# The French Connection: Comparing French and American Civilian Nuclear Energy Programs

*By Rahul Sastry and Bennett Siegel*

*The production and consumption of energy is a problem that continues to play an important role in societies across the world. The United States, in its push towards greener energy, has long wavered on the role that nuclear energy will play in the larger picture of non petroleum-based energy consumption. Despite current politcal and economic difficulties, nuclear energy has the potential to play a large role in the shifting US energy policy. In this article, the authors discuss the success of the French nuclear energy program. They compare the economic and politcal factors that have lead to the success of the French nuclear program and the failure of the nuclear program in the US, and conclude with policy recommendations drawn from the French case study.*

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Nuclear Plant in Saint Laurent des Eaux, France

## Introduction

A comprehensive analysis of France's nuclear energy program can provide important lessons for the United States as it seeks to confront the energy challenges of the 21st century. France currently has the most sophisticated and expansive nuclear energy program on the globe and derives more than 75 percent of its energy from nuclear reactors.[1] Within this report, we intend to conduct a thorough examination of France's nuclear energy program, focusing on its implementation, effectiveness, and long term sustainability. In order to achieve this goal, it is necessary to examine the technological features employed within the reactors, the regulatory framework that oversees the program as well as the economic, environmental, and political considerations that lie in the background of such a major energy initiative. The central question that motivates the research and argumentation within this paper is simple: What can the US learn from France's civilian nuclear energy program? There are many issues that arise in any comparative study between these two countries, taking into account their different political climate, geography, population size, and inherent national personalities. Yet, as the United States continues to debate the future of its energy policy, there exists no more important a case study than France's civilian nuclear energy program.

France's program has proven to be a great success and the government continues to look forward. A recent *US News and World Report* article discussed how France sees its nuclear-powered future: Namely, it desires to expand its "use of nuclear energy at home and seeks to increase nuclear-technology sales abroad."[2] On the other hand, the United States nuclear energy program has been in most views a failure. Though the U.S made many of the initial developments in the technology, it "suffered major economic disappointment when building its current nuclear capacity," leading to a period of nuclear decline within the country.[3] Indeed, the US nuclear industry continues to be plagued by high "construction costs, public concern about nuclear safety and waste disposal, and regulatory compliance costs."[4] So what accounts for the large gap between these two programs? The remainder of this paper seeks to answer this question by examining the political, regulatory and economic factors that affect the nuclear power industries in both the United States and France. It concludes by recommending a course of action for the US to take with regards to the role of nuclear power in its energy future.

## Historical Background

Analyzing the history of the French and American civilian nuclear energy programs provides a useful backdrop for analyzing contemporary nuclear policy. Both the French and American programs grew out of their respective countries' military apparatuses at the dawn of the "nuclear age" during the early 1940s, but have followed drastically distinct trajectories in the decades since. In the United States, the military retained exclusive control over nuclear research and development until 1946; private nuclear development began in 1954 with the passage of the Atomic Energy Act. Despite the Act, American companies refused to develop nuclear energy due to the astronomical risk of a potential accident. Congress responded by passing the Price-Anderson Act of 1957, which established a $560 million liability cap for nuclear producers and required producers to have $60 million of insurance.[5] From the mid-1950s to the mid-1970s, the US nuclear industry, spurred on by volatility in fossil fuel prices and support from the government and the public, built more nuclear plants than any other industry in the world.[6]

The year 1974 marked an important turning point for the nuclear industry in the United States; it was around this time that the nuclear option was "virtually abandoned by US developers."[7] This paradigm shift occurred for a variety of reasons: (1) overly optimistic forecasts of energy demand growth, (2) increase in public opposition, and (3) shifting production costs.[8] Today, there are 112 nuclear reactors run by 55 different companies operating in the United States; together, they provide over 20 percent of domestic energy production. No nuclear plants have been built in the US since 1973; nearly fifty percent of US nuclear facilities since then have been cancelled, rejected, or delayed infinitely.[9]

Rahul Sastry is a freshman from Nashville, TN. Though undeclared, he is planning on majoring in biology and economics; specifically, he is interested in studying the areas of interaction between science and public policy, such public health and alternative energy, and plans to pursue them in his future years of study.

Bennett Siegel is a freshman who is undeclared, but leaning towards political science. He is from Boca Raton, FL and is interested in energy policy. He wrote this paper with Rahul for an Introductory Seminar called "Energy Options for the 21st Century."

The French civilian nuclear program, like its American counterpart, also expanded rapidly during the early 1970s due to volatility in the prices of fossil fuels. As a response to price volatility, the Pompidou Government in France developed a long-term plan to develop civilian nuclear power production. The plan notably called for 55 1,000 MW nuclear reactors to be built by 1985; the plan also chose a single reactor design (the Pressurized Water Reactor) and sited plants close to each other in order to reduce political opposition.[10] The reduction of oil prices in the 1980s placed the French government in the difficult position of supporting a costly nuclear industry; in the end, policymakers convinced the public to continue supporting the program on the grounds of achieving energy independence and being a net exporter of electricity.

In France, the EDF (Electricité de France), the state-owned utility, is solely responsible for electricity production, transmission and end-user sales; the CEA (Commissariat à l'Energie Atomique), which is 100 percent state-owned, administers all nuclear research and controls all nuclear activities.[11] Cogema, a subset of the CEA, has a monopoly on fuel cycle processes. The national-government standardization has become the defining characteristic of the French nuclear industry. Today, France's 59 nuclear reactors produce 75 percent of France's domestic energy consumption.[12] As a result of its past actions, France now enjoys a substantial level of energy independence and nearly the lowest cost of energy in Europe.[13]

## Political Realities

The most striking difference between France and America is how their public views nuclear energy and their government's role in it. "In France, unlike America, nuclear energy is accepted, even popular."[14] Support for nuclear energy among Americans is at a record high of 59 percent today (with 27 percent strongly favoring it), compared to about two-thirds of the French who support it.[15] This recent surge in acceptance among Americans is mostly related to the energy crisis that struck in 2008, but today, nuclear energy is not at the forefront of America's discourse regarding future energy sources. The French, in contrast, see nuclear energy as not only the best way to achieve energy independence, but also as a necessity to their modern day to day lives. A PBS article asks what is it about "French culture and politics that allowed them to succeed where most counties have failed."[16] The article goes on to cite Claude Mandil, the General Director for Energy and Raw Materials at the Ministry of Industry. He states that the three main factors that allowed for France's nuclear program are the independence of the French people, the long French tradition of large centrally managed projects, and the French authorities work to educate the public about the merits of nuclear energy. Director Mandil's points help reveal the political dimensions in France that allow for a nuclear program. A study by psychologist Paul Slovic and his colleagues at Decisions Research in Eugene, Oregon, corroborate this opinion, they "discovered in their surveys that many French people have similar negative imagery and fears of radiation and disaster as Americans … the difference is that cultural, economic and political forces in France act to counteract these fears."[17] For whatever reason, the French feel that nuclear energy is more of a necessity in their lives and thus they are willing to take the safety risks that come along with its widespread use.

### *Building Political Consensus*

Yet the French are not alone in understanding that decisive action is needed in energy policy, Americans also see how dangerous it is to be dependent for energy on one of the most volatile regions in the world. There is widespread political consensus in the US that something needs to be done, but little agreement on what. Many Republicans, who are supportive of oil companies, wish to expand domestic drilling both in ANWR and off-shore in several areas. Many Democrats, seek heavy investment in all sorts of renewable fuels and a windfall-profit tax on oil companies. Every politician has a unique view and there is very little agreement on what should be done. In recent years within the US, nuclear energy has become more prominent in the energy debate: "supporters say that's essential to jumpstart a clean, dependable source of power...[while] critics say it will keep the country reliant on a dangerous and expensive technology."[18] If any action is to be taken, it is quite clear as one study put it "that nuclear energy needs a positive attitude on the part of public authorities (federal, but also regional) to be able to compete with other sources of electricity."[19] A nuclear power program requires government legislation on safety and the disposal of waste, careful regulation, subsidies to help construction, and insurance liability aid. A Brookings Institute Policy Brief takes an unconventional stance on US nuclear energy, believing that the US government has been more involved and supportive of the industry than is generally perceived. Yet, what is significant about this brief is that it still concedes that a few unique countries such as France and Japan have put their nuclear industries through far less political turbulence.[20] The freedom from political interference and pressure that French regulators and nuclear officials possess has been instrumental in the success of France's nuclear program. Simply put, nuclear energy requires governmental involvement in order to address important issues that private industry cannot solve alone. That is one major factor why France was able to succeed when America was not.

### *Public Support*

A nuclear program may need governmental support in order to be implemented successfully, but it requires public support to even exist in the first place. The public needs to understand the necessity of the program in order to counterbalance negative stereotypes. Whereas the French government has made an effort to publicize the positives of building nuclear reactors by soliciting people to take tours of sites and creating "glossy television advertising campaigns [that] reinforce the link between nuclear power and the electricity that makes modern life possible," the US has made little concerted effort to inform its own citizens.[21] As a result, French citizens trust their government to control and manage this critical national security project, while US citizens simply do not. Obviously, France and the US inherently have very different political cultures. Unlike the French, who have a long history of central planning in economic policy, Americans are wary of any expansion of governmental authority, especially into typically free market economic areas. Yet, an MIT study on future energy policy concluded that the public's attitude toward nuclear power was informed "almost entirely by their perceptions of the technology, rather than by politics or by demographics."[22] Most of the public does not connect their views on nuclear energy to any political ideology or party platform, but simply to the effectiveness of the technology. Simply put, Americans are a very open-minded audience and only by educating them can any real political push for nuclear energy come. Like the French, Americans need to be educated so they can understand how nuclear power can improve their lives and therefore fear the technology less.

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Nuclear energy remains unpopular in most of the world.

## Regulation

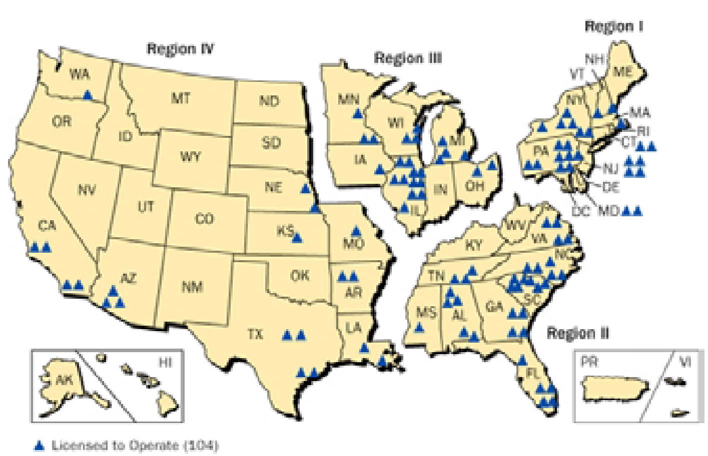
Although it is true that credible government and public support is absolutely necessary for a successful nuclear industry, they are not sufficient by themselves. It also matters in what ways a given government intervenes within the energy sector in the context of nuclear power. We find that significant differences exist between the French and American nuclear-power regulatory structures, and that these differences are in part responsible for the viability gap of nuclear power in the two countries. According to Delmas, the American nuclear industry has been significantly hurt by delays in the construction times of new nuclear plants.[23] Over the 10-year period from 1974 to 1984, the United States experienced an average delay in plant construction of 33.9 months more than France did; by comparison, the average French plant was delayed by 5.5 months.[24] Additionally, from 1954 to 1979, the average review time for a construction permit grew by a factor of four; the average time for an operating license grew by a similarly large factor.[25] Finally, as of 1979, the average lead time (time between the order and commercial operation) was six years in France and thirteen years in the United States.[26] It seems certain that these delays can be, in part, attributed to differences in the regulatory mechanisms between the United States and France; delays as a result of the regulatory process have resulted in higher interest rates (and, therefore, higher electricity prices for consumers) along with large legal expenses necessary for defending proposals.[27]

Both France and the United States have overhauled their regulatory mechanisms over the last two decades. In France, the Autorité de Sûreté Nucléaire (ASN) transitioned from a government-integrated, cross-ministerial commission to an independent commission appointed by the French President and the Presidents of the National Assembly and Senate.[28] The French system is particularly streamlined due to a stable and centralized organizational structure: there is only one utility (EDF), one reactor supplier (Framatome) and one turbine-generator supplier (Alsthom).[29] Additionally, "concentrated power in the Executive [branch]…, a strong, expert bureaucracy, and no access for the public to an independent Judiciary" are responsible for the efficient approval of plans for new nuclear power plants.[30] In the French system, the regulatory process is broken into four distinct segments: (1) a pre-review of site-characteristics and reactor design, (2) a siting, design and environmental-impact study, (3) pre-commissioning tests, and (4) the authorization of continuous operation.[31]

The American regulatory system has also been significantly altered in the last two decades. The historical system is a two-step process: (1) the construction permit is issued after design, site and construction plans are reviewed and (2) the operation permit is issued after the final design and as-built plant and operational tests are performed.[32] The new system divides this process into more specific parts: (1) design certification, (2) an early site permit, issued after the NRC evaluates site compatibility with different plant designs and (3) the combined construction and operation license.[33] These 1989 NRC rule changes were motivated by the fact that "licensing proceedings for nuclear power have historically been long, contentious battles between nuclear operators, nuclear plant designers, public interest groups and the NRC…"[34] Neal Lewis notes that the new system allows safety and environmental issues to be addressed early; this change, in turn, allows the main focus of the final licensing to be on operational safety instead of tangentially related issues.[35] In the older system, the design of the nuclear reactor in question was considered independently in both stages of the process; the new system, on the other hand, allows the NRC to effectively create pre-approved "off-the-shelf" kits for companies to pick from when building a nuclear power plant.[36] Additionally, the early-site permit process allows "a company to apply for a site permit authorizing the construction of a reactor-design-to-be-determined nuclear facility.[37] Although this new regulatory structure was approved in 1989, it was 2003 before any company had even applied for an early-site license; as of today, no proposal has completed the regulatory process and, therefore, it is impossible to evaluate whether or not the new process will actually yield a more efficient system of nuclear power plant approval.

There are also other important factors that need to be considered when analyzing the American nuclear regulatory structure. Paul David and Geoffrey Rothwell note that the rapidly increasing times required to complete the regulatory process in the 1970s were due to an inability of the NRC to keep up with a fast-changing industry; an important component of these rapid changes was the large diversity of nuclear power plant designs, a problem that was obviously avoided in France.[38] It is also important to note the effects of the Three Mile Island disaster on the history of nuclear power in the United States; the accident mobilized the anti-nuclear movement, which subsequently focused its efforts on targeting the state-level regulations and filing lawsuits against regulators.[39] On the whole, access to an independent judiciary and a relatively weak bureaucracy led to frequent changes in regulations; these changes, in turn, increased the uncertainty in forecasting the prices of nuclear reactors, ultimately resulting in increased costs and lead times.

On the whole, it seems that the NRC has undertaken significant efforts to logically streamline the regulatory process for nuclear power plants in the United States. The move to pre-approve certain sites and reactor designs represents perhaps as big a shift to a French-style standardization as could ever realistically occur in the United States, given the current aversion to "big government" intervention into the economy. At the same time, the continued lack of approved reactor designs suggests that the challenges faced by the American nuclear industry are much broader than just the regulatory structure; any potential solution would have to address a wide variety of these challenges.




**US Nuclear Regulation Commission**

Map of the regulatory regions and power plants under NRC jurisdiction

## Safety

Several basic safety issues need to be addressed when considering any expansive national program of nuclear energy. Nuclear reactors have long been considered to be the "epitome of low-probability but high consequence risks," where accidents are rare, but devastating when they do occur.[40] The main concern with nuclear energy has always been the possibility of the escape of radioactive material. Over time, as technology has improved, reactors have become safer. Indeed, since the origin of the technology, reactor accidents have been relatively rare. Yet, those few instances like Three Mile Island and Chernobyl have irrevocably attached a stigma to nuclear power.[41] Every nation must balance inherent safety concerns with the benefits that nuclear energy can provide. Anthony V. Nero, a physicist and supporter of nuclear technology, asserts that "with vigorous safety regulations, accidents will be highly improbable and reactors will be safe enough, even safer than most of the alternatives.[42] To illustrate his point, he cites fuels rods, the primary system, the water coolant and, in case of any abnormal function, a scram system (where control rods can be shoved into the core and break up the chain reaction) which can be used to shut down the plant. A comprehensive MIT study titled "The Future of Nuclear Power", among other publications, has corroborated this view, claiming that "modern reactor designs can achieve a very low risk of serious accidents, but best practices in construction and operation are essential."[43] In the post 9/11 world we inhabit today, there is always the potential for terrorist attacks on nuclear plants. Yet, with the construction and security that the US and France have in place, "experts have concluded that civil works and security provisions make nuclear plants hard targets."[44] Overall, safety concerns, while existent, are by no means prohibitive to the success of nuclear energy.

### *Safety Oversight*

Safety oversight in the US is conducted by the Nuclear Regulatory Commission (NRC), which oversees reactor safety, reactor licensing and renewal, radioactive material safety, and spent fuel management. In 1974, Congress created the NRC as an independent agency "to enable the nation to safely use radioactive materials for beneficial civilian purposes while ensuring that people and the environment are protected."[45] Nuclear reactors are technologically complex structures and the NRC has formulated an extensive list of safety standards that must be applied. These prescriptions apply to nearly all aspects of plant operation "particularly those related to the core nuclear reaction, coolant systems, accident response, emergency backup systems, and radioactive waste disposal."[46] Inspections are carried out on a frequent basis to ensure compliance.

While the nuclear operating experience under NRC guidance has been mostly successful, one glaring failure does exist in an incident at the Davis-Besse reactor in 2002. Despite clear signs of deterioration, "the Nuclear Regulatory Commission (NRC) capitulated to First Energy pressure to delay inspections of a vital safety component [of the plant] beyond a requested December 31, 2001 deadline in order to accommodate the industry rather than force an early shutdown to conduct inspections on deteriorating equipment."[47] Essentially, the NRC abdicated its regulatory responsibility because its relationship had grown too close with the nuclear power companies it was meant to oversee. It was discovered that boric acid had eaten a six inch deep hole in the shell that holds the coolant layer around the reactor core, coming very close to penetrating altogether. This situation could have lead to a complete reactor meltdown and a catastrophic accident.

The NRC has learned many lessons from the Davis-Besse reactor incident. Following the accident, it ordered a task force to review the situation and make recommendations to improve existing safety procedures. The NRC task force ultimately concluded that corrosion occurred for three central reasons: 1) "the NRC, Davis-Besse and nuclear industry failed to adequately review relevant operating experience at other nuclear power plants," 2) Davis-Besse did not give appropriate attention to plant safety issues, 3) the NRC failed to integrate available information in assessing the reactors safety performance.[48] In response to these findings, the NRC has completely revamped its safety protocols. It has changed inspector procedures, standardized information sharing across the agency, improved its communication with the nuclear industry for generic issues that affect all plants, and sought to raise awareness and maintain an industry-wide questioning attitude on all safety issues.[49] The NRC clearly took the David-Besse incident seriously, recognizing that plant safety is instrumental to the continuance of any nuclear program. Moving forward, the US is better prepared to operate plants more safely and securely.

With regards to nuclear accidents, France has had an even cleaner safety record than the United States, with the exception of a minor incident in 2008 Tricastin Nuclear Power Center. Like the US's NRC, France's Nuclear Safety Authority (ASN) is an independent administrative authority that oversees the nuclear industry. The major factor that accounts for the discrepancy in safety records between the two countries is the standardization of plants across France. This allows for uniformity in the training of plant operators and regulators, ensuring they understand their inspection duties regardless of plant design. Also as a result of a common plant template, French regulators possess a vast quantity of data, making probabilistic safety analysis more effective: "the results of these analyses can therefore identify not only the weaknesses but also the strengths with regard to the plant's safety, and thus assist in setting priorities and focusing efforts on the points identified as the most sensitive in terms of the contribution they can make to improving the safety of facilities."[50] Overall, both regulatory bodies have demonstrated their effectiveness in ensuring that nuclear plants are operated safely. That is not to say that the possibility of accidents is nonexistent, but rather that with a continual review of practices, it is clear that plants can continue to function as they have, in conjunction with existing safety protocols, the expert training of operators, and with stringent and frequent regulatory inspections.

### *Nuclear Waste*

The storage of nuclear waste has been referred to as "the Achilles heel of the nuclear industry," a fact that has so far been proven true as no country has found a solution to the problem.[51] The central issue at stake here is that no town or suburb wants highly-toxic radioactive waste buried anywhere near them and any attempts by the government to go ahead with plans have been met with stiff protest. The US government initially desired to store its waste inside of Yucca Mountain in Nevada, but political pressure from Senate Majority Leader Harry Reid has effectively ended the plan for the time being.

France's 1991 Waste Management Act (updated in 2006) was its attempt to address the problem. It established the National Radioactive Waste Management Agency, known simply as ANDRA, which has set up research sites to study the problem. Yet, the body still has not been able to find a suitable site to put the country's nuclear waste in permanently due to public protests. In an attempt to deal with the issue head on, France has for the last 25 years reprocessed its waste, a process strongly opposed by the US, in order to minimize the waste problem and ensure the lasting availability of uranium.[52] The US is concerned about the process, because it requires separating uranium from plutonium, which in theory could then be used to make nuclear weapons. The effectiveness of reprocessing is a subject of contention, since it does "not eliminate the waste disposal problem entirely."[53] There is certainly room for debate over which policy best furthers national interest, but the merits of reprocessing do not seem to make sense technologically (as it barely minimizes waste), economically or in terms of security as the spent fuel rods could be used by terrorists to make bombs. Nonetheless, any country that intends to maintain a nuclear energy industry well into the future must find a long-term way to deal with nuclear waste in a safe and acceptable manner for the public.

## Economics

The differences between the French and American civilian nuclear programs cannot be solely attributed to differences in public policy between the two countries; economic differences also play an important role in determining the relative viability of nuclear electricity generation in each of the two countries. Examining the economics of nuclear power in both countries can provide valuable insights into the future of the nuclear industry in the US.

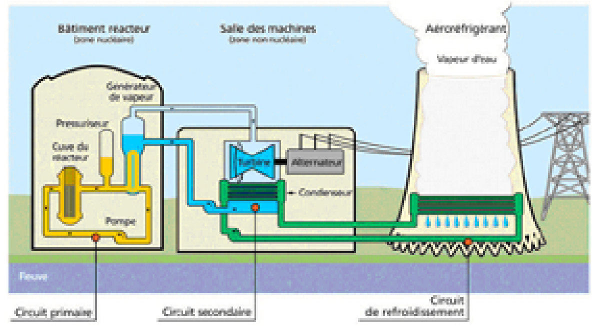
### *Construction Time and Overnight Cost*

Costs and construction times are two of the most frequently cited inadequacies of the American nuclear energy sector. Investment costs, specifically, are disproportionately important: according to a study compiled by the OECD Nuclear Energy Agency, investment is responsible for 70 percent of the global lifetime cost of nuclear-generated electricity; O&M (Operations and Maintenance) and Fuel together account for the remaining 30 percent (OECD).[54] In order to quantify the amount of investment in a given nuclear power plant, analysts utilize the overnight cost, which is defined as "the total of all costs incurred for building the plant as if they were spent instantaneously."[55] Generally, the unit of dollars per megawatt is used in order to make comparisons between the costs of differently-sized nuclear reactors.

Nuclear reactors in both countries are frequently criticized for being over-budget and frequently delayed; these problems are often due to fluctuations in the costs of resources necessary to build the reactors, on-site engineering, and interest accrued over the course of a lengthy construction process.[56] Despite these general trends, however, there are stark differences in construction costs and times between the United States and France. An OECD survey concluded that a nuclear reactor in France takes an average of 7.1 years to be built; the reactors ranged from a minimum of 4.9 years to a maximum of 16.3 years.[57] The same survey found that a nuclear reactor built in the United States takes an average of 9.2 years to be built; the reactors ranged from a minimum of 3.4 years to a maximum of 16.3 years.[58] Additionally, in a separate study, the average overnight capital cost of a French nuclear reactor was found to be $1350 (in 2004 dollars) per installed kW; the MIT report on nuclear power estimated that the average overnight capital cost of an American nuclear reactor to be $2040 (in 2004 dollars) per installed kW.[59]

Analysts have attributed these discrepancies to several factors. Foremost among these is the inefficient organization of the nuclear industry in the United States; although free-market principles dictate the opposite, it turns out that the French decision to standardize nuclear reactor designs has allowed for targeted innovation. David and Rothwell note that the French were able to cut the construction cost of a Westinghouse-based light water reactor far below the US Westinghouse levels; the ability to spread costs over a large number of identical reactors, they conclude, is essential to reducing these costs.[60] The University of Chicago's Nuclear Industry Study goes further and concludes that "reductions in capital costs between a first nuclear plant and an nth plant of the same design can be critically important to eventual commercial viability."[61] The American model, on the other hand, encourages competition of reactor-types, and therefore innovation for a specific reactor does not occur at the same rate. Furthermore, the transmission of lessons learned is exceedingly difficult without the French regulatory structure.[62] Government involvement in France also makes it much easier for the utility to recover its initial investment; well-formed environmentalist and anti-nuclear lobbying groups have the opposite effect in America.

The standardization of the French industry has several additional benefits. For example, standardized plant designs allow quicker responses to safety crises and allow for pre-emptive measures to be taken that can prevent similar failures in the other similar plants.[63] Additionally, studies have found that standardization in France has been a key reason for the higher rates of operating performance of light-water reactors than in the United States.[64]




**EDF, Creative Commons**

Basic layout of the standardized French plant design

### *Non-Fuels Operations and Maintenance Cost*

Another traditional assumption regarding nuclear power is that the reactors are very inexpensive to actually operate. While this is true in the current context, it has not always been so: in the late 1980s, several American nuclear reactors were forced to shut down because the cost of operation was actually higher than it would be to close the plant and open a gas-fired one. By 2010, the OECD report expects that the annual O&M cost for a nuclear reactor in the United States will be $63/kWe; in France, it is projected to be $46.1/kWe; the report attributes this difference primarily to differences in wages and equipment costs.[65] On a percentage basis, however, this difference seems to be fairly large and may play a significant role in explaining the difference in economic viability of nuclear power in the United States and France. It remains possible that the standardization of the French nuclear industry may also be responsible for this difference.

### *Financing*

One of the primary economic differences between the American and French nuclear industries is the financing structure for new nuclear power plants. As noted by Fabien Roques et. al., "with its capital intensity and cautionary experiences of engineering difficulties and regulatory creep during construction, new nuclear build is likely to require a substantial risk premium over competing technologies."[66] According to Roques, the average discount rate, essentially the opportunity cost of investing money in nuclear power, for a French nuclear plant is eight percent;

for an American plant, the rate is 12.5 percent.[67] The difference is largely attributable to the government backing of nuclear power in France which helps reduce the risk to the lender.[68] Seemingly small changes in the discount rate can have large impacts on the cost effectiveness of nuclear power generation.[69] Over its lifetime, France's nuclear industry has cost FF 400 billion in 1993 currency: 50 percent was self-financed by EDF, 8 percent was invested by the state and 42 percent was financed by commercial loans.[70] While the American nuclear program has been dependent on private financing in the past, recent legislation obligates the federal government to provide loan guarantees for up to 80 percent the construction cost of new nuclear plants.[71] While this is certainly a step in the right direction by the US government, the lack of proposed new nuclear reactors suggests that further strides will be necessary in order to attract financing at a viable level for economically competitive nuclear power.

### *Reprocessing and Storage*

The reprocessing of spent nuclear fuel is another important distinguishing characteristic of the French commercial nuclear program, though it contributes little, if at all, to the cost-competitiveness of nuclear energy in France. Reprocessing carries the advantage of maximizing the usefulness of nuclear fuel, and thereby reducing the amount of waste generated in the generation process. The trade-off is increased costs; a recent study conducted by the Belfer Center at Harvard University reached the conclusion that "at a reprocessing price of $1000 per kilogram of heavy metal…reprocessing and recycling plutonium in existing light-water reactors will be more expensive than the direct disposal…until the uranium price reaches over $360 per kilogram…"[72] The current price of uranium is currently around $40 per kilogram.[73] Yet, despite the fairly broad consensus that reprocessing is not economically competitive, it still occurs in France. This is partly due to the fact that half of the nuclear fuel that France reprocesses is of foreign-origin, which helps to mitigate some of the costs involved.[74] Although the total costs of reprocessing in France amount to about a billion dollars per year, the difference between reprocessing and not reprocessing, as estimated by the French Government in 2000, is .2 cents/kWh, or five percent the cost of nuclear electricity generation.[75] In recent years, the amount of foreign fuel being reprocessed has virtually dried up, yet the French reprocessing efforts continue; this is largely due to the fact that money spent on building the plants has already been spent, and thousands of jobs would be lost without the effort. Reprocessing in the United States at the price assumed in this study would increase the cost of nuclear electricity .13 cents/kWh. In comparison with the total back-end cost of disposal of .15 cents/kWh, reprocessing would reflect nearly an 80 percent increase in disposal costs.[76]

### *Competitiveness with other fuels*

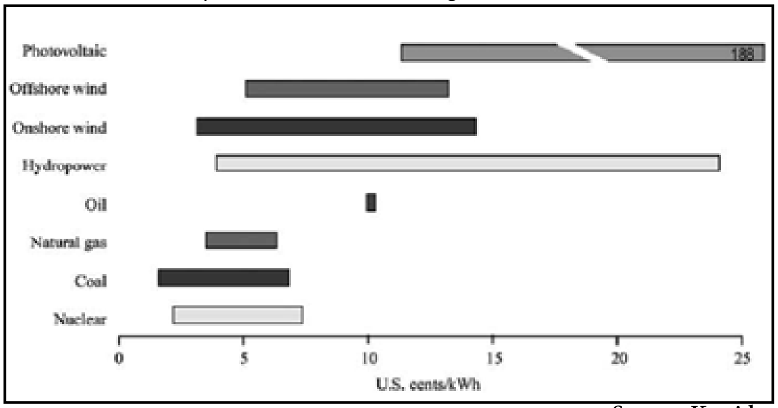
Many analysts note that nuclear energy is not cost-competitive in the United States due to high initial capital costs; however, discrepancies between the US and Europe are also due to differences in the costs of non-nuclear energy between the two. According to Zaleski, the costs of fossil fuel energy production are actually higher in France than they are in the United States.[77] In order to make a relevant comparison, it is useful to consider levelized electricity, which essentially takes into account the total lifetime cost of a power plant and divides by the expected power output of the plant. It is important to note that although the levelised cost provides us with a thorough measure of the costs of a power plant, it does not necessarily reflect investors' perceptions regarding costs. Zaleski notes the following data:

| Fuel Source | United States (MIT Study; 2002 USD) | Europe (EDF, 2004 USD) |
|---|---|---|
| Nuclear | 4.2 – 6.7 cents/kWh | 4.1-5.0 cents/kWh |
| Natural Gas | 3.8 – 5.6 cents/kWh | 5.1 – 5.5 cents/kWh |
| Coal | 4.2 cents/kWh | 4.7 cents/kWh |

According to Zaleski, "the difference in gas and coal estimates may be explained by the different market situations between the US and Europe."[78] It is also evident that nuclear energy in both situations is cost-competitive with gas assuming moderate-to-high gas prices. A second conclusion is that the relative cost of coal is very important for determining the cost competitiveness of nuclear power as an energy source. In France, a combination of these factors has had the result of nuclear energy being the most cost-competitive option of the three. In the US, that is not necessarily the case absent government intervention.

It is also useful to consider the levelized costs of nuclear electricity generation in comparison to the costs of renewable energy in both countries; such a comparison reveals that the costs of non-nuclear energy sources, too, vary between the two countries. Currently, in the United States, non-hydropower sources of renewable energy account for 2.5 percent of domestic energy production; in France, non-hydropower sources account for roughly one percent of domestic energy production.[79,80] In a survey of several contemporary levelized-costs studies, Ioannis Kessides finds the costs of nuclear, coal, and natural gas electricity generation to be lower than those of their renewable counterparts.[81]

Figure 1: Levelised Costs Associated with New Construction for Different Electricity Generation Technologies (US cents/kWh)




Source: Kessides

Analyzing levelized costs is, however, a complex process: the wide ranges in this data are indicative of many varying assumptions regarding plant construction time and life, load factor, fuel prices and other factors.[82] At this point in time, however, it would seem that neither wind nor solar energy is as cost competitive with fossil fuels as nuclear power. It is certain that the costs associated with wind and solar electricity generation will continue to decrease with time; however, as generation IV nuclear power plants develop, it could very well be the case that nuclear power also sees significant price reductions in the future. At this time, nuclear energy looks to be cost-competitive with renewable sources both now and in the future.

## Conclusion

The success of the French civilian nuclear program demonstrates not only that nuclear power can be implemented successfully, but also that it can be done in a way that makes it cost-competitive with fossil fuel-based energy sources. The sources of this success are many. For one, France has built a political consensus around their energy policy that is strong and enduring. The French regulatory system has effectively managed to combine a relatively quick time required for nuclear plant approval with a large enough amount of oversight that ensures that safety protocols are met. The streamlined organization of the French nuclear industry has resulted in substantially lower costs of construction as well as fewer delays in the construction process; France's one utility and one supplier stand in sharp contrast to the patchwork of operators and suppliers that exist in the United States. While there are still issues to be ironed out, particularly in the area of waste, France's nuclear program has achieved its goal of providing a successful independent source of energy for the country.

The United States, on the other hand, has not developed a nuclear industry at all comparable to the dreams and expectations it had in the 1950s and 1960s. As has been analyzed above, there are a large number of factors that are preventing the effective development of the American nuclear industry. It is our opinion that America can and should look to the French example as it begins to develop the foundations of a green, low-carbon economy in the 21st century and beyond. On one hand, we recognize the fact that it will be impossible to transplant the French model into the US; it seems obvious that the America's political structure and national character will not be compatible with a high degree of government involvement in the industry. At the same time, we feel that it is both feasible and advisable for the US to tweak its current system in a manner that is conducive to the growth of a revitalized domestic nuclear industry. The 1989 reforms of the NRC process and the expansion of nuclear loan guarantees in the Renewable Energy Act of 2005 are both steps in the right direction, but hardly sufficient by themselves. We recommend the following measures:

1. The US government can take an active role in building a political consensus around the idea and bringing it to the attention of the public. One scholarly study concluded that for nuclear energy to succeed in a state, "public authorities should take positions by comparing the positive attributes of nuclear power---security of energy supply, absence of harmful emissions including $C0_2$--to some problems of the technology: radioactive waste disposal, the possibility, even if small, of severe accidents, vulnerability to terrorist attacks, influence on the proliferation of nuclear weapons."[83] That is the only way for a real and informed debate to occur within this country.

2. It is imperative that the United States government undertake joint developmental projects alongside nuclear energy producers; government support is vital for getting newer generations of nuclear reactor designs off the ground by providing stable sources of financing and expertise. Additionally, a successful government project can provide reassurance to investors that a given project can be completed under specific budgetary and time constraints. Finally, with regards to the current generation of nuclear reactors, the NRC should designate four reactor designs (as opposed to France's one) as required templates for any future nuclear power plant construction in order to reduce construction costs and to streamline regulatory and safety procedures.

3. The United States government should also institute a carbon tax of some variety, such as the cap-and-trade model currently being debated in Congress, in order to increase the cost of fossil fuel-based electricity generation. In addition, the United States government should designate nuclear power as a clean/renewable energy source so that new nuclear reactors can fill in for current carbon-intensive electricity generation methods. According to the MIT report on Nuclear Power, if carbon dioxide were taxed at $50 per ton, nuclear power would be competitive with coal and natural gas pending a 1-year decrease in average construction time.

Clearly, a nuclear future could exist in the United States if the right steps are taken. Many have come to the conclusion that the government should preferentially invest in these technologies and simply ignore the possibility of nuclear power. However, both renewable sources like solar/wind and nuclear energy can and should play an important role in the energy future of the United States. Nuclear energy has the advantage of being able to provide a baseline production of electricity that operates at a significantly higher up-time than its renewable counterparts; this, in turn, alleviates the need for energy-storage solutions and updates to the underlying infrastructure of electricity transmission. In the context of the imminent threat of global warming, avoiding these short-term obstacles can be very valuable. Additionally, both renewable energy sources and nuclear energy will require significant amounts of government investment in any case; it makes the most sense to make subsidies and incentives available to both sources.

We conclude that nuclear energy should be a major part of the United States' energy policy for the beginning of the 21st century. Our comparative research has demonstrated that a sustainable national nuclear energy program can be politically feasible, economically competitive, and safely and efficiently implemented with the proper regulation. Nuclear power has distinct advantages: the technology exists already and can be easily scaled. It can serve either as a bridge to an all-renewable economy or as a long-term solution by itself pending frequent reevaluation in the future. But if the promise of nuclear technology in the United States is ever to be realized, decisive action will be necessary. §

## Endnotes


1 Nuclear Power in France. Oct. 2009. World Nuclear Association. Dec. 2009 <http://www.world-nuclear.org/info/inf40.html>.

2 Cue, Eduardo. "How France Sees Its Nuclear-Powered Future." *US News and World Report*. 10 Mar. 2009. <http://www.usnews.com/articles/news/energy/2009/03/10/how-france-sees-its-nuclear-powered-future.html>.

3 Zaleski, Pierre C. "The future of nuclear power in France, the EU and the world for the next quarter-century." Nonproliferation Policy Education Center Feb. 2005:

4 Holt, Mark, and Carl E Behrens. "Nuclear Energy in the United States." Almanac of Policy Issues. 23 July 2003. <http://www.policyalmanac.org/environment/archive/nuclear_energy.shtml>.

5 Daemen, Thomas J. "Comment: The Need for Liability Constraints in Succesful high-Technology Development: A Comparison of the French and US Commercial Nuclear Programs." *Northwestern Journal of International Business & Law 13.3* (1993): 684-710. LexisNexis Academic Universe. 17 Nov. 2009.

6 Delmas, Magali, and Bruce Heiman. "Government Credible Commitment to the French and American Nuclear Power Industries." *Journal of Policy Analysis and Management 20.3* (2000): 433-456. EBSCOhost Business Source Preimier.

7 Daemen, Thomas J.

8 Ibid.

9 Ibid.

10 Ibid.

11 Delmas, Magali, and Bruce Heiman.

12 Nuclear Power in France.

13 Ibid.

14 Palfreman, Jon. "Why the French like nuclear energy". PBS. Dec. 2009 <http://www.pbs.org/wgbh/pages/frontline/shows/reaction/readings/french.html>.

15 Jones, Jeffrey M. Support for Nuclear Energy Inches Up to New High. Mar. 2009. Gallup. Dec. 2009 <http://www.gallup.com/poll/117025/support-nuclear-energy-inches-new-high.aspx>.

16 Palfreman, Jon.

17 Ibid.

18 Hargreaves, Steve. "Nuclear renaissance -- not dead yet". Nov. 2009. Cnn. <http://money.cnn.com/2009/11/02/news/economy/nuclear_renaissance/index.htm>.

19 Zaleski, Pierre C.

20 Nivola, Pietro S. "The Political Economy of Nuclear Energy in the United States." *Brookings Policy Brief Series 138*. Sept. 2004:

21 Palfreman, Jon.

22 Massachusetts Institute of Technology. “The Future of Nuclear Power: Overview and Conclusions.” *The Future of Nuclear Power.*
23 Delmas, Magali, and Bruce Heiman.
24 Ibid.
25 Ibid.
26 Ibid.
27 Ibid.
28 Bredimas, Alexandre, and William J Nuttall. “An International Comparison of Regulatory Organizations and Licensing Procedures for New Nuclear Power Plants.” Energy Policy 36 (2007): 1344-1354. Elseveir. Web. 30 Nov. 2009.
29 David, Paul A, and Geoffery S Rothwell. “Measuring standardization: An Application to the American and French Nuclear Power Industries.” European Journal of Political Economy 12 (Sept. 1994): 291-308. Elsevier. Web. 30 Nov. 2009.
30 Delmas, Magali, and Bruce Heiman.
31 Bredimas, Alexandre, and William J Nuttall.
32 Ibid.
33 Ibid.
34 Lewis, Neal H. “Article: Interpreting the Oracle: Licensing Modifications, Economics, Safety, Politics, and the Future of Nuclear Power in the United States.” Albany Law Journal of Science & Technology 16.27 (2006): 27-58. LexisNexis Academic. Web. 30 Nov. 2009.
35 Ibid.
36 Ibid.
37 Ibid.
38 David, Paul A, and Geoffery S Rothwell.
39 Delmas, Magali, and Bruce Heiman.
40 Hore-Lacy, Ian. Safety of nuclear power reactors. Ed. Cutler J. Cleveland. June 2009. the encyclopedia of earth. Dec. 2009 <http://www.eoearth.org/article/Safety_of_nuclear_power_reactors>.
41 Nero, Anthony V. “Reactor Safety.” Nuclear Power: Both Sides. Ed. Michio Kaku and Jennifer Trainer. New York: W.W. Norton & Company, 1982. p 86.
42 Ibid.
43 Massachusetts Institute of Technology.
44 Ibid.
45 About NRC. Sept. 2009. United States Nuclear Regulatory Commission. <http://www.nrc.gov/about-nrc.html>
46 Feinstein, Jonathan S. “The Safety Regulation of U.S. Nuclear Power Plants: Violations, Inspections, and Abnormal Occurrence.” *Journal of Political Economy 97.1* Feb. 1989: 115-54.
47 Gunter, Paul and Mary Olson. Davis-Besse Nuclear Plant Comes Close To Disaster As Lax Regulator Places Company Interests Ahead of Public Safety. Mar. 2002. Nuclear Information and Research Service. Dec. 4 <http://www.nirs.org/press/03-13-2002/1>.
48 Fact Sheet on Improvements Resulting from David-Besse Incident. Sept. 2009. United States Nuclear Regulatory Commission. 4 Dec. 2009 <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-davis-besse-improv.html>.
49 Ibid.
50 Probabilistic Safety Assessment: An analytical tool for assessing nuclear safety. n.d. 4 Dec. 2009 <http://www.nuce.boun.edu.tr/psaover.html>.
51 Palfreman, Jon.
52 Cue, Eduardo.
53 Nero, Anthony V.
54 Nuclear Energy Agency, International Energy Agency, and Organization for Economic Cooperation and Development. "Projected Costs of Generating Electricity: 2005 Update". Paris, France: OECD Publications, 2005.
55 Ibid.
56 Thomas, Steve. The Economics of Nuclear Power: Analysis of Recent Studies. N. pag. Public Services International Research Unit, University of Greenwich, July 2005. Web. 30 Nov. 2009. <www.psiru.org/reports/2005-09-E-Nuclear.pdf>.
57 Nuclear Energy Agency, International Energy Agency, and Organization for Economic Cooperation and Development.
58 Ibid.
59 Roques, Fabien E, et al. “Nuclear Power: A Hedge Against Uncertain Gas and Carbon Prices?” *The Energy Journal 27.4* (2006): 1-23. Google Scholar.
60 David, Paul A, and Geoffery S Rothwell.
61 The University of Chicago. *The Economic Future of Nuclear Power*.
62 Zaleski, Pierre C.
63 David, Paul A, and Geoffery S Rothwell.
64 Ibid.
65 Nuclear Energy Agency, International Energy Agency, and Organization for Economic Cooperation and Development.
66 Roques, Fabien E, et al.
67 Ibid.
68 Ibid.
69 Thomas, Steve. *The Economics of Nuclear Power: Analysis of Recent Studies*. Public Services International Research Unit, University of Greenwich, July 2005. <www.psiru.org/reports/2005-09-E-Nuclear.pdf>.
70 Nuclear Power in France.
71 Nuclear Energy Institute. “Financing New Nuclear Power Plants.” Nuclear Energy Institute. <http://www.nei.org/keyissues/newnuclearplants/policybriefs/financingnewplants>.
72 van der Zwaan, Bob. “The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel.” Belfer Center for Science and International Affairs at John F. Kennedy School of Government Dec. 2003.
73 Ibid
74 Von Hippel, Frank N. "Plutonium and Reprocessing of Spent Nuclear Fuel." Science 293.5539 (2001): n. pag. Google Scholar. Web. 30 Nov. 2009. <http://www.princeton.edu/sgs/publications/articles/Sciencev293n5539.pdf>.
75 Ibid.
76 van der Zwaan, Bob.
77 Zaleski, Pierre C.
78 Ibid.
79 Energy Information Administration. “Electricity Explained.” *Electricity in the United States*.
80 France. Commiserat General au Developpement Durable. L'electricite en France en 2008.
81 Kessides, Ioannis N. Nuclear Power and Sustainable Energy Policy: Promises and Perils. Google Scholar. The World Bank Research Observer, 30 July 2009. Web. 4 Dec. 2009.
82 Ibid.
83 Ibid.