

# The Future of Nuclear Energy in a Carbon-Constrained World

- Findings from a new MIT study -

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**NSE**  
Nuclear Science  
and Engineering

science : systems : society

# **Take-away messages**

- **The opportunity is carbon**
- **The problem is cost**
- **There are ways to reduce it**
- **Government's help is needed to make it happen**

# Why a new study

**BBC**

Switzerland votes to phase out nuclear power

 **REUTERS**

South Korea's president says will continue phasing out nuclear power

**The State**

SCANA leaves failed nuclear project to rot, upsetting some who want it finished

**The Telegraph**

Hinkley Point's cost to consumers surges to £50bn

**The Washington Post**

San Onofre nuclear power plant to shut down

**FINANCIAL TIMES**

Cheap gas has hurt coal and nuclear plants, says US grid study

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**Davis-Besse nuclear power plant to shut down permanently in 2020**

**NEW YORK POST**

**More problems with closing Indian Point**

**Los Angeles Times**

Regulators vote to shut down Diablo Canyon

 **REUTERS**

**France will need to close nuclear reactors: minister**

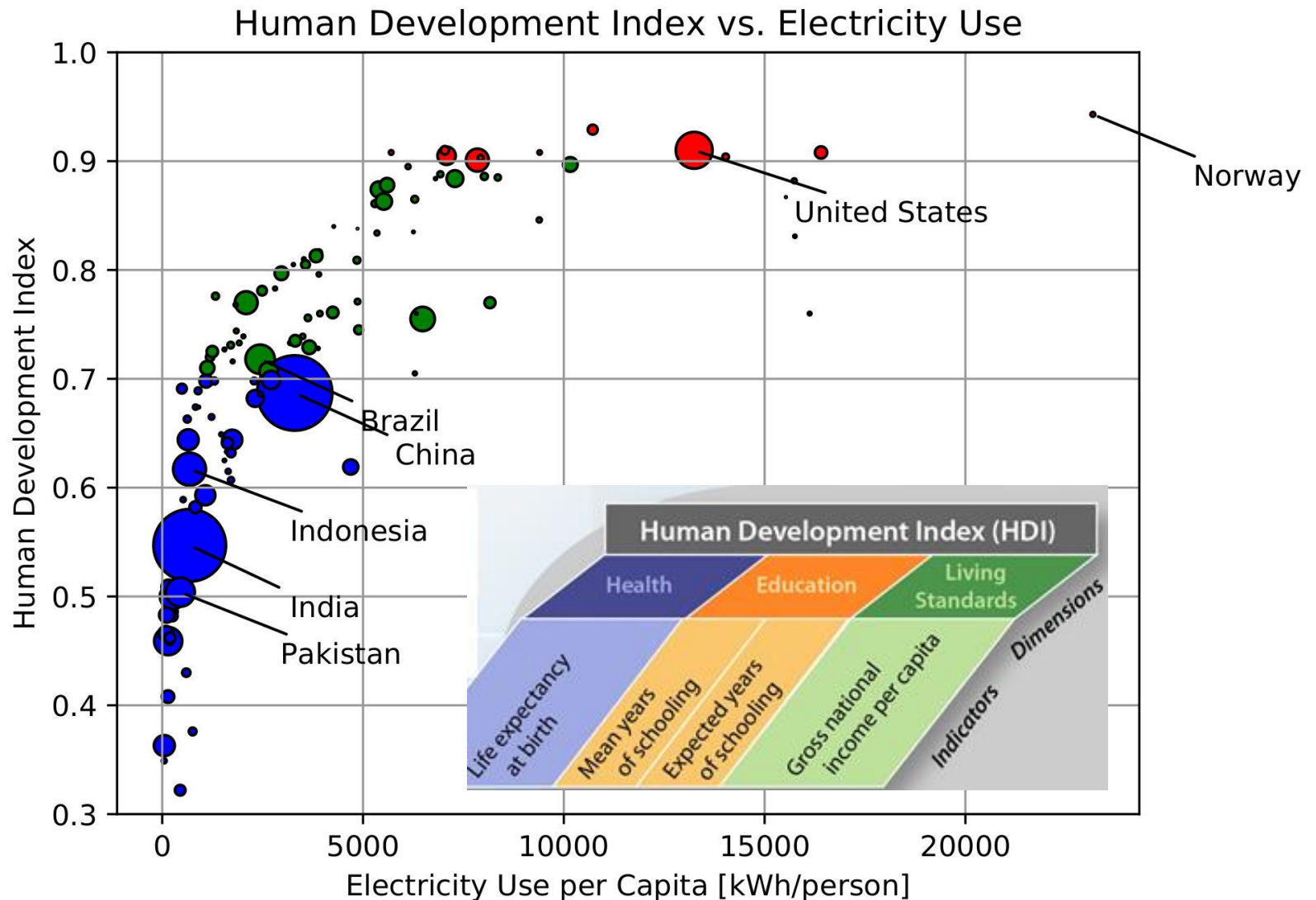
**The New York Times**

*Westinghouse Files for Bankruptcy, in Blow to Nuclear Power*

**The nuclear industry is facing an existential crisis  
(especially in the U.S. and Europe)**

**The big picture**

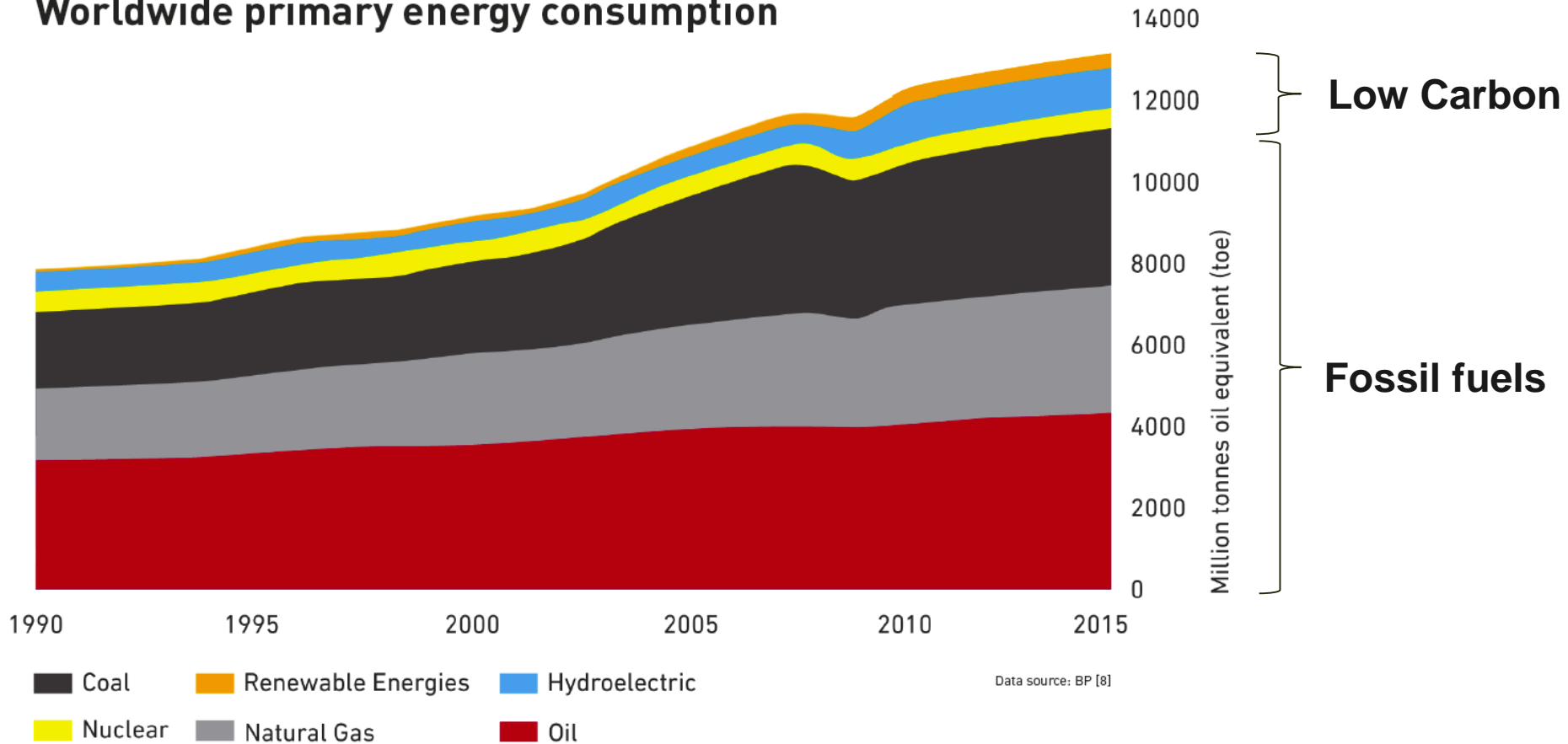
# The World needs a lot more energy



**Global electricity consumption is projected to grow 45% by 2040**

# The key dilemma is how to increase energy generation while limiting global warming

Worldwide primary energy consumption



CO<sub>2</sub> emissions are actually rising... we are NOT winning!

Can we decarbonize using *only* wind and solar?





# Some say yes



**IPCC: Renewables to Supply 70%-85% of Electricity  
by 2050 to Avoid Worst Impacts of Climate Change**



**Mark Jacobson**

(Civil and Environmental Eng., Stanford)

“There is no technical or economic barrier to transitioning the entire world to 100 percent clean, renewable energy with a stable electric grid at low cost”



**Barbara Hendricks**

(Minister for the Environment, Germany)

“The Energiewende is the cornerstone of our climate policy. We want to encourage other countries to follow our example.”



# Some say no

## Union of Concerned Scientists For Nukes!

Activist group finally recognizes that it can't achieve its energy and climate goals without nuclear power.

We need a low-carbon electricity standard. A well-designed LCES could prevent the early closure of nuclear power plants while supporting the growth of other low carbon technologies.



**Emmanuel Macron** (President of France)

"My priority in France, Europe and internationally is CO<sub>2</sub> emissions and (global) warming... What did the Germans do when they shut all their nuclear in one go?... They developed a lot of renewables but they also massively reopened thermal and coal. They worsened their CO<sub>2</sub> footprint, it wasn't good for the planet. So I won't do that."



**Ken Caldeira, Kerry Emanuel, James Hansen, Tom Wigley**  
(Climatologists)

"There is no credible path to climate stabilization that does not include a substantial role for nuclear power."



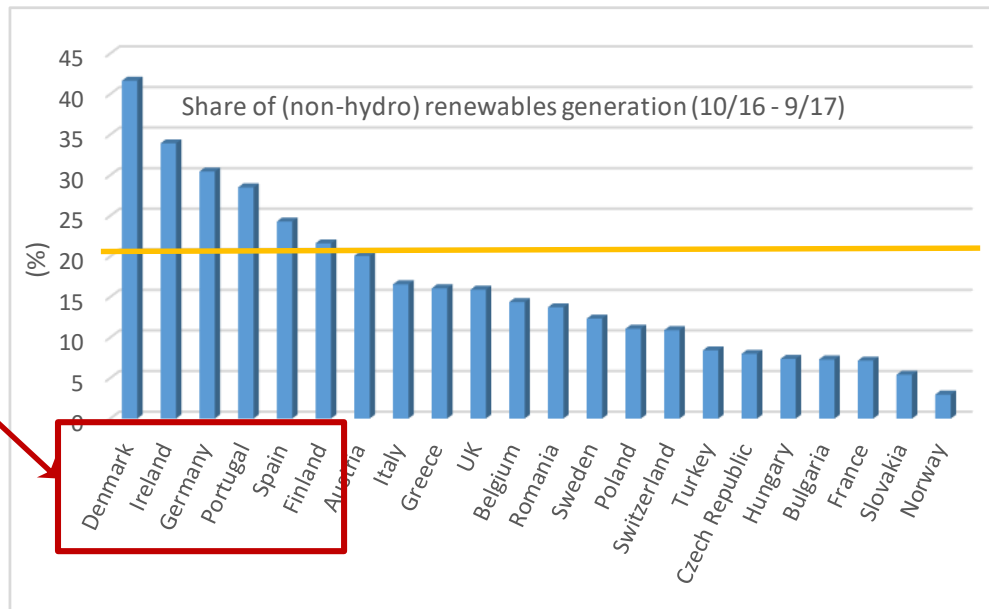
**Ernie Moniz** (former U.S. Energy Secretary)

"I know we can't get there [meeting carbon dioxide reduction goals] unless we substantially support and even embolden the nuclear energy sector."

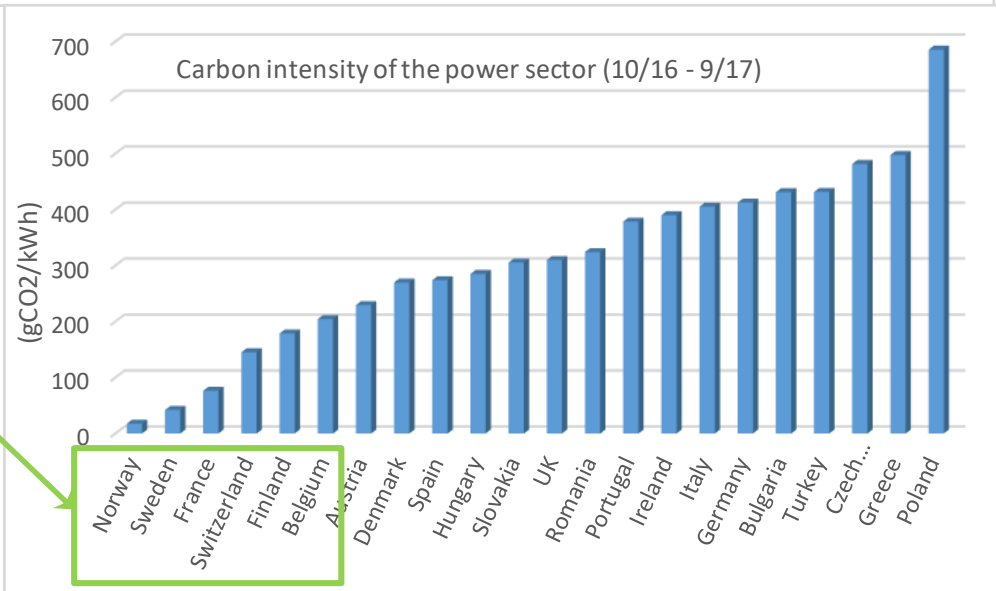
# Let's look at the evidence

Data source: European Climate Leadership report 2017  
(Energy for Humanity, Tomorrow, the Electricity Map Database)

EU countries  
with high  
capacity of solar  
and wind



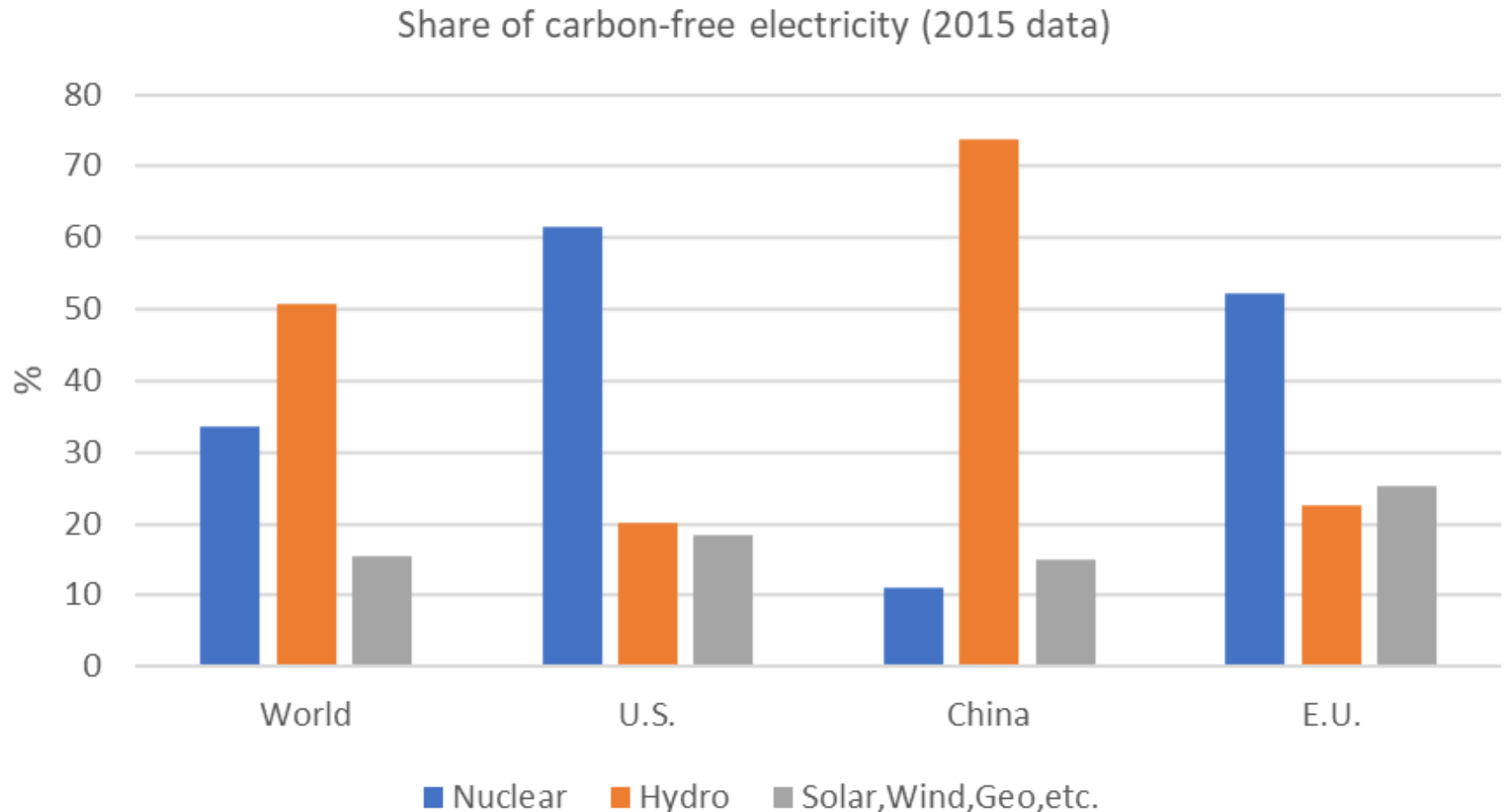
EU countries  
with low carbon  
intensity



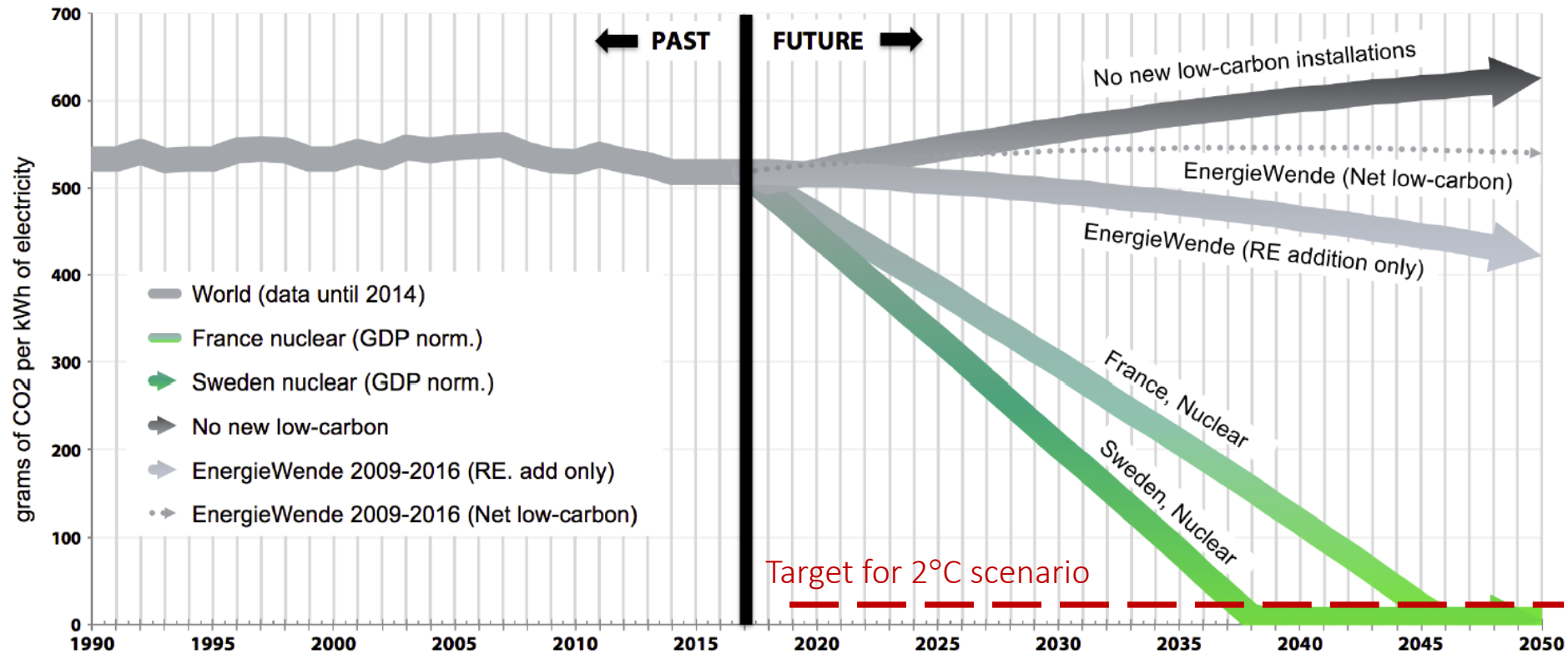
Low carbon intensity in the EU correlates with nuclear and hydro

**Do we need nuclear to  
deeply decarbonize the  
power sector?**

# Nuclear is the largest source of emission-free electricity in the US and Europe



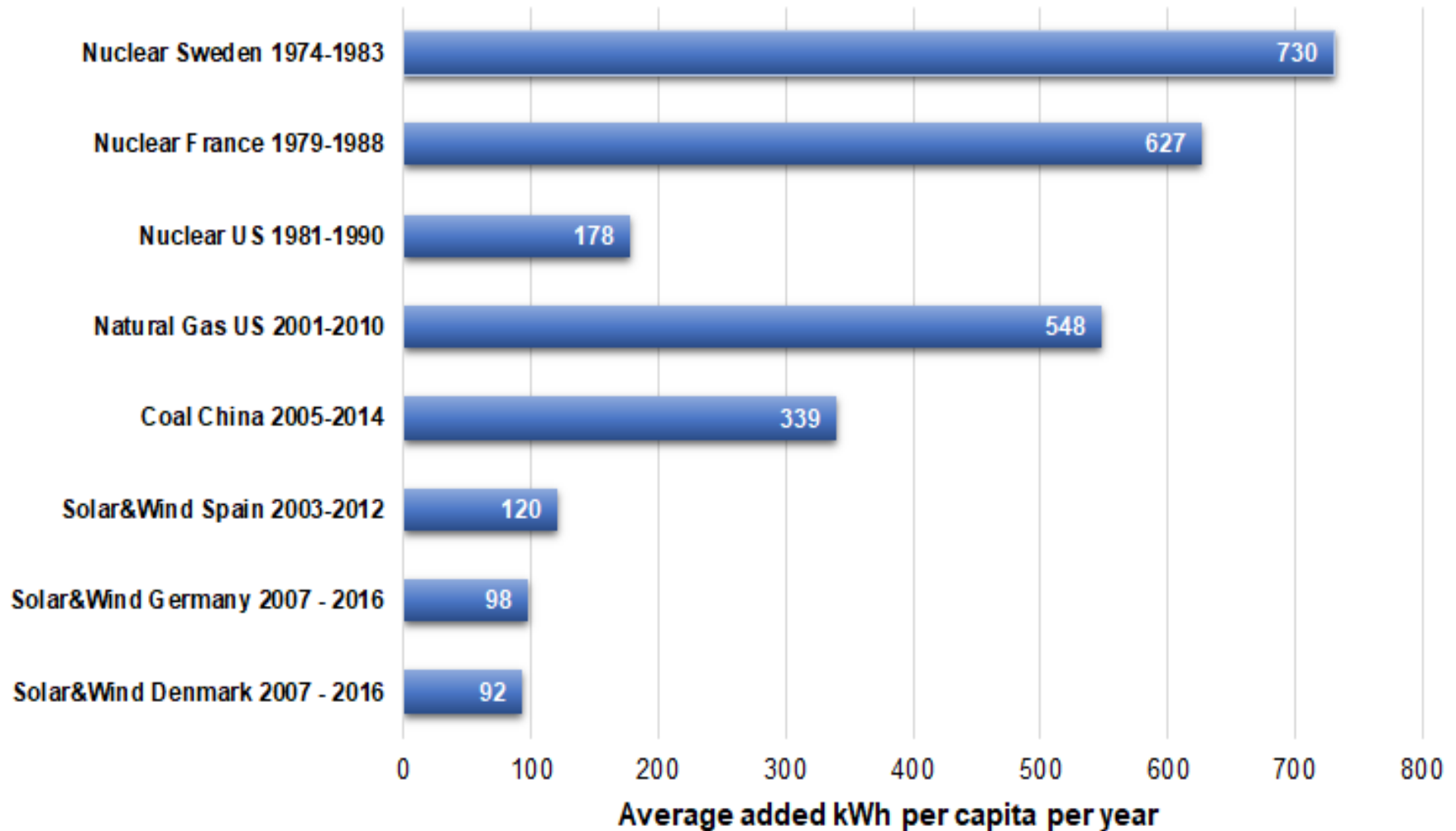
# The scalability argument



Source: Staffan Qvist, 2018

**A nuclear build-up (at historically feasible rate) can completely decarbonize the World's power sector within 30 years**

# The scalability argument (2)

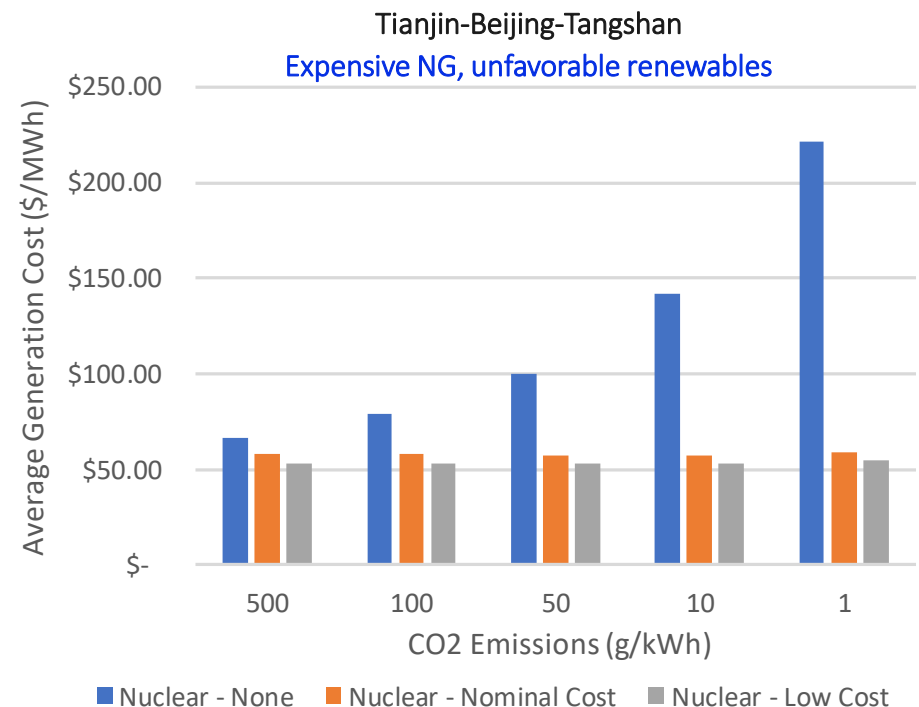
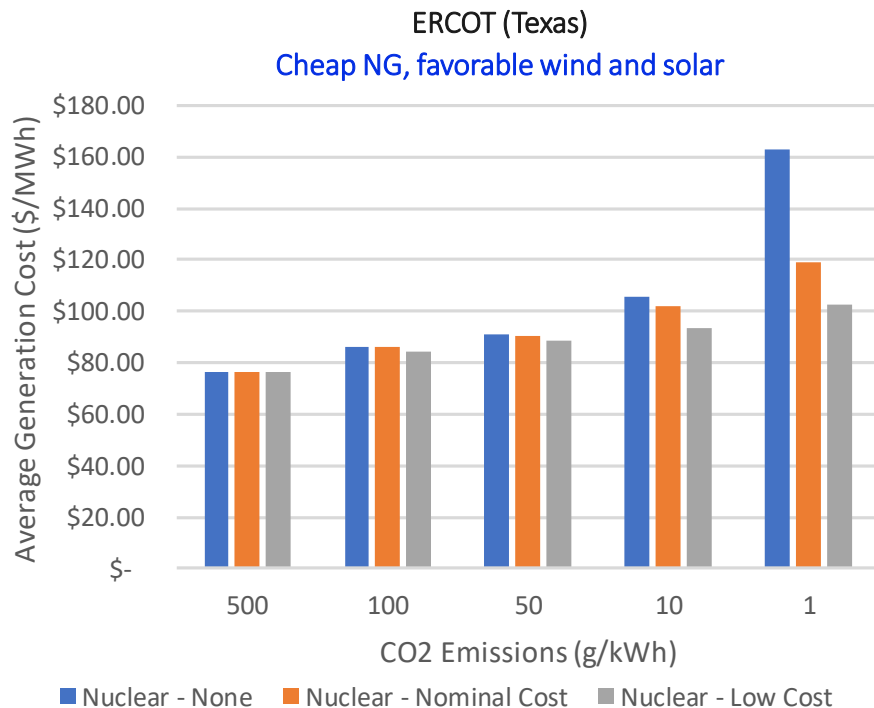


**Nuclear electricity can be deployed as quickly as coal and gas at a time of need**



# The economic argument

**Excluding nuclear energy drives up the average cost of electricity in low-carbon scenarios**

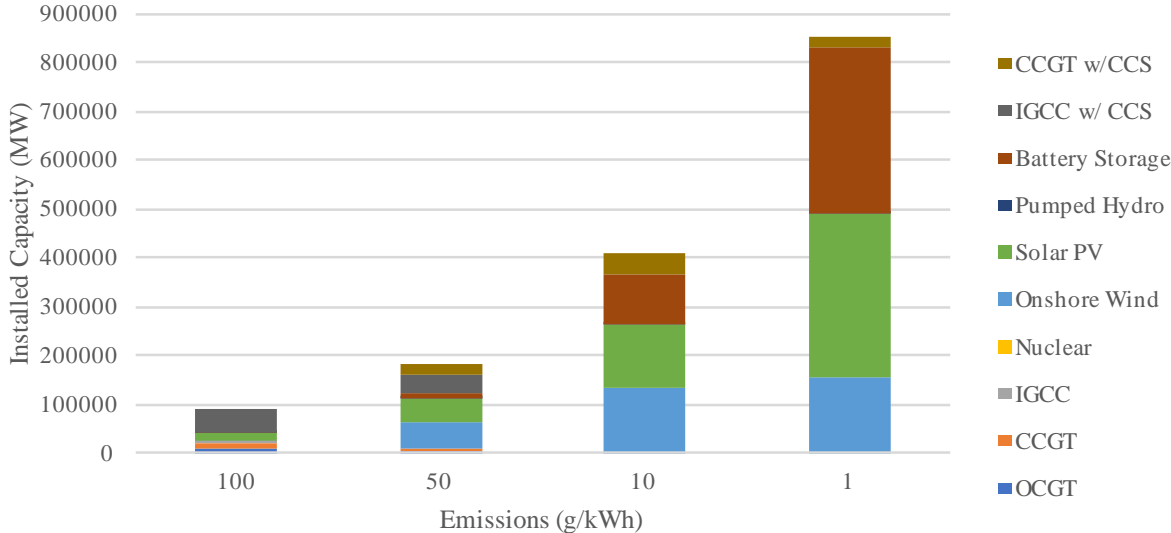


**Simulation of optimal generation mix in power markets in US, EU and Asia**

MIT tool: hourly electricity demand + hourly weather patterns + capital, O&M  
and fuel costs of power plants, backup and storage + ramp up rates

# Tianjin-Beijing-Tangshan Results

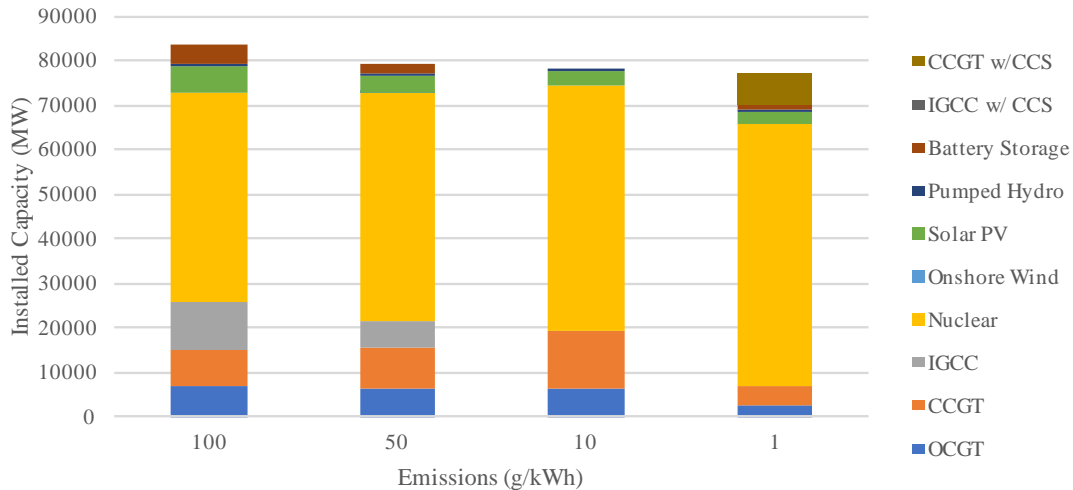
## Installed Capacities in Tianjin: No Nuclear



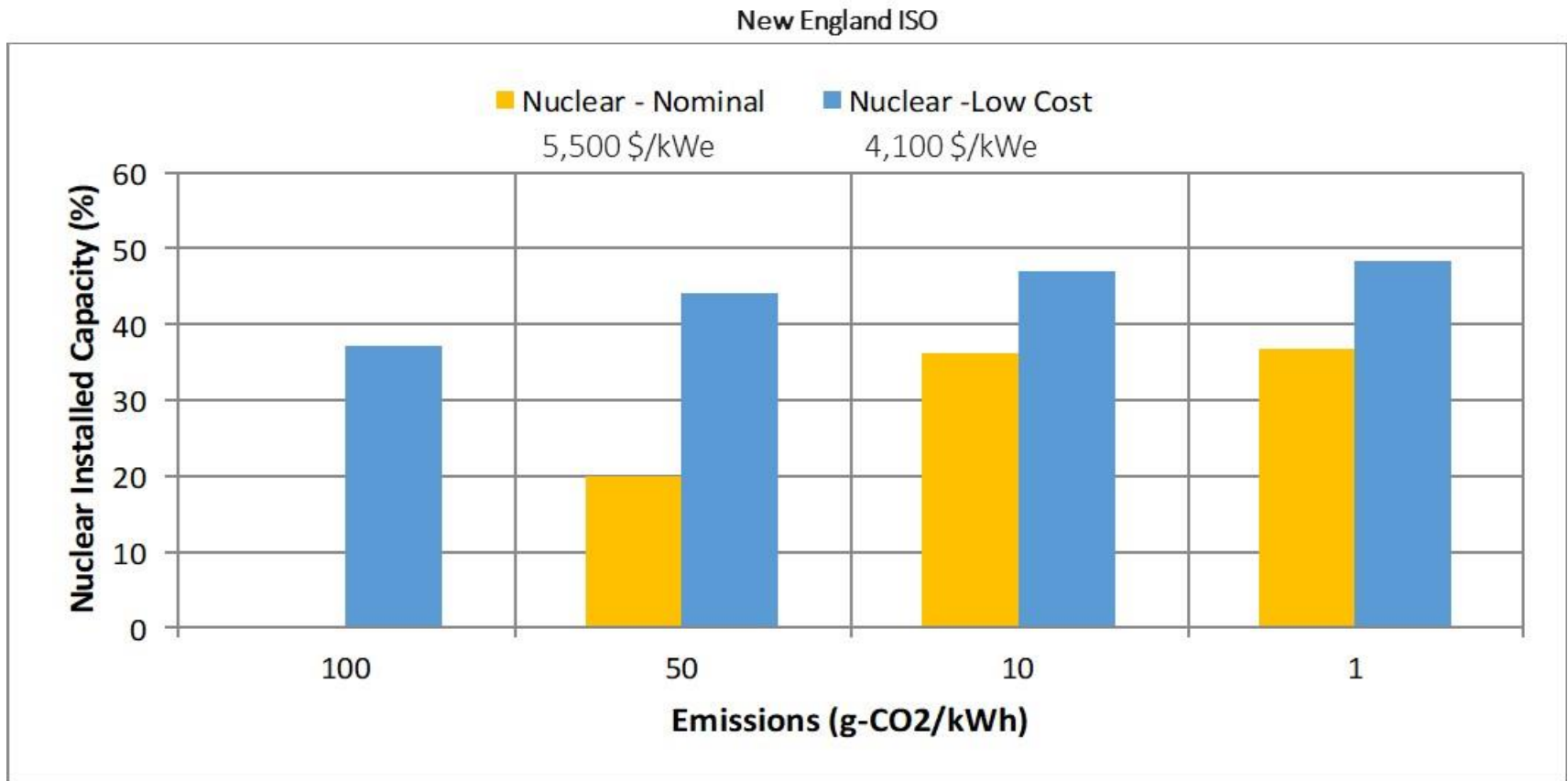
To meet constraint without nuclear requires significant overbuild of renewables and storage

By contrast, installed capacity is relatively constant with nuclear allowed

### Installed Capacities in Tianjin: Nuclear - Nominal

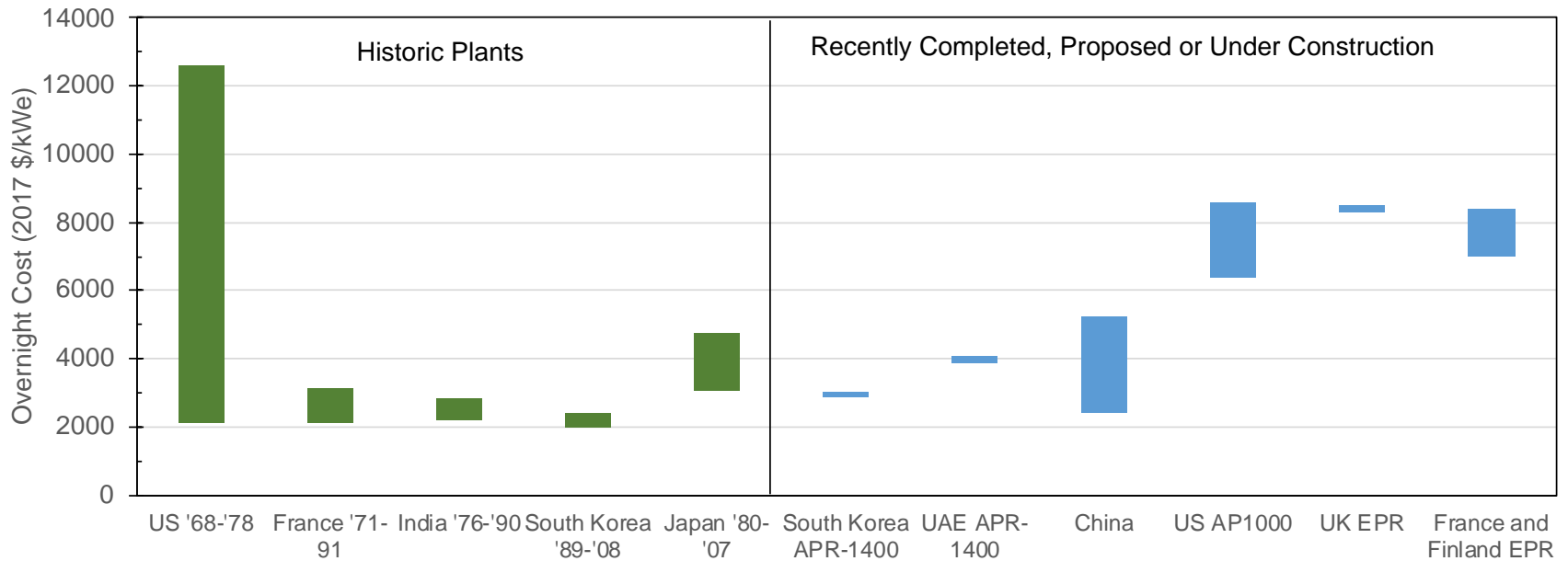


# The business opportunity for nuclear expands dramatically, even at modest decarbonization targets, if its cost decreases



# **The cost issue**

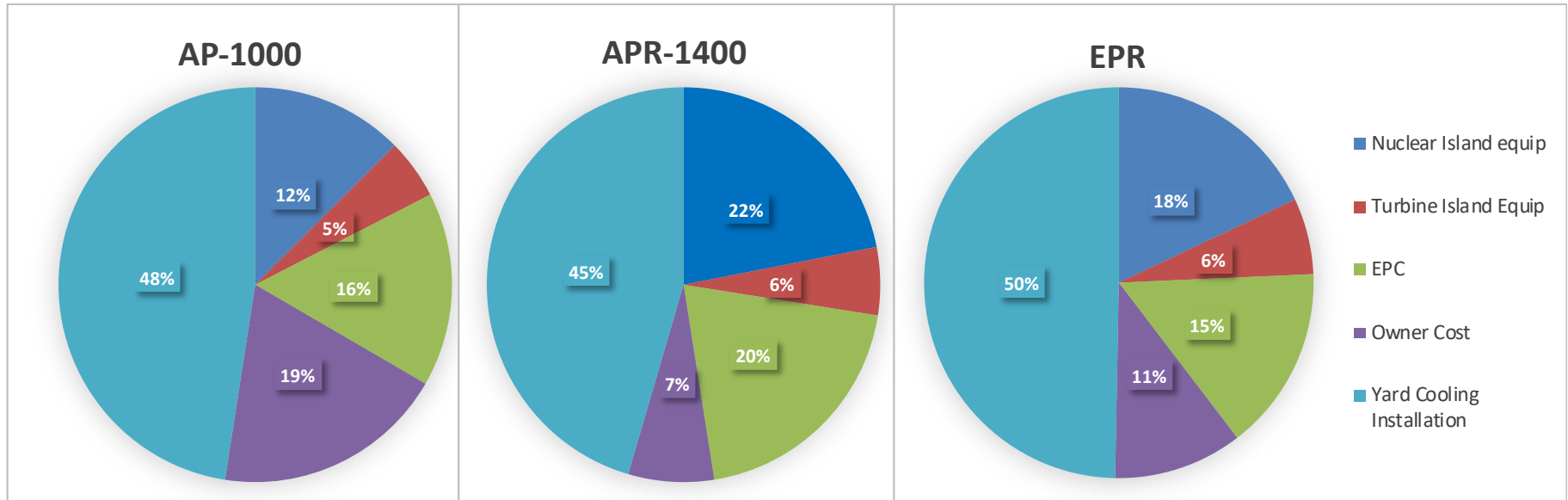
# Nuclear Plant Cost



**An increased focus on using proven project/construction management practices will increase the probability of success in execution and delivery of new nuclear power plants**

- Complete design before starting construction,
- Develop proven NSSS supply chain and skilled labor workforce,
- Include fabricators and constructors in the design team,
- Appoint a single primary contract manager,
- Establish a successful contracting structure,
- Adopt a flexible contract administrative processes to adjust to unanticipated changes,
- Operate in a flexible regulatory environment that can accommodate changes in design and construction in a timely fashion.

# Nuclear Plant Cost (2)



## Sources:

**AP1000:** Black & Veatch for the National Renewable Energy Laboratory, *Cost and Performance Data for Power Generation Technologies*, Feb. 2012, p. 11

**APR1400:** Dr. Moo Hwan Kim, POSTECH, personal communication, 2017

**EPR:** Mr. Jacques De Toni, Adjoint Director, EPRNM Project, EDF, personal communication, 2017

Civil works, site preparation, installation and indirect costs (engineering oversight and owner's costs) dominate

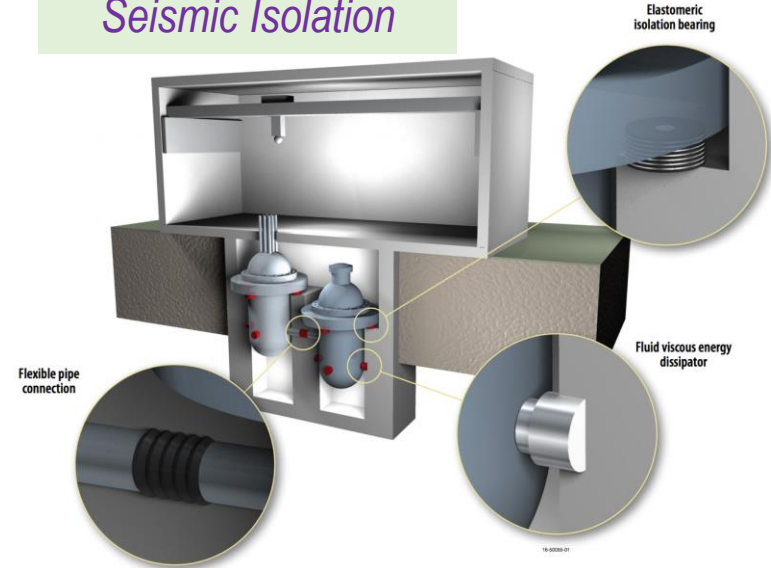


# A shift away from primarily field construction of cumbersome, highly site-dependent plants to more serial manufacturing of standardized plants (True for all plants and all technologies)

## Standardization on multi-unit sites



## Seismic Isolation



## Advanced Concrete Solutions

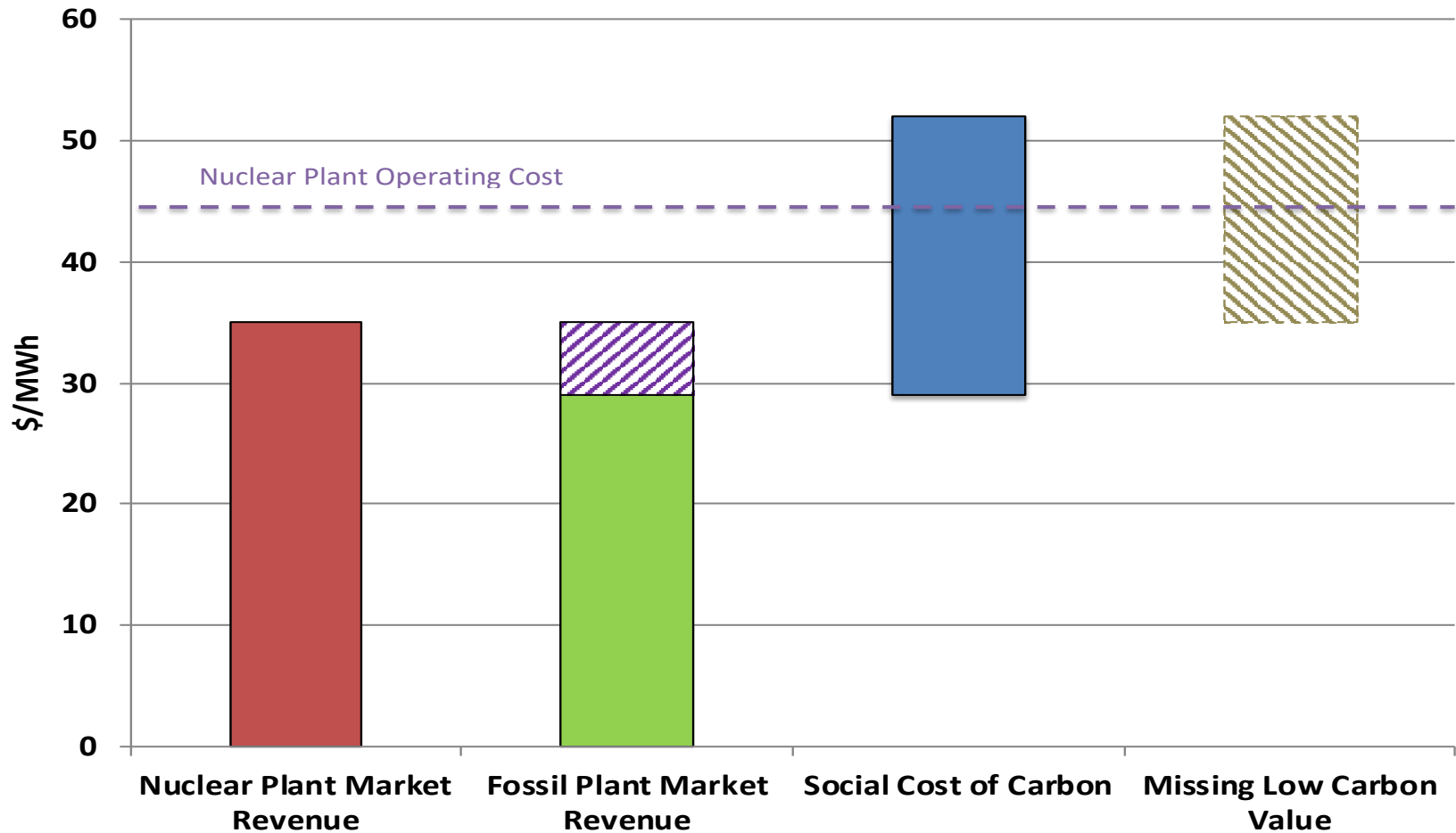
| Work Structure | Rebar arrangement | Form work (assembling) | Placing concrete | Form work (removal) |
|----------------|-------------------|------------------------|------------------|---------------------|
| RC             |                   |                        |                  |                     |
| 28days         | 13days            | 7days                  | 4days            | 4days               |
| SC             | —                 |                        |                  | —                   |
| 14days         | —                 | 10days                 | 4days            | —                   |

## Modular Construction Techniques and Factory Fabrication



# **The government role**

# Preserving the existing nuclear fleet requires compensating it for its zero-carbon value



A \$12-17/MWh credit would be enough to keep US nuclear power plants open

# Government should

## 1) Help to preserve the existing fleet to avoid an increase in emissions:

- Keeping current NPPs is the lowest-cost option for constraining carbon emissions in the US, as recognized by *Zero Emission Credits* in NY, IL and NJ
- True also in Spain:

All 7 Spanish NPPs remain open (with investment of ~600 €/kW)

No-nuclear scenarios

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

Methodology: Calculations find least-cost Spanish generation mix in 2030 with and without NPP life extension. All scenarios have same CO<sub>2</sub>-eq emissions (-43% from 2005) and storage (pumped hydro + batteries) capacity.

## 2) Improve the design of competitive electricity markets

- Decarbonization policies should create a level playing field that allows all low-carbon generation technologies to compete on their merits
- Ensure technology neutrality in capacity markets
- Enable investors to earn a profit based on the full value of their product (including reduction of CO<sub>2</sub> emissions)



## 3) Help to remove the roadblocks (waste and cost)



- Develop a durable political solution for spent fuel disposal to spur private investment in new nuclear
- Focus government research spending on innovations that lower capital cost of NPPs vs. fuel cycle innovations, reductions in waste streams and recycling



# Study Team



Executive Director  
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Co-Director  
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James Del Favero



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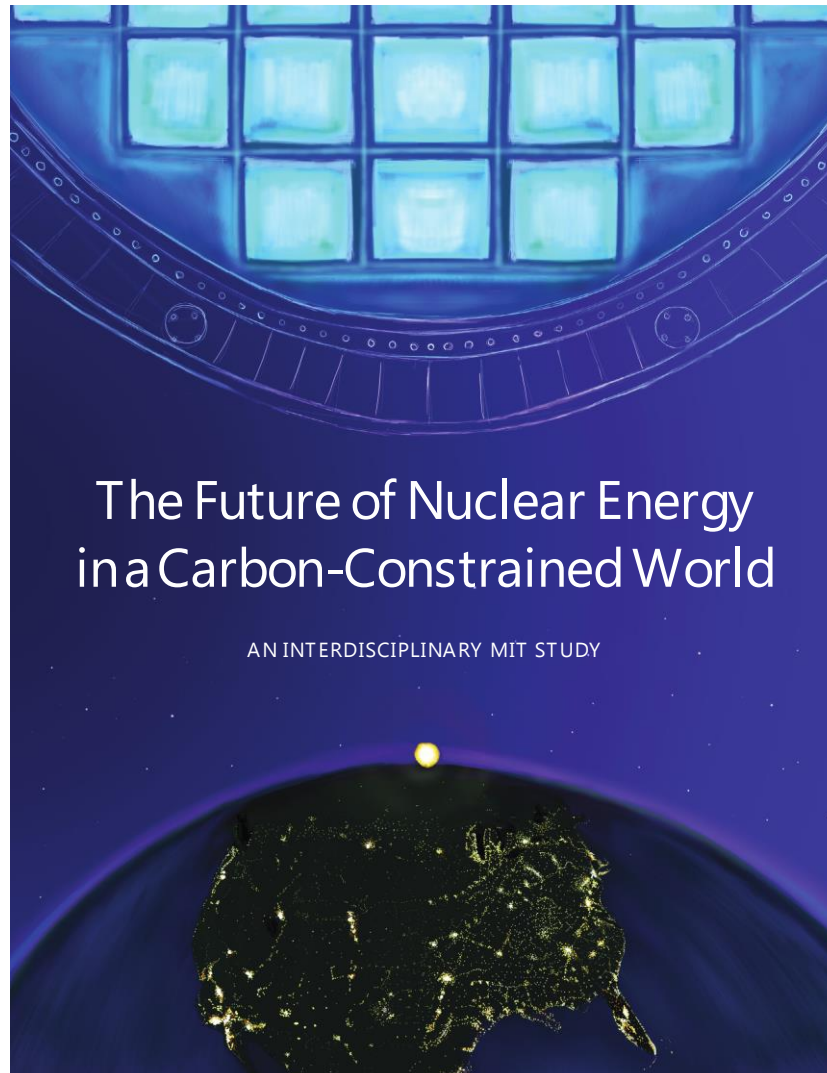
THE  
**BREAKTHROUGH**

Lucid Strategy

**BLUMONT.**

**DISCLAIMER:** MIT is committed to conducting research work that is unbiased and independent of any relationships with corporations, lobbying entities or special interest groups, as well as business arrangements, such as contracts with sponsors.

**Download the report at**  
**<http://energy.mit.edu/studies-reports/>**

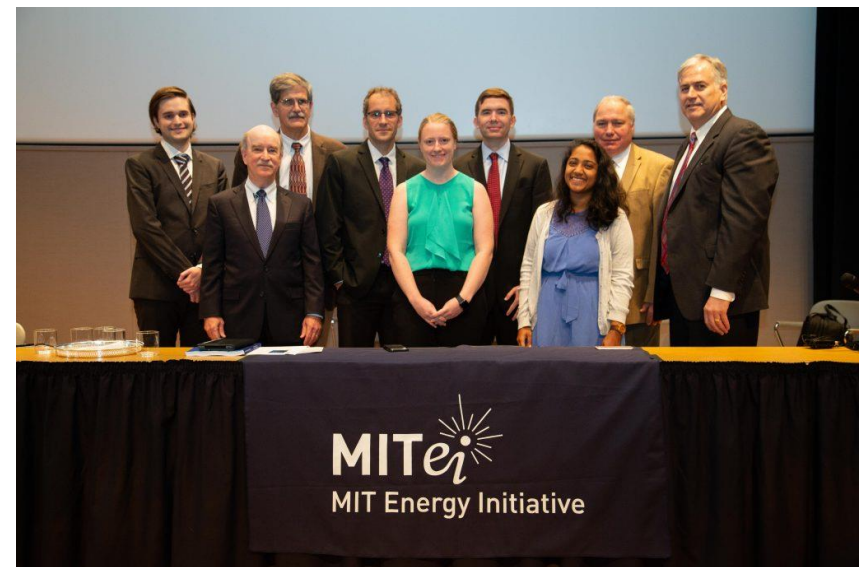


# Dissemination

**Report Online Release:** Sep 3, 2018  
Executive summary translated in French,  
Japanese and Chinese

## Rollout Events

London (Sep 2018)  
Paris (Sep 2018)  
Brussels (Sep 2018)  
Washington DC (Sep 2018)  
Tokyo (Oct 2018)  
South Korea/China (Jan 2019)



**51 presentations at universities, industry organizations, government, conferences, research labs**  
BEIS UK June 2017 (JB), ICAPP Plenary 2018 (JB), CEA Oct 2017 (JB), RMIT Jan 2017 (JB), Yale Univ. Mar 2018 (JB), Imperial College, June 2017 (JB), Zhejiang Univ. Sep 2017 (JB), Curtin Univ. Jan 2017 (JB), TAMU, Oct 2017 (JB), U-Houston, Oct 2017 (JB), Harvard Univ. HBS, Nov 2017 (JB), Harvard Belfer Center, June 2018 (JB), National Univ Singapore (NUS) Jan 2018 (JB), EPRI (Engineering, Procurement, and Construction Workshop), Nov 2017 (JB), Royal Acad. Eng. Nov 2017 (JB), Nuclear Insider SMR Summit, Apr 2017 (JB), MITEI Advisory Board Oct 2017 (JB, Parsons), Forum of India's Nuclear Industry, Jan 2018 (JB), Canadian Nuclear Society, Nov 2018 (JB), MIT Alumni Association of New Hampshire, Jun 2018 (JB), 49<sup>th</sup> Annual Meeting on Nuclear Technology, Berlin, May 2018 (JB), U-Edinburgh Aug 2018 (JB), Duke Energy Aug 2018 (JB), NSE May 2018 (JB, Petti, Parsons), Golay Fest, Mar 2018 (JB, Petti), Nuclear Bootcamp at UCB, July 2018 (Corradini), GA visit to MIT April 2018 (all), Armstrong and Moniz August 2017 (all), ANS Orlando, Nov 2018 (Corradini), Mark Peters INL Lab Director June 2017 (Petti), JASONs June 2017 (Petti, Parsons, Corradini), Wisconsin Energy Institute (MLC) Mar 2018 (Corradini), CNL Oct 2017 (Petti), CSIS Sept 2017 (Petti), DoE Dep Sec and Chief of Staff and NE-1 Jan 2018 (Petti, Parsons, Corradini), NRC Sep 2018 (Corradini), NEI Sep 2018 (Corradini), EPRI/NEI roadmapping meeting Feb 2018 (Petti), INL March 2018 (Petti), Gain Workshop March 2018 (Petti), Golay Workshop March 2018 (Petti), WNA September 2018 (Petti), NENE Slovenia September 2018 (Petti), PBNC SF September 2018 (Petti), Zurich December 2018 (Petti), Undersecretary of Energy – Science P. Dabbar Aug 2018 (JB), INPO CEO Conf Nov 2018 (JB), Total S.A. at MIT Nov 2018 (JB), G4SR-1 Conf. Ottawa Nov 2018 (JB), Masui ILP MIT Nov 2018 (JB), Lincoln Labs MIT Nov 2018 (JB), Foratom Spain Madrid Nov 2018 (JB), Orano Paris Nov 2018 (JB)

# Take-away messages

- The opportunity is carbon
- The problem is cost
- There are ways to reduce it
- Government's help is needed to make it happen



**Bonus slides on waste**



# Nuclear waste

## The volumes are SMALL!

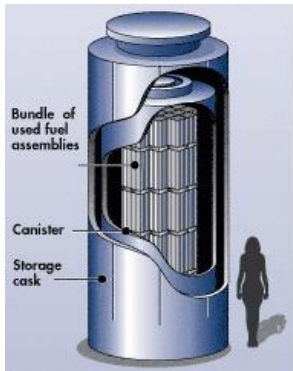
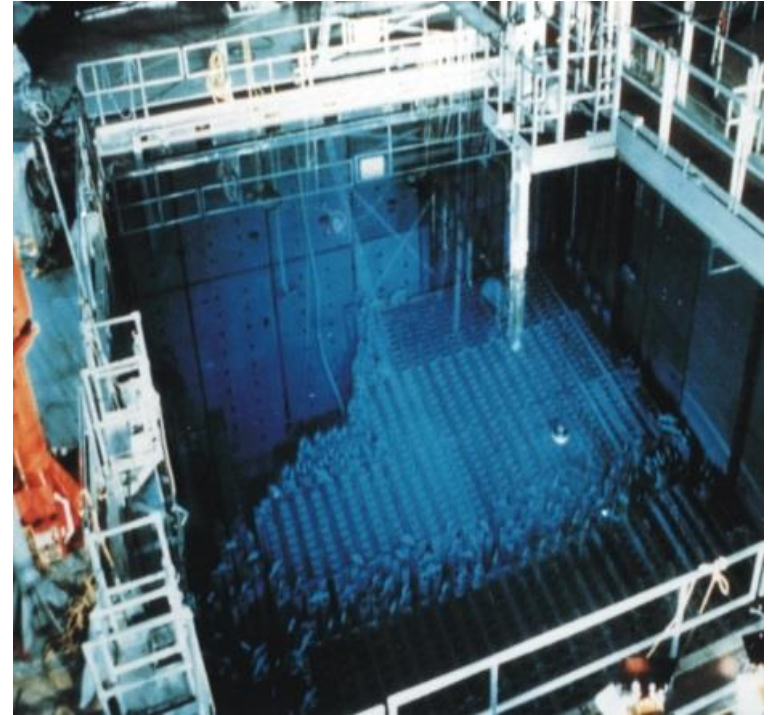
**One person's total lifetime's volume of high level radioactive waste if they used nothing but nuclear energy for their whole life.**





# Current practice in the US

- Spent fuel in storage pools for 5-10 years
- Then transferred to sealed dry casks: 80 casks needed for all spent fuel produced by a 1000-MW reactor in 60 years (small volumes!)
- Dry casks are completely safe to handle and last for decades with minimal maintenance



# Ultimate disposal is in geological repositories



Robust technical options are available (e.g., excavated tunnels or deep boreholes); challenges are always political, with examples of success (Finland, Sweden) and failure (U.S.)

