Nuclear Economics & Safety
A Review of the Evidence
April 2017
U.S. vs. France
U.S. vs. France

Economic study of US and French reactor costs.

Best data.

Advanced economic methods

Note: Overnight costs are shown for the year in which plants came online.
“The French have two kinds of reactors and hundreds of kinds of cheese, whereas in the United States the figures are reversed.”

Ivan Selin, former NRC Commissioner

What lowers costs?

- Long-term commitment
- Standard design
- Centralization (Utility management of construction)
- Same Architect-Engineer.
- More reactors on same site.
- Larger reactors

Centralization reduces costs

“A vertically integrated utility reduces potential asymmetric information problems between the utility and the firms involved in the construction of nuclear reactors, leading to cost reductions.”

Diverse Designs Increases Costs

“When the diversity of nuclear reactors is high, the nuclear safety authority has to assess the potential risks of different models of reactors which prevents rapid monitoring and licensing procedures, due to the heterogeneity in demand which could lead to supply chain constraints and construction delays.”

“Contrary to other energy technologies, innovation leads to construction costs increases.”

Construction delays after TMI
Regulations increased dramatically in 12 Year Period

Source: EIA, Operating Costs of Nuclear Power Plants in the U.S., 1994
New regulations & delays behind higher costs

- “A one-year delay in the start of construction results in costs that are higher by 10.6 percent.”

- “[T]here was an escalation in real construction costs that was independent of factors such as size and lead-times…attempts to control costs should also focus on the regulatory, and other non-pecuniary factors causing the escalation in overnight costs.”

Source: EIA, Operating Costs of Nuclear Power Plants in the U.S., 1994
Construction experience did drive down costs — but was canceled out by new regulations.

In all studies except Zimmerman, “firm learning” is a measure of the doubling of experience, either by constructor or architect-engineer. Zimmerman measured completion of first unit (-11.8%) and second unit (-4%).

Lessons from South Korea
South Korea cost reduction over time

Overnight construction cost (US$/kWe)

<table>
<thead>
<tr>
<th>Year of commercial operation</th>
<th>CP1 (France) (1000 MW)</th>
<th>OPR-1000 (1000 MW)</th>
<th>WH 60 (558 MW)</th>
<th>WH F (1000 MW)</th>
<th>CANDU 6 (660 MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>4200</td>
<td>3450</td>
<td>2700</td>
<td>1950</td>
<td>1200</td>
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<tr>
<td>1980</td>
<td>3600</td>
<td>3000</td>
<td>2400</td>
<td>1700</td>
<td>1000</td>
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<tr>
<td>2020</td>
<td>1200</td>
<td>1000</td>
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</tbody>
</table>

Source: EP Energy Progress Tracker, 2017. Email info@environmentalprogress.org for more information.
“Only when Koreans learned how to replicate and verify it properly after several repeat projects did the time arrive to move on to improving and enhancing the safety and economy without sacrificing the merits of standardization.”

Will smaller be cheaper?
“Larger nuclear reactors take longer to build but are also cheaper per MWe.”

“One of the main factors negatively affecting the capital costs of the SMRs [Small Modular Reactors] is the lack of economy of scale.

As a result, the specific (per MWe) capital costs of the SMR are expected to be tens to hundreds of percent higher than for large reactors.”

“Since large initial orders SMRs are needed to launch production process it is important to know who could be the first customers, and how many SMR designs will really be deployed in the near future.”

Waste
All US “waste” can be stacked 50 ft. high on football field
Q: You don't want [the nuclear waste] problem solved until the industry --

A: No, because it'll just try to prolong the industry, and expand the second generation of nuclear plants subsidized by the tax payer.

— Ralph Nader, 1997, PBS Frontline, “Nuclear Reaction”
“[P]romising to increase the reactor’s fuel efficiency by 75 times is the rough equivalent of saying that, in a single step, you'd developed a car that could get 2,500 miles per gallon.”

“…overstated promises matter because they run the risk of further undermining those negative public perceptions you mention, and making investors more skeptical of the space.”
Will newer designs allay public fears?
Advanced Nuclear Vision (1950s - 2000s)

LWRs → Reprocessing
   Clinch River
   La Hague → Fast Reactors
      EBR-I
      EBR-II
      IFR
      Phoenix
      Superphenix

Waste Repository
Advanced Nuclear Vision (1950s - 2000s)

LWRs ➔ Reprocessing ➔ Fast Reactors

Clinch River
La Hague

EBR-I+II —> IFR
Phenix —> Superphenix

Waste Repository

“hot particles”!

“can explode with their fast neutrons”!
“Imagine the consequences from a fertilizer truck bomb detonated next to a "containment-lite" [molten-salt] reactor with millions of curies of lethal radioactivity to containment the environment for many decades. That would truly be a nuclear nightmare.” (2001)

“[The Liquid Flouride Molten Salt Reactor’s] serious safety issues associated with the retention of fission products in the fuel may not be resolved….LFTRs also present proliferation and terrorism risks... (2012)

— David Lochbaum, Union of Concerned Scientists, 2012
Today’s water-cooled reactors were the underdogs...
“This [nuclear innovation] amendment expends taxpayer resources to expand the already heavily subsidized nuclear industry's research arm in clearly uneconomic areas despite its demonstrated risks.

— NRDC, Sierra Club, Earthjustice, Environment America, League of Conservation Voters, Public Citizen, Jan 27, 2016
Will non-light water designs be cheaper?
Cost of nuclear by reactor type

...that came from behind
Why light water won

- British and French preferred gas-cooled and resisted light-water throughout 50s and 60s.
- Germans and French utility EdF wanted to benefit from American operational experience.
- EdF pushed for LWR after DeGaulle died.
- Soviets independently chose light water
- South Koreans independently chose light water
- Brits paid heavy price for sticking with gas-cooled designs
“Three different types of power reactors... were about equally successful commercially in the world market and the Korean nuclear community was split... a technical feasibility study report... recommended the US reactor types (preferably PWR) over the British one for the technical merits and reactor design characteristics.”

Other reactor designs

Gas-cooled & sodium-cooled fast reactors proved complicated & more expensive than water-cooled.

Sodium-cooled developed at same time as light water and was used in submarine.

Heavy-water makes proliferation easier and was chosen by India and South Korea for that purpose.


What makes nuclear safe and cheap?
Improved efficiency of U.S. nuclear plants

Can nuclear get any safer?

Health effects of electricity generation in Europe by primary energy source

**Source:** Markandya, A. & Wilkinson, Electricity generation and health. Lancet 2007; 370:970-90
Operator Performance Very High and Still Rising

Timely and accurate actions taken by plant personnel (emergency classifications, protective action recommendations, and notifications to offsite authorities) in drills and actual events.

Plant workforce participation in key events is high & rising

This indicator is the percentage of participation by key plant personnel in drills or actual events in the previous 2 years, indicating proficiency and readiness to respond to emergencies.

Heather Matteson

Mother, Environmentalist, Reactor Operator
“Me inspecting Diablo Canyon containment dome. It is in pristine condition.”
**Me:** What do you think of Diablo Canyon?

**Woody:** It’s a great plant.

**Me:** What makes you say that?

**Woody:** Because the people who work there care!

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*Woody Epstein, Nuclear Risk Analyst*
What  Who makes nuclear safe
Rickover’s Wisdom
“An academic reactor or reactor plant almost always has the following basic characteristics:
(1) It is simple. (2) It is small. (3) It is cheap. (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose. (7) Very little development will be required. It will use off-the-shelf components. (8) The reactor is in the study phase. It is not being built now.

“On the other hand a practical reactor can be distinguished by the following characteristics:
(1) It is being built now. (2) It is behind schedule. (3) It requires an immense amount of development on apparently trivial items. (4) It is very expensive. (5) It takes a long time to build because of its engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated.”

— Hyman Rickover, 1953