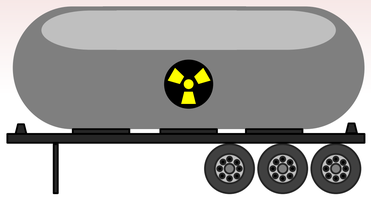

Investigating the Economic Viability of Small, Modular Reactors

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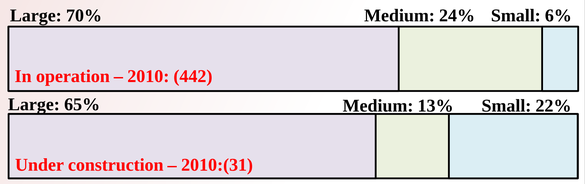
Background Information

There has been much talk recently of the potential of small, modular nuclear reactors (SMRs) to become big players in the field of energy provision, whether for base load power production or for remote applications. SMRs have a capacity of 300MWe or less, and the reasons behind their attractiveness include

1) the simplicity of their design (they do away with most of the plumbing associated with larger plants, nuclear or otherwise),
2) the economies of scale associated with the construction of multiple units on an assembly line,
3) the lower initial capital outlay needed to construct them,
4) their adaptability to settings with less-developed infrastructure (ones that cannot handle a conventional nuclear power plant), and
5) the inherent, passive safety measures they incorporate. These reactors are designed to shut down automatically in the event of any disruption of plant operation.

Number and size of nuclear reactors: the dominance of large reactors may be waning.



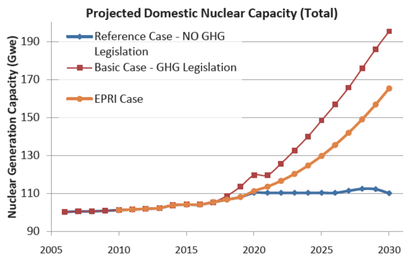
SMR Technologies

Given how immature the field is, there is a variety of SMR technologies. Major players include:

1) Light water designs (LWRs), such as the ones being developed by Babcock & Wilcox, Westinghouse, and NuScale (all based in the USA).
2) High temperature reactors, such as the ones being developed by PBMR Limited (South Africa), Huaneng (China), and Rosatom (Russia).
3) Molten salt reactors, such as the ones being developed by ITHMSO and Toshiba (both based in Japan).
4) Fast neutron reactors, such as the ones being developed by Hyperion and GE-Hitachi (both based in the USA).
5) Exotic designs, like TerraPower's Traveling Wave Reactor (USA).

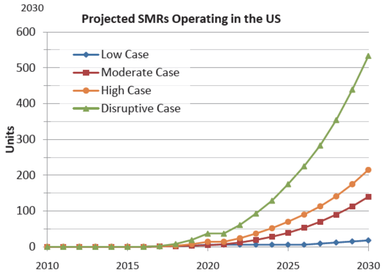
Market Potential of SMRs

A number of scenarios are envisioned both by the EIA and by entities like EPRI and EPI. Estimates for market penetration of SMRS are varied:



EPI estimates of projected increase in US nuclear capacity. Data for GHG legislation and reference cases taken from EIA models.

EPI estimates of the cumulative number of SMRs operating in the US for 4 different economic scenarios. Estimates range from 20 to 533 units.



Solan, David, Geoffrey Black, Michael Louis, Steve Peterson, Larry Carter, Sam Peterson, Ryan Bills, Brogan Morton, and Edward Arthur. *Economic and Employment Impacts of Small Modular Nuclear Reactors*. Rep. Boise, Idaho: Energy Policy Institute, Jun 2010.

SMR Economics

Because most SMRs are still in the design stage, economic considerations have taken a back seat to the engineering. It is unclear how much SMRs will eventually cost. This is due to many factors.

1) There are uncertainties surrounding licensing: how fast will it take to license these new designs? How comfortable will regulatory agencies like the NRC be with unproven technologies (like 'passive safety features')? Will the NRC take steps to ease the deployment and operation of SMRs (by, for example, agreeing to smaller emergency planning zones and fewer operators)? How will the NRC handle licensing of exotic technologies (non-LWR designs with which it has no previous experience)?

Licensing issues have financial ramifications. The NRC has yet to decide on (1) the annual fee for multi-module facilities, (2) insurance and liability issues, and (3) whether to provide funding for decommissioning.

2) Will the history of cost over-runs we have witnessed with larger reactors plague SMRs as well? Or will SMR vendors make full use of the advantages inherent to modularity, like mass production in a controlled factory setting and the utilization of off-the-shelf components where possible to streamline the manufacturing process?
3) Will much learning be realized? Can we overcome the loss of economies of scale by making full use of the economies inherent to SMRs, like (1) technical progress economies, (2) mass production economies, (3) factory fabrication economies, (4) learning economies, and (5) co-siting economies?

All current estimates are based on individual authors' engineering judgment.

SMR-specific features and their contribution to profitability of SMRs

	Generation costs	Financial costs	Market opportunity
Scalability		*Investment deferral*	*Market matching*
Investment flexibility		*Reduced risk premium*	*Market matching*
Plant-grid matching			*Market suitability*
New design strategy	*Technological progress*		
Cogeneration			*Market suitability*

Common NPP features and their contribution to profitability of SMRs

	Generation costs	Financial costs	Market opportunity
Size	***Economies of scale***		
Modularization	*Fabrication economies*		
Modularity	*Learning economies*		
Multiple units	*Co-siting learning*		
Front-end investment			*Reduced entry barriers*

Adapted from Carelli, et al. Economic features of integral, modular, small-to-medium size reactors. *Progress in Nuclear Energy.* 2010.

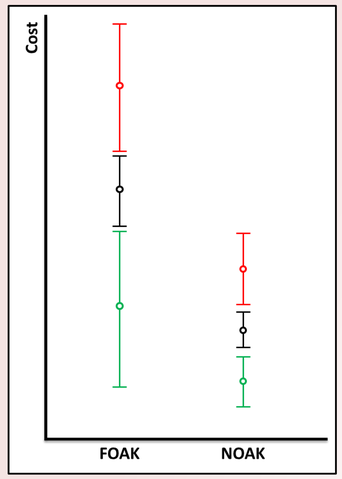
Objective and Proposed Methodology

Is there consensus as to what SMR costs might be? Is the cost of a conventional reactor serving as an anchor for the industry?

We plan to perform an expert elicitation on a sample of nuclear engineers and supply chain engineers working for two major US-based SMR vendors. Both vendors are in the process of designing light water-based SMRs. The results of our research will show one of the following trends emerging:

1) All elicited costs are clustered around the cost of a large reactor (with an appropriate margin of error).
2) Elicited costs are anchored around that of a large reactor, but they do vary significantly from one expert to another.
3) Consensus exists as to whether SMR costs will be higher or lower than those of conventional reactors.

Results



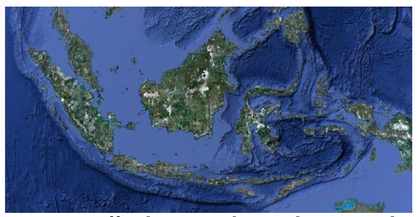
Culture as consensus:

- Has the industry reached a consensus – internally – on what SMR costs will be?
- Is the consensus strong enough to base projections on? Do elicited costs vary widely?
- Is the industry using the cost of large reactors as an anchor for SMR costs?
- Do experts agree that the potential for learning with SMRs will negate the losses of economies of scale?

If a consensus does emerge surrounding the costs of first-of-a-kind (FOAK) and Nth-of-a-kind (NOAK) light water SMRs, we can then begin to map where these SMRs would be viable, both today (FOAK) and when the industry matures (NOAK). We can expand this analysis to locales vendors suggest are especially attractive for SMRs, given their inherent advantages. This analysis would involve looking at, among other factors,

1) a nation's (or entity's) ability to finance the costs associated with buying and operating SMRs,
2) the state of that entity's nuclear regulatory framework, and
3) the state of its electric power infrastructure.

Off-grid: Ruby, Alaska



Difficult geographies Indonesia; India

Oil and gas exploration, Kara Peninsula, Russia

Infrastructure that cannot handle large reactors: Vietnam

We can either investigate a number of specific case studies (above) , or we can apply our rubric internationally (right).