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Review

Small modular reactors and the future of nuclear power in the United States

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ABSTRACT

Small modular reactors are the latest "new" technology that nuclear advocates tout as the game changer that will overcome previous economic failures of nuclear power. The debate over SMRs has been particularly intense because of the rapid failure of large "nuclear renaissance" reactors in market economies, the urgent need to address climate change, and the dramatic success of alternative, decentralized resources in lowering costs and increasing deployment. This paper assesses the prospects for SMR technology from three perspectives: the implications of the history of cost escalation in nuclear reactor construction for learning, economies of scale and other process that SMR advocates claim will lower cost; the challenges SMR technology faces in terms of high costs resulting from lost economies of scale, long lead time needed to develop a new design, the size of the task to create assembly lines for modular reactors and intense concern about safety; and the cost and other characteristics – e.g. scalability, speed to market, flexibility, etc. – of available alternatives compared SMR technology. The paper concludes that the decision of the major vendors (Westinghouse and B&W) to dramatically reduce SMR development efforts reflects the severe disadvantages that SMR technology faces in the next several decades.

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1. Introduction

1.1. Purpose

This paper presents an evaluation of the prospects for development and deployment of significant numbers of Small Modular Reactors (SMR) in the mid-term through the lens of nuclear power's fifty year struggle to be cost competitive with alternative technologies in the United States.

- In that 50 year period there was one round of deployment of a significant number of reactors in the 1970s and 1980s, which came to be known as the "Great Bandwagon Market." It ended up with the number of reactors canceled exceeding the number that were built [67,81]
- A second effort to start another round of major construction,[1] known as the "Nuclear Renaissance," never got off the ground.[2] Only 10 percent of the reactors that were put on the table in response to the regulatory streamlining and financial incentives in the Energy Policy Act of 2005 went into construction and those projects suffered substantial delays and cost overruns [34].
- The economic woes of nuclear power in the U.S. have now extended to aging reactors,[35,39] with five retired early, most major uprates canceled and over two dozen more declared at risk of early closure for economic reasons [41].

The primary reaction of nuclear advocates to these setbacks has been to blame policymakers in one way or another[3] and simultaneously put forward new technologies that they claim address the obvious problems of the old technology. Heralded as a new technology that will solve many of the problems that commercial nuclear power has encountered, SMR technologies fit neatly into this pattern.[4] Yet, even before SMR technology has gotten off the drawing board, it has begun to exhibit the same pattern that has afflicted prior efforts to kick start the industry, with two of the three leading U.S. SMR developers dramatically throttling back on their SMR efforts [11,47,48,63,91,123].

The ingredients for failure have been similar throughout the history of the commercial nuclear industry. The technology proves to be uneconomic for several reasons:

- Initial cost estimates prove to be wildly optimistic as design and construction realities set in.
- Cost escalation results from a combination of the difficulty of executing extremely complex projects and the demands of nuclear safety.
- As the design or construction process unfolds, it becomes clear that there are a number of alternatives available that are less costly and less risky than the construction of new reactors.

However, the current round of debate involves other, more important and ominous elements. The industry is pushing nuclear as an indispensable cornerstone of climate policy, [20,149,146,147,128,13,124,112] while launching a broad campaign to improve nuclear prospects by attacking competing technologies. The attacks include vigorous efforts to alter the market price mechanisms in the Upper Midwest and the Northeast, where the operating aging reactors were closed [38,143] and an attempt to undermine the policies that promote alternative approaches to meeting the need for electricity [30,83,150].

Thus, the 50-year debate over commercial nuclear power is not only being repeated with SMR technology, but it has taken on greater importance. It is not only about the fate of nuclear power, it is about the fundamental direction of electricity and climate policy. A thorough review of the prospects for SMR technology, as the potential savior of nuclear power and a major contributor to climate policy, is an ideal lens through which to view the unfolding debate.

1.2. Approach

This paper takes a broad social science perspective on the economic challenges facing SMRs by emphasizing and locating SMR technology within the patterns of analysis and debate that have recurred in the three rounds of proposed nuclear expansion in the United States. Throughout its history, the fate of nuclear power has been determined by its political economy, in the classic sense of "examining how political forces affect the choice of economic policies,"[5] as much as its basic economics. The resolution of the debate over nuclear power at the pivotal moment of initiation of policies to address climate change is very much a question of the political choices that society will make about how to meet the need for electricity in a low carbon future.

Sections 1–6 briefly describes what SMRs are and how they fit in five recurring themes in the history of commercial nuclear power in the U.S. – the nuclear hype cycle, the rush to market, the absence of learning effects, the inability to estimate costs and nuclear safety and nuclear economics. These traits that are endemic to nuclear technology contribute to its ultimate failure in market economies.

Sections 7–10 examine the economics of SMR technologies from four perspectives – the cost per unit of output, the magnitude of the effort to create an SMR assembly line, demand side characteristics like size, flexibility, time to market and non-economic factors, and the competition with alternatives in terms of cost and cost trends. It concludes by tying the historical and contemporary factors that cast considerable doubt on the economic viability of SMR technologies to the decision of the leading vendors to throttle back their investment in its development.

[1] A figure of 100 reactors was used by Senator Lamar [5].

[2] [34,36,37], 2012c, provide accounts of the difficulties in the ongoing construction in Georgia and South Carolina. The story is similar in other advanced industrial market economies (e.g. Japan, France, Germany, the United Kingdom) that were seen as the potential leaders in deploying a new generation of nuclear reactors [130,56]. Nuclear construction activity is now concentrated in former communist nations, half in China, a quarter in former members of the Soviet Bloc. http://www.world-nuclear.org/info/current-and-future-generation/plans-for-new-reactors-worldwide/.

[3] The perennial target is licensing and safety regulation (see e.g. [23,34]), while the plight of aging reactors is being blamed on electricity market design [37].

[4] An influential University of Chicago study was entitled—*Small Modular Reactors—Key to Future Nuclear Power in the U.S.* [126]; the Senior Director of Policy Development for the Nuclear Energy Institute characterized SMRs as an "elegant evolution relative to large light water reactor technology, one whose development over the next decade will kick start an entire industry [110]. Other operative phrases were—last best hope ([141,99], also [106]), path forward [40].

[5] A rapidly growing mainstream literature from the 1970s has expanded... toward examining how political forces affect the choice of economic policies, especially as to distributional conflicts and political institutions... *Political economy* most commonly refers to interdisciplinary studies drawing upon economics, sociology, and political science in explaining how political institutions, the political environment, and the economic system—capitalist, socialist, or mixed—influence each other [153]. The study and use of how economic theory and methods influences political ideology. Political economy is the interplay between economics, law and politics, and how institutions develop in different social and economic systems, such as capitalism, socialism and communism. Political economy analyzes how public policy is created and implemented. http://www.investopedia.com/terms/p/political-economy.asp. Political Economy. Until recent times the common name for the study of economic process. The term has connotations of the interrelationship between the practical aspects of political action and the pure theory of economics. It is sometimes argued that classical political economy was concerned more with this aspect of the economy and that modern economists have tended to be more restricted in the range of their studies ([123], p. 342).