Innovation in Nuclear Technology: An Academic Perspective

Electricity Markets Are Changing: So Must Nuclear Power

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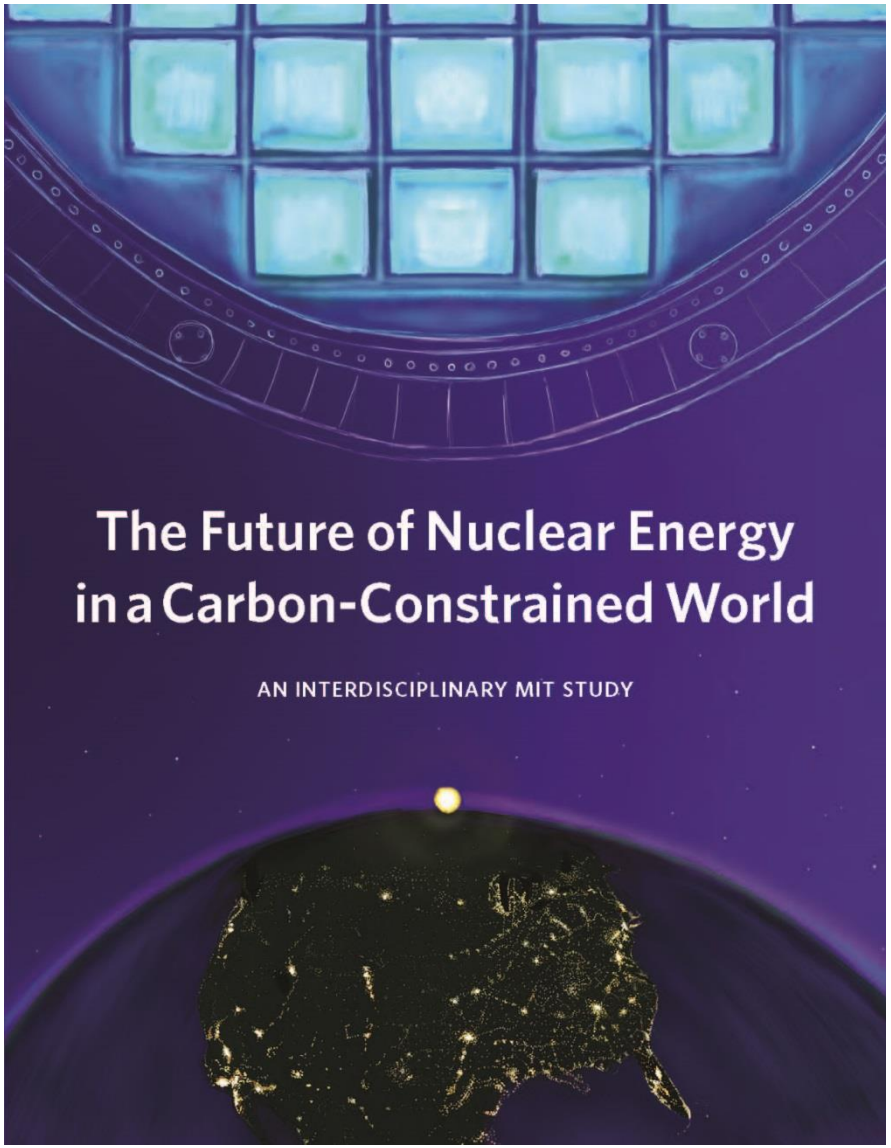
The Challenge: Changing Electricity Markets

Cost Control is Critical

Nuclear Required for Affordable Electricity

Nuclear Replaces Fossil Fuels as the Dispatchable Energy Source



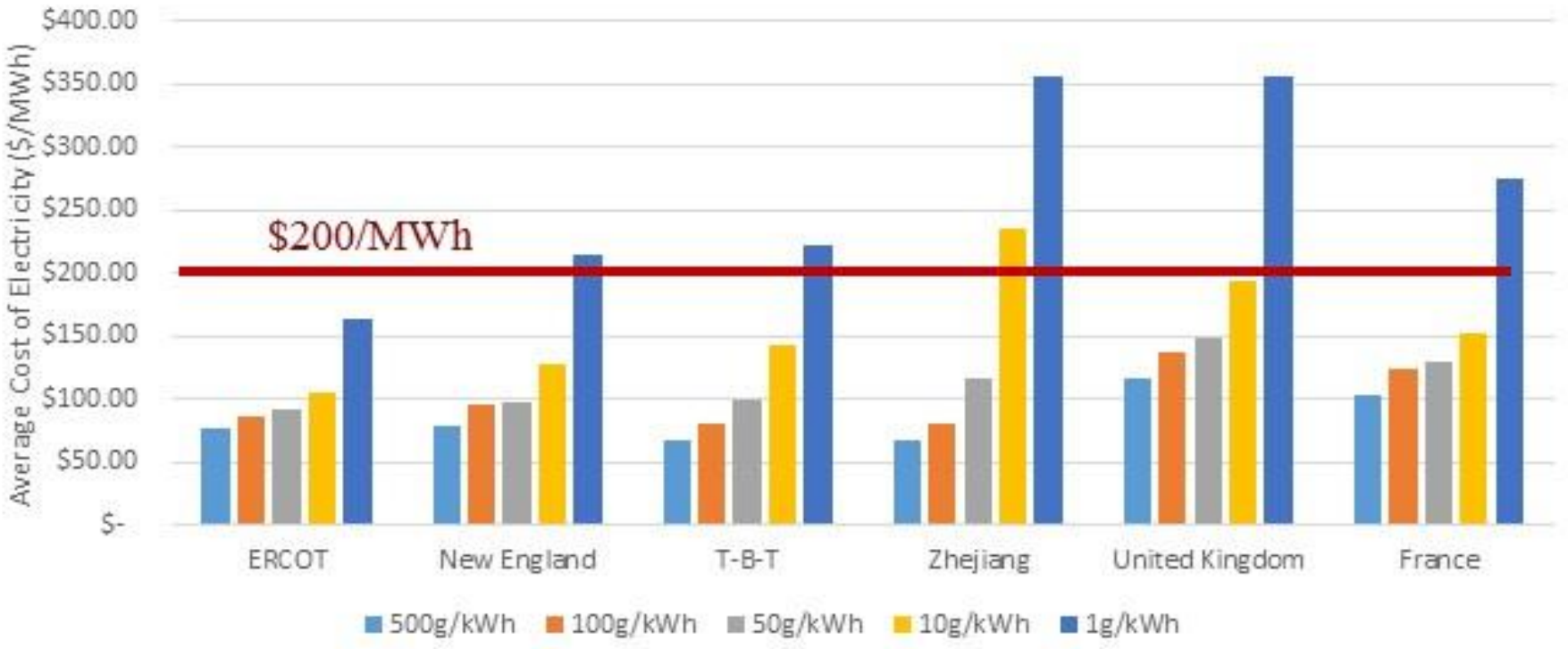
https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf

Average Cost of Electricity for Different Parts of the World with Different Carbon Constraints

Average Cost of Electricity (All Technologies Allowed) Versus Carbon Dioxide Constraint

Average Cost of Electricity for Different Parts of the World with Different Carbon Constraints

Without Using Nuclear Energy



Average Cost of Electricity for Non-Nuclear Scenarios versus Carbon Dioxide Constraint

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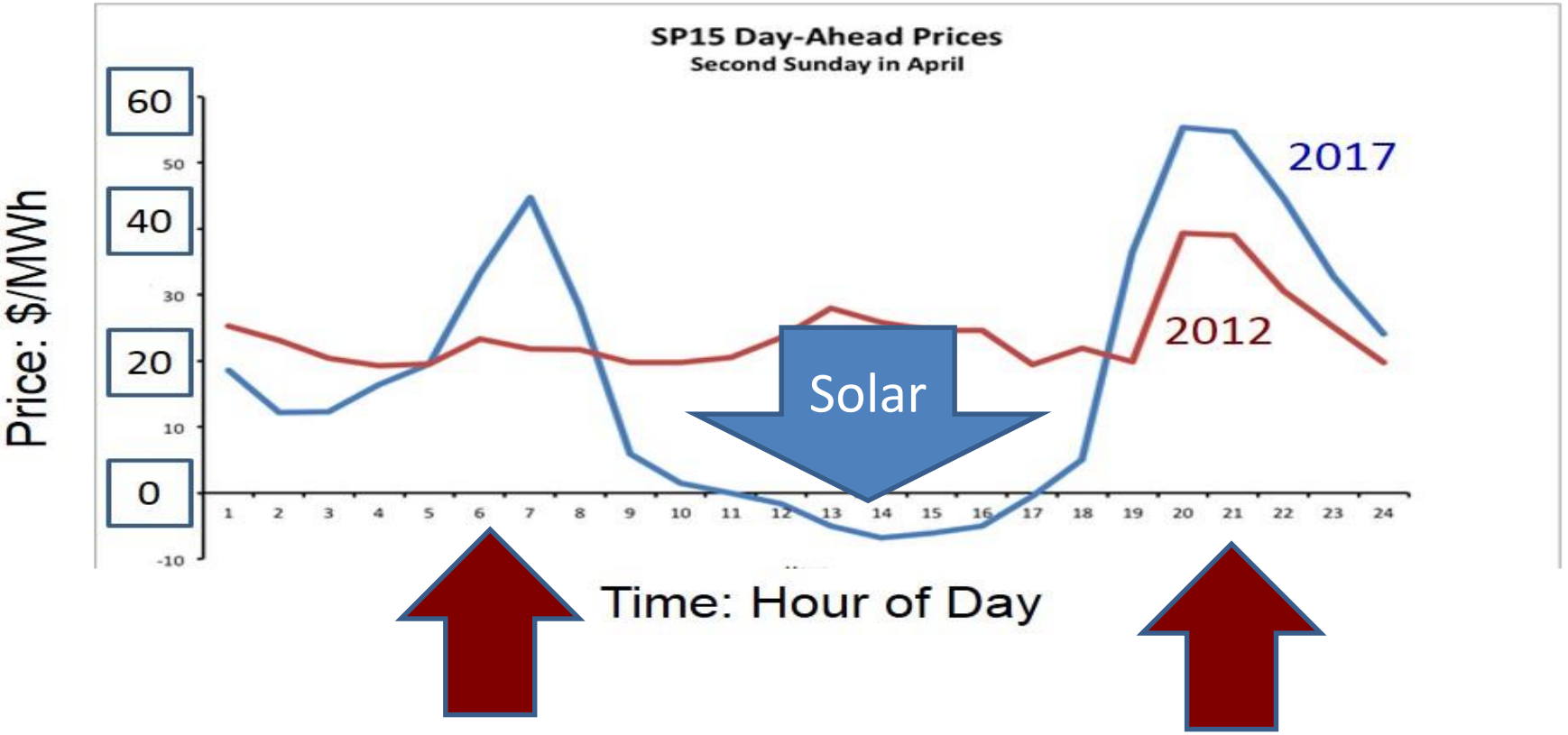
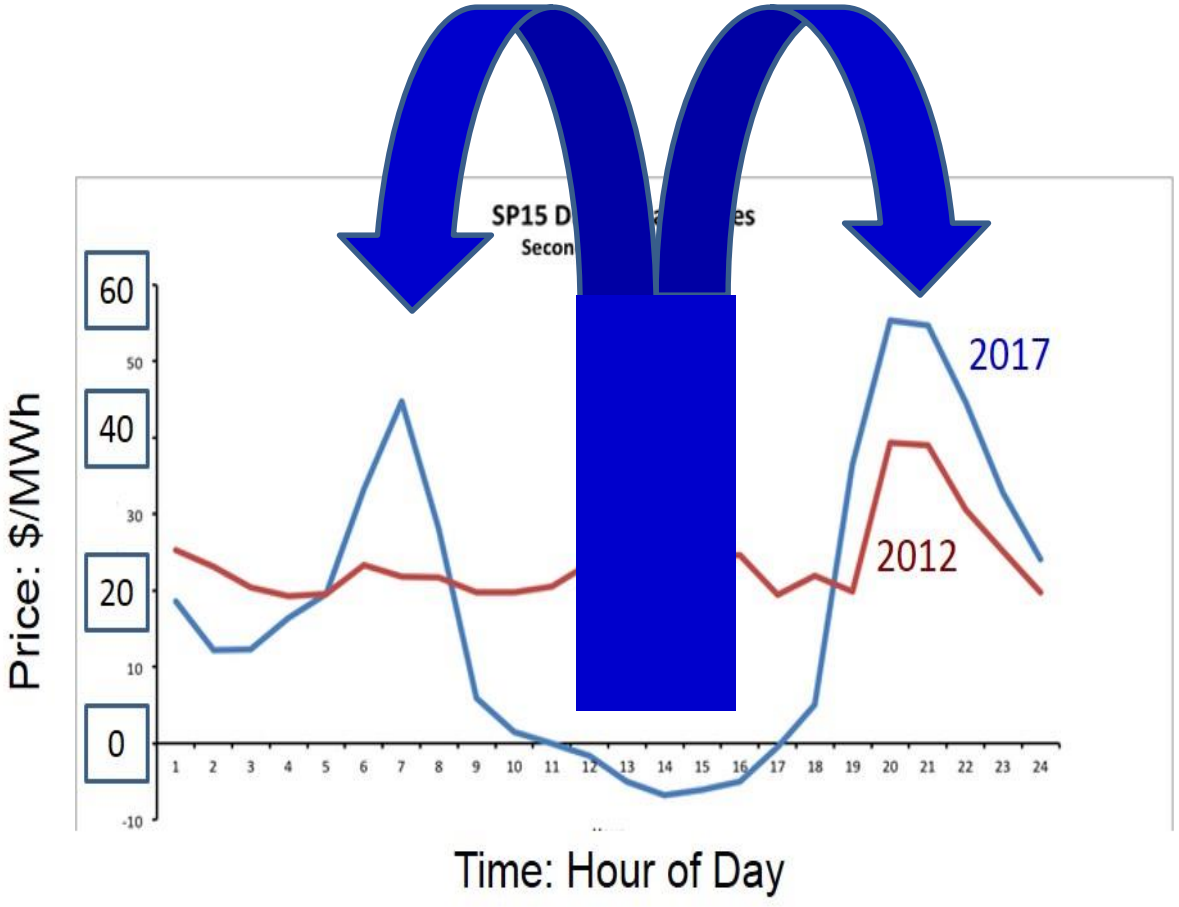
Cost Increase Because Renewables Non-Dispatchable

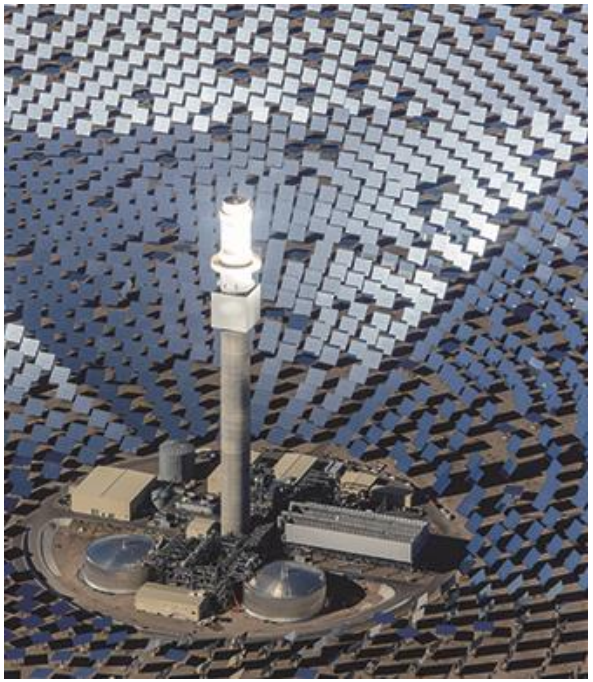
But the Role of Nuclear Energy Changes from Base-Load to Variable Electricity Output



Require Variable Nuclear Electricity Output to Partly Replace the Role of Fossil Fuels

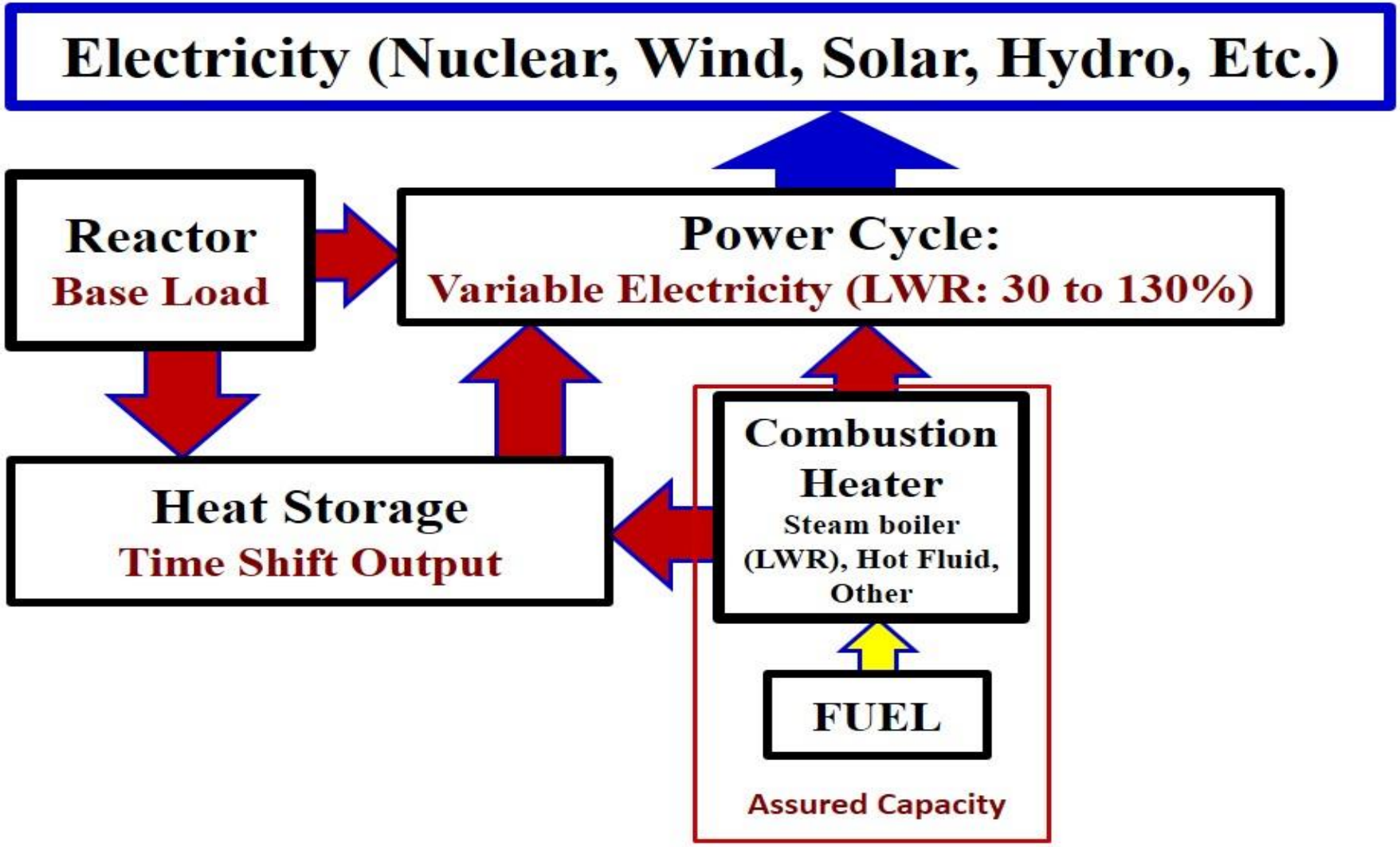
Need Heat Storage to Move Nuclear Output From Times of Low Prices to High Prices





Solar Power Towers Use Gigawatt-Hour Heat Storage to Avoid Selling Electricity When Low Prices

Need Nuclear Reactors With Variable Output and Assured Peak Generating Capacity



Conclusions

- In a low-carbon world, nuclear energy replaces fossil fuels as the dispatchable source of electricity
- Reactor choices for variable electricity to the grid
  - Load following
  - Base-load reactor operation with storage and variable electricity to the grid
- The economic Gen-IV reactor will be the reactor with economic variable output, not necessarily the lowest levelized cost

Questions?

Markets

Electricity Generation

Heat Storage (Electricity Revenue)

Assured Capacity (Capacity Revenue)

Biography: Charles Forsberg

Dr. Charles Forsberg is the Director and a Principle Investigator of the DOE Integrated Research Project on Fluoride-salt-cooled High-Temperature Reactors (FHRs). His research includes large-scale heat storage including Firebrick Resistance-Heated Energy Storage (FIRES) and utility-scale heat storage. He teaches at MIT the fuel cycle and nuclear chemical engineering classes. Before joining MIT, he was a Corporate Fellow at Oak Ridge National Laboratory. He is a Fellow of the American Nuclear Society, a Fellow of the American Association for the Advancement of Science, and recipient of the 2005 Robert E. Wilson Award from the American Institute of Chemical Engineers for outstanding chemical engineering contributions to nuclear energy, including his work in waste management, hydrogen production and nuclear-renewable energy futures. He received the American Nuclear Society special award for innovative nuclear reactor design. Dr. Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. He has been awarded 12 patents and has published over 300 papers.

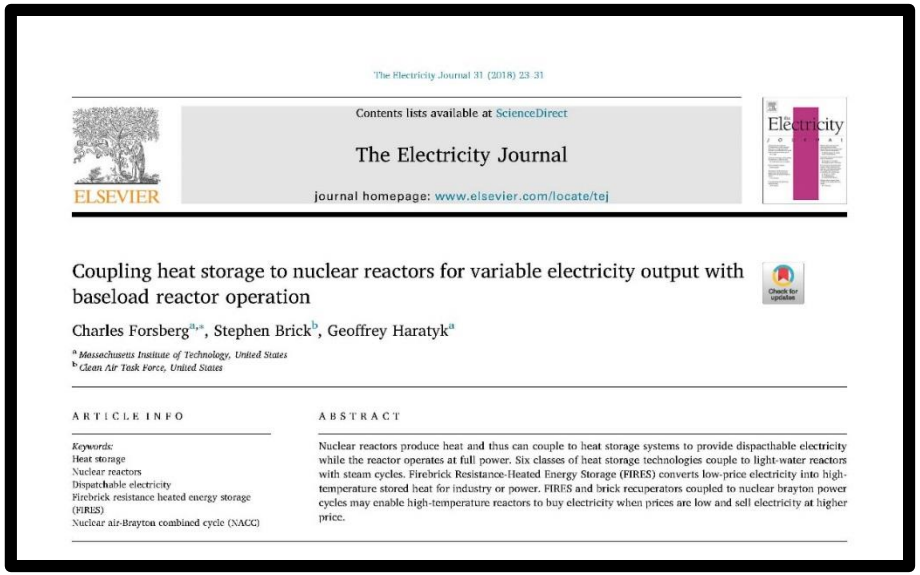
Nuclear Power Systems for a Low-Carbon World

Variable Electricity to Grid

Assured Peak Generating Capacity

Buy Low-Price Electricity

Base-load Operation



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Coupling heat storage to nuclear reactors for variable electricity output with baseload reactor operation

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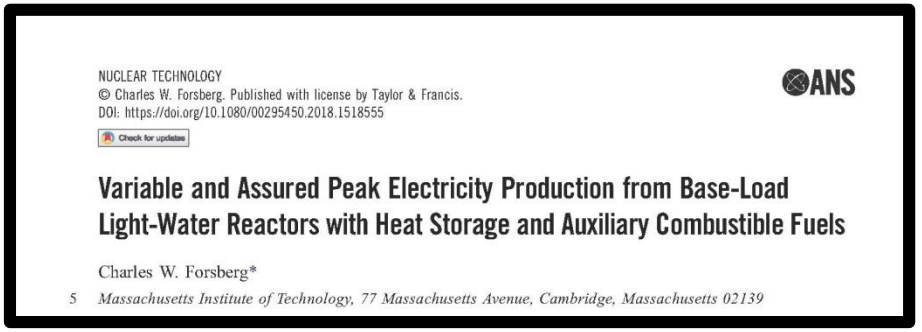
Nuclear air-Brayton combined cycle (NACC)

ABSTRACT

Nuclear reactors produce heat and thus can couple to heat storage systems to provide dispatchable electricity while the reactor operates at full power. Six classes of heat storage technologies couple to light-water reactors with steam cycles. Firebrick Resistance-Heated Energy Storage (FIRES) converts low-price electricity into high-temperature stored heat for industry or power. FIRES and brick recuperators coupled to nuclear brayton power cycles may enable high-temperature reactors to buy electricity when prices are low and sell electricity at higher price.

https://doi.org/10.1016/j.tej.2018.03.008



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Variable and Assured Peak Electricity Production from Base-Load Light-Water Reactors with Heat Storage and Auxiliary Combustible Fuels

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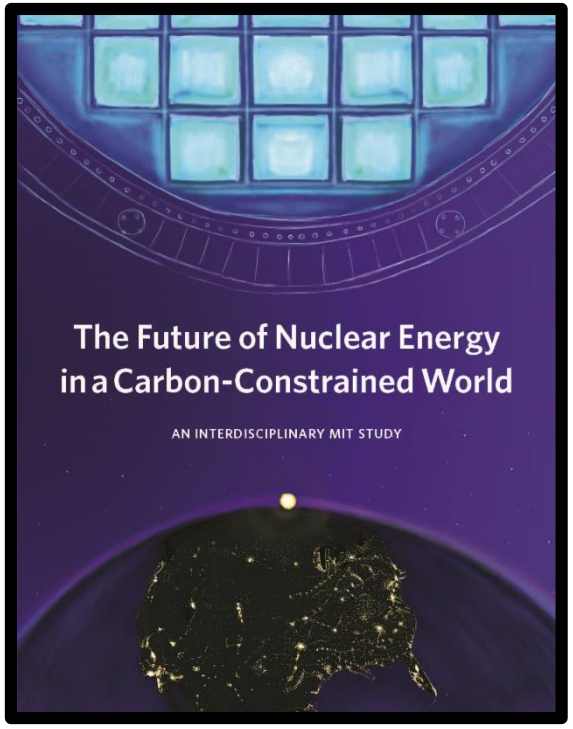
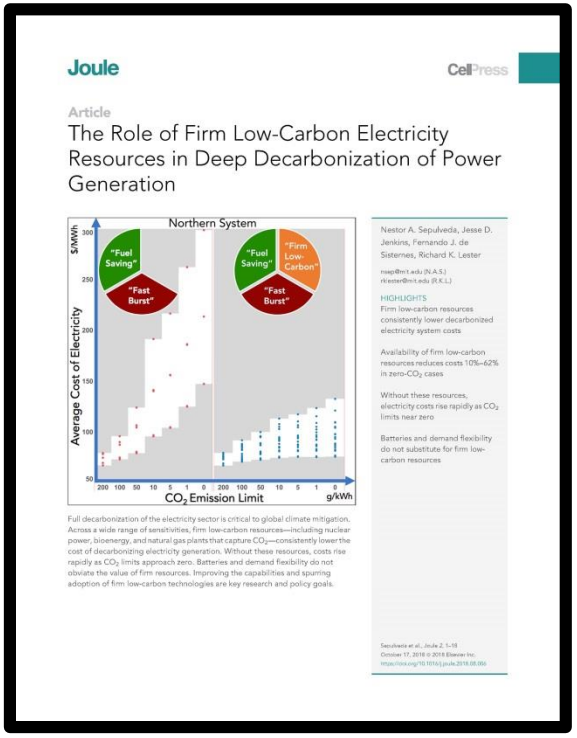
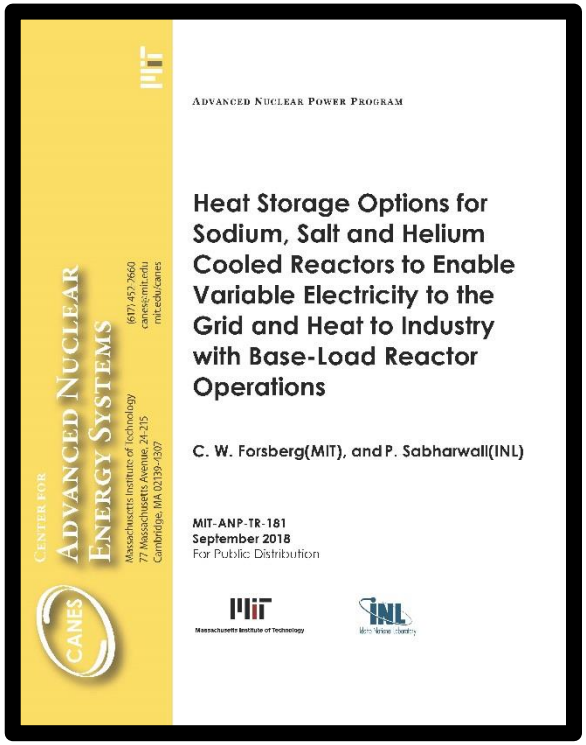
Affordable (1) Large-Scale Wind and Solar and/or (2) Low-Carbon Electricity Grid Requires Large-Scale Nuclear Energy

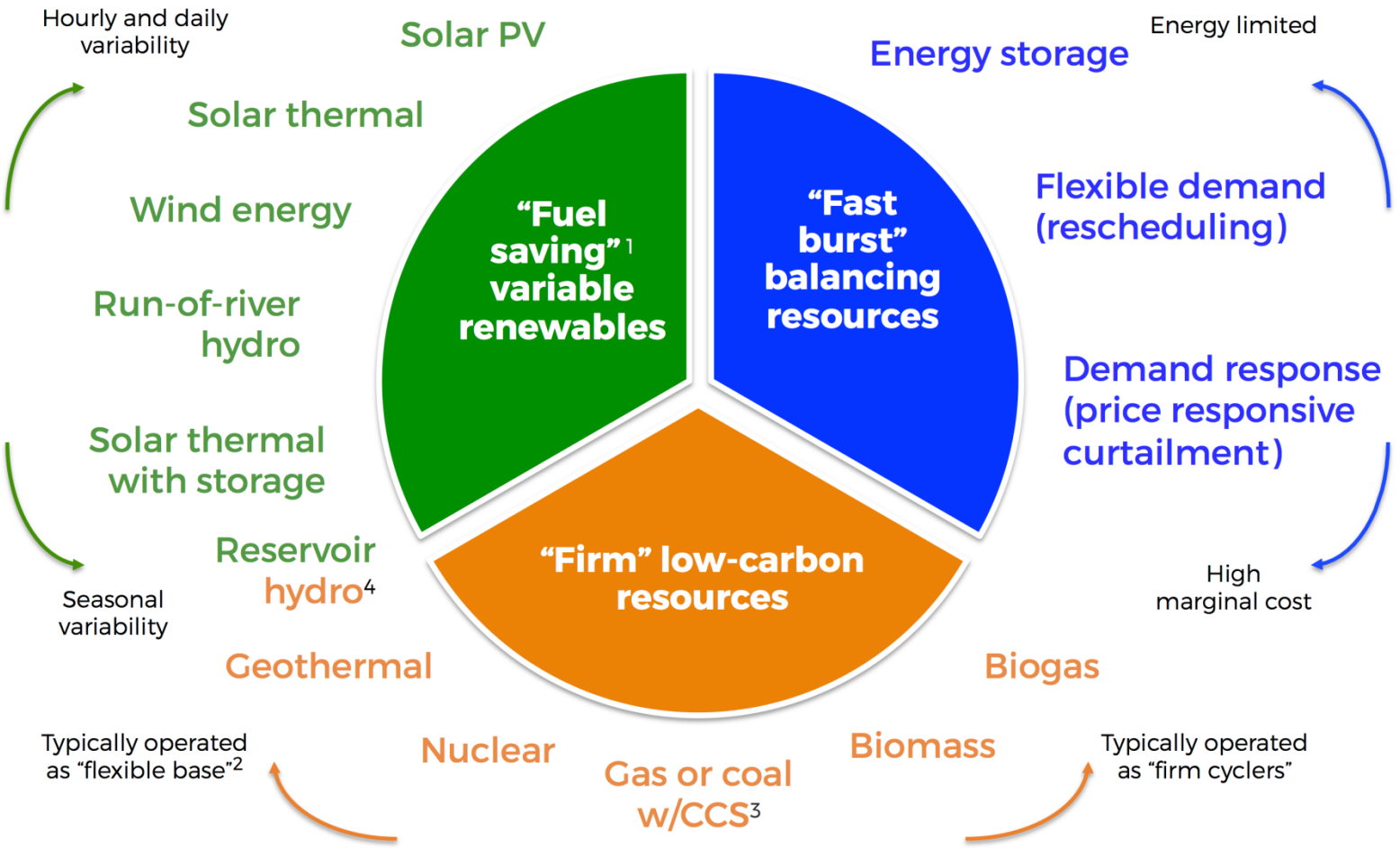






Nuclear Energy Replaces Fossil Fuels for Dispatchable Electricity: (1) Load following or (2) Base-load with Heat Storage and Assured Capacity

The New World of Energy



Nestor A. Sepulveda, Jesse D. Jenkins, Fernando J. de Sisternes, Richard K. Lester, "The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation," *Joule* 2, 1–18, October 17, 2018,