The Future of Nuclear Energy in a Carbon-Constrained World

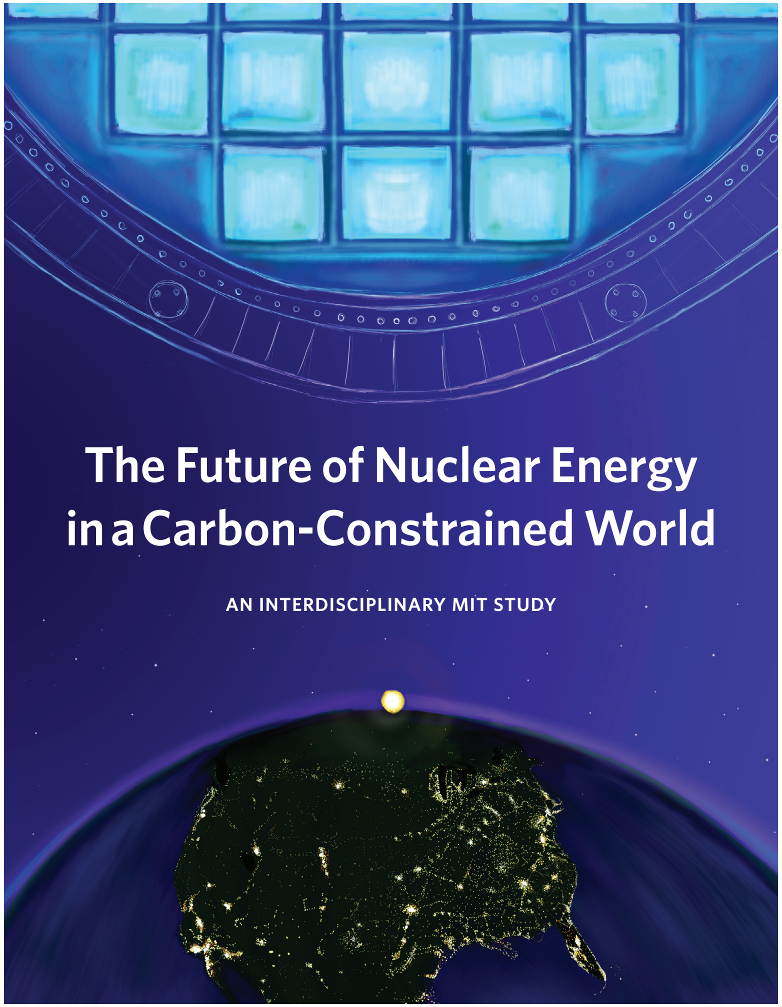
MIT MANAGEMENT SLOAN SCHOOL

JOHN PARSONS

February 25, 2019

International Energy Agency

http://energy.mit.edu



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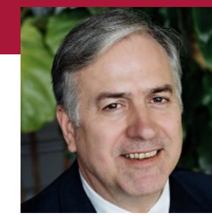
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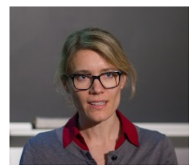
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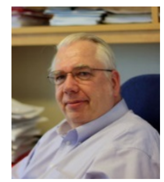
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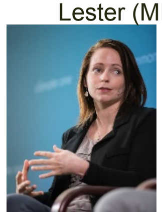
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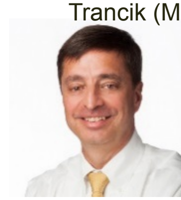
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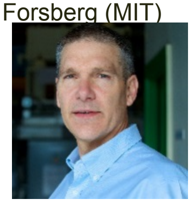
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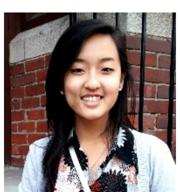
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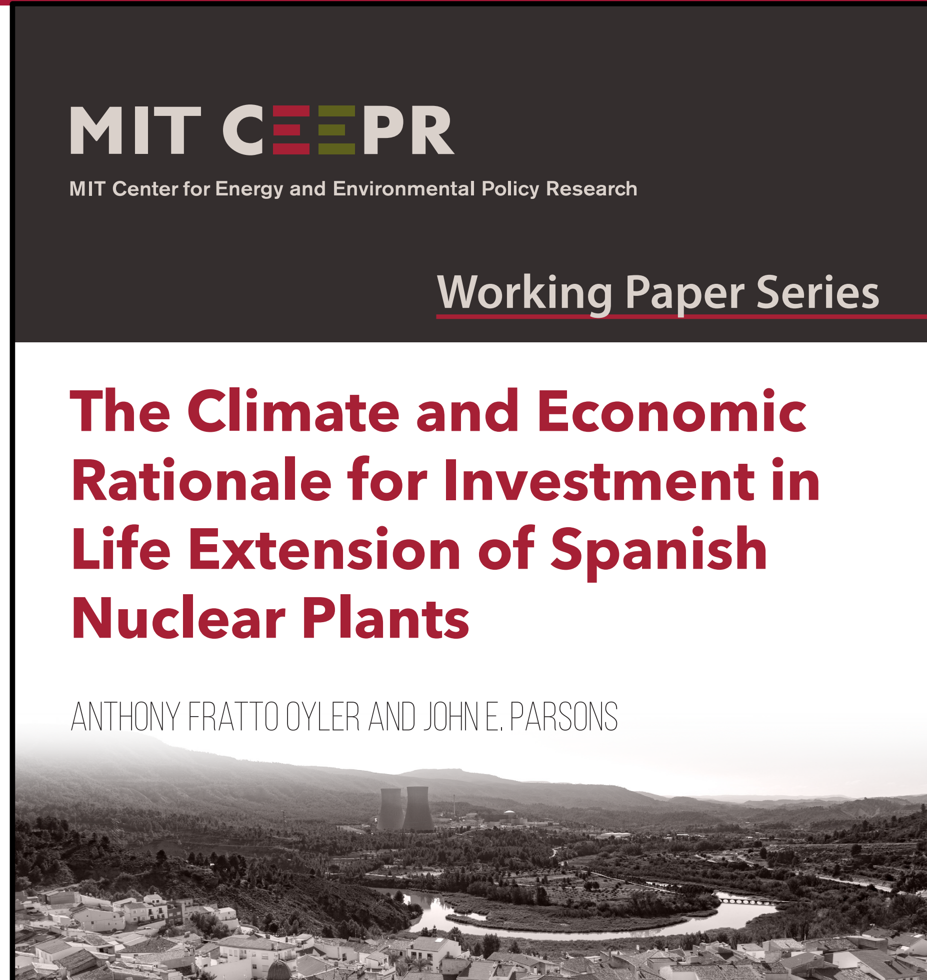
There is nuclear, and there is nuclear

- **Existing reactors**
  - cost efficient sources of low-carbon energy
  - political choice whether to value carbon and whether to use nuclear
- **New builds of traditional designs (large LWRs)**
  - high costs must be reduced ... we identify options
  - an established technology; cost reduction is a task for commercial institutions, but political choice remains
- **Advanced reactors**
  - offer improved safety paradigm with important implications
  - lower cost is hoped for, but not demonstrated
  - significant RD&D costs remain
  - requires state commitment and commercial engagement

Existing Reactors are Cost-Efficient Sources of Low-C Electricity

- **Premature closures undermine efforts to reduce CO2 and other power sector emissions.**
  - **Increases the cost of achieving emission reductions.**
  - **Recognized by individual US states pursuing decarbonization**
- **Life-extensions of existing reactors are usually a cost-efficient investment.**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Working Paper Series

The Climate and Economic Rationale for Investment in Life Extension of Spanish Nuclear Plants

ANTHONY FRATTO OYLER AND JOHN E. PARSONS

ssrn.com/abstract=3290828

Extending the Lives of Spain's 7 Reactors Would Save € Billions/Year

Table 14: Relative System Costs for Incremental Low Carbon Generation from Alternative Portfolios Benchmarked to 7 Nuclear Plant Life Extension

		[A] N7	[B] S7	[C] W7	[D] SW7	[E] WS7
[1] Incremental Capacity	(MW)	7,117	109,800	30,160	49,134	32,411
[2] Incremental Generation	(GWh)	46,015	46,011	46,014	46,838	46,014
[3] Incremental Capacity Factor		74%	5%	17%	11%	16%
[4] Incremental Unit Cost	(€/MWh)	34.96	157.02	61.24	76.27	60.95
[5] Incremental System Cost, gross annual	(€ millions)	1,609	7,225	2,818	3,572	2,804
[6] Incremental System Cost, gross PV 10 years	(€ millions)	11,298	50,743	19,793	25,091	19,697
[7] Difference to Nuclear	(€ millions)		39,446	8,495	13,794	8,399
			349%	75%	122%	74%

Life-Extensions for all 7 reactors.

No nuclear scenarios.

The Climate and Economic Rationale for Investment in Life Extension of Spanish Nuclear Plants, by Anthony Fratto Oyler and John Parsons, MIT Center for Energy and Environmental Policy Research Working Paper 2018-016, November 19, 2018. http://ssrn.com/abstract=3290828

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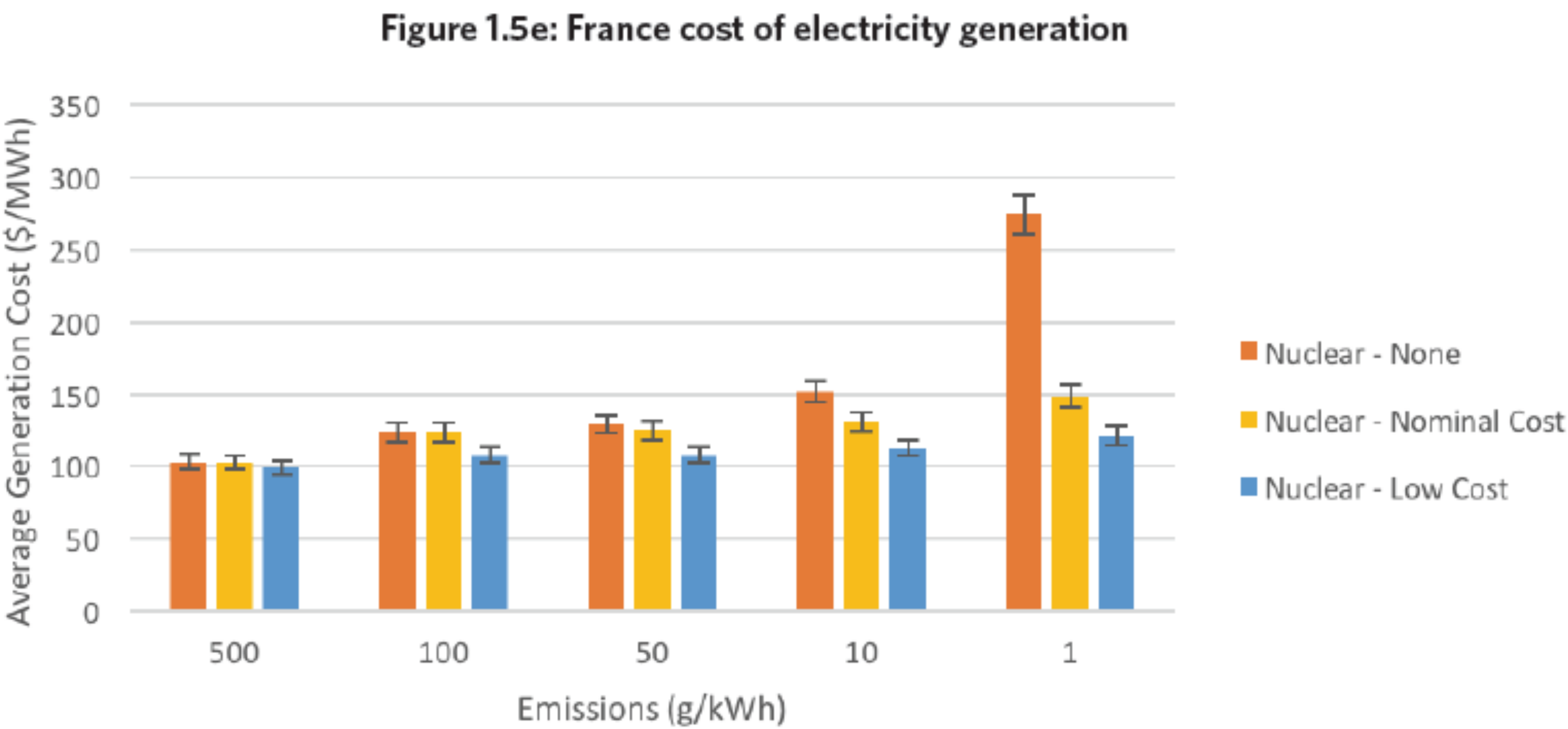
The Opportunity is Carbon

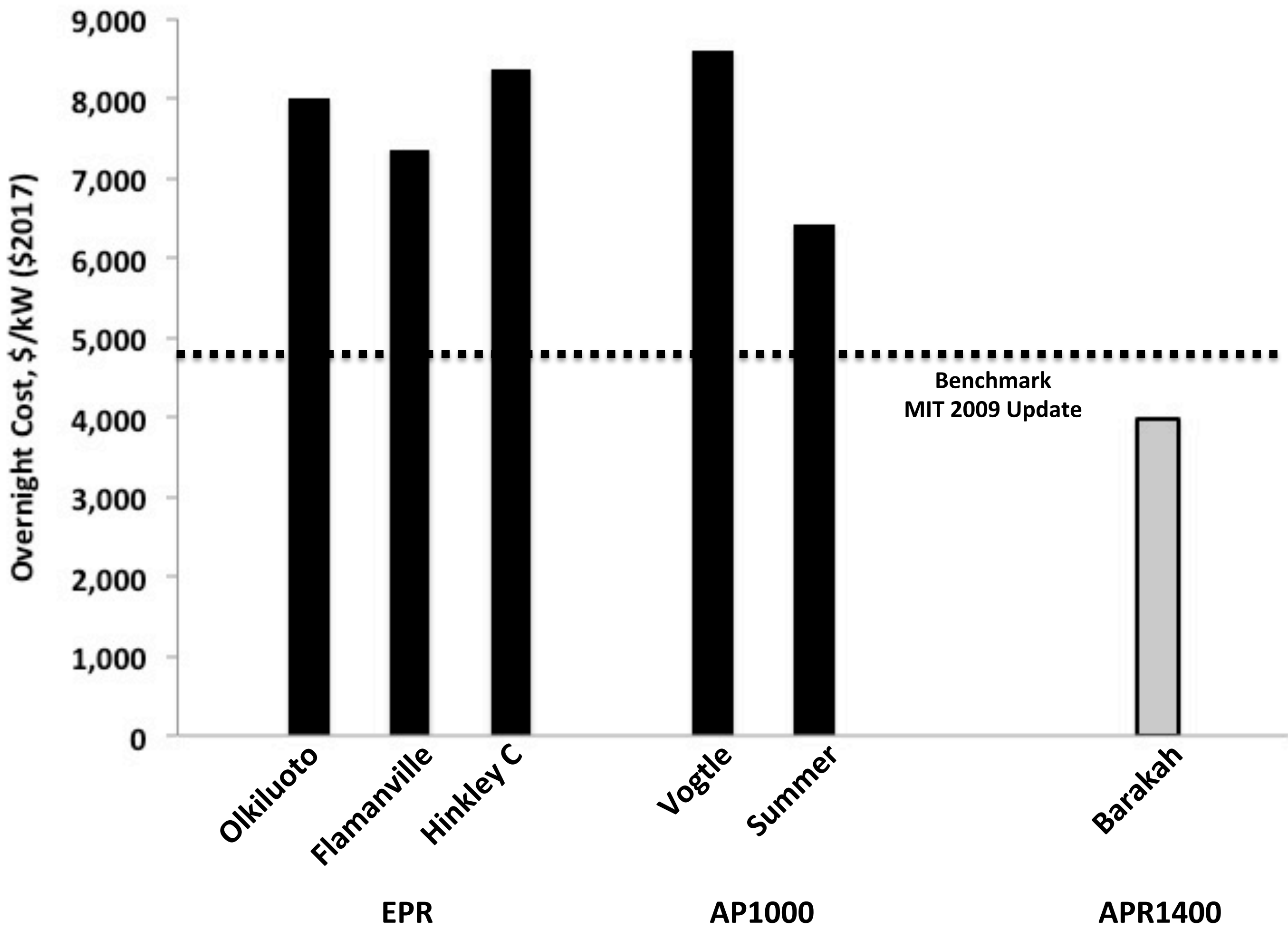
- **The per Megawatt value of a low-carbon source is material.**
  - e.g., in New York, approximately $20+ /MWh
  - currently missing in most electricity markets
    - e.g., the northeastern states of the US have a price on carbon for generators equal to approx $6+ /MWh
- **The case for nuclear based on other attributes is lacking.**
  - US wholesale markets are well designed to appreciate the value of frequency regulation, operating reserves, and near-term system stability and securtity
    - there are debates on the details
  - long-term security via capacity markets is a work-in-progress
- **political choice whether to value carbon and whether to use nuclear**

The Opportunity is Carbon #2: Deep Decarbonization by 2050



5,067
6,797

Recent New Builds in the U.S. and W. Europe Have Proven Expensive



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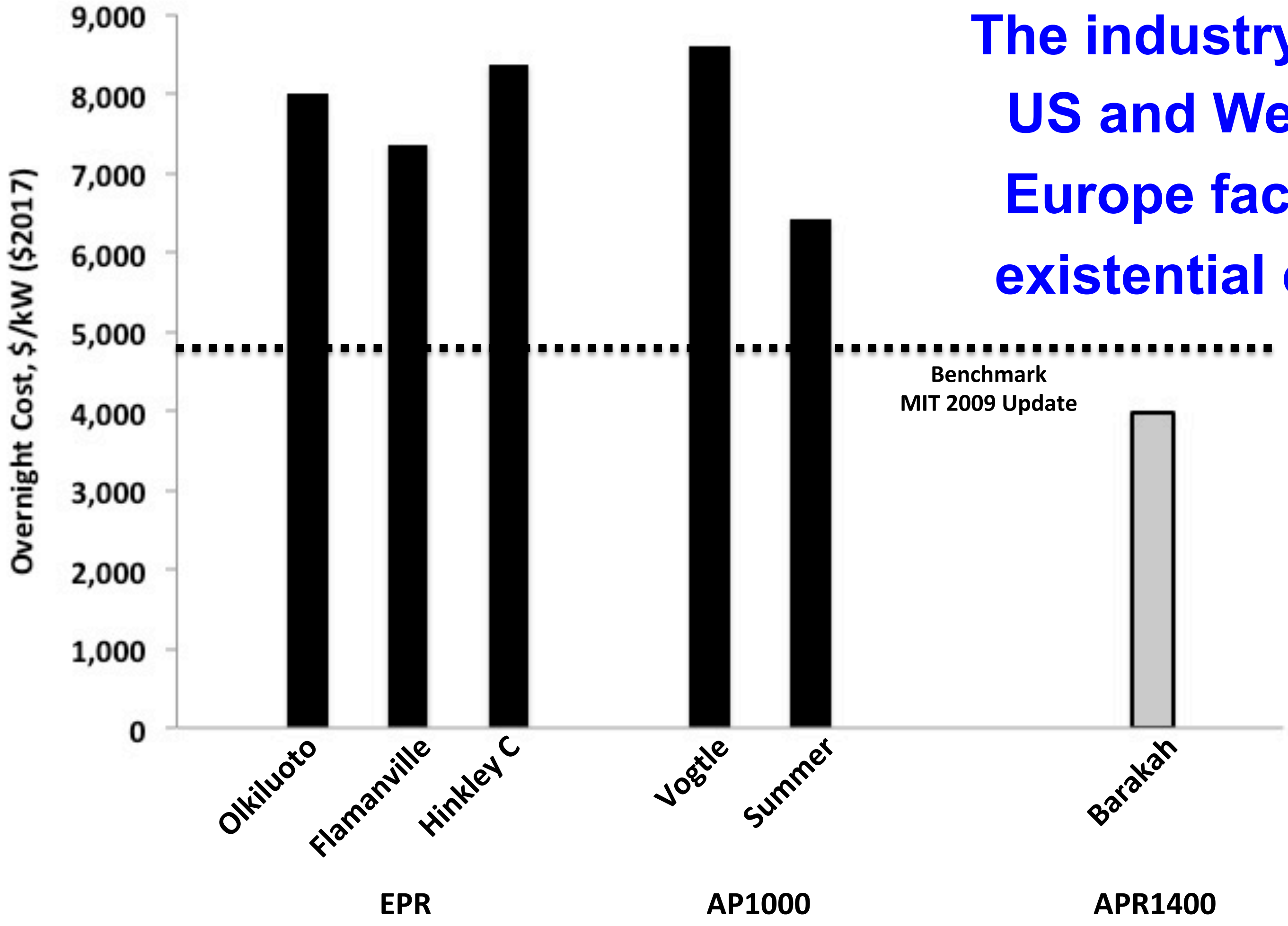
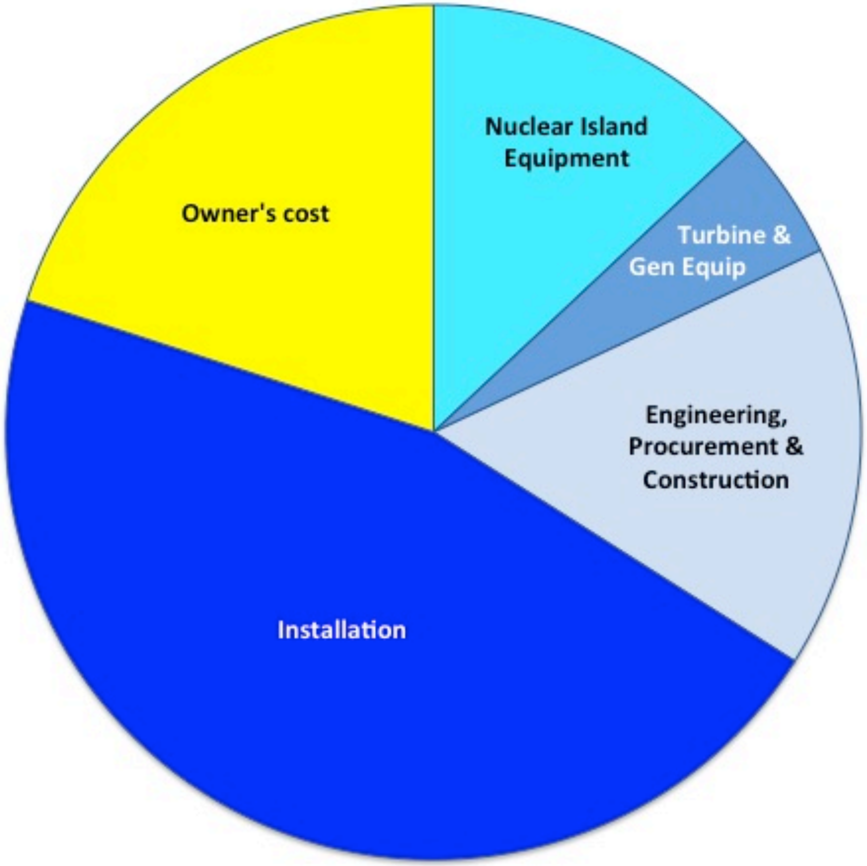


The industry in the US and Western Europe faces an existential crisis.

Where is the Cost in a Nuclear Power Plant?

Nuclear Island Equipment	13%
Turbine & Generator Equipment	5%
Engineering, Procurement & Construction	16%
Installation	46%
Owner's Cost	20%



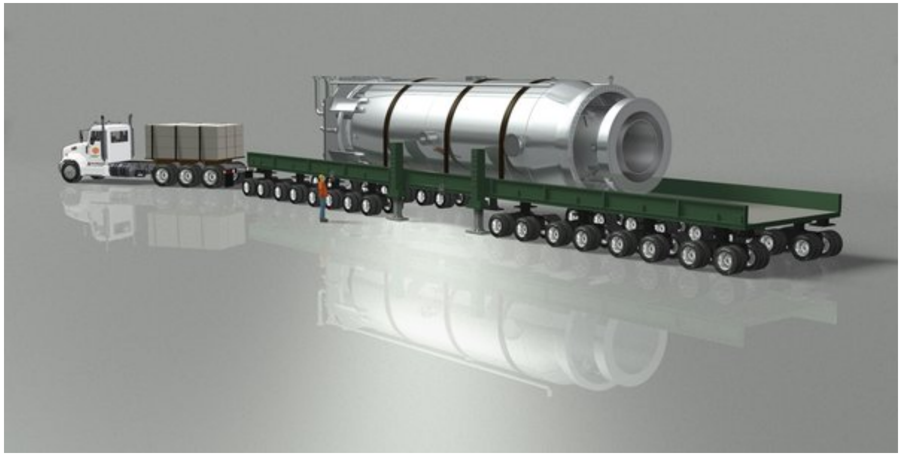
The Civil Works is Where Its At!

There are Ways to Reduce Cost

Basic blocking and tackling comes first.

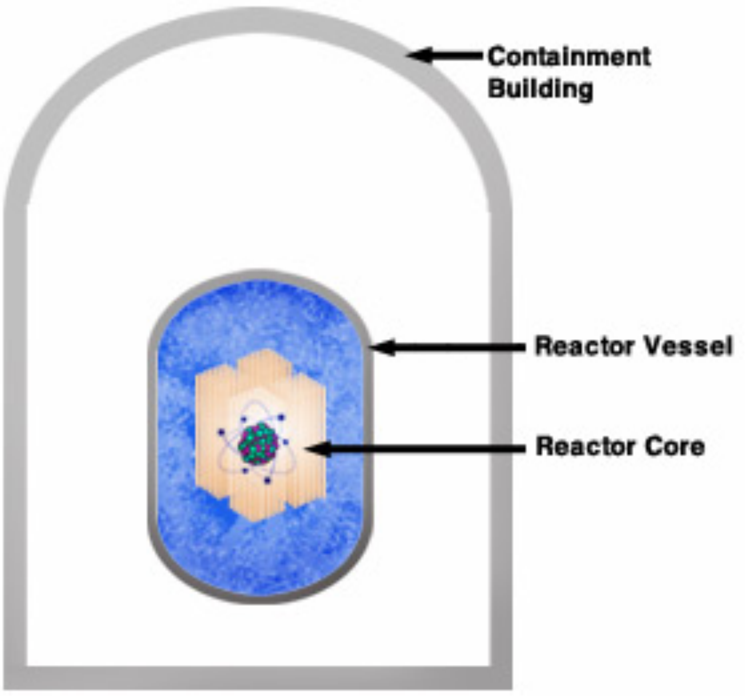
And, then...

- **Advanced concrete solutions**
- **Seismic isolation and embedment**
- **Modular construction and factory fabrication**



What About Advanced Reactors?

- **Opportunities for passive and inherent safety features are valuable.**
- **Reductions in cost are possible, but unproven.**
  - most advertised claims are ill-informed.
- **Parable of the jewel and the box.**
  - cost reductions are potentially available if the focus is on the right items;
  - improved fuel cycles cannot dent total cost;

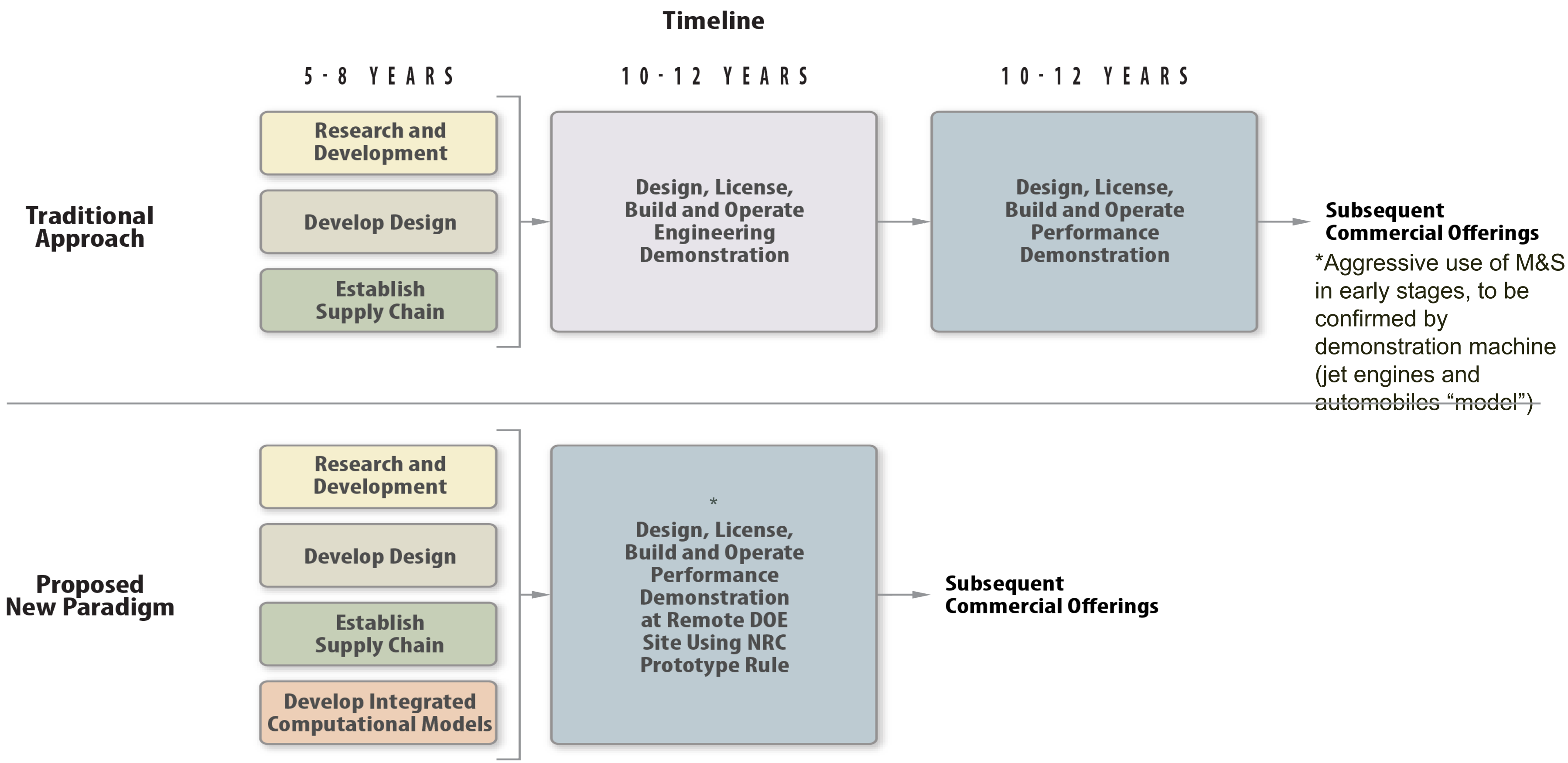


Establish Demonstration Sites

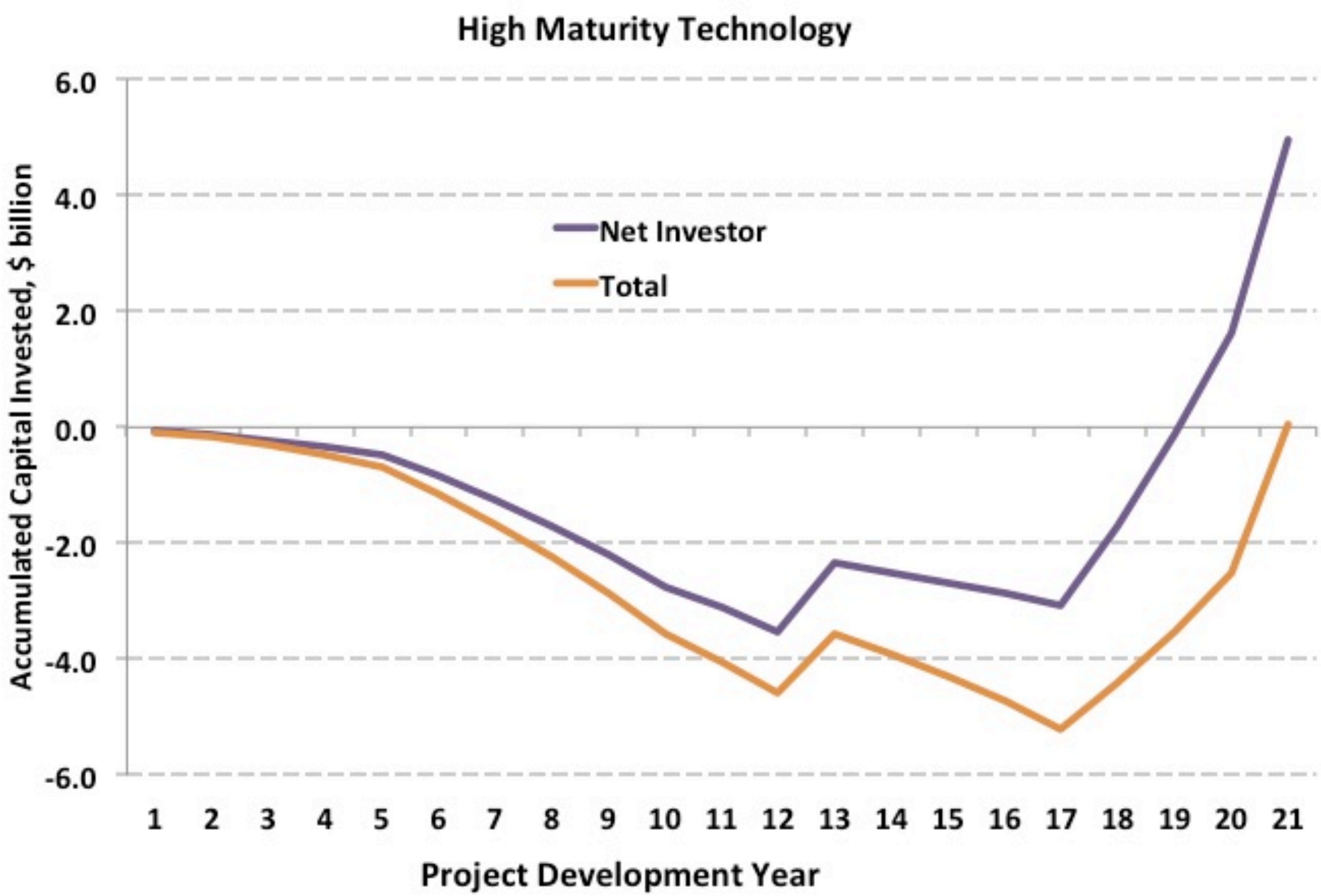
Governments should establish reactor sites where companies can deploy prototype reactors for testing and operation oriented to regulatory licensing.

- **Government provides site security, cooling, oversight, PIE facilities, etc.**
- **Government takes responsibility for waste disposal**
- **Supply high assay LEU and other specialized fuels to enable tests of advanced reactors**
- **Companies using the sites pay appropriate fees for site use and common site services**

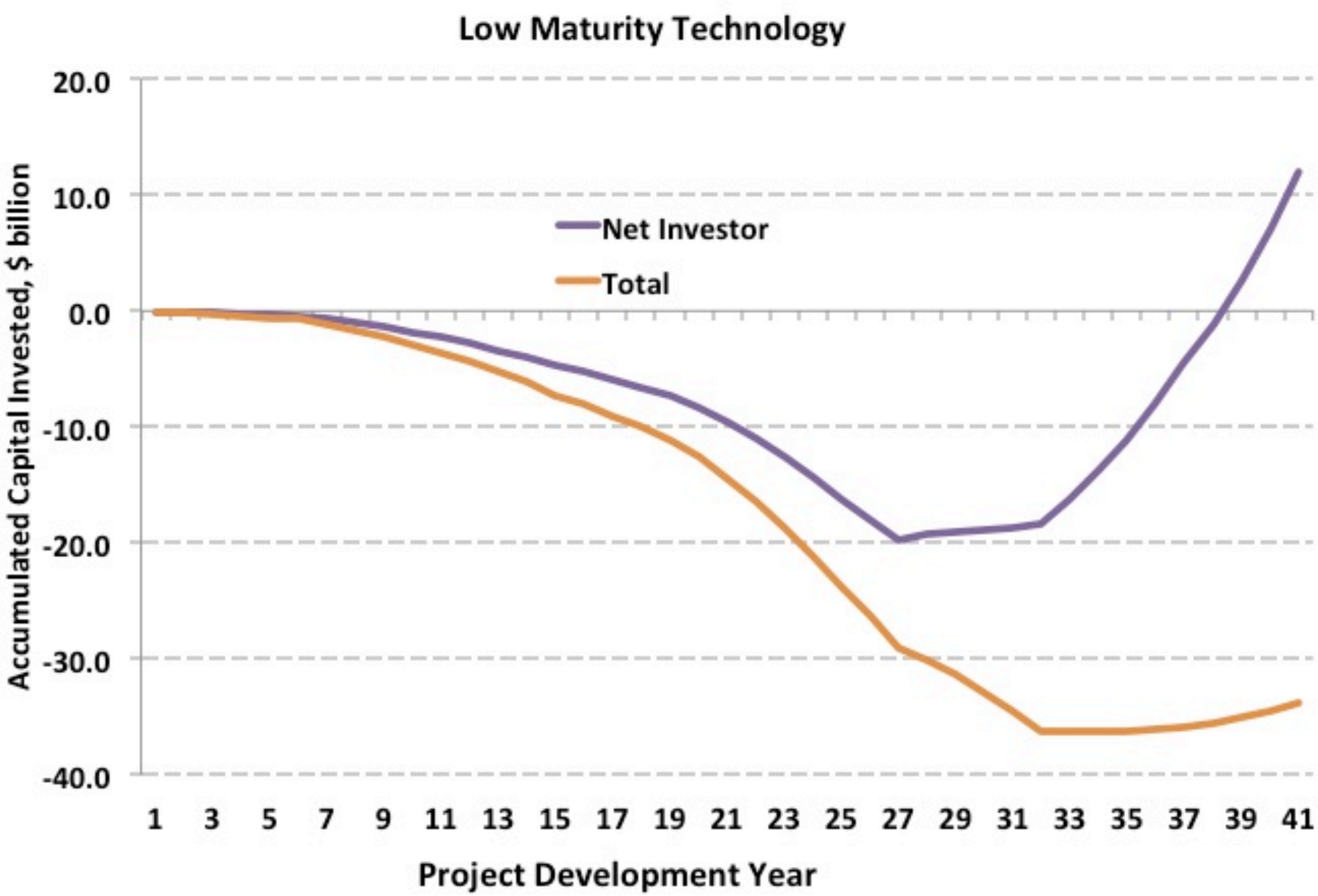
An Accelerated Deployment Paradigm



Financing Needs Are Daunting



Financing Needs Are Daunting (2)



Recommended Support Structure

- **Reducing cost and disciplining construction is the priority.**
  - Commercial firms are well suited to this task, so long as they have the opportunity for profit and the possibility of loss.
  - Choice of mission is the governments, choice of technology and design are up to the companies.
  - Companies must provide up-front expenditures.

- **Government support via 4 “levers”:**
  - Share R&D costs
  - Share licensing costs
  - Milestone payments
    - commercial contracts modeled on NASA’s COTS program
  - Productions credits
    - payment for performance
    - subsidy for demonstration only, not deployment

The Role of the State in Nuclear Investments?

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