category0ACEA/60BF5E5031961564C125702F003B7570/$File/20040317PublicationEmissions.pdf.

ADEME 2004 Agence de l'environnement et de la maîtrise de l'énergie. *Utilisation rationnelle de l'énergie*. [Paris]: ADEME, last updated 2004? On the Web at http://www.ademe.fr/entreprises/energie/themes/problematiques/GdPrincipes.asp. Viewed on March 10, 2006.

ADEME Basse-Normandie Agence de l'environnement et de la maîtrise de l'énergie. *Basse-Normandie Eolien*. Herouville Saint-Clair: ADEME, Délégation Régionale Basse-Normandie, last updated [2003?]. Web page title. On the Web at http://www.basse-normandie.ademe.fr/servlet/KBaseShow?m=3&cid=9981&catid=10103. Viewed on March 9, 2006.

AFP 2002 Agence France-Presse. "Loyola de Palacio lie les accords de Kyoto au nucléaire." *Sortir du nucléaire,* April 2002. Story dated April 28, 2002. On the Web at http://www.sortirdunucleaire.org/avril2002/afp280402.htm.

ANS 2002 American Nuclear Society. *ANS President Touts Economic, Environmental Benefits of Nuclear Energy*. News Release, June 11, 2002. LaGrange Park, IL: ANS, 2002. On the Web at http://www.ans.org/pi/media/news/1023823096.html. Viewed on July 8, 2002.

AREVA 2005 AREVA. *COGEMA, pionnier de l'industrie du nucléaire*. [Paris]: AREVA, last updated 2005. On the Web at http://www.cogema.fr/servlet/ContentServer?pagename=cogema_fr/html_libre/html_libre_full_template&c=FreeHtml&cid=1030541099192#, entry for 2001. Viewed on July 8, 2005.

Arrêté du 8 juin 2001 "Arrêté du 8 juin 2001 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie mécanique du vent telles que visées à l'article 2 (2o) du décret no 2000-1196 du 6 décembre 2000." *Le Journal officiel de la République Française. J.O n° 143 du 22 juin 2001* (8 juin 2001). Page 9889-9891. NOR: ECOI0100258A. Décrets, arrêtés, circulaires: Textes généraux. Ministère de l'économie, des finances et de l'industrie. On the Web at http://admi.net/jo/2001/09889.html and following two pages. Also searchable at http://www.legifrance.gouv.fr/WAspad/RechercheExperteJorf.jsp.

ASN 2001b Michel Debès and Gilles Zask. *Contrôle 138: Le combustible MOX dans la production d'électricité à EDF*. [Paris]: Autorité de sûreté nucléaire, last updated February 28, 2001. On the Web at http://www.asn.gouv.fr/Publications/dossiers/c138/02.asp. Viewed on 2002.

ASN 2004 Autorité de sûreté nucléaire. *Les domaines de la sûreté nucléaire: Liste des installations nucléaires de base arrêtées définitivement au 31 décembre 2003*. [Paris]: ASN, last updated July 2, 2004. On the Web at http://www.asn.gouv.fr/domaines/demantel/5/index.asp. Viewed on May 20, 2005.

ASN 2004a Autorité de sûreté nucléaire. *Les domaines de la sûreté nucléaire: Les dispositions techniques et administratives*. [Paris]: ASN, last updated September 21, 2004. On the Web at http://www.asn.gouv.fr/domaines/demantel/1/index.asp. Viewed on September 22, 2005.

Audi 2001 Audi AG. *Audi A2 1.2 TDI*. AudiWorld, last updated February 16, 2001. On the Web at http://www.audiworld.com/news/01/A2TDI/content.shtml. Viewed on November 20, 2002.

Barrillot 1999 Bruno Barrillot. *Audit atomique: Le coût de l'arsenal nucléaire français, 1945-2010*. Études du CDRPC. Lyon: Centre de Documentation et de Recherche sur la Paix et les Conflits, 1999.

Bataille and Birraux 2003 Christian Bataille and Claude Birraux. *Rapport sur la durée de vie des centrales nucléaires et les nouveaux types de réacteurs*. Assemblée nationale : 832 (12ème législature); Sénat : 290 (2002-2003). Paris: Assemblée nationale; Sénat, 2003. At head of title: Office Parlementaire D'évaluation des Choix Scientifiques et Technologiques. Enregistré à la Présidence de l'Assemblée nationale le 13 Mai 2003. On the Web at http://www.assemblee-nationale.fr/12/pdf/rap-oecst/i0832.pdf.

Bataille and Galley 1999 Christian Bataille and Robert Galley. *L'aval du cycle nucléaire. Tome II. Les coûts de production de l'électricité*. Rapport Assemblee nationale n° 1359. Rapport Sénat n° 195 (1998-1999). [Paris]: Office parlementaire d'évaluation des choix scientifiques et technologiques, 1999. On the Web at http://www.assemblee-nat.fr/rap-oecst/nucleaire/r1359.asp. Viewed on July 15, 2002.

Bezat 2005 Jean-Michel Bezat. "Privatisation partielle d'EDF : les syndicats se mobilisent." *Le Monde*, September 5, 2005. On the Web at http://www.lemonde.fr/web/article/0,1-0@2-3234,36-685682@51-665146,0.html.

Bloomberg 2004 Bloomberg. *Oil Windfall Gives Saudi the Capital to Add New Output Capacity*. [New York?]: Bloomberg, last updated October 17, 2004. On the Web at http://quote.bloomberg.com/apps/news?pid=10000087&sid=aJ7MoJ.kIbS8&refer=top_world_news. Viewed on July 7, 2005.

Budget 2000 France. Ministère de l'Économie, des Finances et de l'Industrie. *Le budget de l'État 2000*. last updated 04/2000. At head of title: Les finances de l'Etat. On the Web at http://www.minefi.gouv.fr/pole_ecofin/finances_Etat/LF/2000/budget2000/budget2000.htm. Viewed on Nov. 18, 2004.

CEA 2001 Commissariat à l'Energie Atomique. *L'effet de serre: Quels sont les pays qui émettent le plus de gaz à effet de serre?* [Paris]: CEA/Direction de la communication, last updated 2001. On page 2/4. Table cites OECD. At head of title: De la recherche à l'industrie. Quelques notions scientifiques. On the Web at http://www.cea.fr/fr/pedagogie/EffetDeSerre/QuestionReponse2.htm. Viewed on June 22, 2005.

CEC 2000 Commission of the European Communities. *Green paper: Towards a European strategy for the security of energy supply*. COM(2000) 769 final. Luxembourg: Office for Official Publications of the European Communities, for the European Commission, 2001. "The current Green Paper was adopted by the European Commission on 29 November 2000." On the Web at http://europa.eu.int/comm/energy_transport/doc-principal/pubfinal_en.pdf.

Charbonnages 2003 Charbonnages de France. *La bataille du charbon*. [Freyming-Merlebach?]: Charbonnages de France, last updated 2003. At head of title: L'historie du charbon en France. On the Web at http://www.charbonnagesdefrance.fr/dArticle.php?id_rubrique=132&id_article=362. Viewed on September 26, 2005.

Charpin, Dessus and Pellat 2000 Jean-Michel Charpin, Benjamin Dessus and René Pellat. *Étude économique prospective de la filière électrique nucléaire*. [Paris?]: Premier ministre, Commissariat général du Plan, 2000. On the Web at http://lesrapports.ladocumentationfrancaise.fr/BRP/004001472/0000.pdf.

ClimateMaster 2005 ClimateMaster. *All Products Guide: 2005*. Oklahoma City, OK: last updated 12/30/04. "Water-source heat pump systems." On the Web at http://www.climatemaster.com/download/Commercial%20Literature/LC007.pdf. Viewed on April 8, 2005.

CNIC 1997 Baku Nishio. "Economics of MOX use in LWRs: an analysis based on Japanese realities" in *Comprehensive social impact assessment of MOX use in light water reactors: Final report of the International MOX Assessment*, by J. Takagi, M. Schneider, F. Barnaby, I. Hokimoto, K. Hosokawa, C. Kamisawa, B. Nishio, A. Rossnagel and M. Sailer. Tokyo: IMA Project, Citizens' Nuclear Information Center, 1997. Chapter 4 (pages 157-172). On the Web at http://cnic.jp/english/publications/pdffiles/ima_fin_e.pdf.

CNIC 2004 Hideyuki Ban. "Japan's separated plutonium inventory (2003 fiscal year)." *Nuke Info Tokyo* no. 102 (Sep./Oct. 2004). On the Web at http://cnic.jp/english/newsletter/nit102/nit102articles/plutonium03a.html, viewed on 22 Feb 2006.

DaimlerChrysler 2005 *DaimlerChrysler Delivers Fuel-Cell Buses to Beijing*. DaimlerChrysler, last updated November 23, 2005. On the Web at http://www.daimlerchrysler.com/dccom/0,,0-5-7145-1-564535-1-0-0-0-0-0-243-0-0-0-0-0-0-0-0,00.html. Viewed on March 22, 2006.

Davis 2001 Mary Byrd Davis. *La France nucléaire: matières et sites 2002*. Paris: Wise-Paris, 2001. On the Web at http://www.francenuc.org.

de Pracontal 2005 Michel de Pracontal. "Tchernobyl: retour sur un mensonge d'Etat: Des «erreurs» d'appréciation délibérées." *Le Nouvel Observateur* n°2109 (Semaine du jeudi 7 avril 2005).

Débat National 2003b France. Ministère de l'Économie, des Finances et de l'Industrie. *Débat National sur les Energies: Questions / Réponses: Le changement climatique*. [Paris?]: last updated [2003?]. On the Web at http://www.debat-energie.gouv.fr/site/quest_rep_9_0.php. Viewed on 2003.

Décret no 2000-1196 France. Ministère de l'Économie, des Finances et de l'Industrie. *Décret no 2000-1196 du 6 décembre 2000 fixant par catégorie d'installations les limites de puissance des installations pouvant bénéficier de l'obligation d'achat d'électricité*. Le Journal officiel de la République Française. J.O n° 285 du 9 décembre 2000. NOR: ECOI0000505D. [Paris]: 6 décembre 2000. Textes généraux. On the Web at http://admi.net/jo/20001209/ECOI0000505D.html or http://admi.net/jo/2000/19550.html.

Demarcq 2000 François Demarcq. "Les actions de maîtrise de l'énergie de l'Ademe depuis 1999." *Énergie et Matières Premières* No13 (3ème trimestre 2000). pages 20-33. La lettre de la Direction Générale de l'Énergie et des Matières Premières, Paris. On the Web at http://www.industrie.gouv.fr/energie/publi/pdf/ldg13.pdf.

Deneux 2002 Marcel Deneux. *Rapport sur l'évaluation de l'ampleur des changements climatiques, de leurs causes et de leur impact prévisible sur la géographie de la France à l'horizon 2025, 2050 et 2100. Tome I - Rapport*. Assemblée nationale : n° 3603 (11ème législature) - Sénat n° 224 (2001-2002). Paris: Assemblée nationale; Sénat, last updated 2002. At head of title: Office parlementaire d'évaluation des choix scientifiques et technologiques. On the Web at http://www.senat.fr/rap/r01-224-1/r01-224-11.pdf. Viewed on September 26, 2005.

DGEMP 1999 France. Direction Générale de l'Énergie et des Matières Premières. *L'energie nucleaire en 110 questions*. France. Direction Générale de l'Énergie et des Matières Premières, last updated 1999? On the Web at http://www.industrie.gouv.fr/energie/nucleair/pdf/nucleair.pdf. Viewed on 2002.

DGEMP 2001 Christian Pierret. "Ouverture par Christian Pierret, (lue par Dominique Maillard) du séminaire européen sur la sécurité d'approvisionnement énergétique." *Énergie et Matières Premières* No 15 (1er trimestre 2001). pages 3-6. Issued by: Direction Générale de l'Énergie et des Matières Premières, Paris. On the Web at http://www.industrie.gouv.fr/energie/publi/pdf/ldg15.pdf.

DGEMP 2001b Charles Lamiraux. "Du pétrole en France?" *Énergie et Matières Premières* No 17 (3ème trimestre 2001). pages 22 - 25. Issued by: Direction Générale de l'Énergie et des matières premières, Paris. On the Web at http://www.industrie.gouv.fr/energie/publi/pdf/ldg17.pdf.

DGEMP 2003a France. Direction Générale de l'Énergie et des Matières Premières. *L'évolution de l'intensité énergétique et des économies d'énergie en France entre 1973 et 2001*. [Paris?]: Ministère de l'Économie, des Finances et de l'Industrie, last updated 04/04/2003. On the Web at http://www.industrie.gouv.fr/energie/developp/econo/textes/se_intensite.htm. Viewed on Nov. 18, 2004.

DGEMP 2003b France. Direction Générale de l'Énergie et des Matières Premières. *Énergies, comprendre pour choisir: Environnement, qualité de vie, développement durable*. [Paris]: Ministère de l'Économie, des Finances et de l'Industrie, DGEMP, last updated [08/07/2003?]. At head of title: Débat National sur les Énergies. On the Web at http://www.industrie.gouv.fr/energie/publi/pdf/broch16p.pdf. Viewed on September 20, 2005.

DGEMP Charbon France. Direction Générale de l'Énergie et des Matières Premières. *Le charbon en France*. [Paris?]: Ministère de l'Économie, des Finances et de l'Industrie, DGEMP, last updated 23/09/2005. Web page heading: Statistiques: Importations de charbon en France. On the Web at http://www.industrie.gouv.fr/energie/statisti/se_chafi.htm. Viewed on April 6, 2006.

DGEMP Gaz France. Direction Générale de l'Énergie et des Matières Premières. *Le gaz en France*. [Paris?]: Ministère de l'Économie, des Finances et de l'Industrie, DGEMP, last updated 20/09/2005. Web page heading: DGEMP - Les statistiques sur le gaz. On the Web at http://www.industrie.gouv.fr/energie/statisti/se_gazfi.htm. Viewed on April 6, 2006.

Directive 96/92/EC "Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity." *Official Journal of the European Union, L 027, 30/01/1997*. 31996L0092. (19 December 1996). pages 0020 - 0029. Directive of the European Parliament and the Council of the European Union. "No longer in force." Also known as the European Electricity Directive of 1996. Viewed Web page on May 3, 2005. On the Web at http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=31996L0092&model=guichett.

Directive 2001/77/CE "Directive 2001/77/CE du Parlement Européen et du Conseil du 27 septembre 2001 relative à la promotion de l'électricité produite à partir de sources d'énergie renouvelables sur le marché intérieur de l'électricité." *Journal officiel des Communautés européennes, 27.10.2001, L 283/33* (27 septembre 2001). pages 33-40. Volume 44 of the *Journal officiel*. On the Web at http://www.industrie.gouv.fr/energie/renou/directive-enr.pdf. English version on the Web at http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_283/l_28320011027en00330040.pdf.

Documentation française 2003 Documentation française. *Quels sont les différents impôts perçus par l'État?* [Paris?]: Direction de la Documentation française, last updated 2003. On the Web at http://vie-publique.fr/decouverte_instit/finances/finances_1_1_0_q4.htm or http://vie-publique.fr/decouverte_instit/animations/finances/pdf/Q_02.pdf. Viewed on Nov. 18, 2004.

EDF 1989 Électricité de France. *Combustible MOX : aspects techniques, économiques et stratégiques*. [Paris?]: EDF, Direction Production Transport, Service des Combustibles, November 24, 1989.

EDF 2002a Électricité de France. *Société électrique de consommation*. [Paris?]: EDF, last updated [2002?]. Formerly on the Web at http://www.edf.fr/htm/fr/mieux_connaitre_edf/legroupe/histoire/consomm. Viewed on July 9, 2002.

EDF 2003a Électricité de France. *Les sites français*. [Paris?]: EDF, last updated 2003. On the Web at http://www.edf.fr/index.php4?coe_i_id=35008. Viewed on Nov. 16, 2004.

EDF 2003b Électricité de France. *Groupe EDF: Organisation et chiffres clés 2003*. [Paris?]: EDF Direction de la Communication et des Affaires Publiques, Juillet 2004. On the Web at http://www.edf.fr/download.php4?coe_i_id=51351.

EED 2005 Espace Eolien Développement. *Infos*. Lille: EED, last updated 14 Septembre 2005. Web page heading: Informations éolienne, nouvelles de l'éolien, presse éolienne. On the Web at http://www.espace-eolien.fr/Infos/INFO01_2005.htm. Viewed on September 26, 2005.

EIA 2003 United States. Energy Information Administration. *The Global Liquefied Natural Gas Market: Status & Outlook*. DOE/EIA-0637 (2003). Washington, DC: EIA, United States Department of Energy, December 2003. On the Web at http://tonto.eia.doe.gov/FTPROOT/natgas/eia_0637.pdf.

EIA 2004 United States. Energy Information Administration. *International Energy Outlook 2004: Highlights*. IEO2004; Report #: DOE/EIA-0484(2004). [Washington, DC]: EIA, last updated May 17, 2004. "Release date: April 2004." On the Web at http://www.eia.doe.gov/oiaf/archive/ieo04/highlights.html. Viewed on June 22, 2005.

EIA 2005 United States. Energy Information Administration. *World Proved Reserves of Oil and Natural Gas, Most Recent Estimates*. Washington, DC: EIA, last updated March 4, 2005. "Table Posted: March 4, 2005." On the Web at http://www.eia.doe.gov/emeu/international/reserves.html. Viewed on April 13, 2005.

EIA 2005b United States. Energy Information Administration. *International Energy Outlook 2005 - Highlights*. DOE/EIA-0484(2005). [Washington, DC]: EIA, last updated September 19, 2005. "Report Released: July 2005." On the Web at http://www.eia.doe.gov/oiaf/ieo/highlights.html. Viewed on September 26, 2005.

EIA 2005d United States. Energy Information Administration. *Annual Energy Outlook 2005 With Projections to 2025*. DOE/EIA-0383 (2005). Washington, DC: U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, February 2005. On the Web at http://www.eia.doe.gov/oiaf/archive/aeo05/pdf/0383(2005).pdf.

Engelbert et al. 2004 Christian Engelbert, Joseph J Fadok, Robert A Fuller and Bernd Lueneburg. *Introducing the 1S.W501g single-shaft combined-cycle reference power plant.* Proceedings of ASME Power: ASME Power, March 30 -April 1, Baltimore, Maryland. PWR2004-52072. [New York]: American Society of Mechanical Engineers, last updated 2004. On the Web at http://www.siemenswestinghouse.com/download/pool/W501G_single.pdf. Viewed on April 12, 2005.

Eole 2005 Électricité de France. *Production d'électricité par énergie éolienne: situation dans le monde et programme français EOLE 2005*. [Paris?]: R&D d'EDF, last updated 1998? Formerly on the Web at http://retd.edf.fr/futur/mois/eole.pdf. Viewed on 2002.

Evanoff 2000 Ted Evanoff. "GM debuts fuel cell Precept Prototype midsize car." *Detroit Free Press*, January 12, 2000. Reprinted by Discount New Cars. On the Web at http://www.discountnewcars.com.au/news/car-article-18-Jan-2000.cfm.

EWEA 2005 European Wind Energy Association. *Wind power continues to grow in 2004 in the EU, but faces constraints of grid and administrative barriers*. News release. Brussels: EWEA, last updated 27th January 2005. There is a link to this at: http://www.ewea.org/ - under Latest news, for 28 January 2005. On the Web at http://www2.ewea.org/documents/0127%20Stats%202004_final.pdf. Viewed on April 8, 2005.

EWEA 2006 Map European Wind Energy Association. *Wind power installed in Europe by end of 2005 (cumulative)*. Brussels: EWEA, last updated [unknown]. There is a link to this at: http://www.ewea.org/ - under Latest publications. On the Web at http://www.ewea.org/fileadmin/ewea_documents/documents/publications/statistics/2005statistics.pdf. Viewed on March 9, 2006.

Finon 2001 Dominique Finon. *The Destabilisation of the French electricity supply industry: nascent competition in an open environment*. Grenoble: Institut d'economie et de politique de l'energie, 2001. "Presentation to the First Gas and Electricity Forum, Enrico Mattei School, Milan, June 21-22, 2001-10-12." On the Web at http://www.upmf-grenoble.fr/iepe/textes/DF_01.27ElecMilan.PDF.

Fioravanti 1999 Marc Fioravanti. *Wind Versus Plutonium: an Examination of the Potential of Wind Energy and a Comparison of Offshore Wind Energy to Plutonium Use in Japan*. Takoma Park, MD: Institute for Energy and Environmental Research, January 1999. Summary on the Web at http://www.ieer.org/reports/wind/index.html.

FNB 2003 Biomasse Normandie. *Le bois-énergie, une composante essentielle de la filière forêt - bois*. [Paris?]: Fédération nationale du bois, last updated 17 juin 2003. Note préparée par Biomasse Normandie, établie à la demande de la Commission bois-énergie de la FNB. On the Web at http://www.debat-energie.gouv.fr/site/pdf/fnb.pdf. Viewed on September 26, 2005.

Galley and Bataille 1998 Robert Galley and Christian Bataille. *Rapport fait au Nom de la Commission d'Enquête sur Superphénix et la Filière de Réacteurs à Neutrons Rapides*. Assemblée nationale No 1018. [Paris]: Assemblée nationale, 25 juin 1998. Also published in *Journal Officiel*, 26 juin 1998. In two volumes. On the Web at http://www.assemblee-nat.fr/rap-enq/r1018-1.asp.

Galus 2003 Christiane Galus. "Mobilisation contre le réchauffement climatique." *Le Monde*, July 3, 2003. On the Web at http://www.lemonde.fr/.

GEO 2000 United Nations Environment Programme. *Global Environment Outlook 2000: Chapter Two: The State of the Environment - Europe and Central Asia - Urban areas*. Nairobi: UNEP, last updated 1999. Web page title: GEO-2000. On the Web at http://www.unep.org/geo2000/english/0081.htm. Viewed on September 26, 2005.

Houghton 2003 John Houghton. "Global Warming Is Now a Weapon of Mass Destruction: It Kills More People Than Terrorism, Yet Blair and Bush do Nothing." *Guardian Unlimited*, July 28, 2003. On the Web at http://www.guardian.co.uk/comment/story/0,3604,1007042,00.html.

IAEA 2005 International Ministerial Conference: "Nuclear Power for the 21st Century, " Paris, 21 and 22 March 2005. *Final Statement*. Vienna: International Atomic Energy Agency, last updated 2005. "Organized by the International Atomic Energy Agency. In co-operation with the Organisation for Economic Cooperation and Development. Hosted by the Government of the Republic of France." On the Web at http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2004/cn122-final-statement.pdf. Viewed on April 11, 2005.

IEA 2002 International Energy Agency. *Energy Policies of IEA Countries: 2002 Review*. Paris: IEA, Organisation for Economic Co-operation and Development, 2002. Section on France Standards Reviews on the Web at http://www.iea.org/textbase/nppdf/free/2000/france_comp02.pdf. Whole book on the Web at http://library.iea.org/textbase/nppdf/free/2000/compendium2002.pdf.

IPCC 2002 Intergovernmental Panel on Climate Change. Working Group I. *Climate change 2001 : The Scientific Basis : Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change / edited by J.T. Houghton ... [et al.]*. Cambridge ; New York : : Cambridge University Press, 2001. On the Web at http://www.grida.no/climate/ipcc_tar/wg1/004.htm. Viewed on July 10, 2002.

Jacoby 2004 Mitch Jacoby. "Composite materials." *Chemical & Engineering News* **82**, 35 (August 20, 2004). pages 34-39.

Jensen 2003 James T. Jensen. "The LNG Revolution." *The Energy Journal* **24**, 2 (Spring 2003). pages 1-45. Unofficial version on the Web at http://www.jai-energy.com/pubs/iaeepapr.pdf, with slightly different pages.

Johnson 2001 Jeff Johnson. "Plugging into Energy Efficiency." *Chemical & Engineering News* **79**, 46 (November 12, 2001). pages 19-20.

Kyoto status 2005 United Nations Framework Convention on Climate Change. *Status of Ratification*. Bonn: UNFCCC, last updated 6 April 2005. Status of the Kyoto Protocol. On the Web at http://unfccc.int/essential_background/kyoto_protocol/status_of_ratification/items/2613.php. Viewed on April 11, 2005.

Lepeltier 2004 Serge Lepeltier. *Climate plan 2004: Let's act together to the challenge of climate change*. Paris: Ministere de l'Ecologie et du Développement Durable; Mission interministérielle de l'Effet de Serre, 12 novembre 2004 2004. Also issued as "Plan climat 2004: Face au changement climatique, Agissons ensemble" on 12 novembre 2004, which is on the Web at http://www1.environnement.gouv.fr/IMG/pdf/plan_climat.pdf. English version is on the Web at http://www.ecologie.gouv.fr/IMG/pdf/PLANCLIMATANGLAIS.pdf.

LLNL 2003 Arnie Heller. "Maglev on the Development Track for Urban Transportation," *Science & Technology Review* (November 2003). pages 14-17. Published by Lawrence Livermore National Laboratory. "UCRL-52000-03-11." On the Web at http://www.llnl.gov/str/November03/pdfs/11_03.3.pdf.

Loi N° 46-628 du 8 avril 1946 "Loi N° 46-628 du 8 Avril 1946 sur la Nationalisation de l'Electricité et du Gaz (J.O. du 9 avril 1946. Rect J.O. des 17 avril et 3 mai 1946), modifiée par...la loi n°84-512 du 29 juin 1984 (J.O. du 30 juin 1984)." *Le Journal Officiel* (1984). Last updated June 30, 1984. On the Web at http://www.admi.net/jo/l46-628.html.

Loi N° 2000-108 *Loi N° 2000-108 du 10 février 2000. Loi relative à la modernisation et au développement du service public de l'électricité*. last updated 2005. "Publication au JORF du 11 février 2000 [i.e. Journal Officiel, Numéro 35]." "NOR : ECOX9800166L." "[V]ersion consolidée au 31 décembre 2005." On the Web at http://www.legifrance.gouv.fr/texteconsolide/RIEAY.htm. Viewed on April 6, 2006.

Makhijani 1996 Arjun Makhijani. "Comparison of Fossil Fuels and Nuclear Power: A Tabular Sketch." *Energy and Security* No.1 (September 1996). On the Web at http://www.ieer.org/ensec/no-1/comffnp.html. Viewed on July 10, 2002.

Makhijani 1998 Arjun Makhijani. "Reducing Greenhouse Gases and Creating a Sustainable Energy Supply." *Science for Democratic Action* **6**, 3 (March 1998). 5-7; 13. On the Web at http://www.ieer.org/ensec/no-5/sustain.html.

Makhijani 2001 Arjun Makhijani. *Plutonium end game: managing global stocks of separated weapons-usable commercial and surplus nuclear weapons plutonium*. Takoma Park, MD: Institute for Energy and Environmental Research, January 22, 2001. On the Web at http://www.ieer.org/reports/pu/.

Makhijani 2001a Arjun Makhijani. *Securing the energy future of the United States: oil, nuclear, and electricity vulnerabilities and a post-September 11, 2001 Roadmap for action*. Takoma Park, MD: Takoma Park, MD: Institute for Energy and Environmental Research, November 2001. A preliminary report of IEER's energy assessment project. On the Web at http://www.ieer.org/reports/energy/bushrpt.pdf.

Makhijani and Saleska 1999 Arjun Makhijani and Scott Saleska. *The Nuclear Power Deception: U.S. Nuclear Mythology from Electricity "Too Cheap to Meter" to "Inherently Safe" Reactors*. New York: Apex Press, 1999. A report of the Institute for Energy and Environmental Research.

Makhijani et al. 2004 Arjun Makhijani, Peter Bickel, Aiyou Chen and Brice Smith. *Cash Crop on the Wind Farm: A New Mexico Case Study of the Cost, Price, and Value of Wind-Generated Electricity. Prepared for presentation at the North American Energy Summit Western Governors' Association, Albuquerque, New Mexico, April 15-16, 2004*. Takoma Park, MD: Institute for Energy and Environmental Research, April 2004. Revised as of February 8, 2005. On the Web at http://www.ieer.org/reports/wind/cashcrop/index.html.

Makhijani, Annie, 2001 Annie Makhijani. "French Report Doubts Merits of Reprocessing and MOX." *Science for Democratic Action* **9**, 2 (February 2001). pages 9-11. On the Web at http://www.ieer.org/sdafiles/vol_9/9-2/charpin.html.

Medvedev 1990 Zhores A. Medvedev. *The Legacy of Chernobyl*. New York: W. W. Norton, 1990.

MIT 2003 Massachusetts Institute of Technology. *The Future of nuclear power: an interdisciplinary MIT study*. Cambridge: MIT, 2003. "The members of the study team are: John Deutch (co-chair), Ernest Moniz (co-chair), S. Ansolabehere, Michael Driscoll, Paul Gray, John Holdren (Harvard), Paul Joskow, Richard Lester, and Neil Todreas." On the Web at http://web.mit.edu/nuclearpower/.

Moisan 1998 François Moisan. *Énergie 2010-2020: Rapport de l'Atelier, Trois scénarios énergétiques pour la France*. Paris: Commissariat Général du Plan, Septembre 1998. Président, François Moisan. Rapporteur, Olivier Godard. Summary on the Web at http://www.industrie.gouv.fr/energie/prospect/pdf/trois-scenarios.pdf.

NAS 1994 National Academy of Sciences. Committee on International Security and Arms Control. *Management and Disposition of Excess Weapons Plutonium*. Washington, DC: National Academy Press, 1994.

Nau 2003 Jean-Yves Nau. "La canicule du mois d'aout a fait 14 800 morts." *Le Monde*, 26 septembre 2003. On the Web at http://www.lemonde.fr/.

Ngô 1999 Christian Ngô. *Quelles énergies pour demain?* [Paris]: Commissariat à l'Energie Atomique, [1999?]. On the Web at http://www.cea.fr/fr/actualites/pdf/FeteScience.pdf, viewed April 8, 2005.

ODE 2001 France. Direction Générale de l'Énergie et des Matières Premières. Observatoire de l'Énergie. *Bilan énergétique provisoire de la France en 2000*. Paris: ODE, April 26, 2001. On the Web at http://www.industrie.gouv.fr/energie/pdf/bilan2000.pdf.

ODE 2001a France. Direction Générale de l'Énergie et des Matières Premières. Observatoire de l'Énergie. *L'énergie en France repères*. Chiffres Clés. Paris: Ministère de l'Économie, des Finances et de l'Industrie, édition 2001. Latest edition on the Web at http://www.industrie.gouv.fr/energie/statisti/pdf/reperes.pdf.

ODE 2001c France. Direction Générale de l'Énergie et des Matières Premières. Observatoire de l'Énergie. *Les émissions de CO2 dues à l'énergie dans l'OCDE en 1999-2000.* Paris: Ministère de l'Économie, des Finances et de l'Industrie, Direction Générale de l'Énergie et des matières premières, Observatoire de l'Énergie, Août 2001. On the Web at www.energie.minefi.gouv.fr/energie/statisti/pdf/note-CO2.pdf,.

ODE 2001d France. Direction Générale de l'Énergie et des Matières Premières. Observatoire de l'Énergie. *L'énergie en France en 2000: Que retenir?* Énergie & matières premières. [Paris]: DGEMP / Observatoire de l'énergie, last updated Juin 2001. On the Web at http://www.industrie.gouv.fr/energie/statisti/pdf/4page2000.pdf. Viewed on April 12, 2005.

ODE 2002a France. Direction Générale de l'Énergie et des Matières Premières. Observatoire de l'Énergie. *Électricité en France: les principaux résultats en 2001* Énergie & matières premières. [Paris]: DGEMP / Observatoire de l'énergie, last updated Mai 2002. 2001 report formerly on the Web at http://www.industrie.gouv.fr/energie/statisti/se_elec.htm. Viewed in 2002.

Ortoli 1996 François-Xavier Ortoli. "Le pétrole: enjeux et défis pour la France." *Revue des Sciences Morales et Politques* **151e année**, No 3 (1996). page 295. As quoted by Pierre Noël in "Indépendance énergétique versus marché mondial" (Genoble: Institut d'Etudes Politiques et IEPE, 1999). On the Web at http://www.upmf-grenoble.fr/iepe/textes/Noel9910.PDF.

Plan Etat-ADEME 2001 France. Ministère Délégué à la Recherche. *L'Etat et l'ADEME signent un contrat de plan pour 2000-2006*. Communiqué de Presse. 19 juin 2001. Communiqué conjoint des ministères de la Recherche, de l'Aménagement du Territoire et de l'Environnement, du Secréatariat à l'Industrie, et de l'ADEME. On the Web at http://www.recherche.gouv.fr/discours/2001/ademe.htm.

PNLCC 2000 France. Mission Interministérielle de l'Effet de Serre. *Le Programme National de lutte contre le Changement Climatique (PNLCC)*. Paris: MIES, Ministère de l'Écologie et du Développement Durable, January 19, 2000. Title page missing from Web. Running title used. On the Web at http://www.effet-de-serre.gouv.fr/fr/actions/PNLCC.pdf.

Popular Science 2002 John Matras. "Volkswagen's canoe-skinny mini could do New York to D.C. on 1 gallon of gas." *Popular Science*, July 12, 2002. On the Web at http://www.popsci.com/popsci/auto/article/0,12543,320360,00.html.

PPI 2002 France. Ministère de l'Économie des Finances et de l'Industrie. *Programmation pluriannuelle des investissements de production électrique. Rapport au Parlement*. Paris: 29 janvier 2002. On the Web at http://www.industrie.gouv.fr/energie/electric/pdf/ppi_2002.pdf.

Reuters 2002-04-06 Reuters. *Japanese nukes could counter China - politician*. last updated April 6, 2002. Dateline: Tokyo. On the Web at http://www.nci.org/02NCI/04/japan-articles.htm. Viewed on March 13, 2006.

Revol 1997-1998 Henri Revol. *Politique énergétique de la France*. Rapport 439. [Paris]: Sénat, Commission d'Enquete, 1997-1998. On the Web at http://www.senat.fr/rap/l97-4391/l97-4391_mono.html. Viewed July 24, 2002.

RMI Rocky Mountain Institute. *Rocky Mountain Institute - Home Page*. On the Web at www.rmi.org.

Roche 2003 François Roche. *TotalFinaElf : une major française*. Paris: Le Cherche midi, 2003.

Scénario Vert Alain Dorange, Olivier Finet and Khadija Gamraoui. *Scénario Vert Pour La France*. [Paris?]: Détente, May 1999. "Sur la base de travaux INESTENE Antoine Bonduelle, Nicolas Houdant, Lionel Cauret, Sébastien Fenet, Dominique Giraud, Pascale Le Stat, Nathaly Dubuis."

Smithsonian 1995 Smithsonian Institution. *Ocean Planet: Marine Pollution One*. [Washington, DC?]: Smithsonian, last updated 1995. Ocean Planet, premiered at the Smithsonian Institution's National Museum of Natural History from April 1995 to April 1996. On the Web at http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/peril_pollution1.html. Viewed on July 8, 2005.

Sullivan 2002 Mike Sullivan. "Honda's New Fuel Cell Cars Hits [sic] Los Angeles Streets." *VOA news* (December 3, 2002). Reprint. On the Web at http://greennature.com/article2003.html.

Steenkamp 2006 Willem Steenkamp. *SA solar research eclipses rest of the world*. Cape Town, SA: Independent Online, last updated February 11, 2006. "Originally published on page 1 of *The Saturday Argus*, on February 11, 2006." On the Web at http://www.int.iol.co.za/index.php?set_id=1&click_id=143&art_id=vn20060211110132138C184427. Viewed on March 14, 2006.

Toyota 2002 Toyota Motor Corporation. *Toyota FCHV: Approaching the Eco-car*. [Toyota City?]: Toyota, last updated December 12, 2002. On the Web at http://www.toyota.co.jp/en/tech/environment/fchv. Viewed on April 7, 2006.

UFE et al. 2003 Union française de l'électricité, Électrabel france groupement producteurs autonomes, D'Énergie hydroélectrique, Compagnie nationale du rhône and Société hydroélectrique du midi. *Livre blanc sur les energies : Le potentiel hydroélectrique : un enjeu national de 10TWh*. last updated 23 décembre 2003. On the Web at http://www.industrie.gouv.fr/energie/politiqu/pdf/lb-cnr.pdf. Viewed on September 26, 2005.

VW 2003 LupoUSA.com. *The VW Polo TDI*. last updated 2003. Formerly on the Web at http://www.lupousa.com/vw_polo.htm. Viewed on Nov. 18, 2004.

Yergin 1991 Daniel Yergin. *The Prize: The Epic Quest for Oil, Money, and Power*. New York: Simon & Schuster, 1991.

Zaidi 2005 Ammar Zaidi. *Iran piped gas to be cheaper than shipping LPG*. rediff.com, last updated June 8, 2005. On the Web at http://in.rediff.com/money/2005/jun/08gas.htm. Viewed on March 9, 2006.