NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# Advancing Renewable Energy Systems

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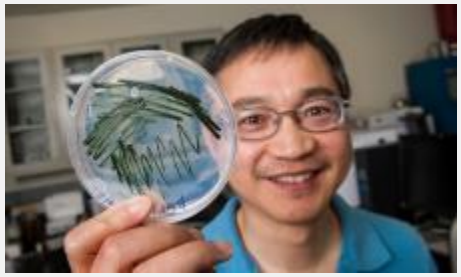
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

# Nearly 40 Years of Clean Energy Research

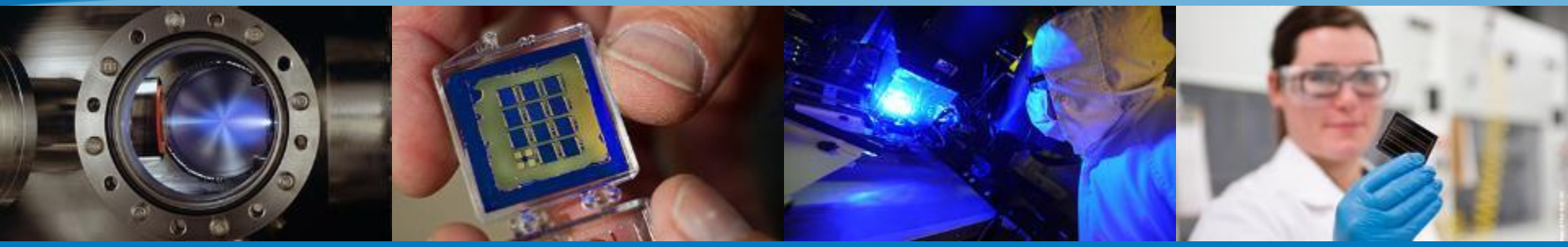
- Founded as Solar Energy Research Institute (SERI) in 1977
- Designated national laboratory in 1991 and renamed National Renewable Energy Laboratory
- Today managed by the Alliance for Sustainable Energy, LLC, for the U.S. Dept. of Energy

- World-class facilities, renowned scientists
- Nearly 1,700 employees
- Annual budget of nearly $380 million
- More than 650 partnerships
- Campus is a model of sustainable energy

# Integrated Approach to Market-Relevant Solutions

| | Analysis & System Integration | Innovation & Application | Foundational Knowledge |
|---|---|---|---|
| Core Capabilities | | | |
| Market-Relevant Solutions | | |  |
| Impact | Provides market insight and informs landscape | Responds to market challenges with solutions and identifies knowledge gaps | Scientific discovery that fills gaps and disrupts current-generation technology |

# Solar : From Research to Markets



***PV is closing the cost parity gap with fossil energy***

**U.S. Capacity:**

- 12.1 GW

**U.S. Forecast (through 2040):**

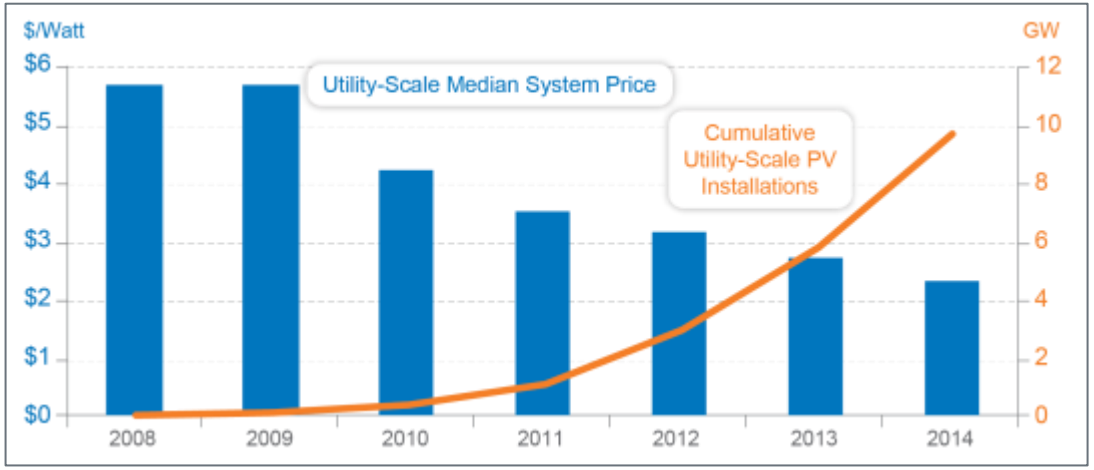
- ~40 GW of PV capacity in pipeline

**Costs:**

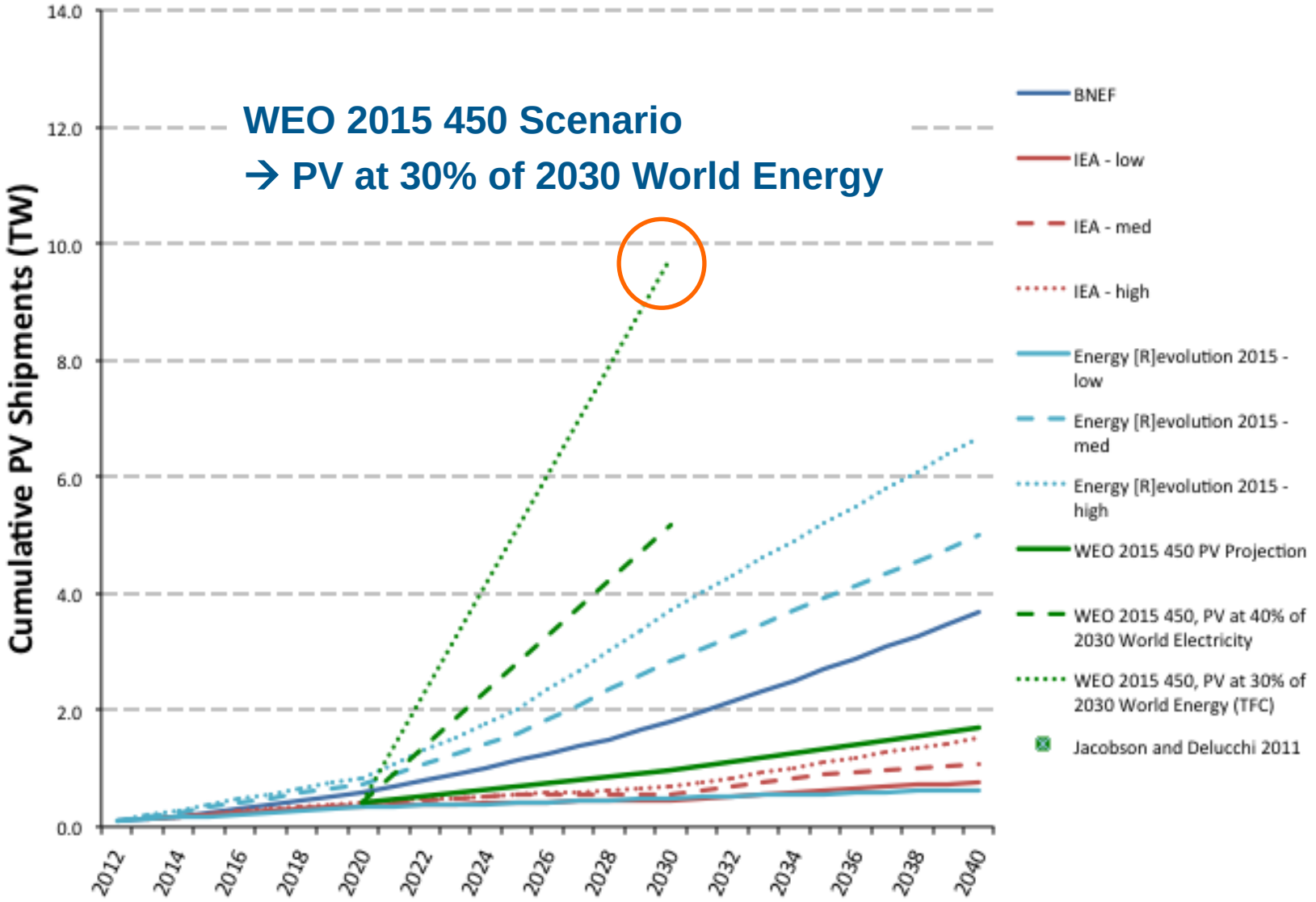
- <$2 to $6/W: *LCOE 7 to 16¢/kWhr
- <1% of U.S. power generation

The cost of solar energy has fallen 96% and now stands at less than a dollar a watt for solar module, pre-installation.

Globally, solar energy grew by more than 50% each of the past five years (2011-2015).



# ~10 Terawatts of PV by 2030



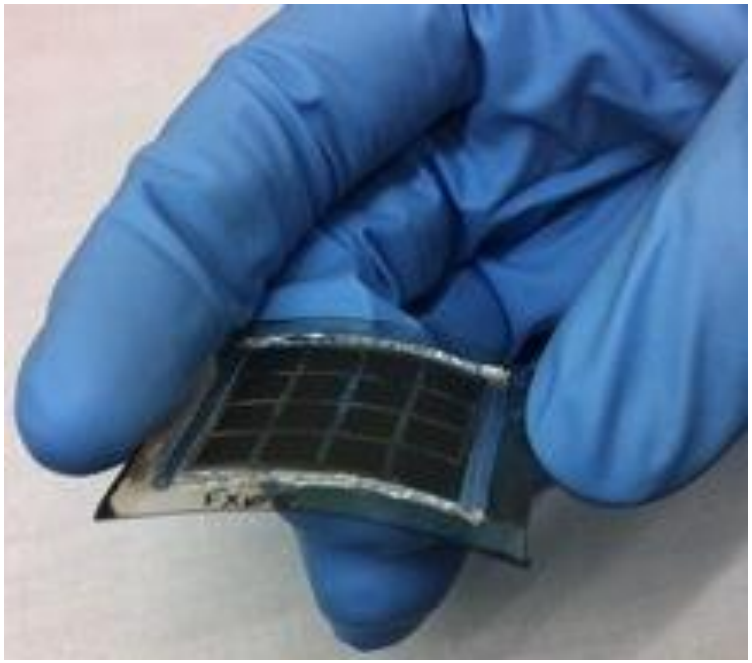
# Flexible CdTe Solar Cells and Transparent Conducting Oxides

## Scientific Approach

- Pursue high-efficiency CdTe cells that also have a flexible form factor.
- Develop flexible transparent conducting oxides (TCOs) for use as contacts in CdTe.

## Significance and Impact

- 16.4% efficient, flexible CdTe.[1, 2] This enables lightweight, flexible, *and low-cost* PV.
- Demonstration of flexible transparent conducting oxides
- TCOs must be polycrystalline in order to maintain conductivity when flexed.[3]

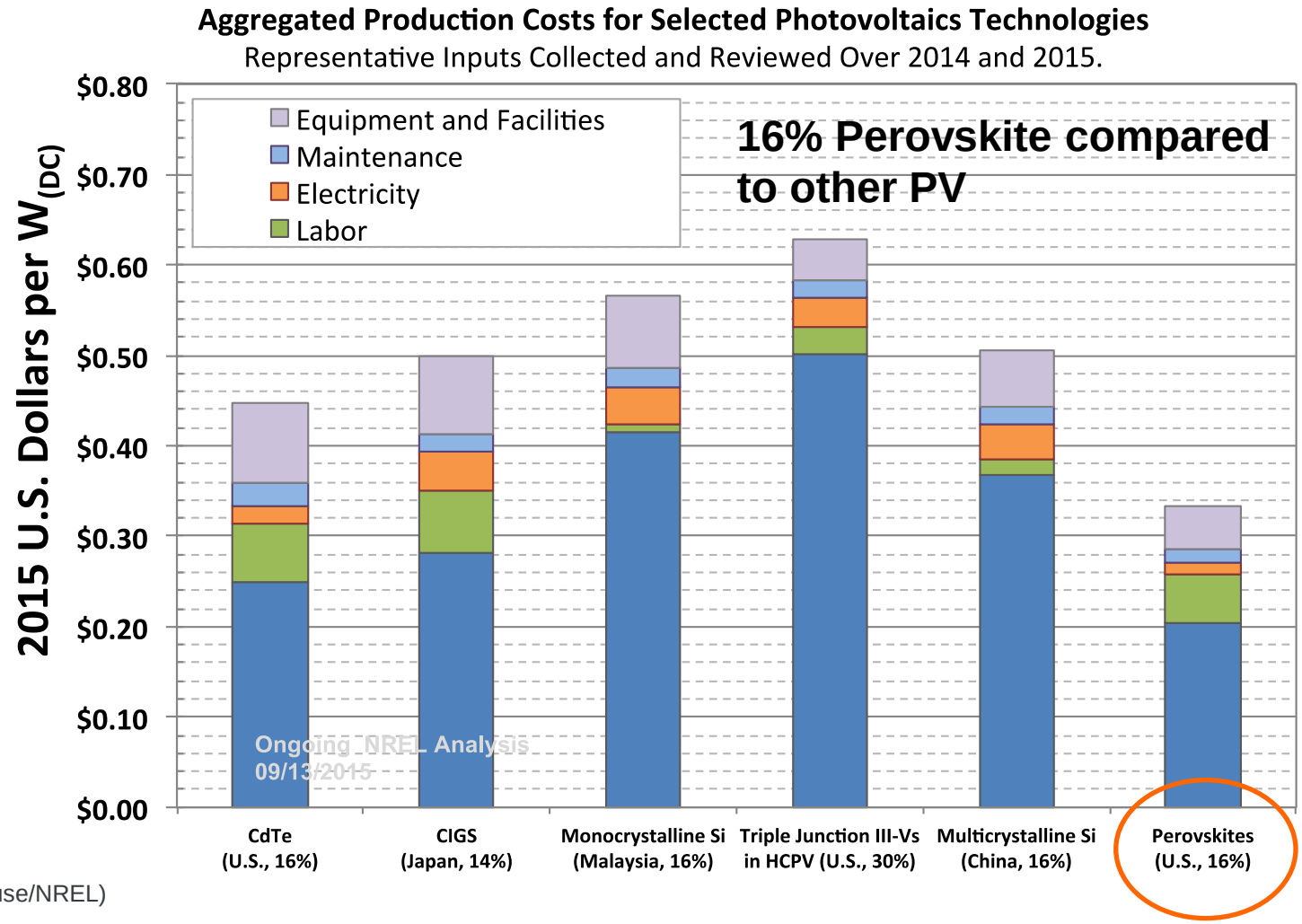


*Willow Glass substrate with 16 CdTe solar cells and an indium metal contact made at NREL, show the flexibility of the cells on a small piece of glass.*

[1] Rance, et al., *Appl. Phys. Lett.* 2014, dx.doi.org/10.1063/1.4870834,
[2] Mahabaduge et al., *Appl. Phys. Lett.* 2015, dx.doi.org/10.1063/1.4916634,
[3] Burst et. al., submitted to *Nature Materials*, 2016

# Outlook on Cost of Perovskite Photovoltaics

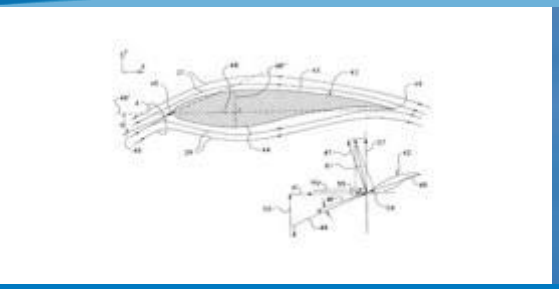
## Stable perovskite PV can meet 2020 cost targets




(Woodhouse/NREL)

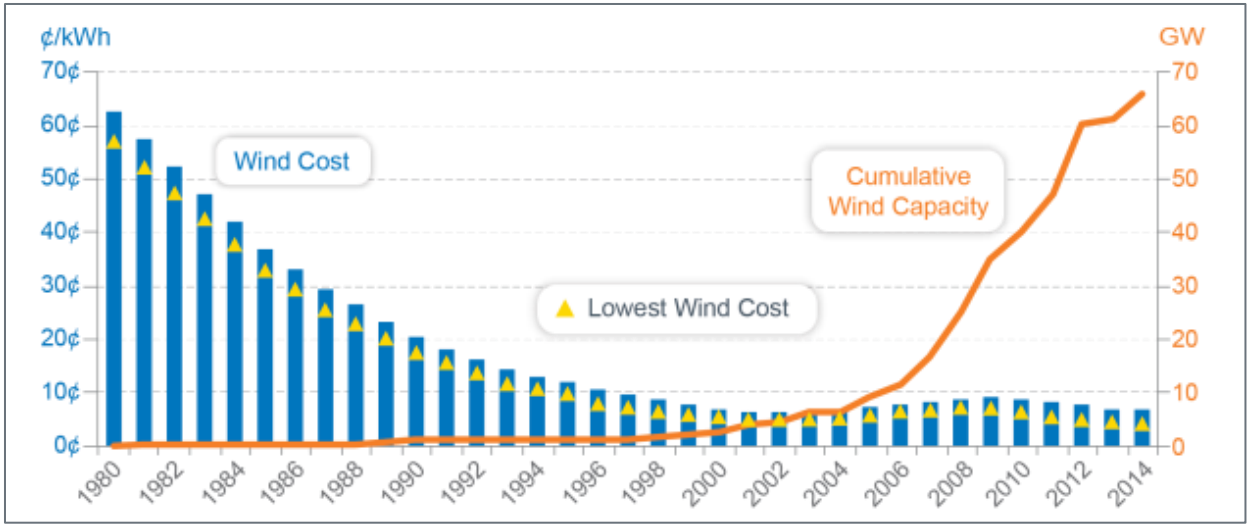
The American wind industry is striving toward **supplying 20% of the nation's electrical demand in 2030**—or *four times* the current U.S. installed wind capacity.

# Impact of NREL's Wind Research

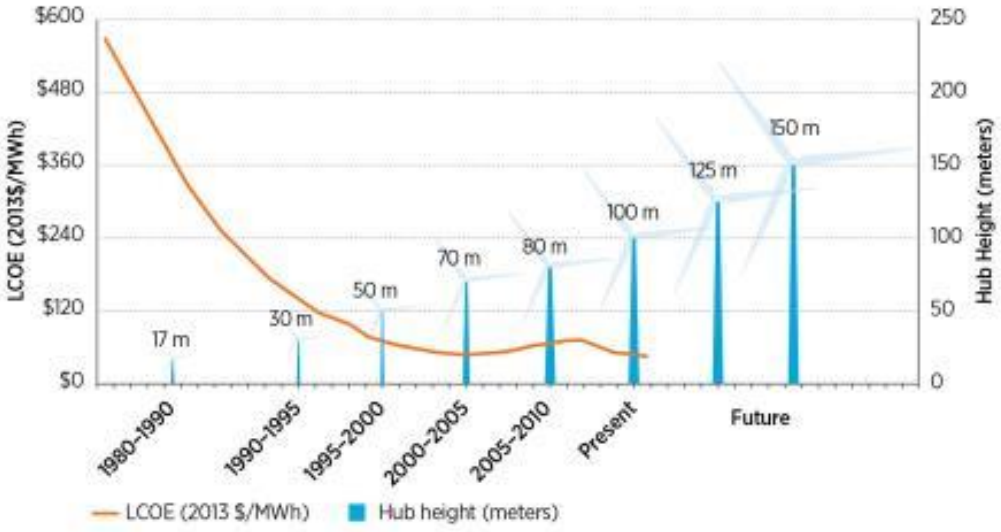


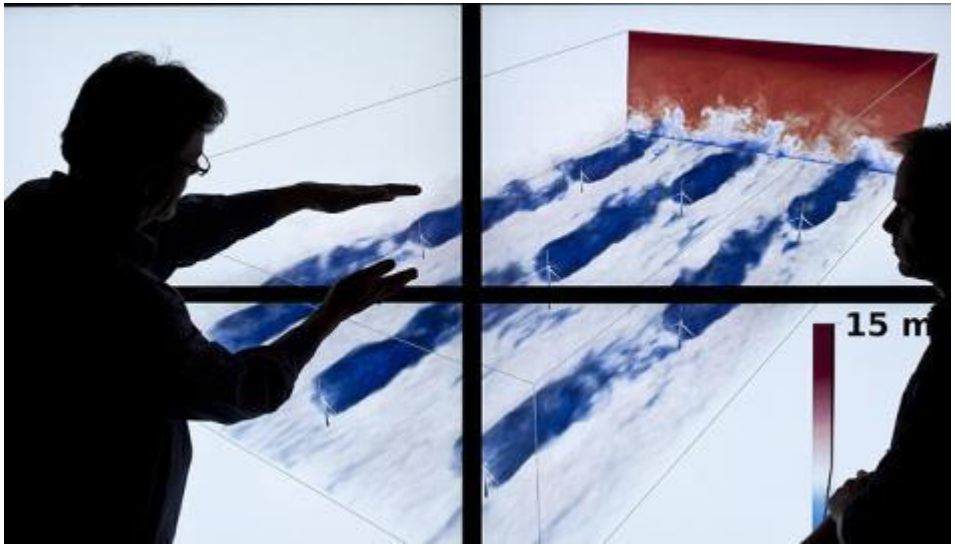
- Current Costs: 4-7 cents/kWh
- Installed capital cost between $1,300 and $1,900/kW
- U.S. ranks 2nd in world for installed capacity (74 GW)
- Nearly 5% of U.S. total electrical demand

The levelized cost of wind energy has declined from 40 cents per kilowatt-hour when the lab was founded to 4 to 7 cents today, enabling industry success.

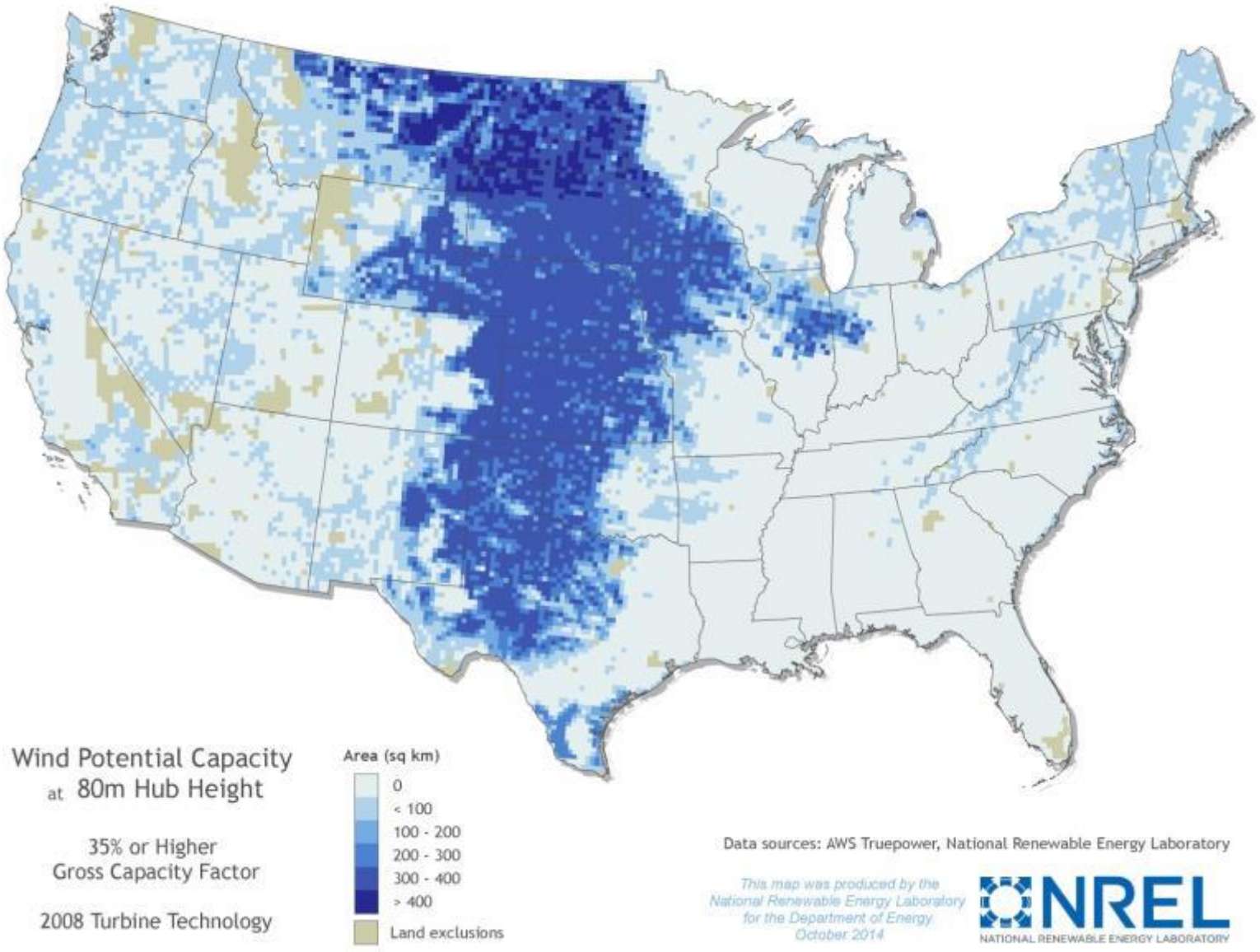


# Untapped Potential of Wind

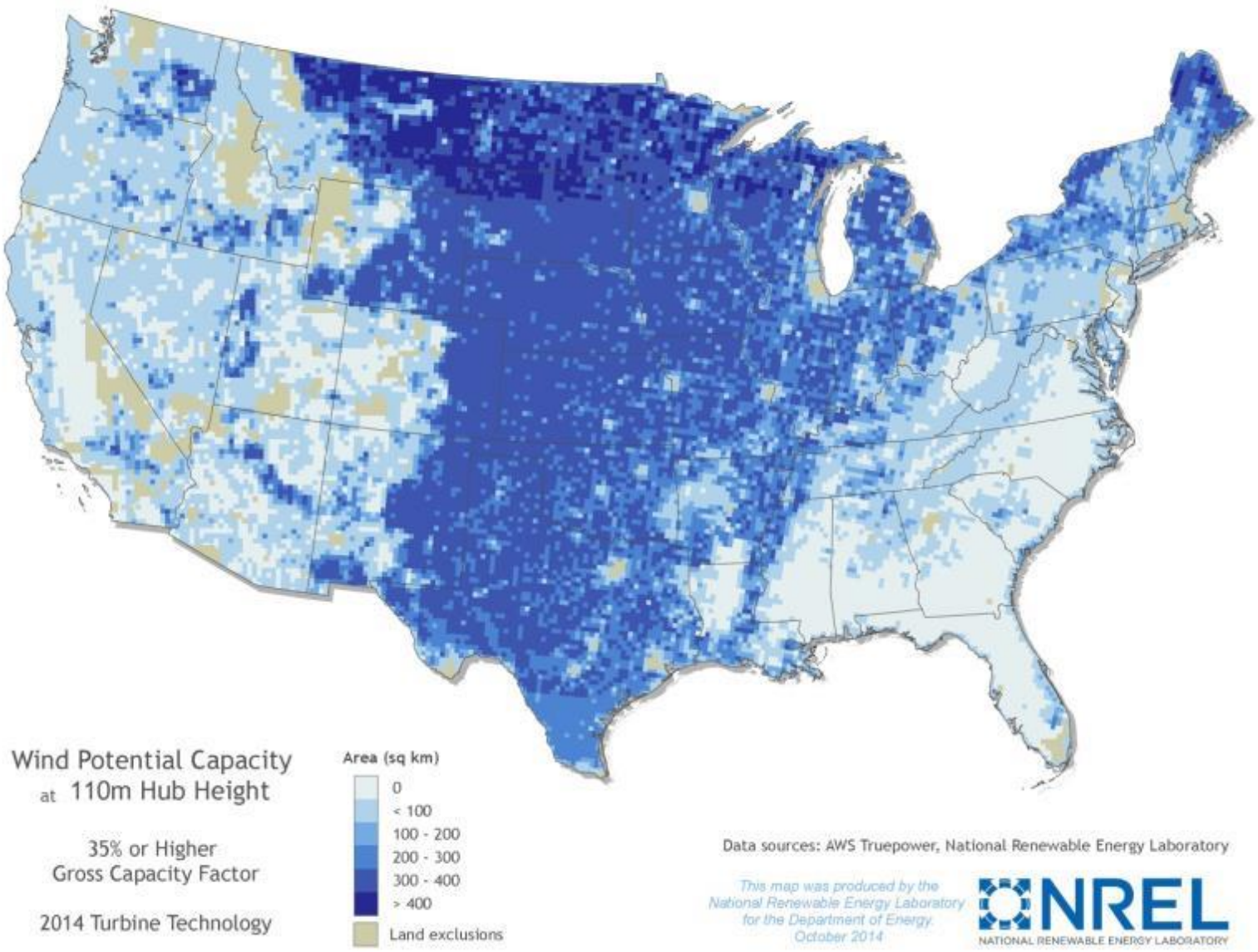


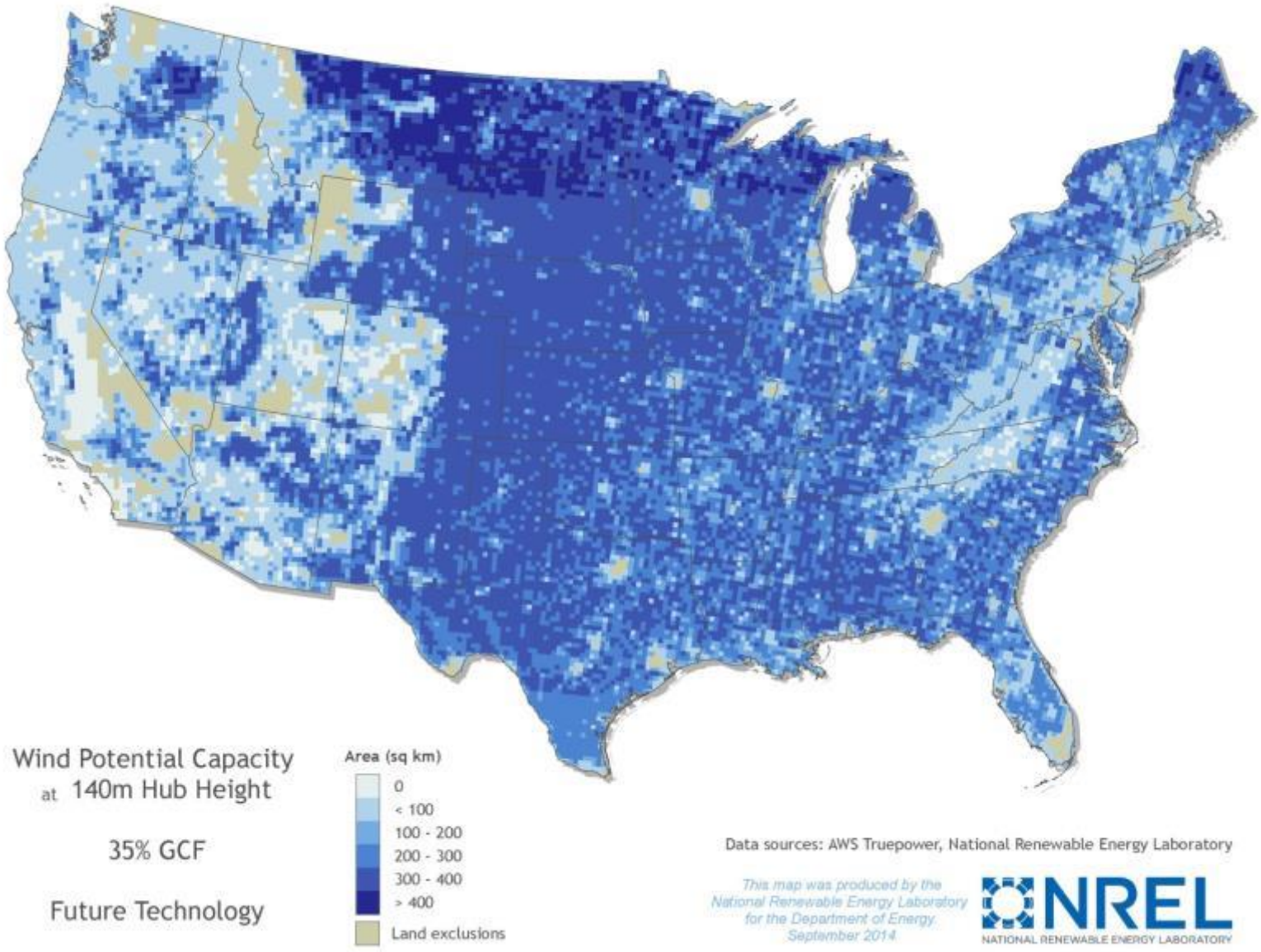
# Wind Energy Potential Capacity at 80m Hub Height 2008 Turbine Technology



# Wind Energy Potential Capacity at 110m Hub Height 2014 Turbine Technology



# Wind Energy Potential Capacity at 140m Hub Height ‘Near Future’ Turbine Technology (150W/m$^2$)



# On-site Manufacturing

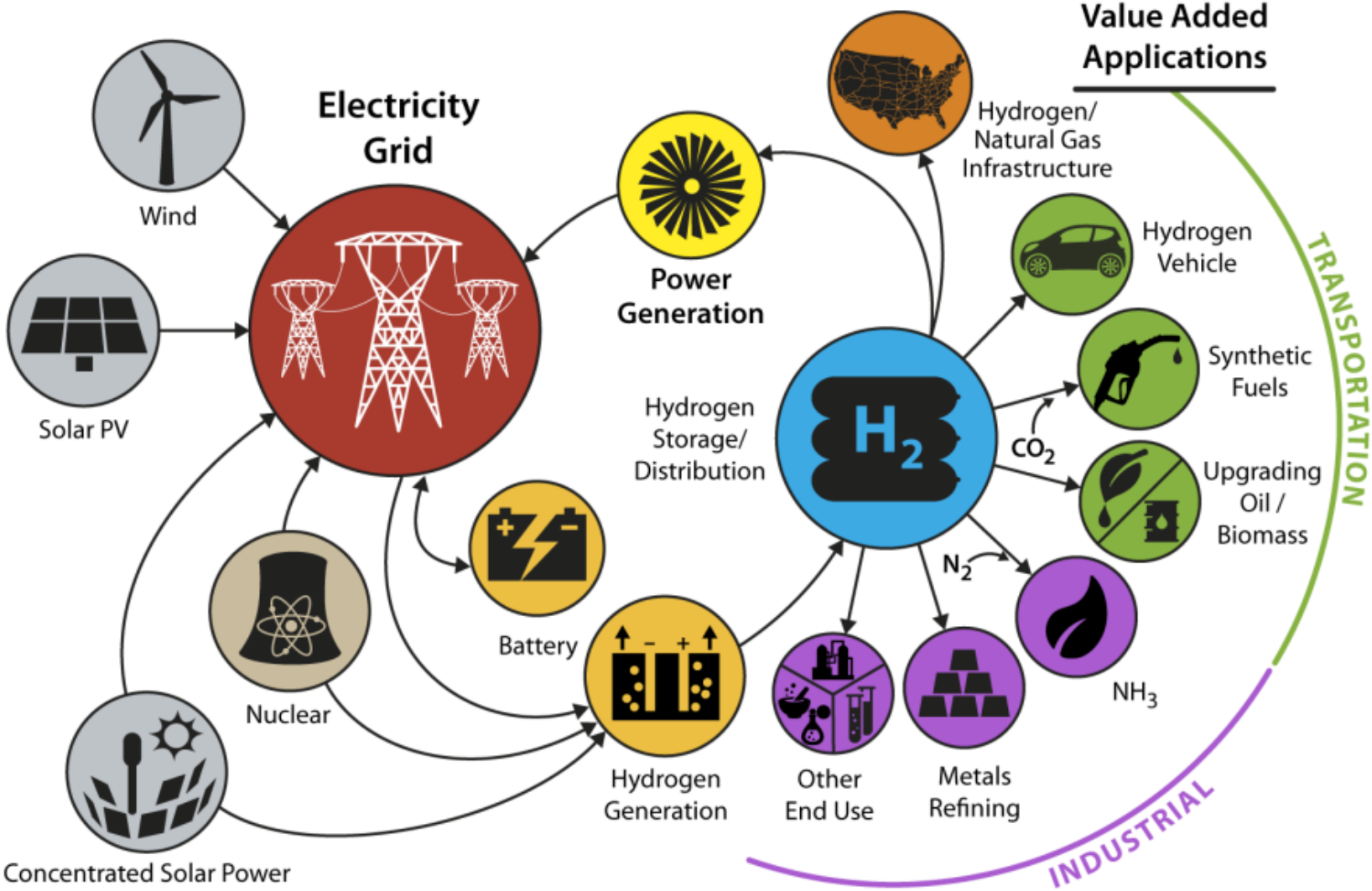
## Major development for wind energy through elimination of transportation barriers

- Enables more efficient turbine design
  - Broader tower base (4.3m → 7m)
  - Larger blade root diameter
- Efficient tall towers and long blades are very difficult to achieve without on-site manufacturing
- Eliminates significant transportation costs for components for large turbines
- Leverage recent advantages in manufacturing
- Leverage National Wind Technology Center (NWTC) validation capabilities to demonstrate part quality
- Eliminates safety issues from component transport

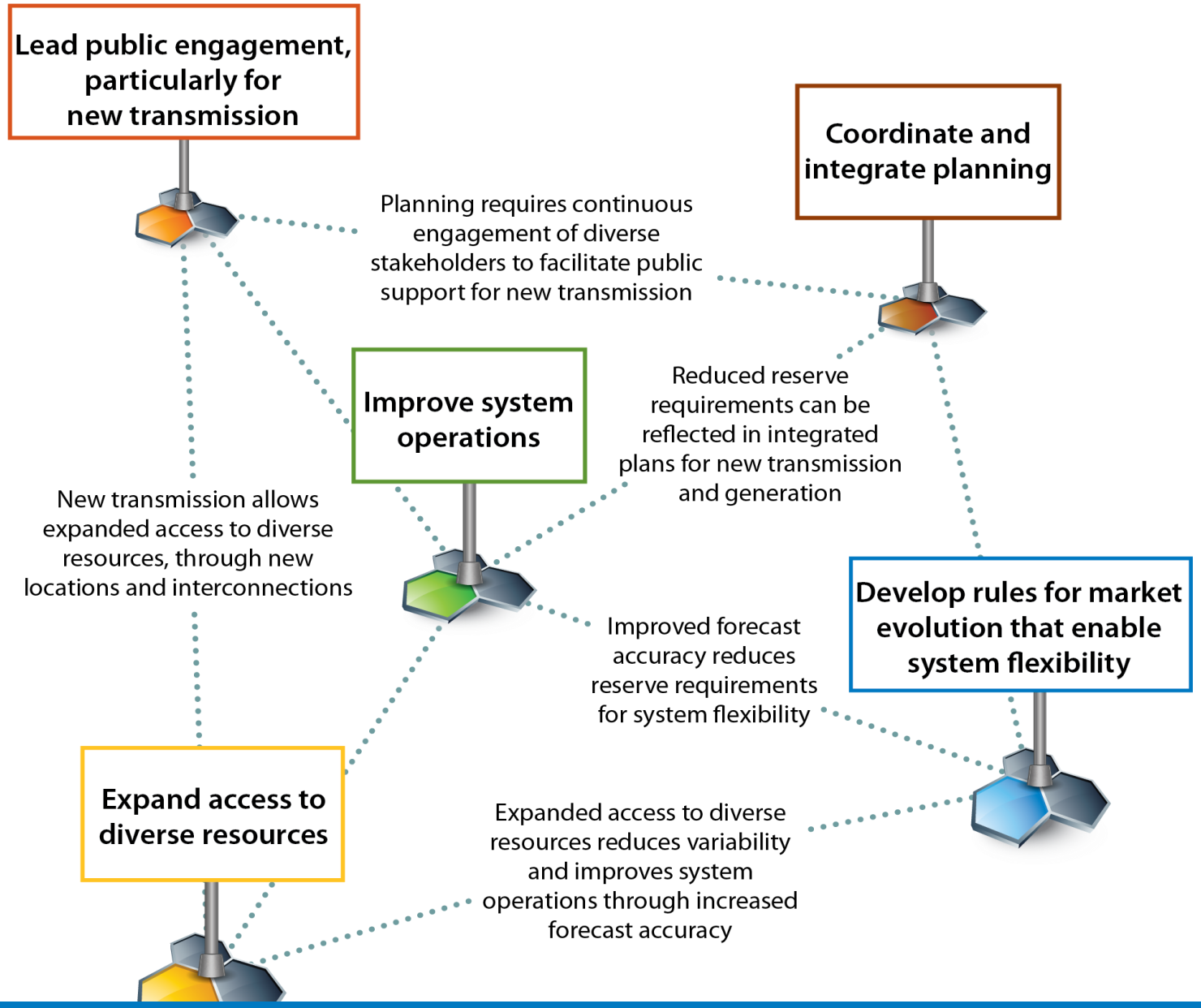
# Energy Systems Integration

Fortifying U.S. energy infrastructure at a ***pace and scale that matters***.

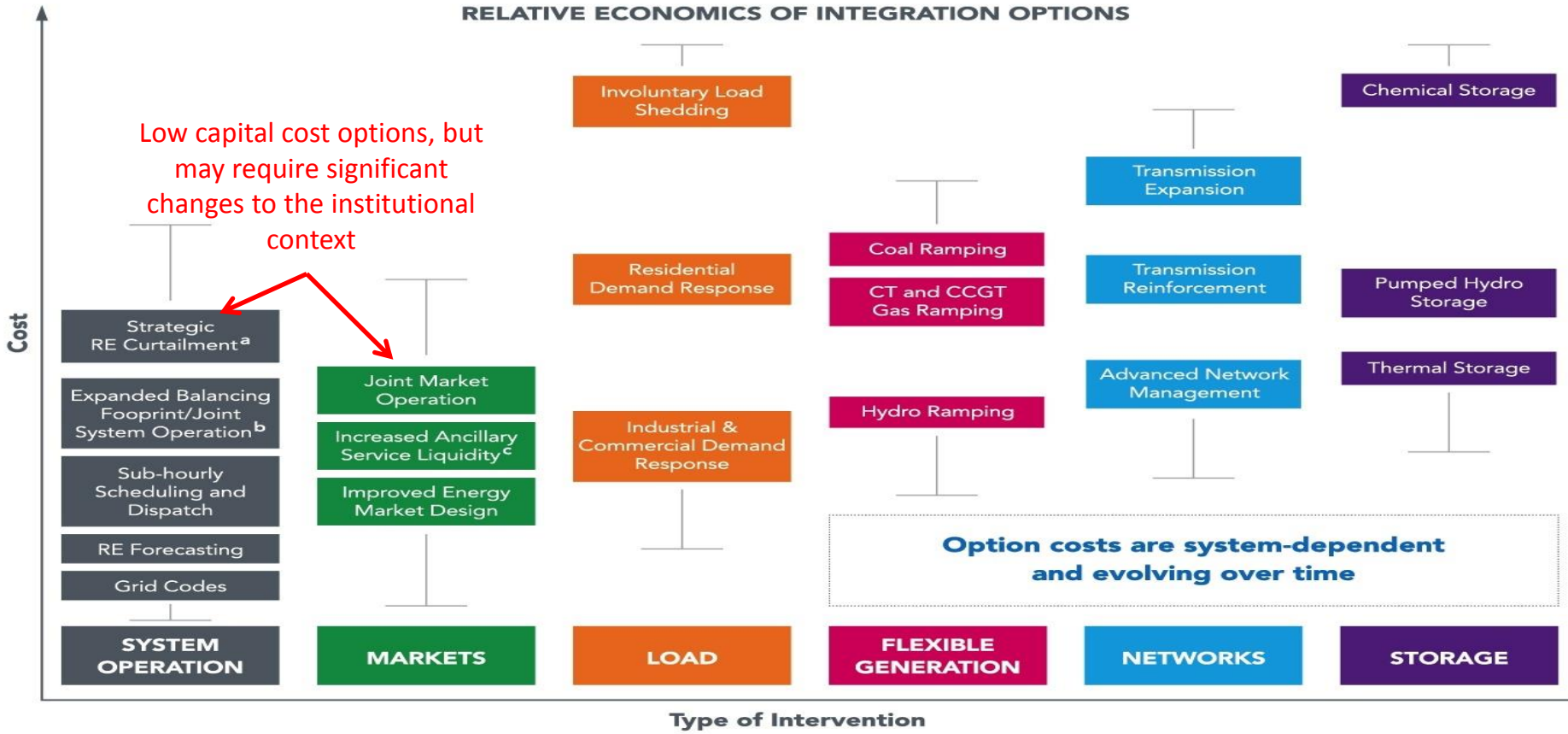
# Future H2@Scale Energy System



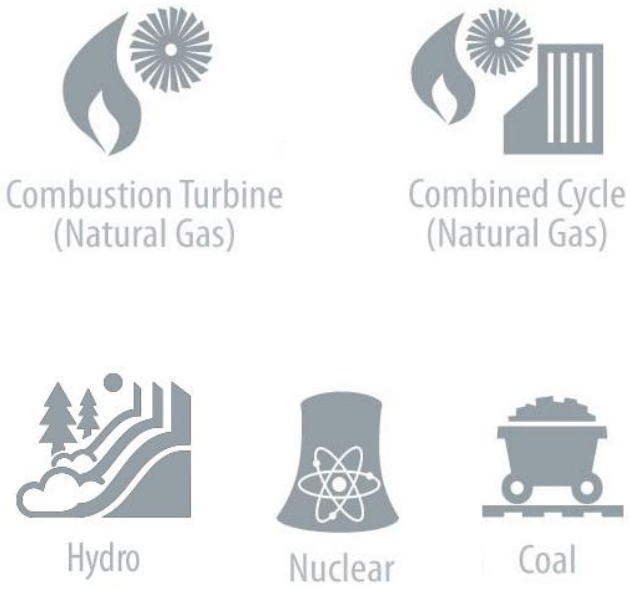
# Strategic Leadership Areas to Realize High RE Futures

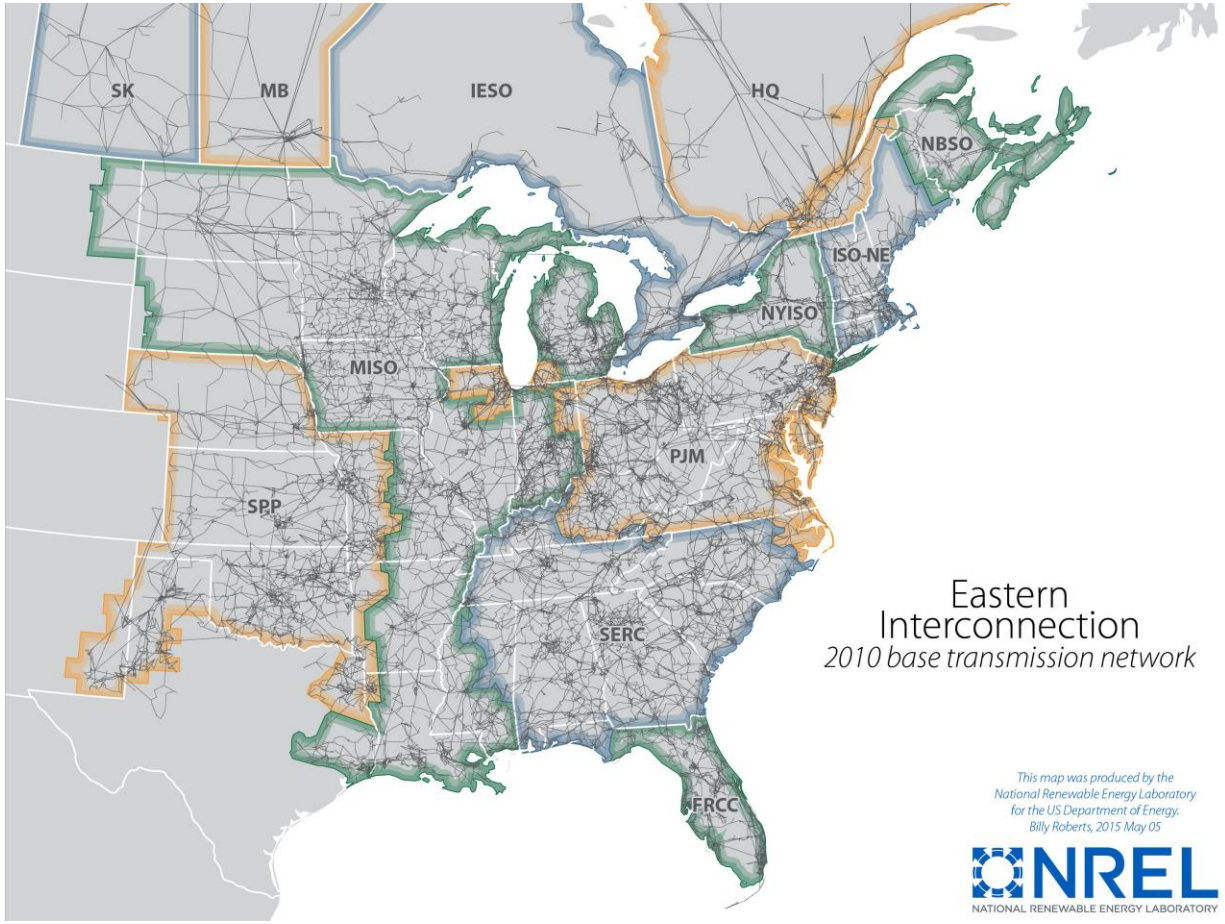


# Flexibility in 21st Century Power Systems



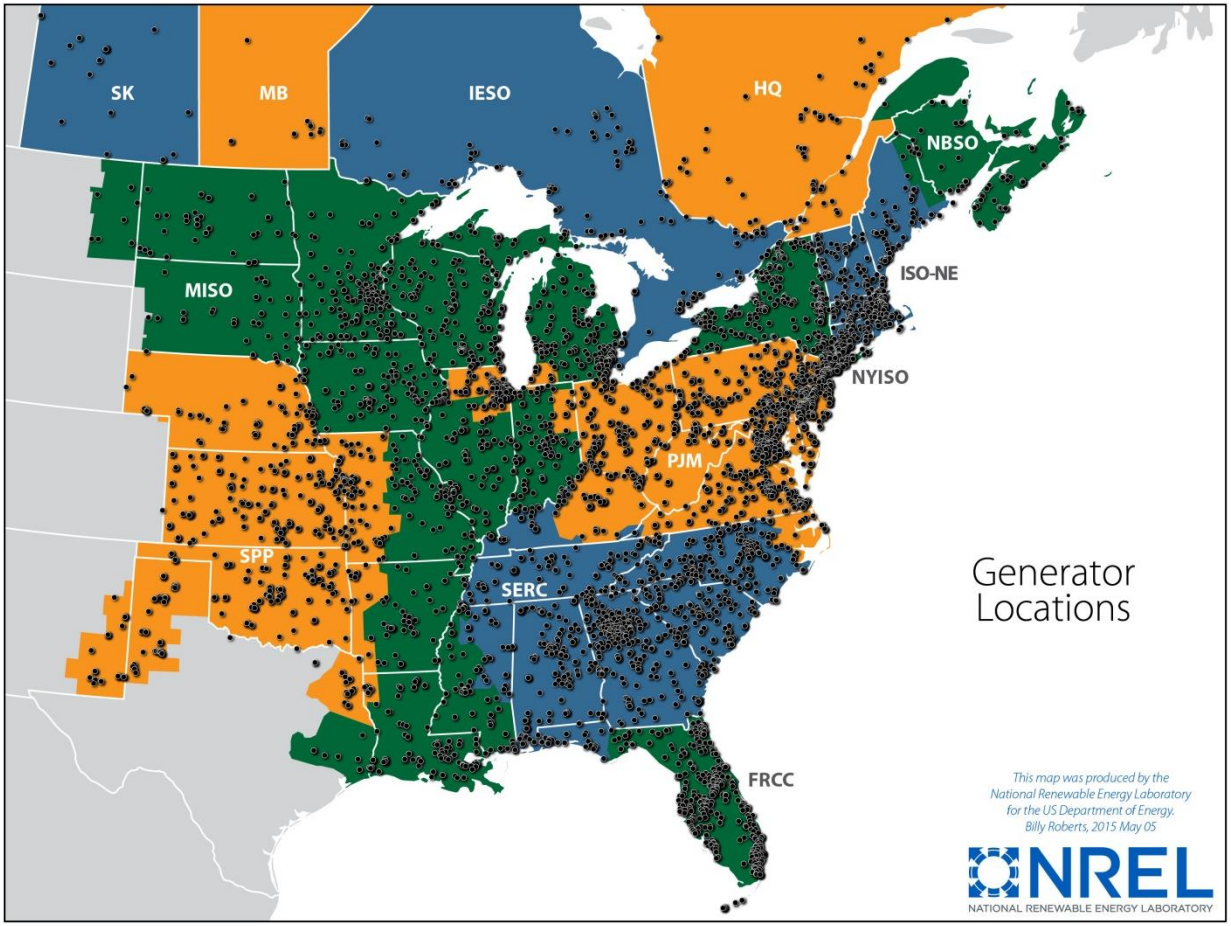
# Eastern Interconnect – Reliably Designed for Conventional Sources




*The largest coordinated power system in the world*

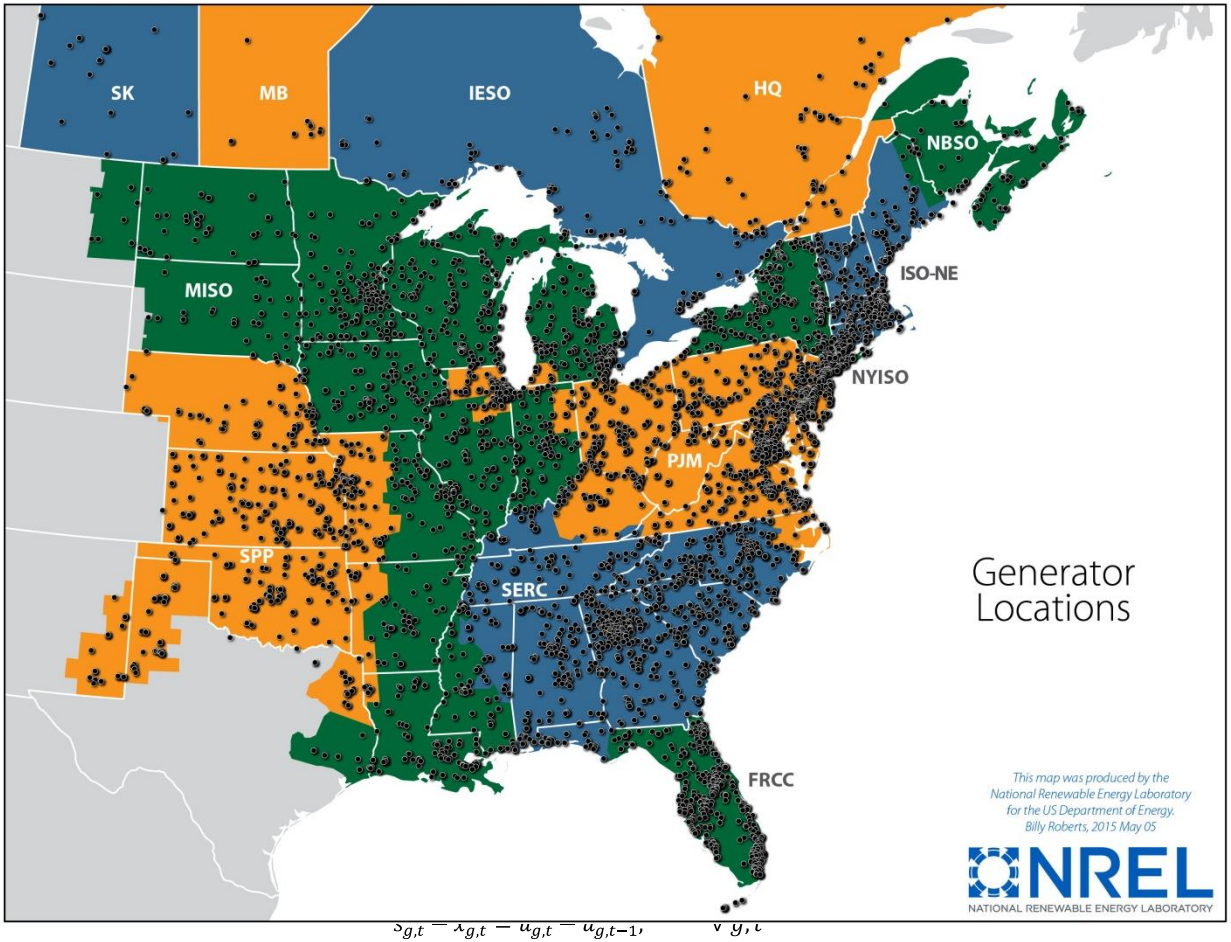
# The Eastern Interconnection – Statistics




- Generating capacity: 700 GW
- Generating units: 7,500
- Load: 3,000 TWh
- Population: 240 million people
- 70% of US Load
- Transmission length: 459,000 miles
- Nodes: 60,000
- Transmission lines: 50,000

# The Eastern Interconnection – Statistics

- Minimize operating costs according to constraints:
  - Transmission




$$
\begin{aligned}
s_{g,t} - x_{g,t} - u_{g,t} - u_{g,t-1}, &\quad \forall\, g,t \\
s_{g,t} \le 1 - u_{g,t-1}, &\quad \forall\, g,t \\
x_{g,t} \le u_{g,t-1}, &\quad \forall\, g,t \\
u_{g,t} \in \{0,1\} &\quad \forall\, g,t \\
x_{g,t} \in \{0,1\} &\quad \forall\, g,t \\
s_{g,t} \in \{0,1\} &\quad \forall\, g,t
\end{aligned}
$$

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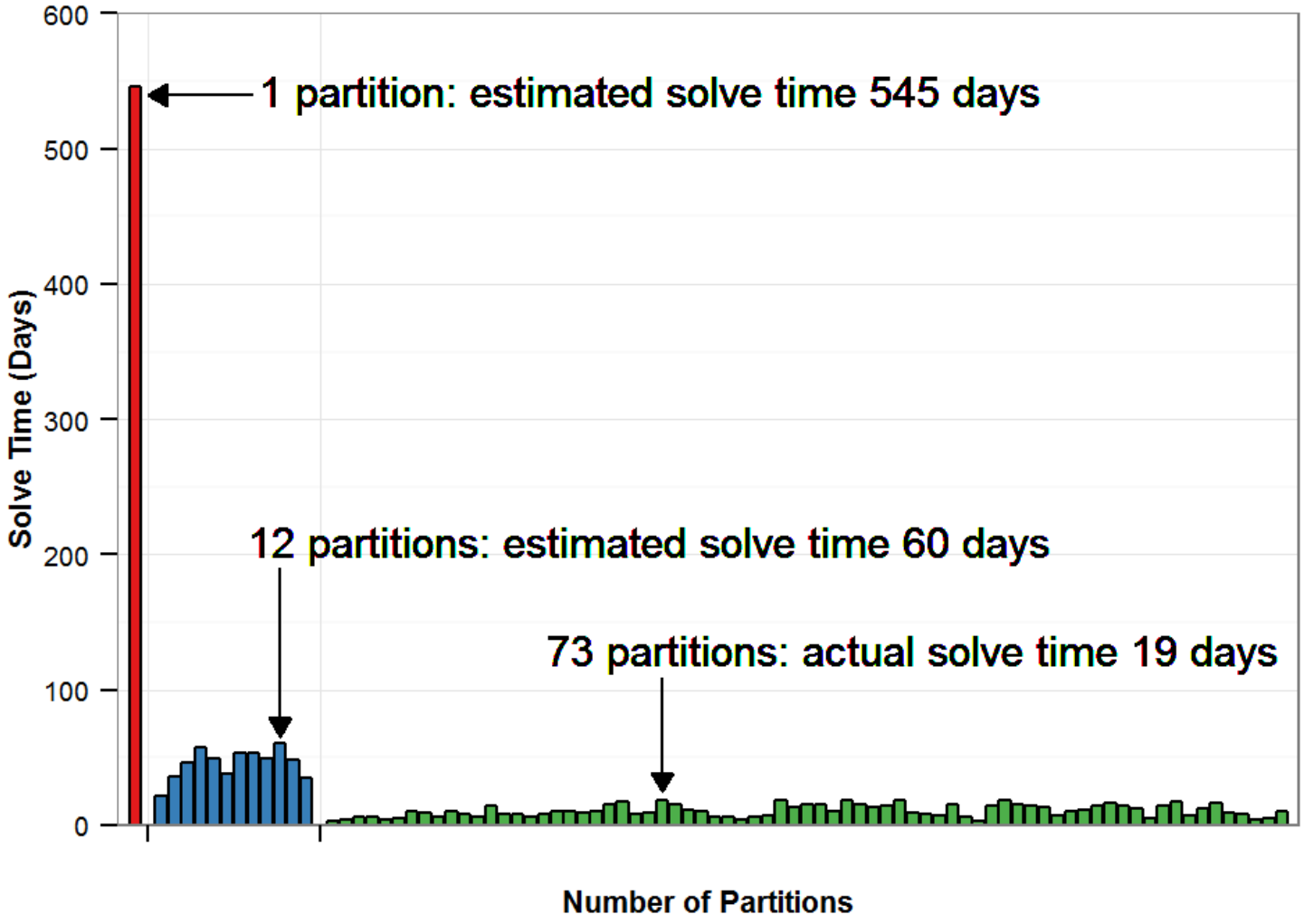
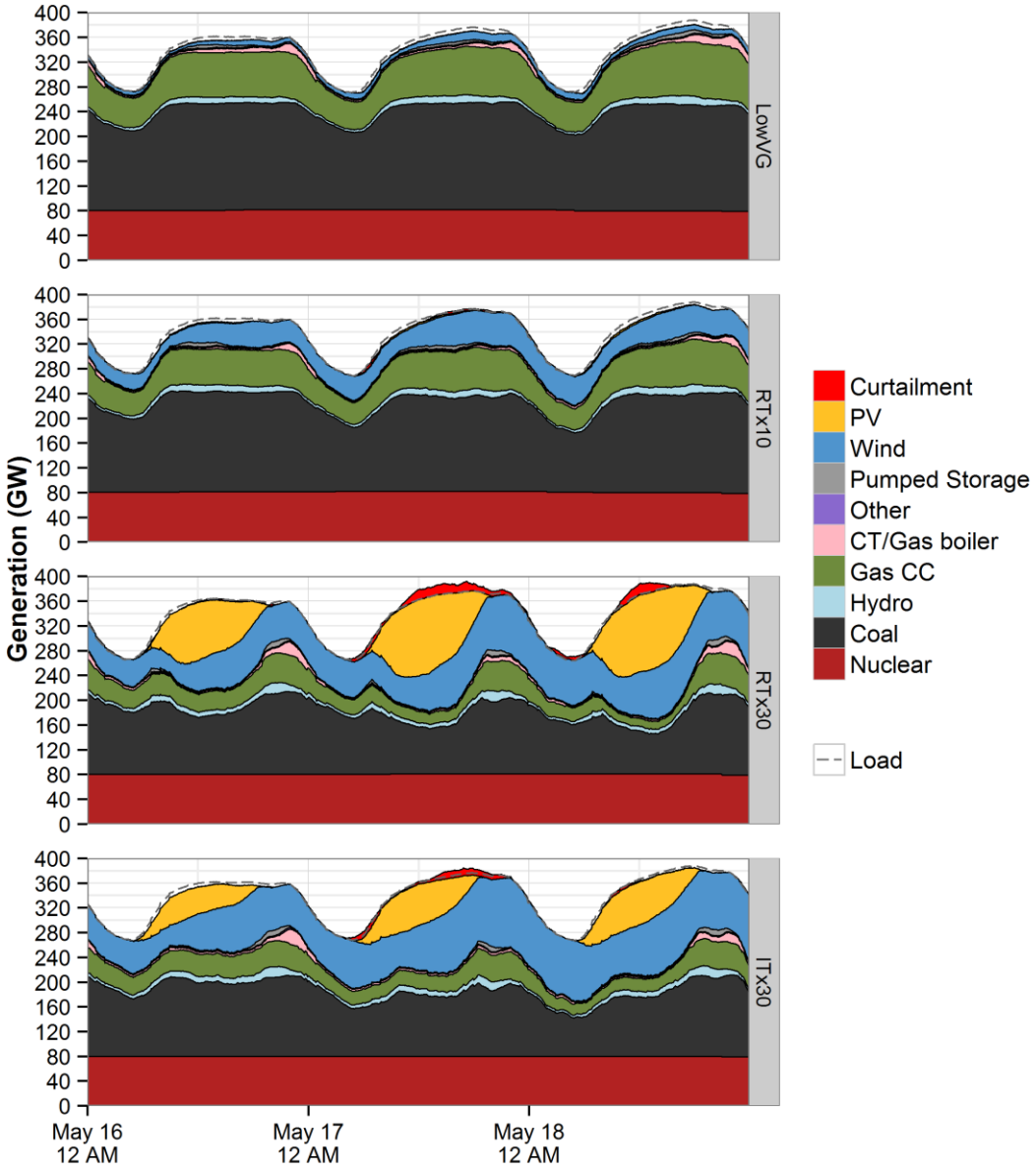
# Peta-scale Supercomputer

# Computational Challenge

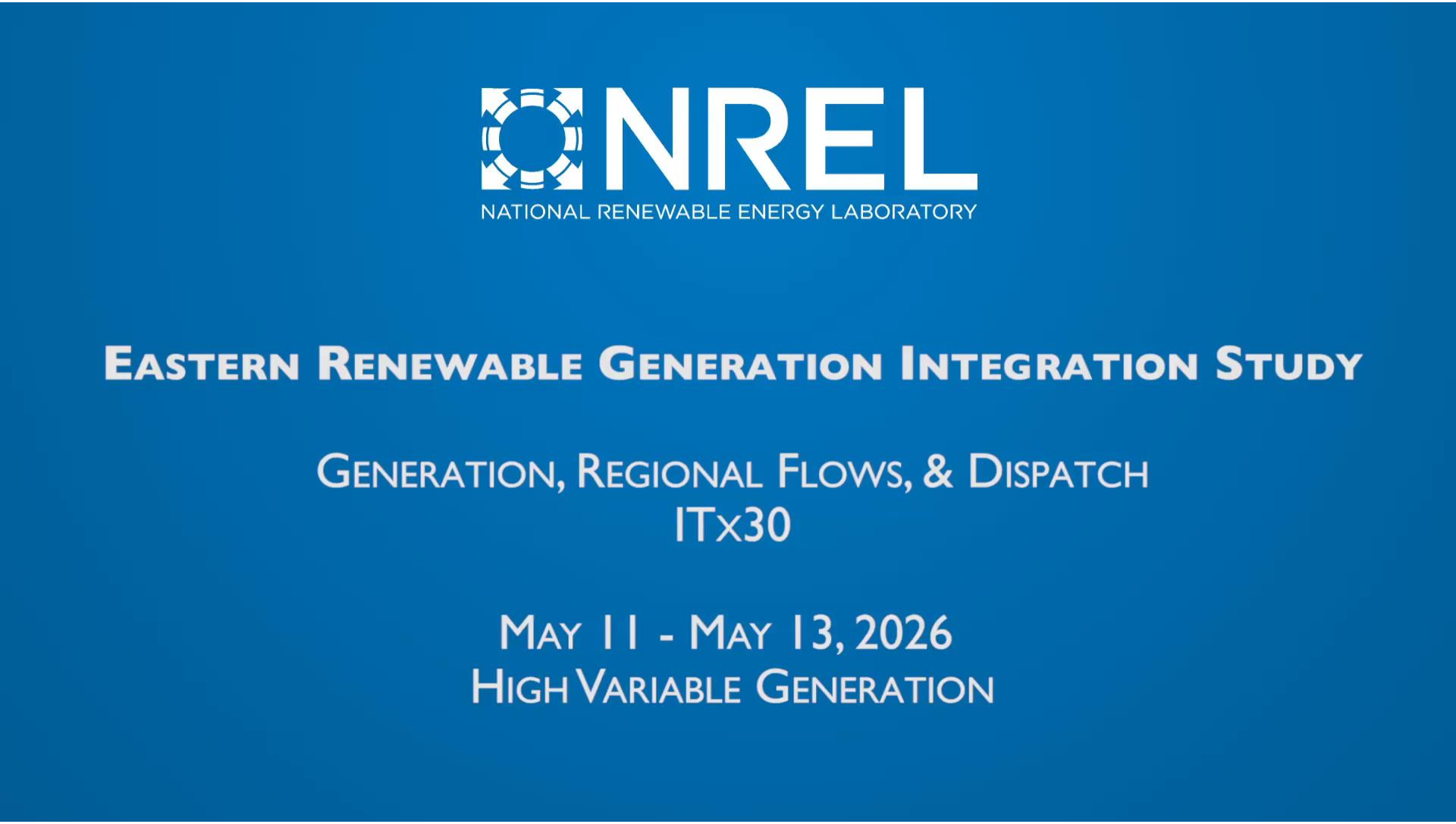
*Solve for the least cost dispatch over 105,000 times for each scenario.*



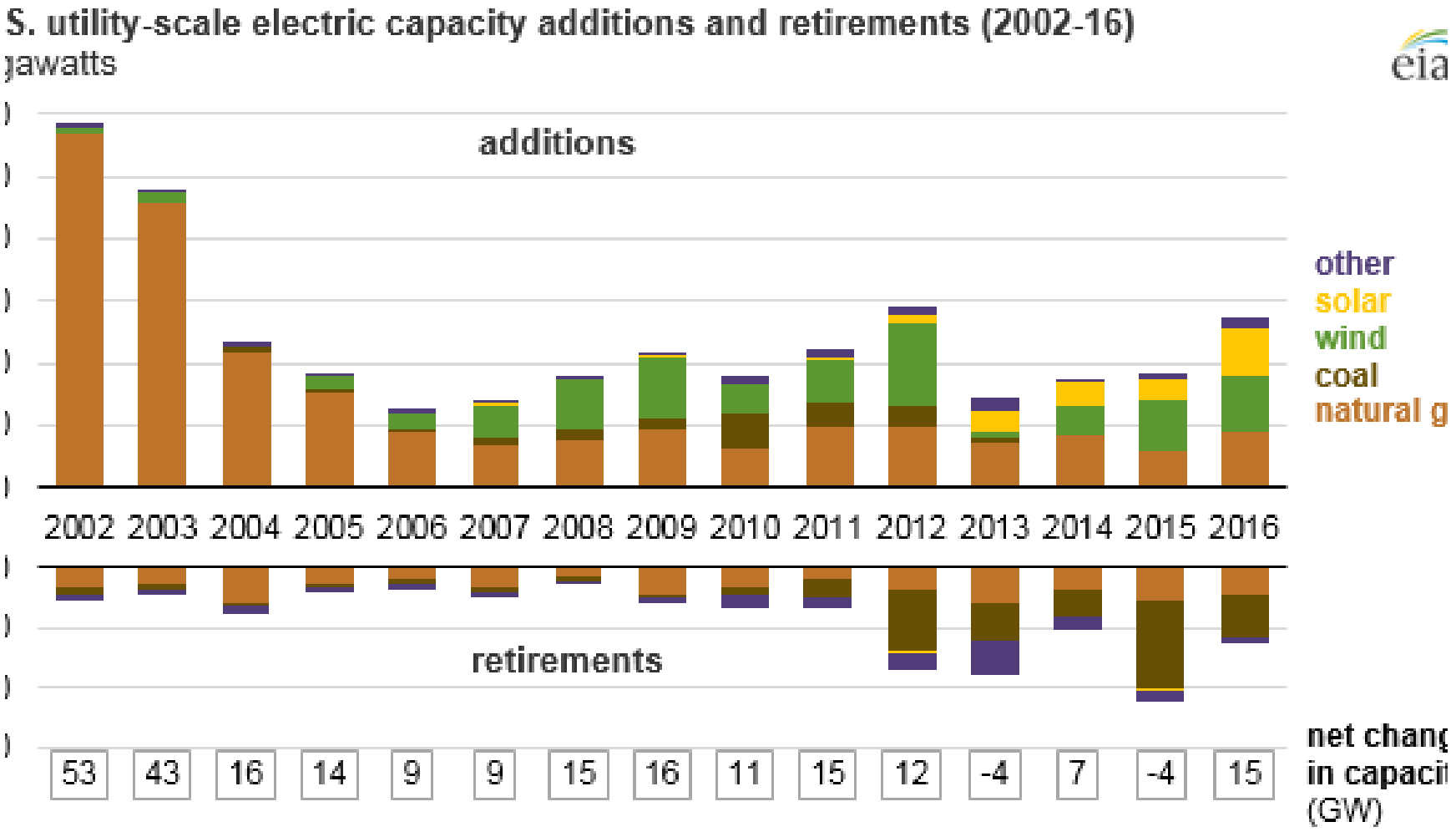
# High Solar the Eastern Interconnection



# ERGIS Visualization



# Changes in US Power Generation



“The best way to predict your future is to create it.”
*–Abraham Lincoln*

At NREL, we believe we can help create the future through our core capabilities, market-relevant solutions and their impacts

Innovation & Impact

Analysis & System Integration

Foundational Knowledge