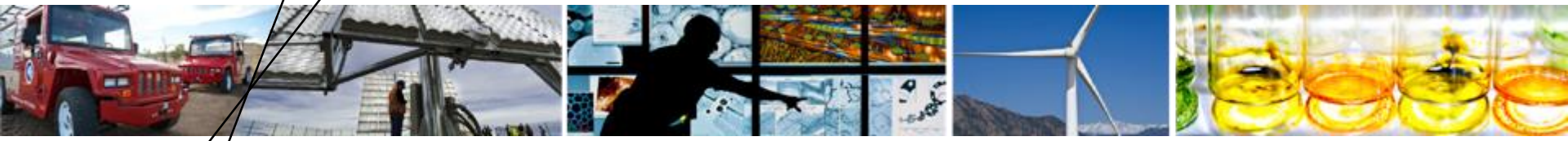
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. Experiences with Wind and Solar Energy Markets



David Mooney, Ph.D.

March 2016

OUTLINE

1. National Renewable Energy Laboratory Overview
2. History and Current Status of the US Wind and Solar Energy Markets
3. Policy Drivers for Increased Renewable Energy Deployment
4. Integrating Renewables into the Grid

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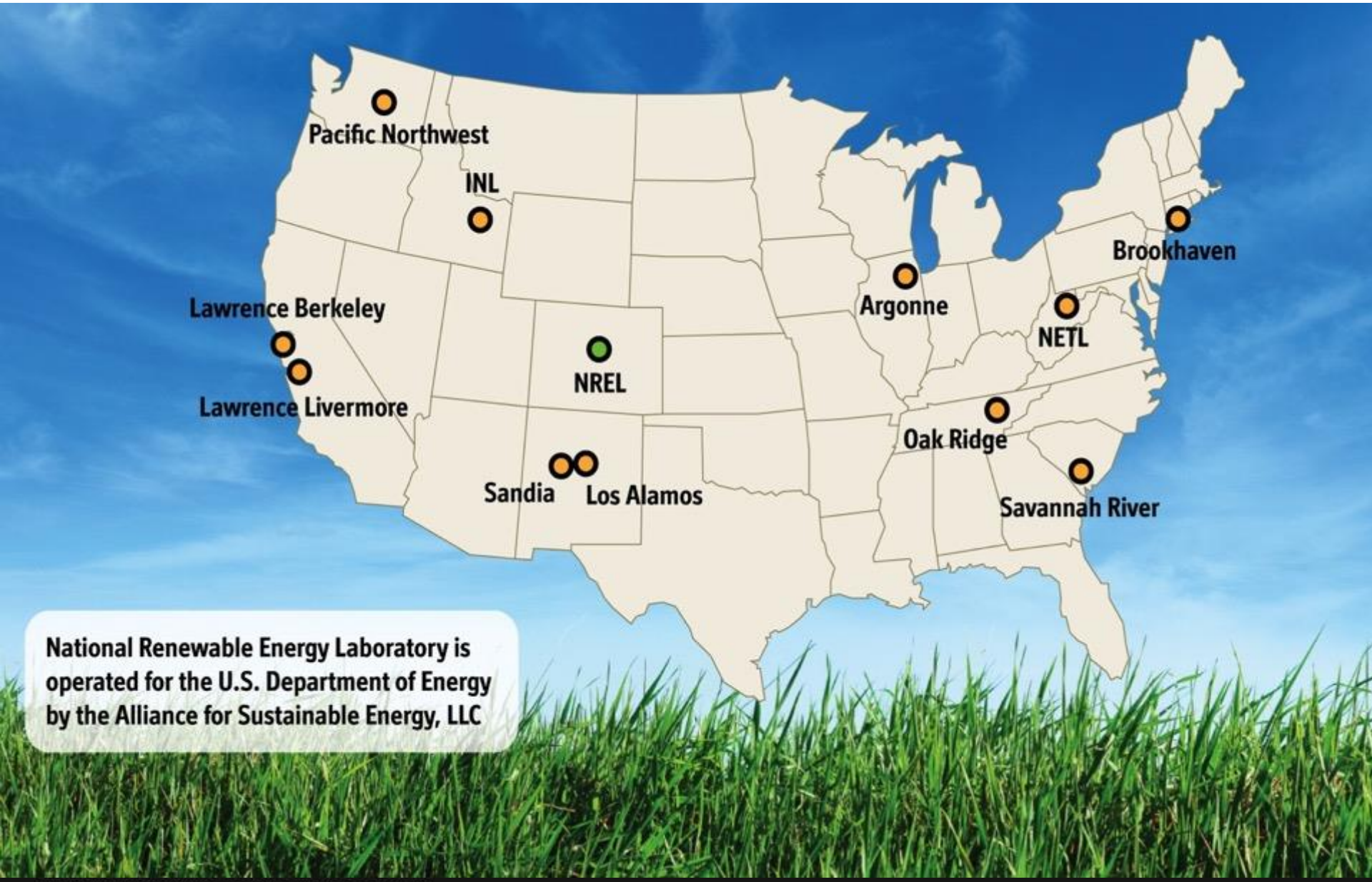
U.S. DEPARTMENT OF ENERGY'S NATIONAL LAB COMPLEX



NATIONAL ASSET WITH A DEDICATED MISSION

- Nearly 1,700 employees
- Campus is a model of sustainable energy
- National economic impact of $872M annually - $400M annual budget
- 657 active partnerships with industry, academia, and governments

SCOPE OF MISSION

Energy Efficiency

- Residential Buildings
- Commercial Buildings
- Personal and Commercial Vehicles

Renewable Energy

- Solar
- Wind and Water
- Biomass
- Hydrogen
- Geothermal

Systems Integration

- Grid Infrastructure
- Distributed Energy Interconnection
- Battery and Thermal Storage
- Transportation

Market Focus

- Private Industry
- Federal Agencies
- Defense Dept.
- State/Local Govt.
- International

Cross-Cutting Analysis and Decision Support

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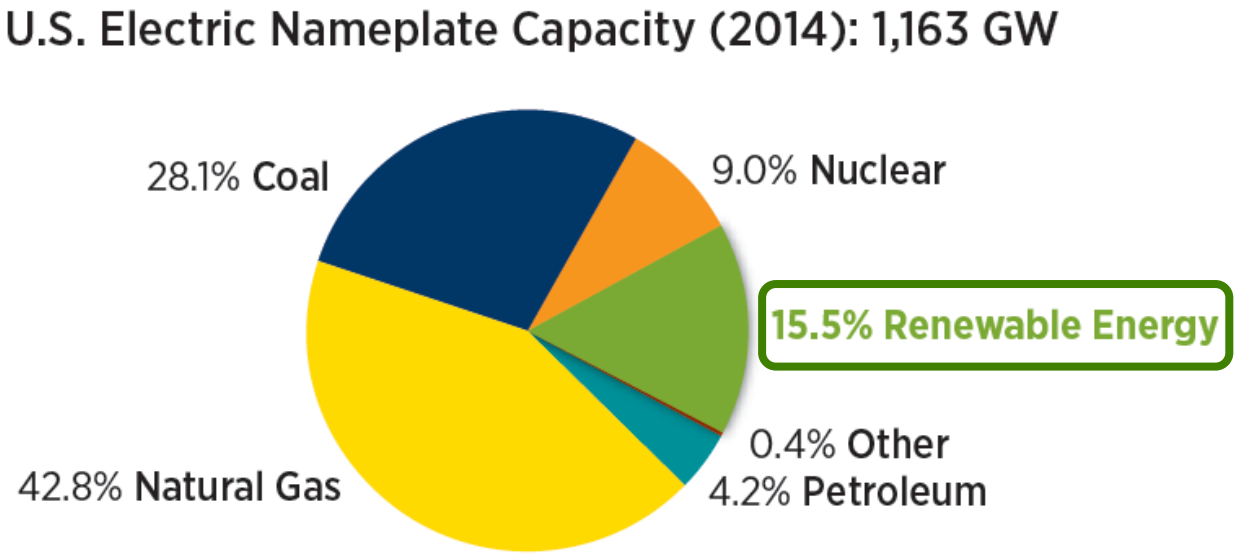
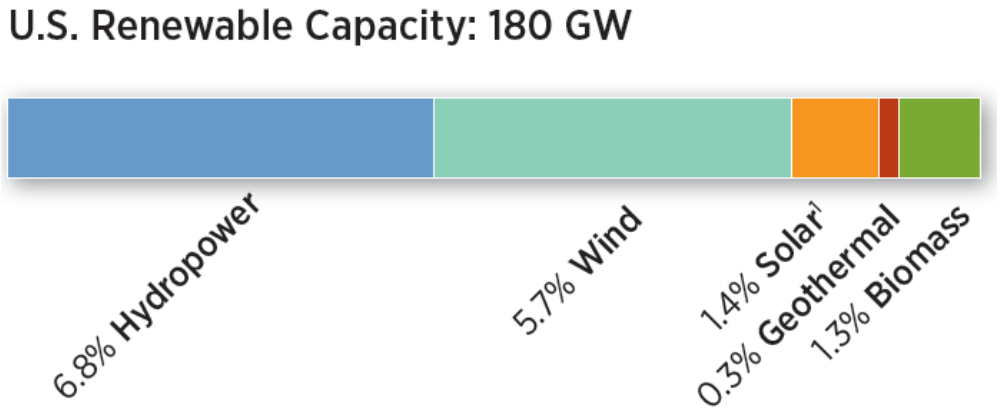
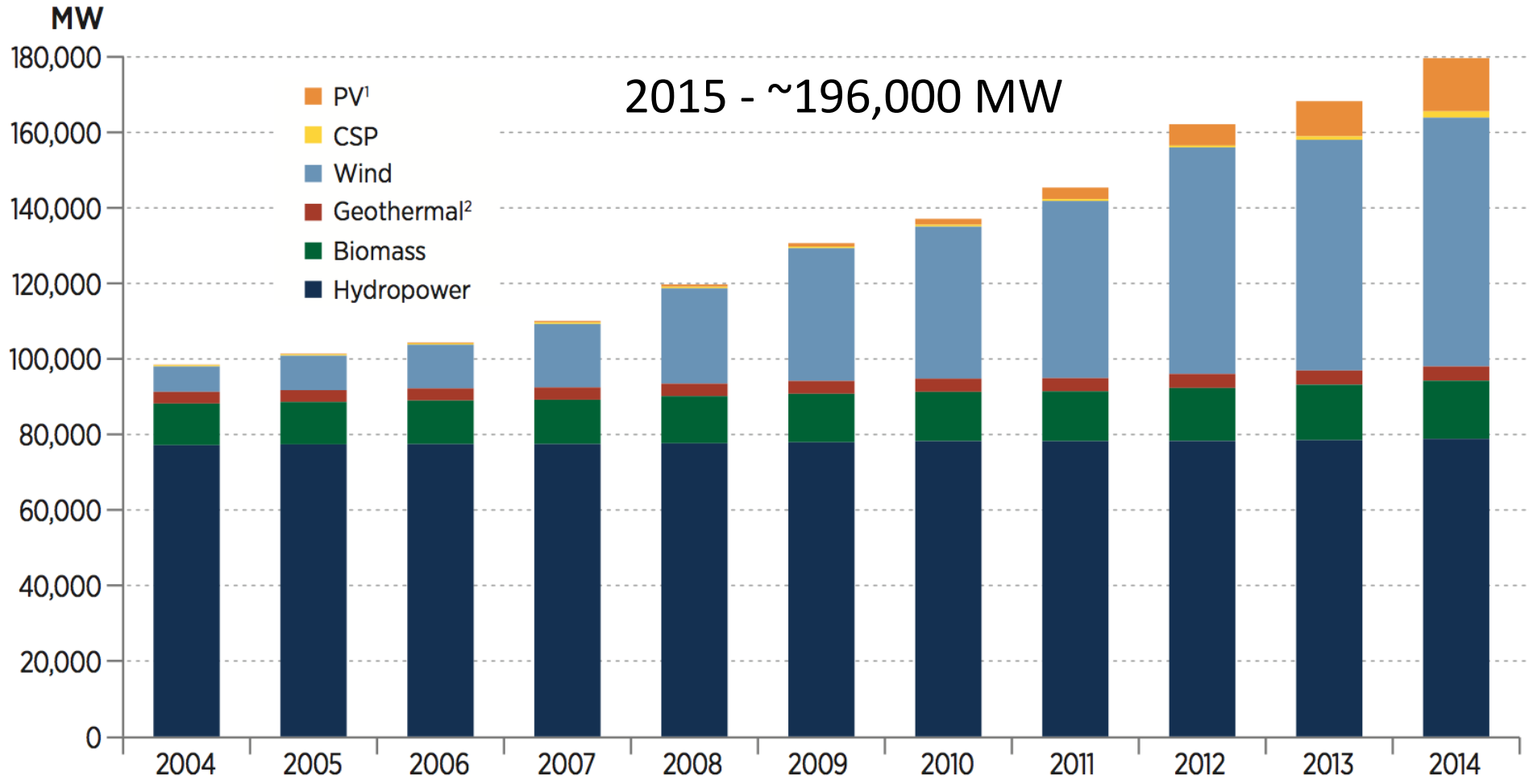
U.S. RENEWABLE ELECTRICITY CAPACITY STATUS

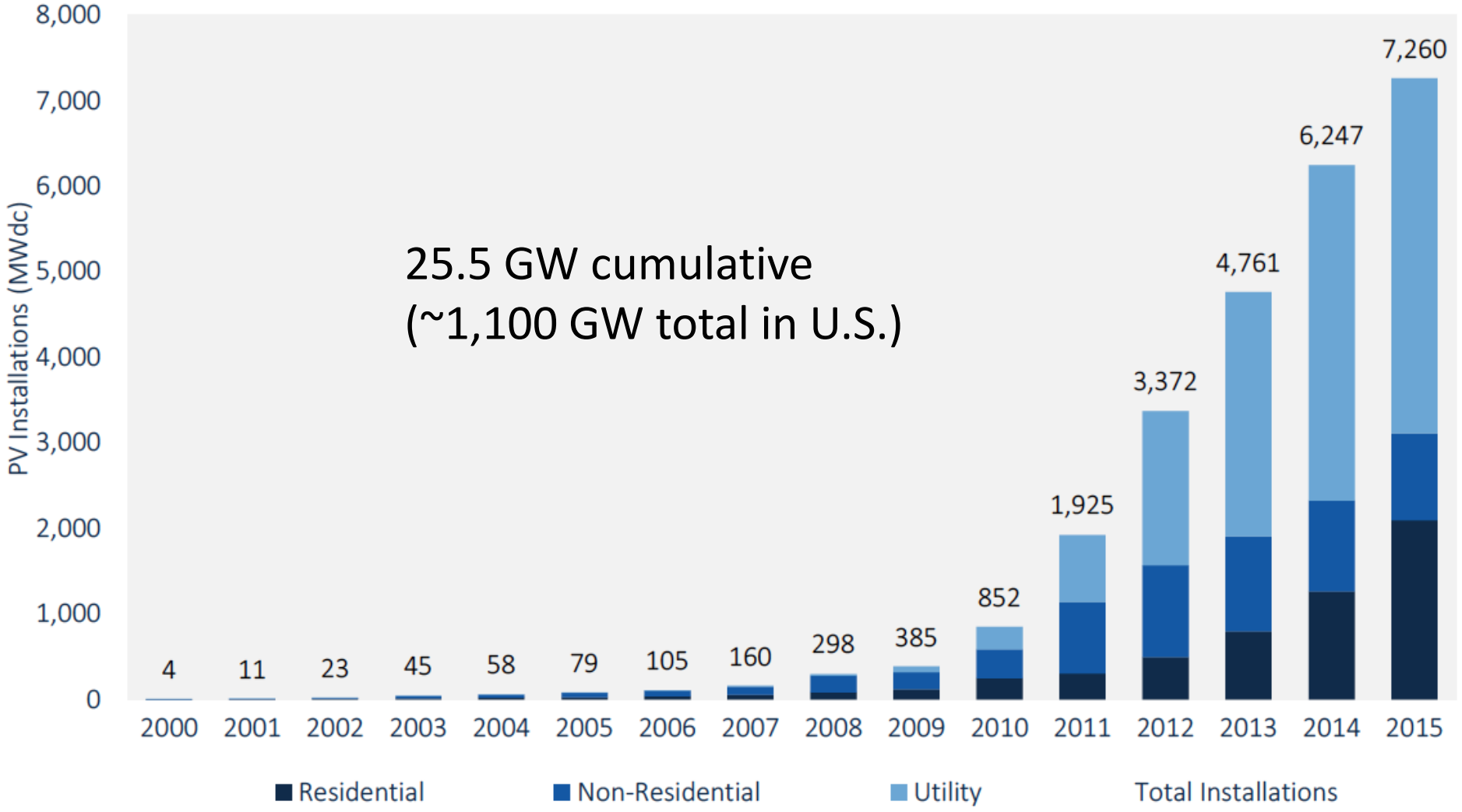




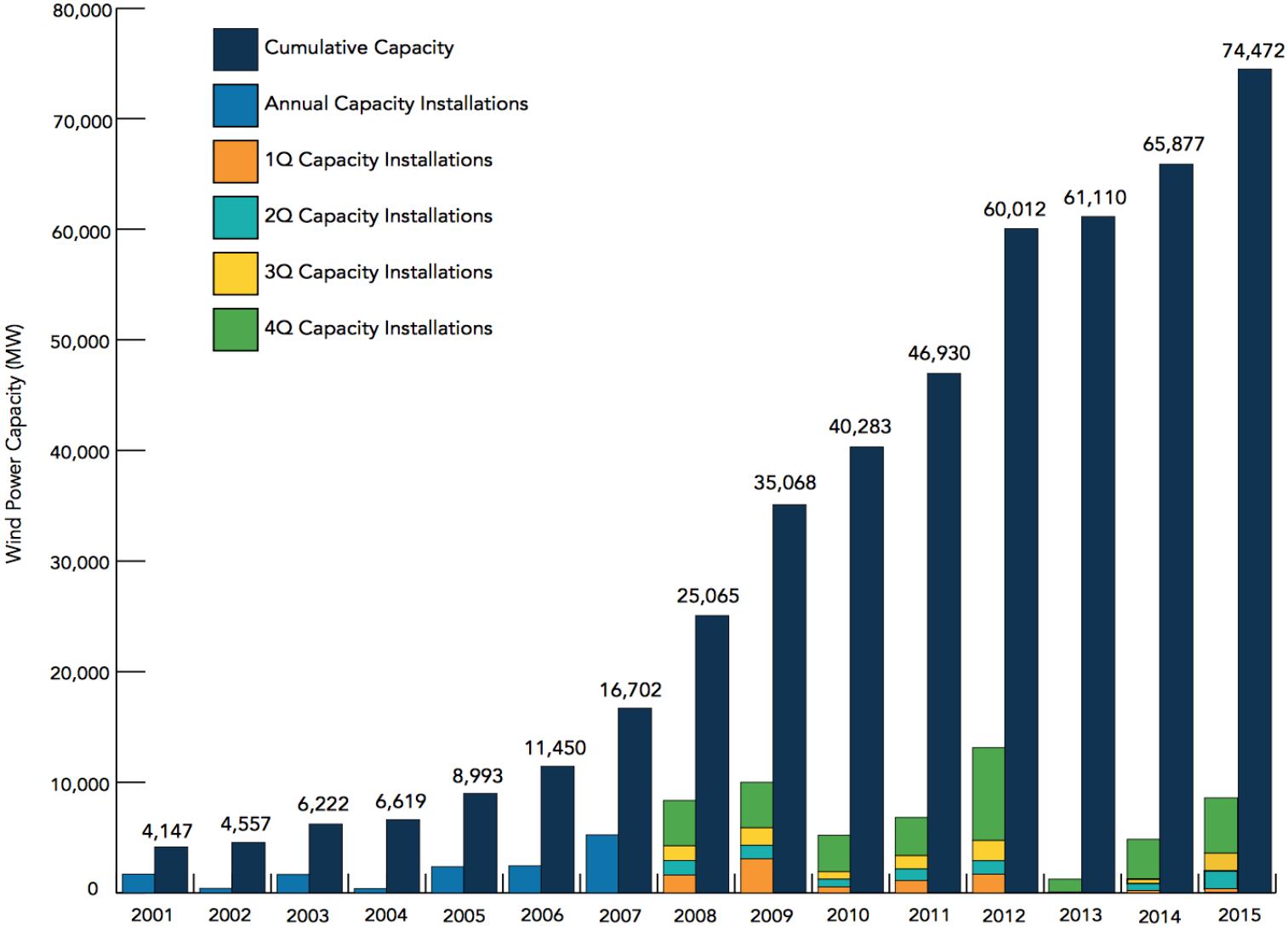
U.S. RENEWABLE ELECTRICITY CAPACITY STATUS



U.S. ANNUAL CAPACITY ADDITIONS



U.S. WIND CAPACITY – ANNUAL AND CUMULATIVE



Note: Utility-scale wind capacity includes installations of wind turbines larger than 100-kW for the purpose of the AWEA U.S. Wind Industry Quarterly Market Reports. Annual capacity additions cumulative capacity may not always add up due to decommissioned, uprated and repowered wind turbines. Wind capacity data for each year is continuously updated as information changes.

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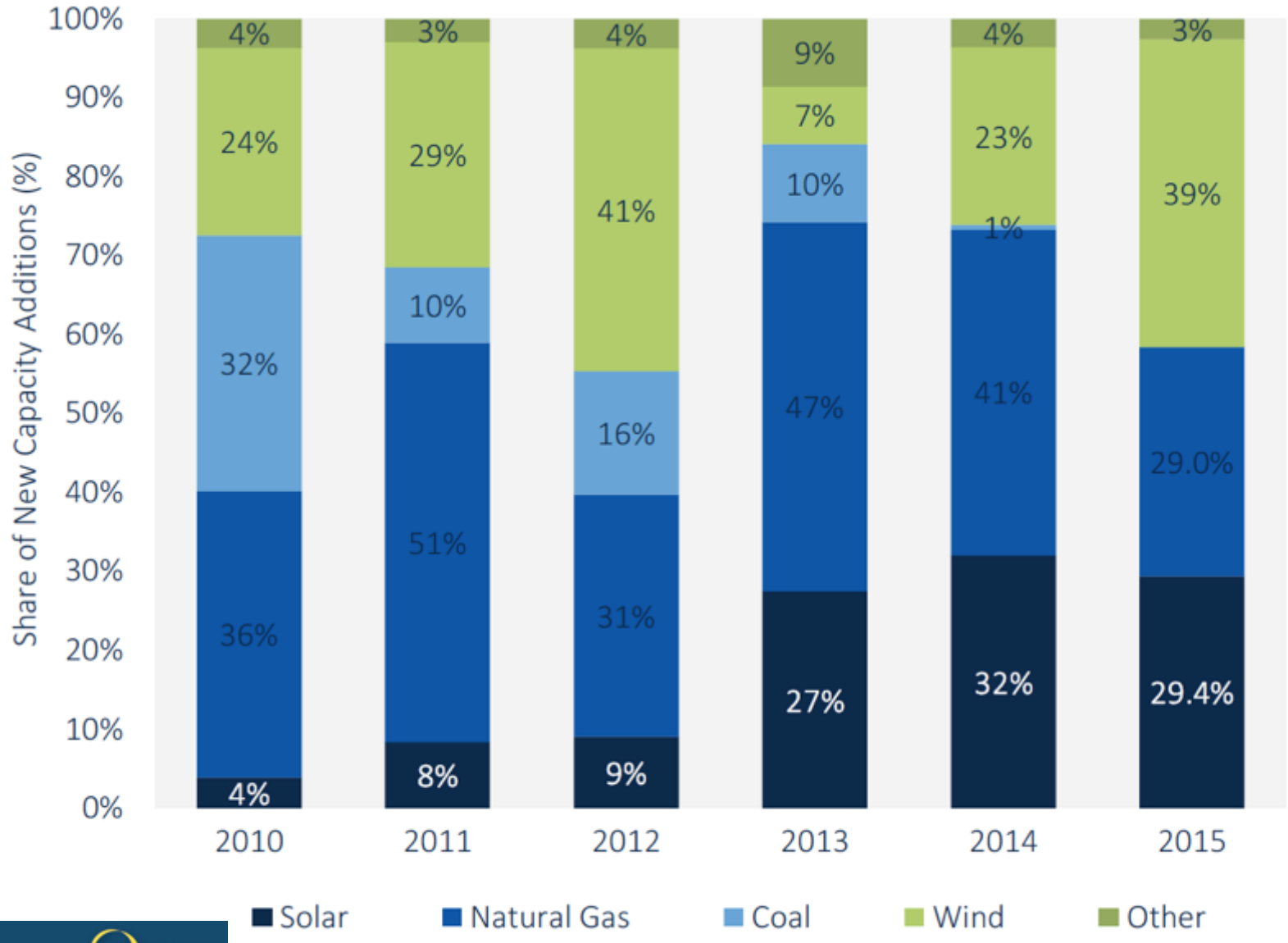
NEW U.S. CAPACITY ADDITIONS



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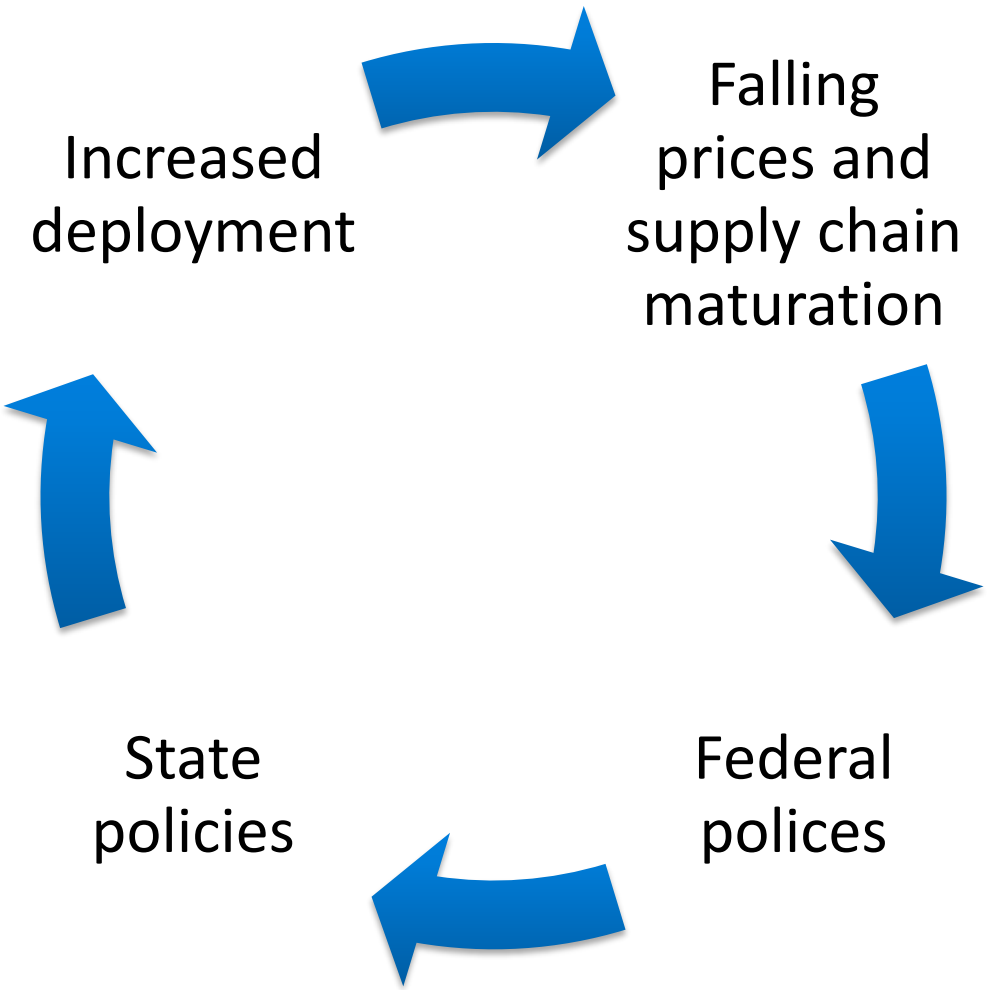
WHAT ARE THE DRIVERS?



Market Ready Technologies

FEDERAL AND STATE POLICY DRIVERS

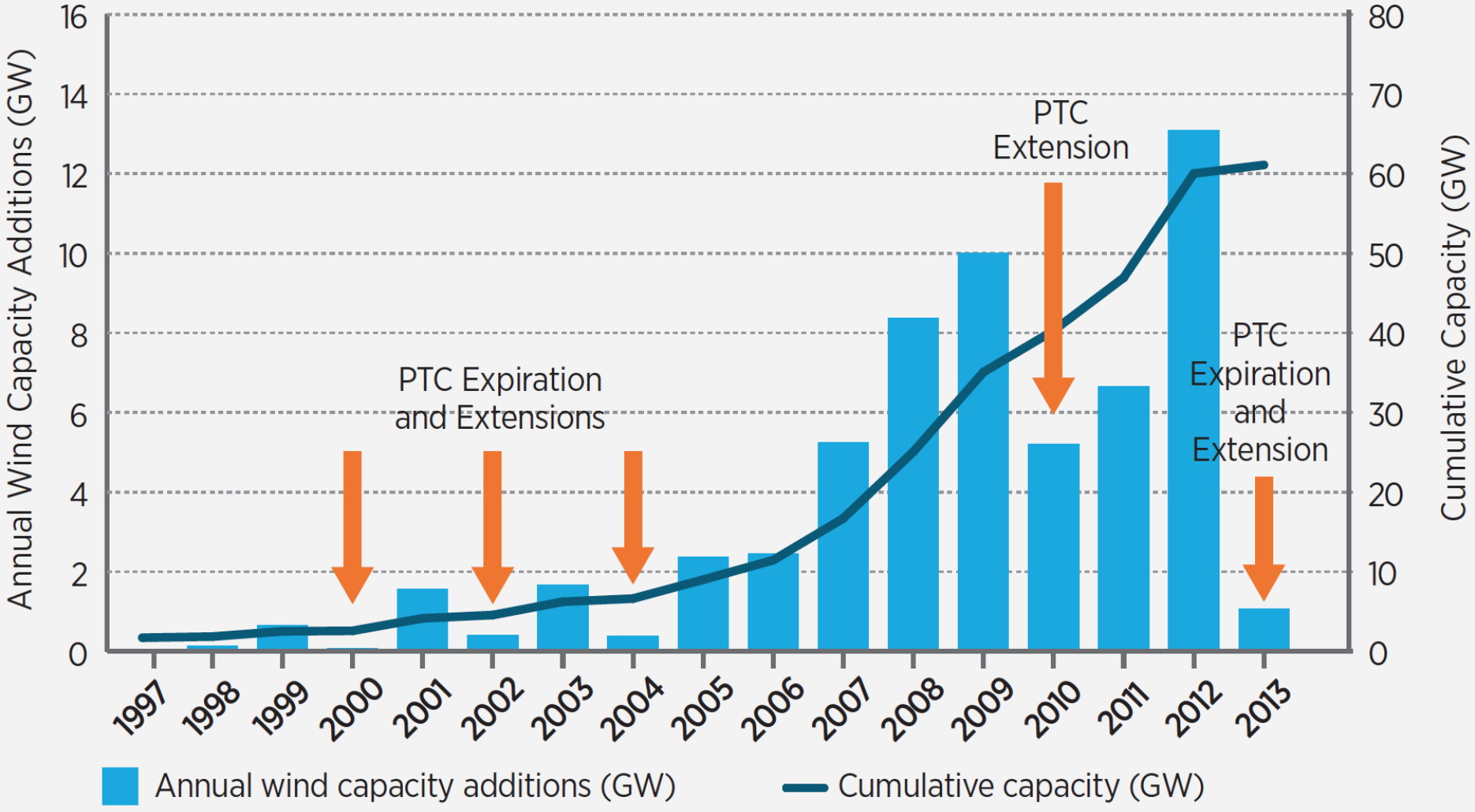
FEDERAL

- Production tax credits
- Investment tax credits
- U.S. Department of Treasury grant program
- EPA Clean Power Plan

STATE

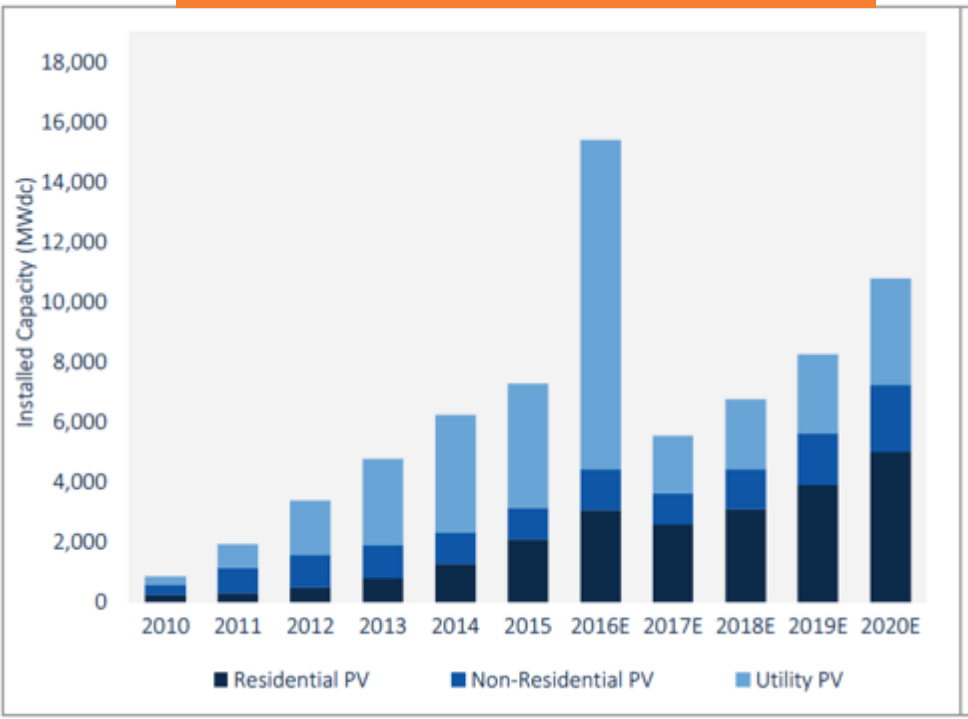
- Renewable portfolio standards (28 states)
- Net Metering

POLICY IMPACTS

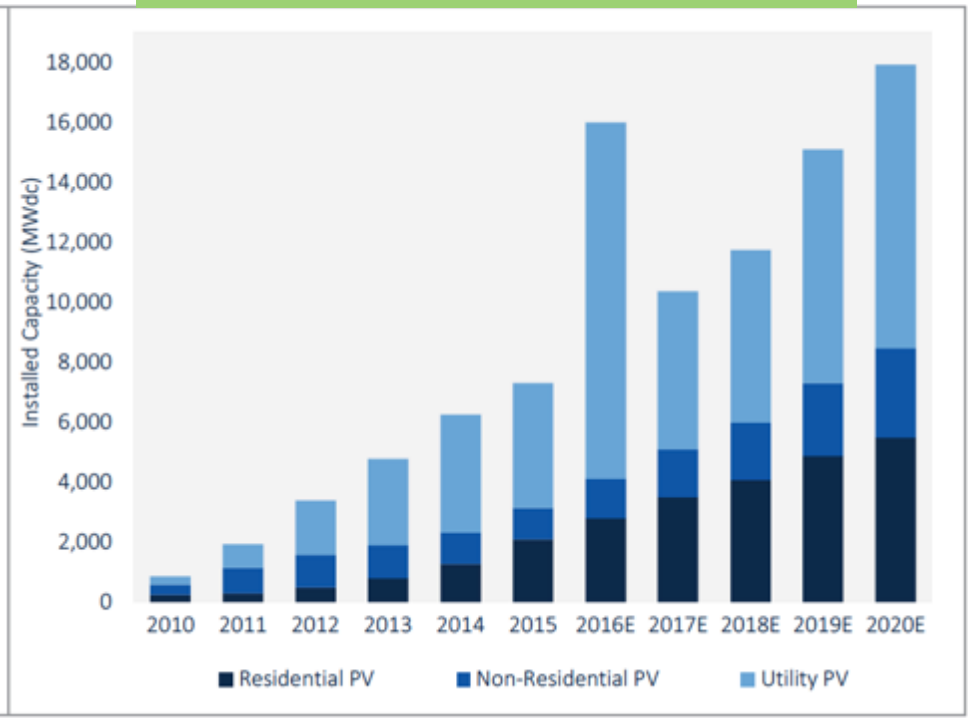


U.S. PV FORECAST

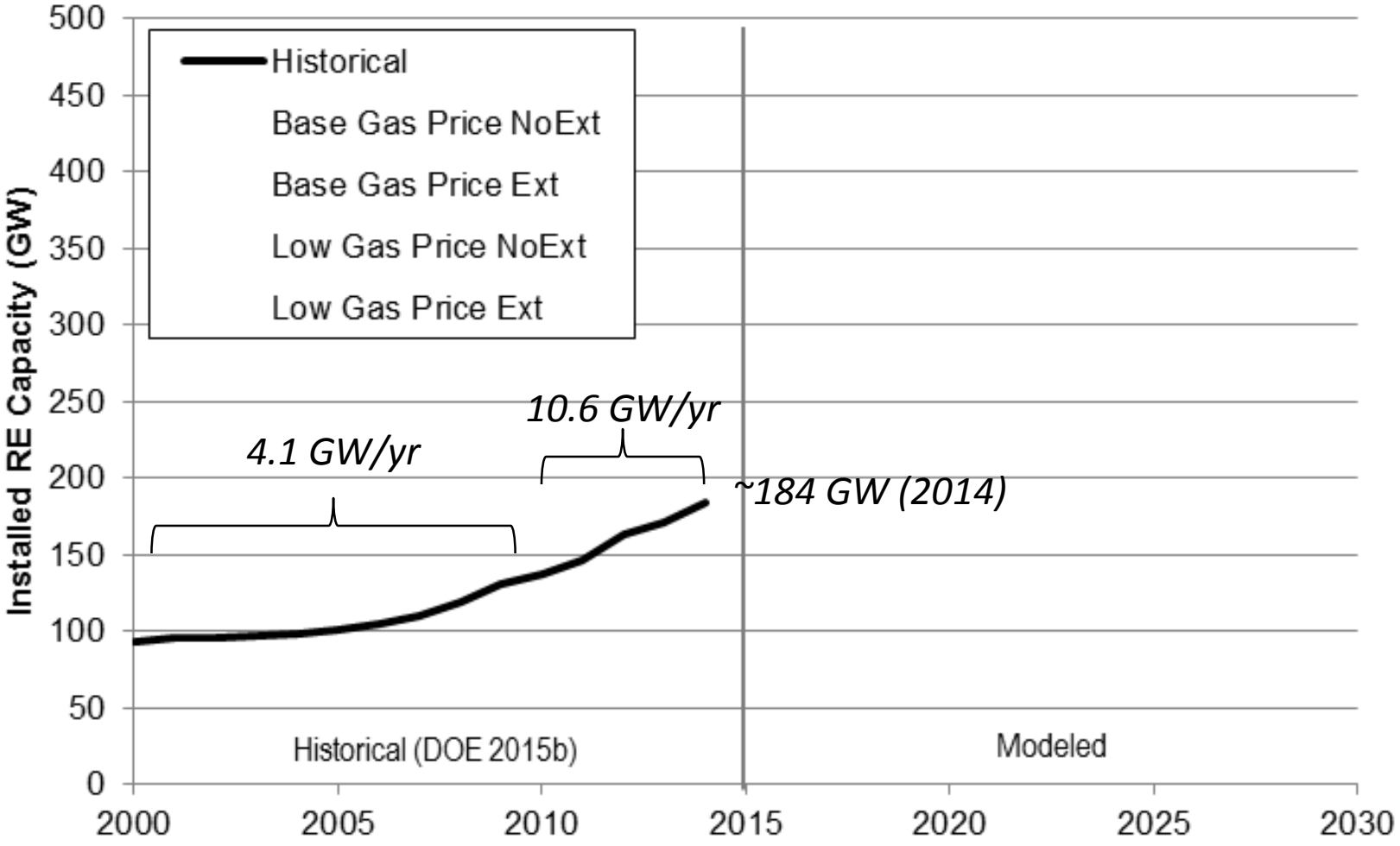
Pre Tax-Credit Extension Forecast



Forecast with Tax-Credit Extension



UPTICK IN RE CAPACITY GROWTH OVER THE LAST 5 YEARS

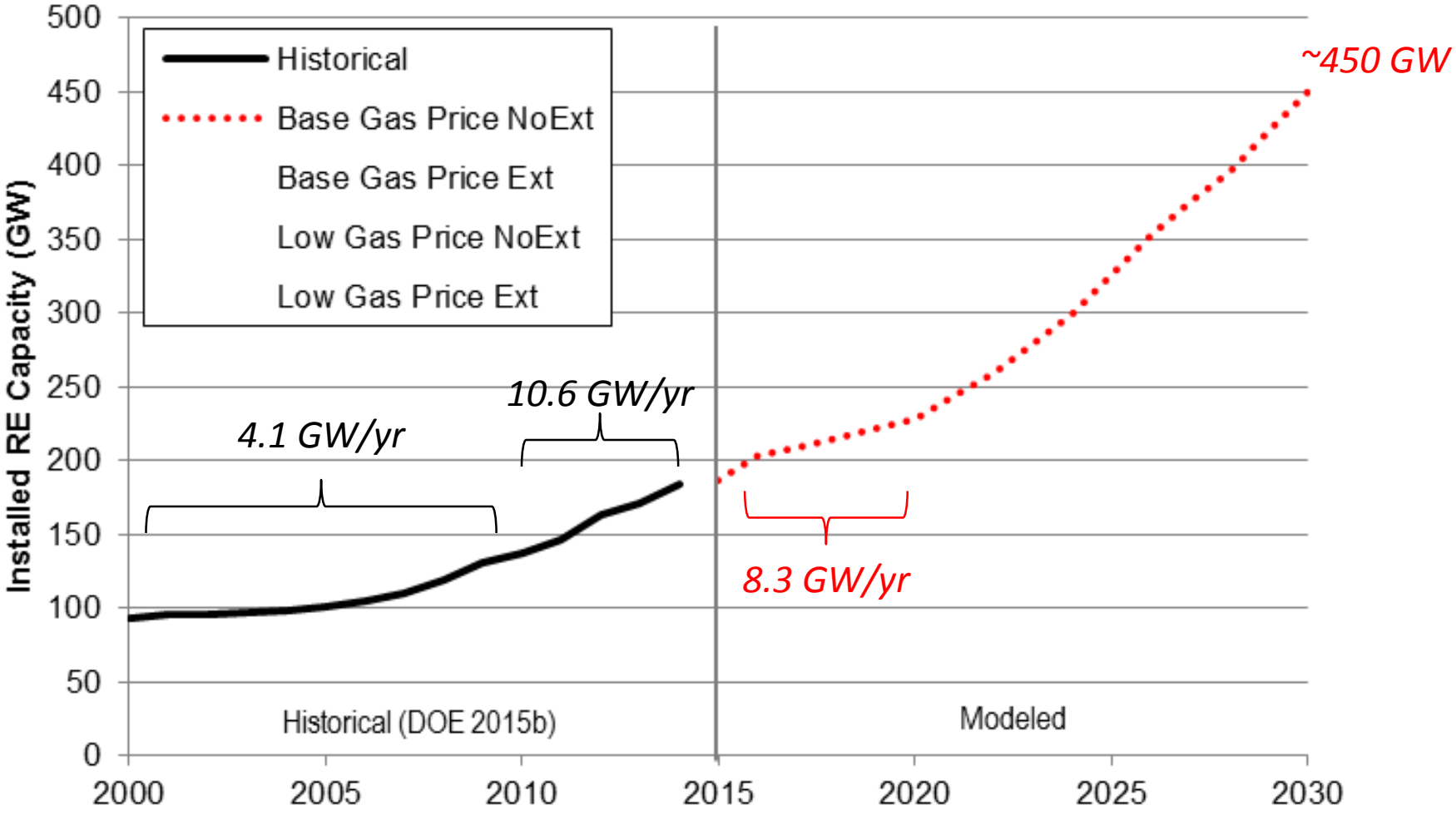


RE = biomass, geothermal, hydropower, solar, and wind

RE additions totaled 12.8 GW in 2014 and 17.6 GW in 2012

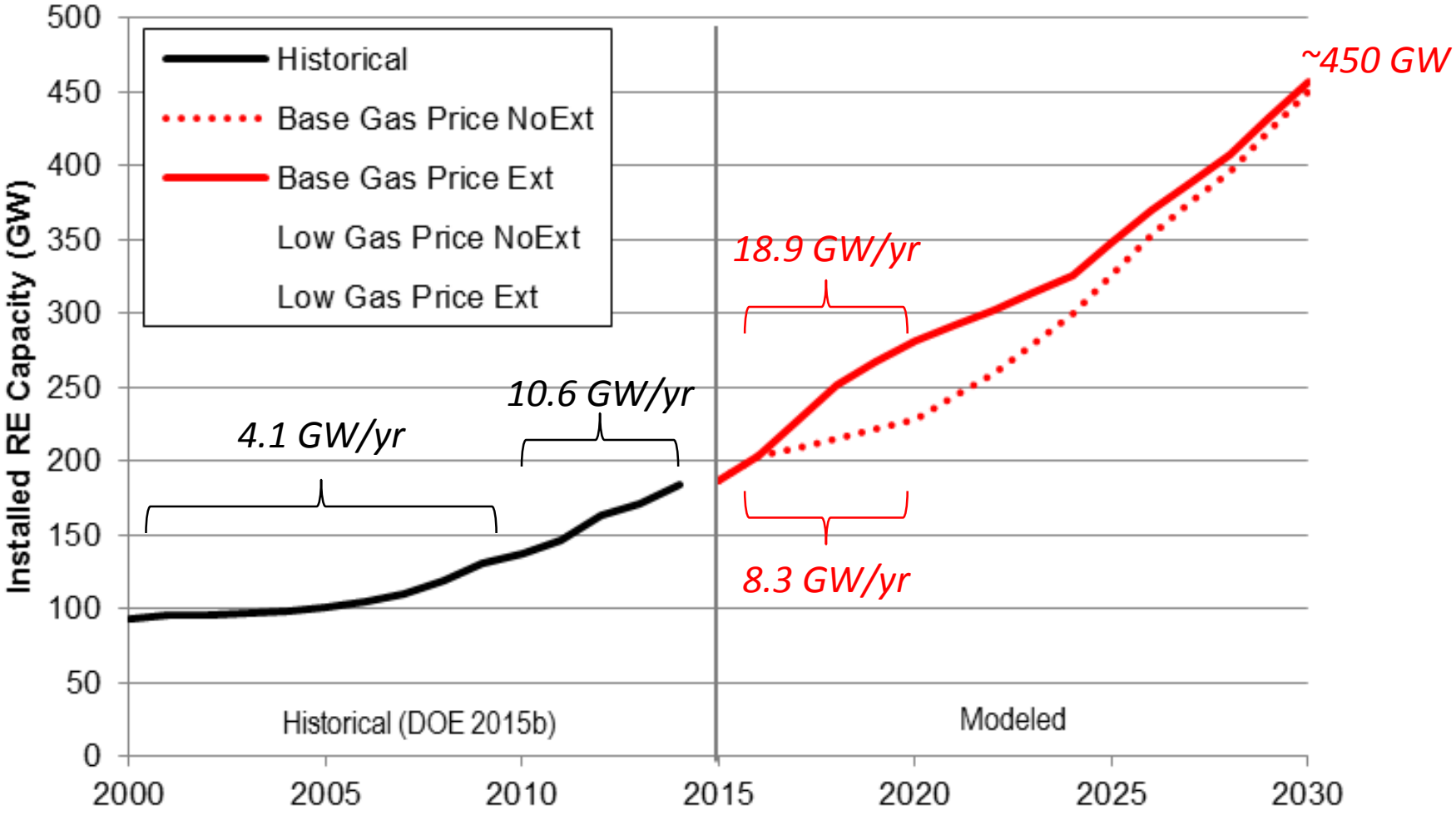
(2015 numbers not available at time of analysis)

BASE GAS PRICES – ABSENT TAX CREDIT EXTENSIONS RE GROWTH IS ESTIMATED TO SLOW DURING THE NEXT 5 YEARS



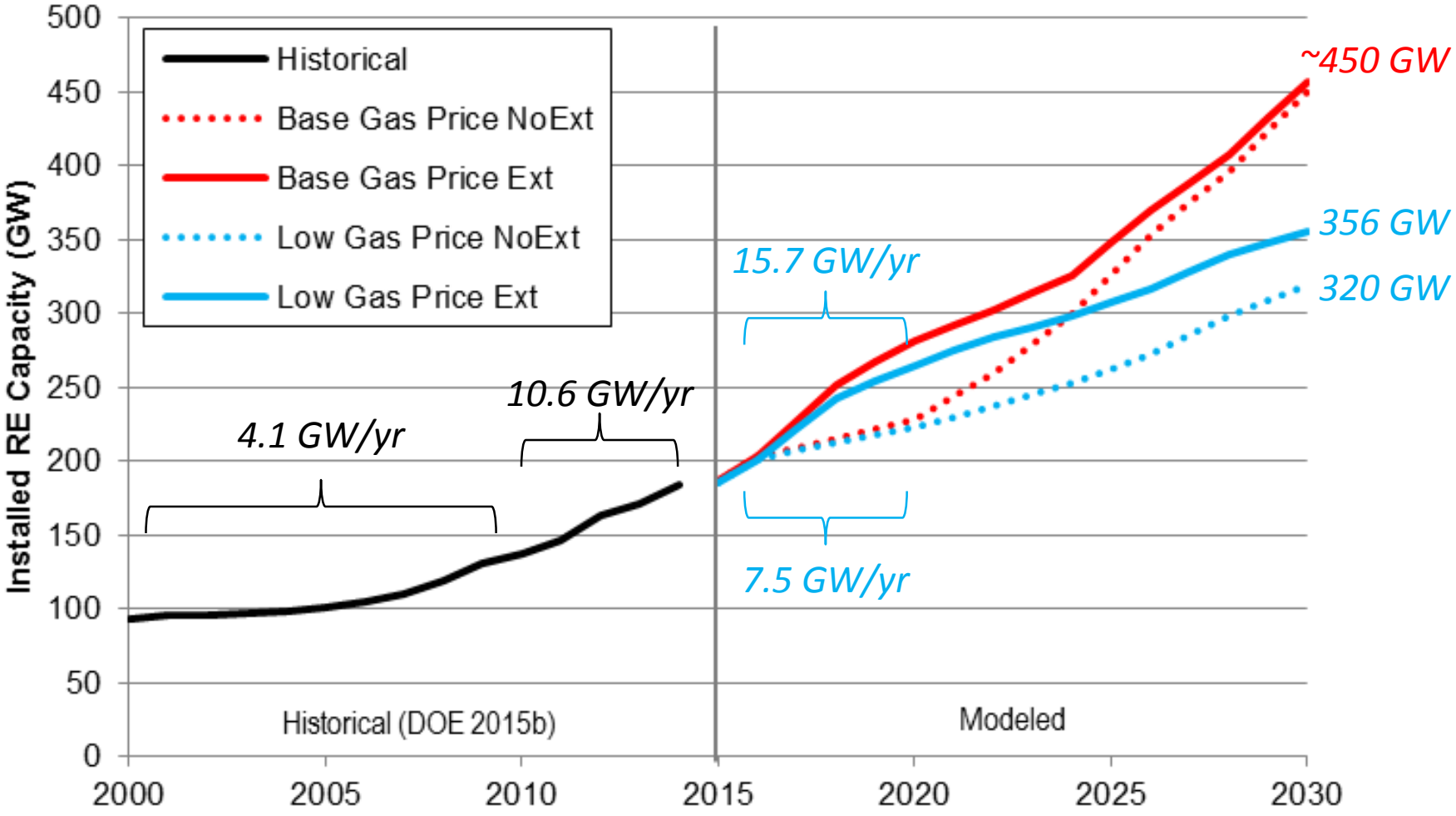
But RE growth increases beyond historical rates during the 2020s due to a combination of (1) decreasing RE costs, (2) increasing NG prices, and (3) policy demand, e.g. CPP, for clean energy

BASE GAS PRICES – TAX CREDIT EXTENSIONS CAN SIGNIFICANTLY BOOST NEAR-TERM RE DEPLOYMENT



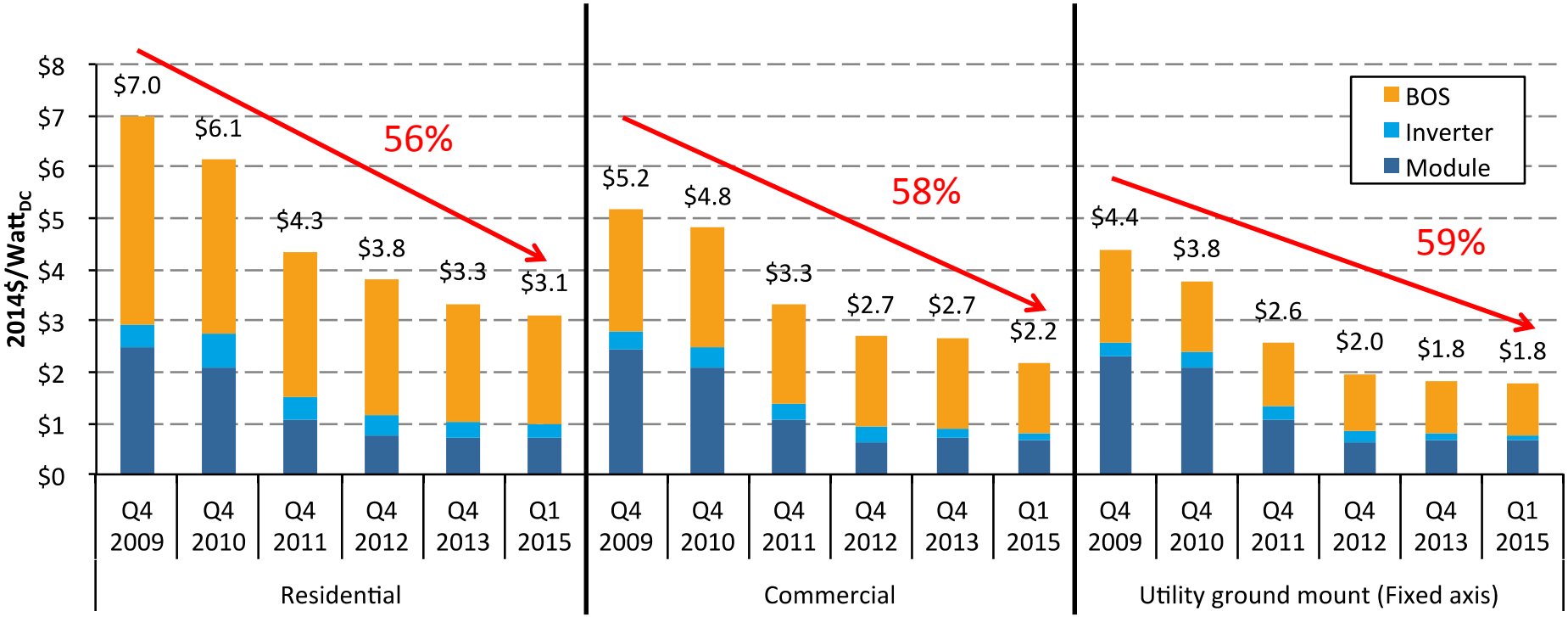
But the impacts of the extensions decline after 2020; cumulative installed capacity in 2030 is nearly identical between the extension and no-extension scenarios

LOW GAS PRICES LEAD TO LOWER RE DEPLOYMENT

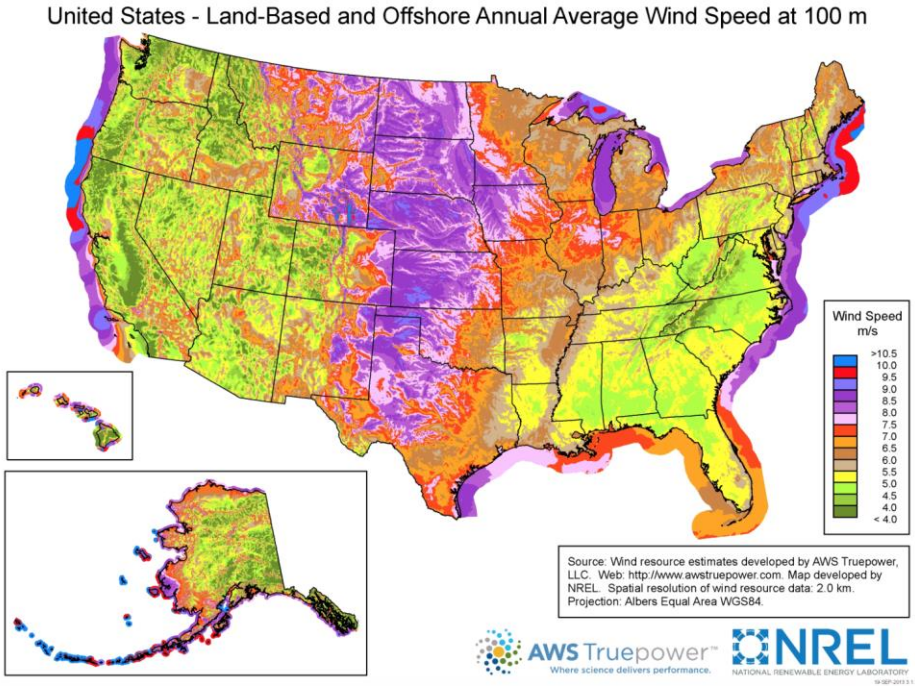


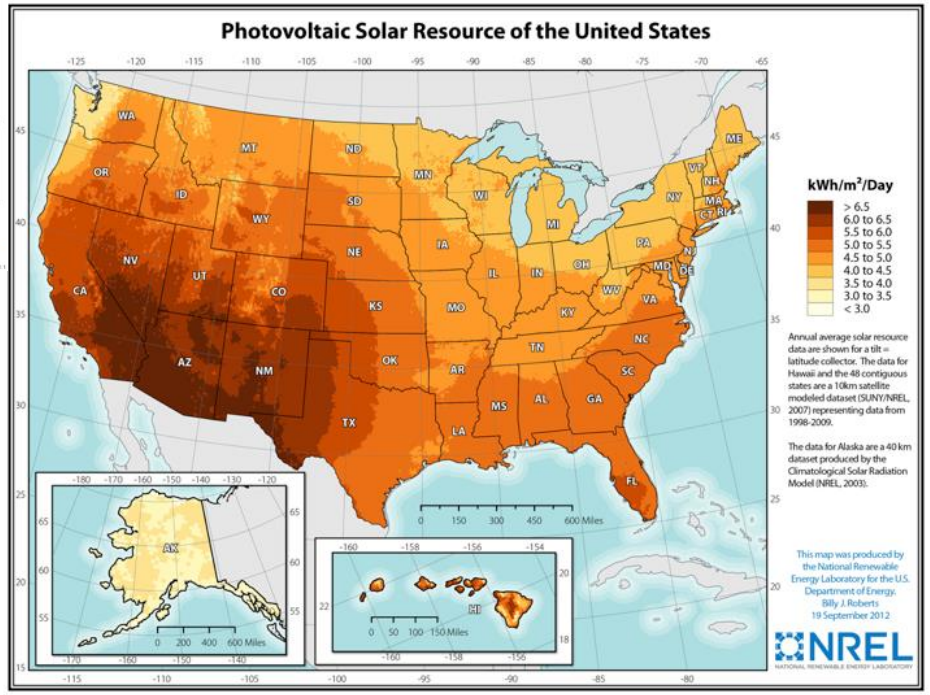
But the impacts of the tax credit extensions to RE deployment are longer lasting

NREL MODELED SYSTEM PRICES

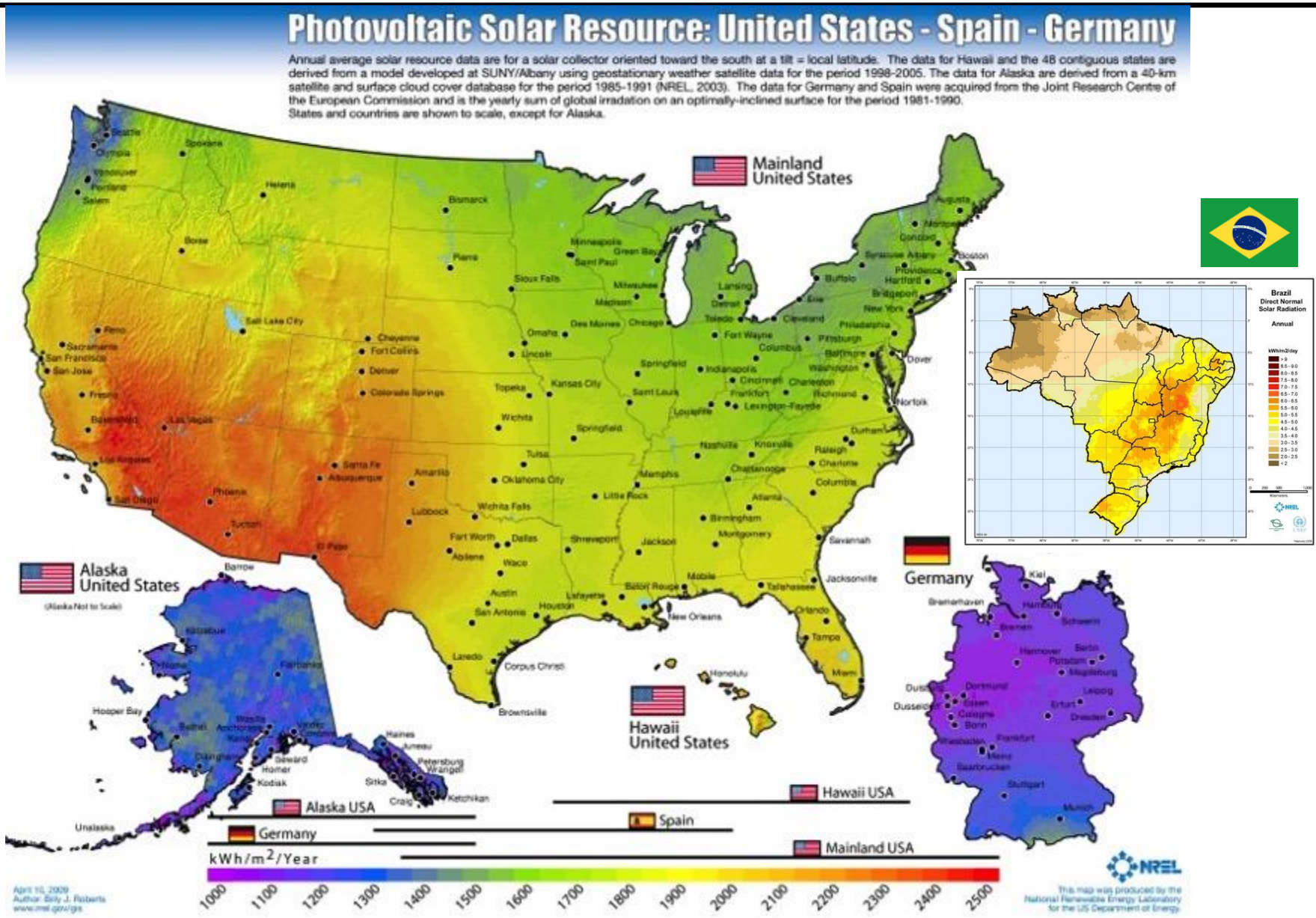


DO RESOURCES DRIVE MARKETS?

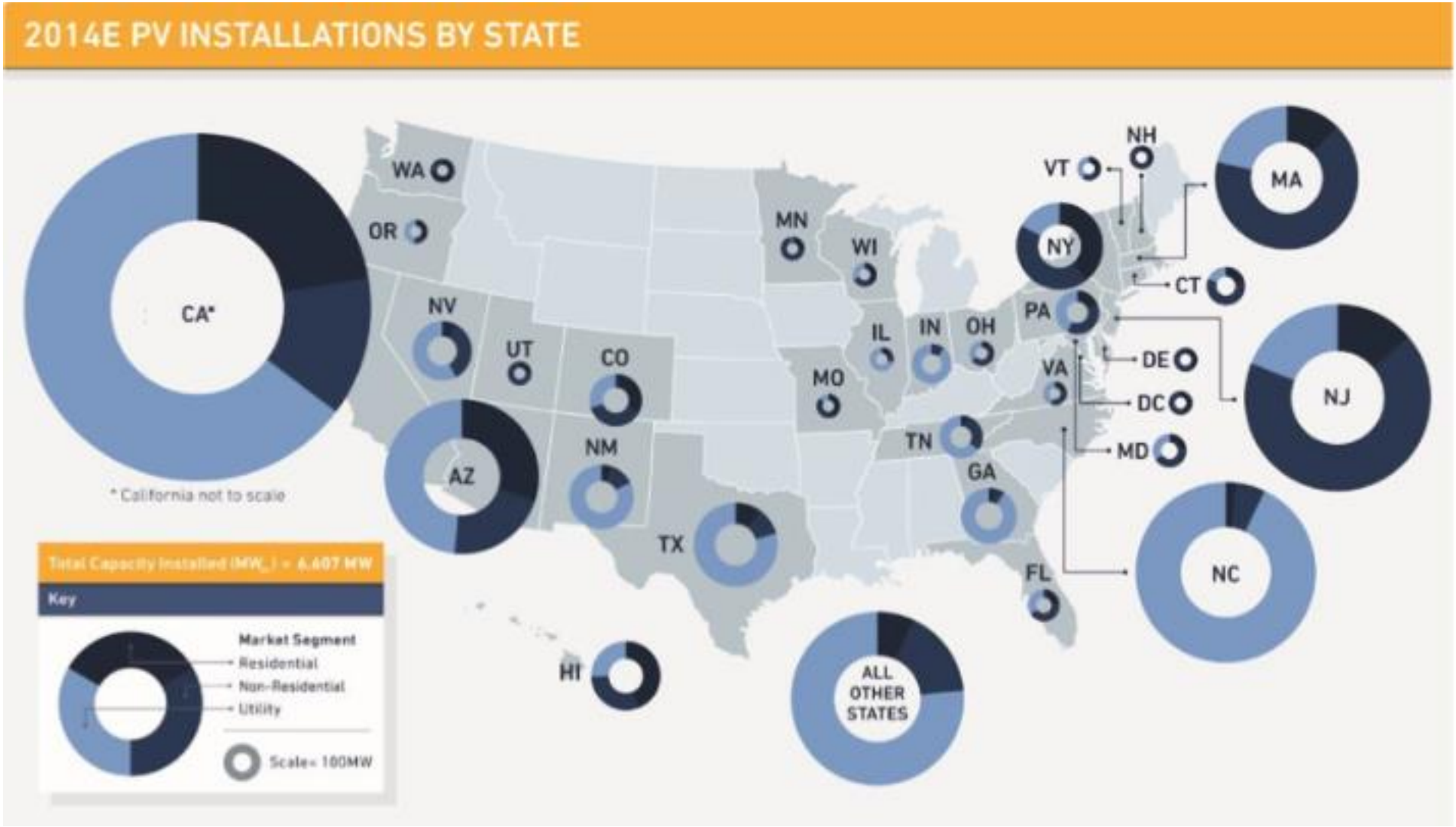




RESOURCE COMPARISONS



US PV DEPLOYMENT BY STATE



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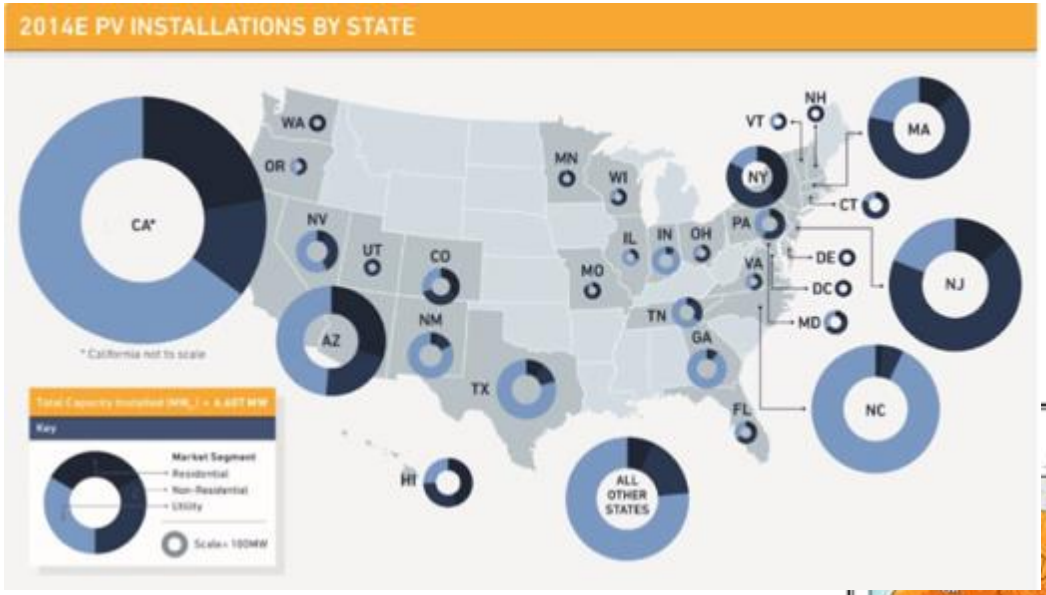
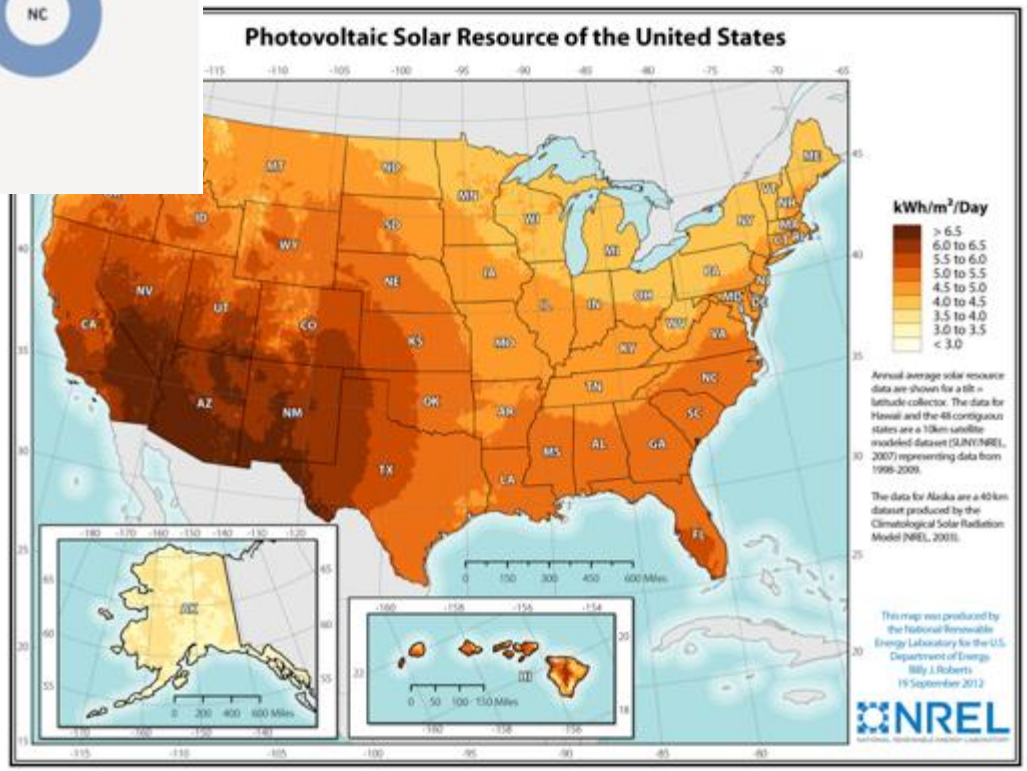
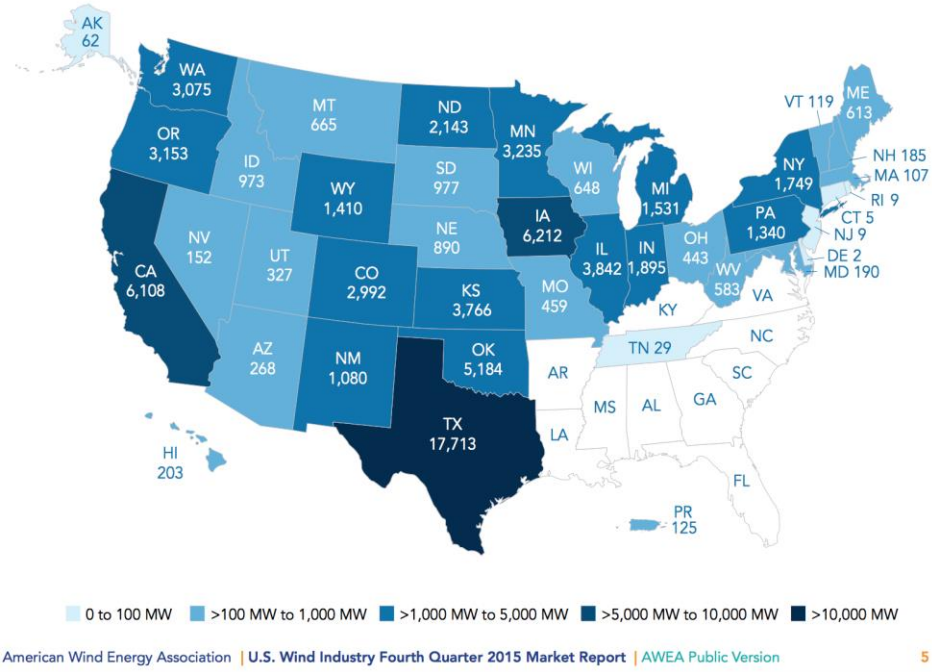




U.S. WIND DEPLOYMENT BY STATE



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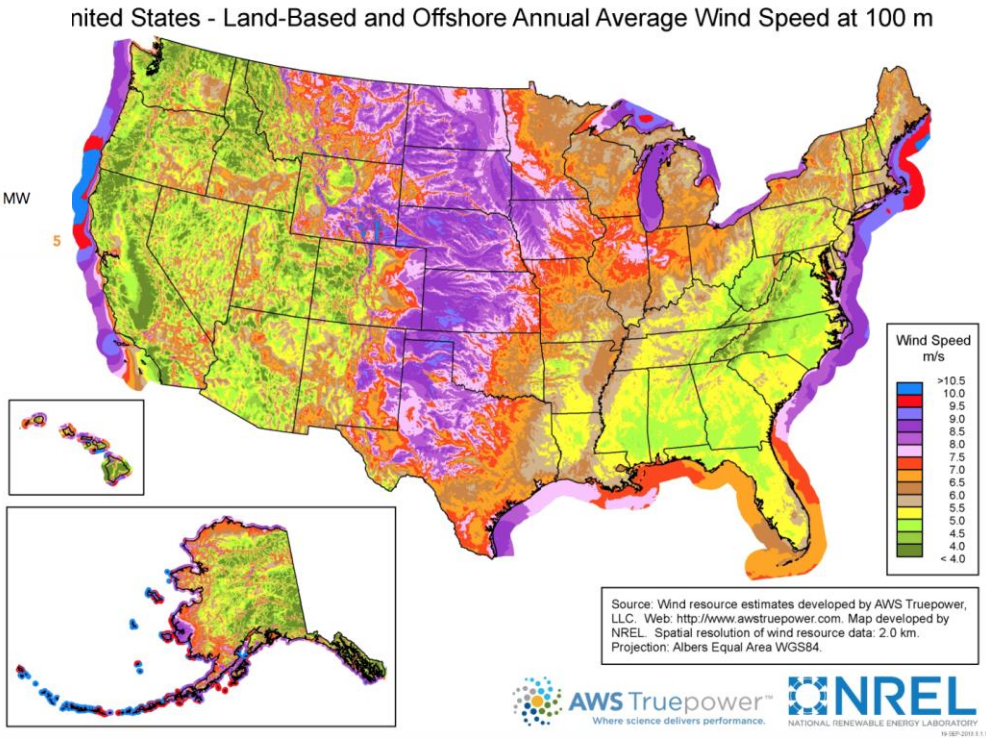

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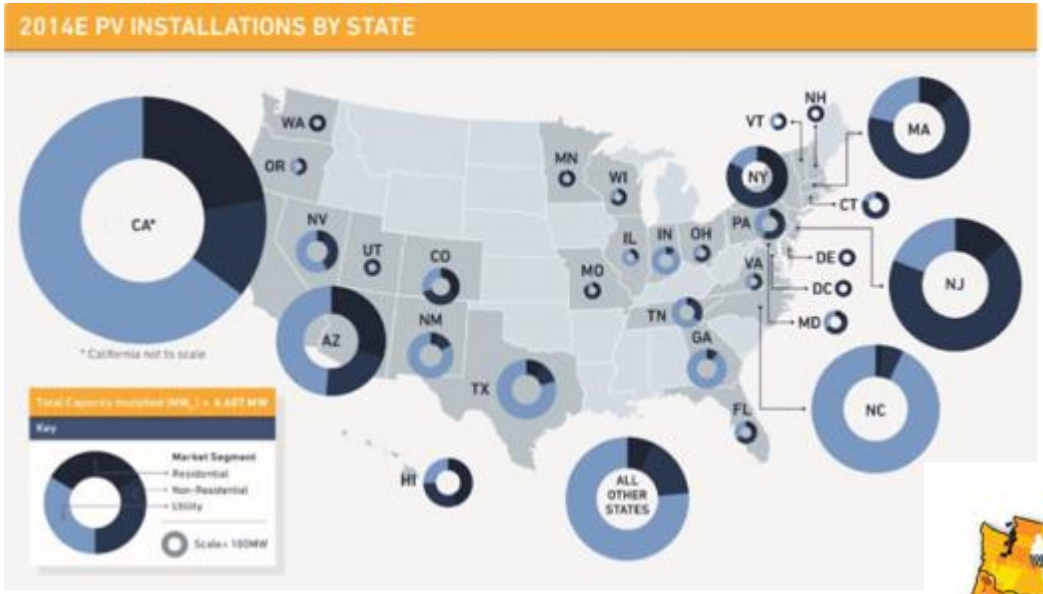

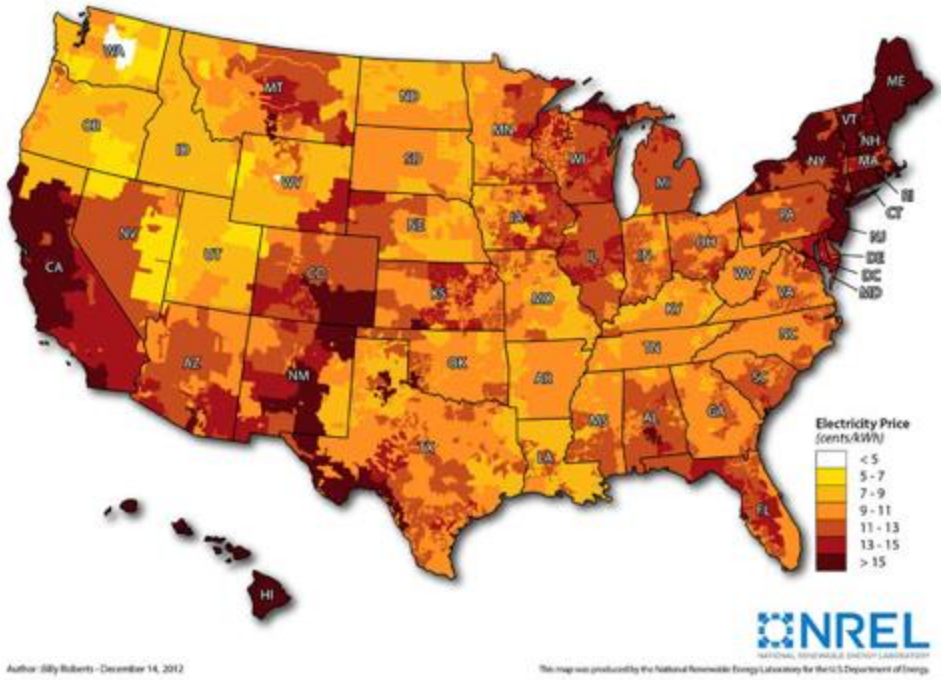

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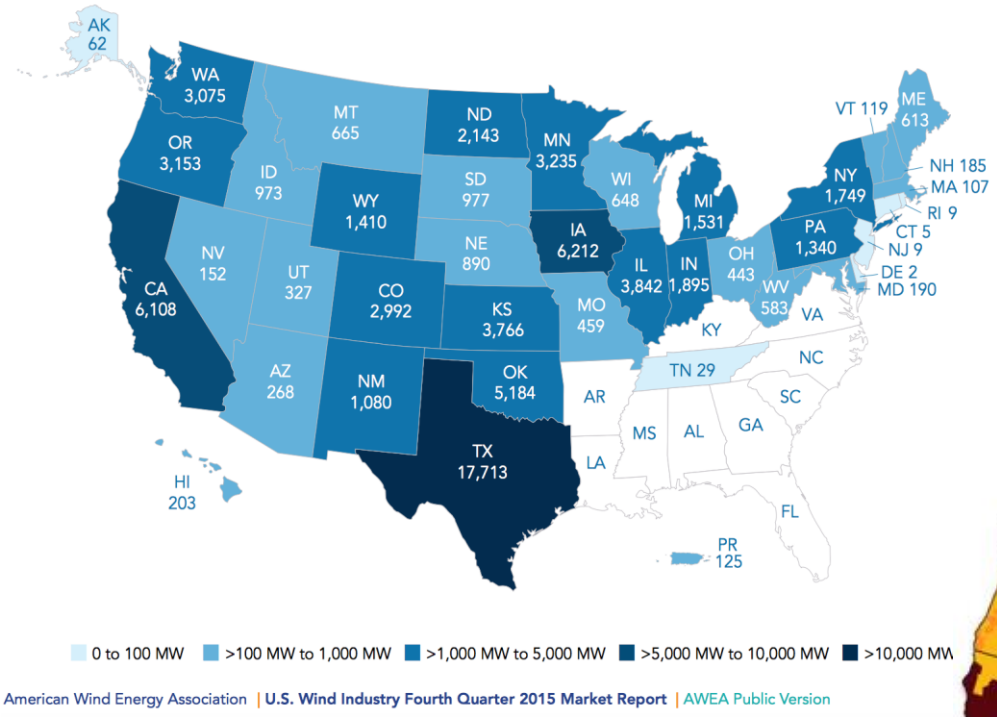

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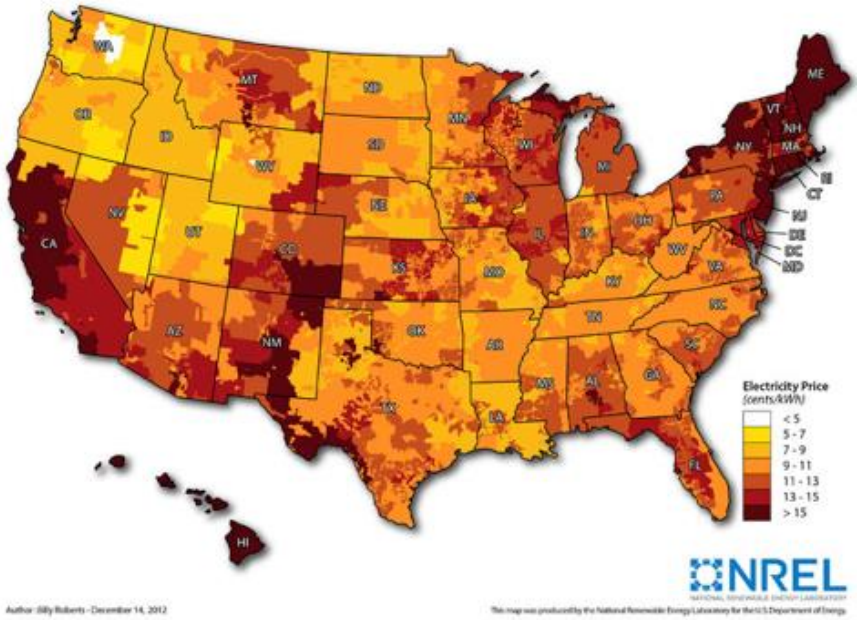

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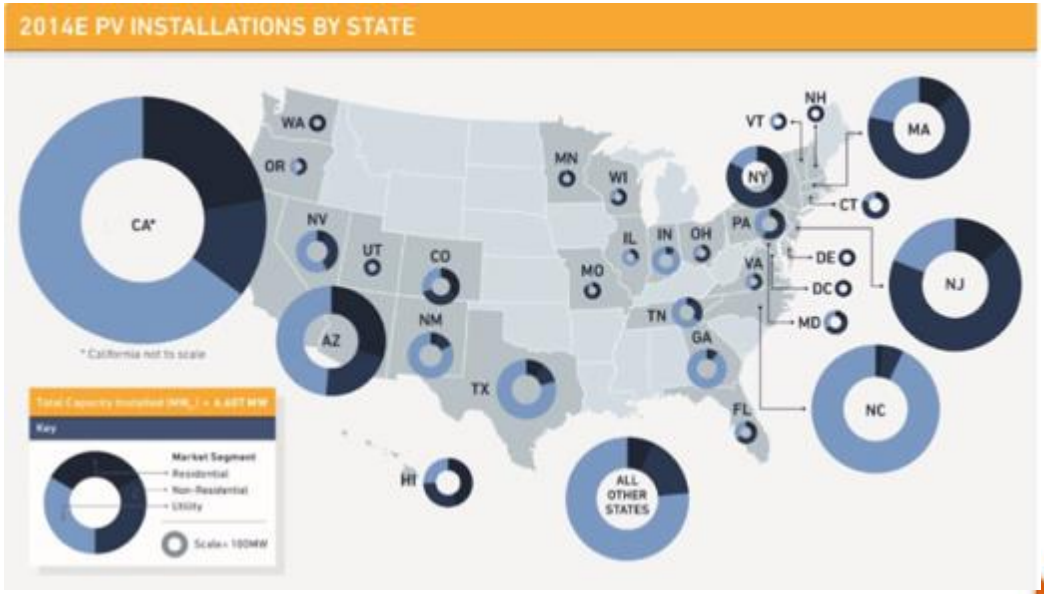

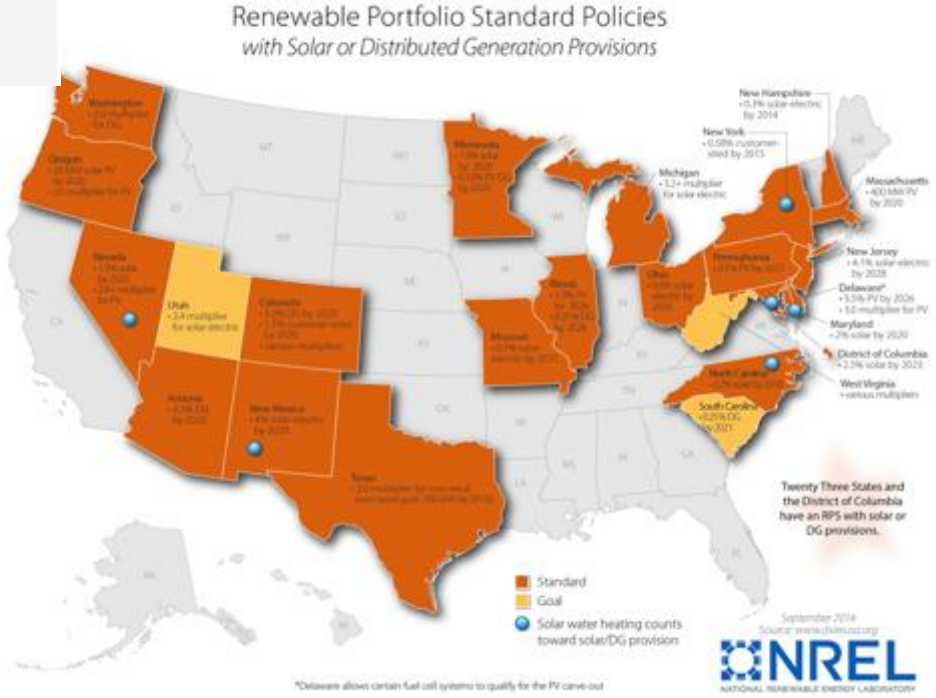

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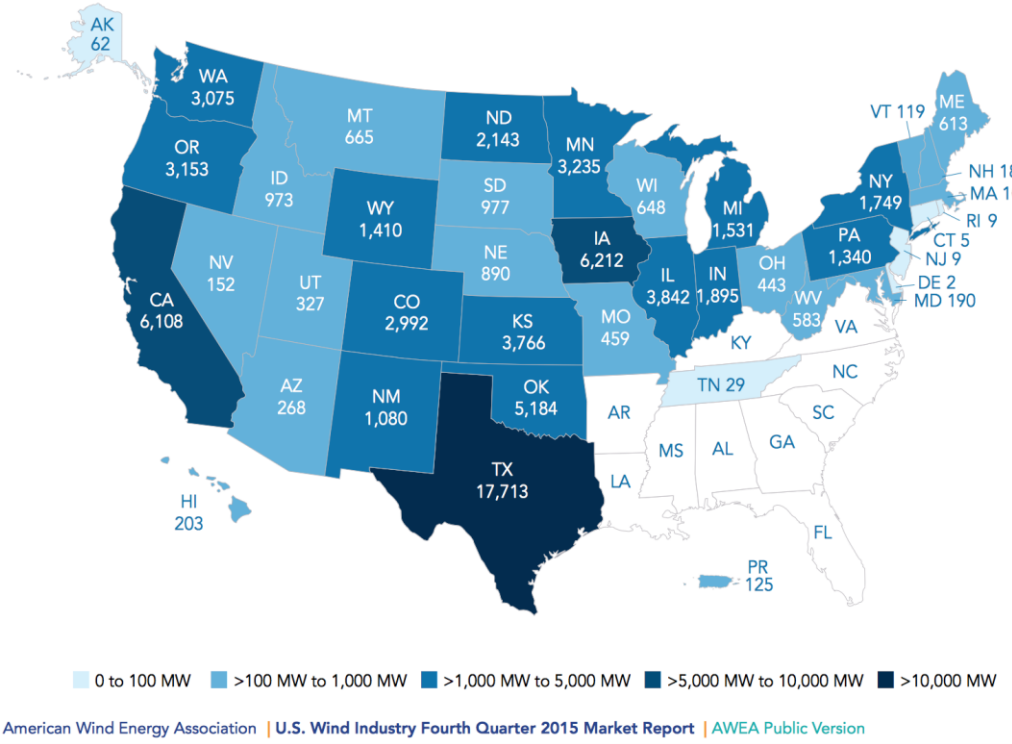

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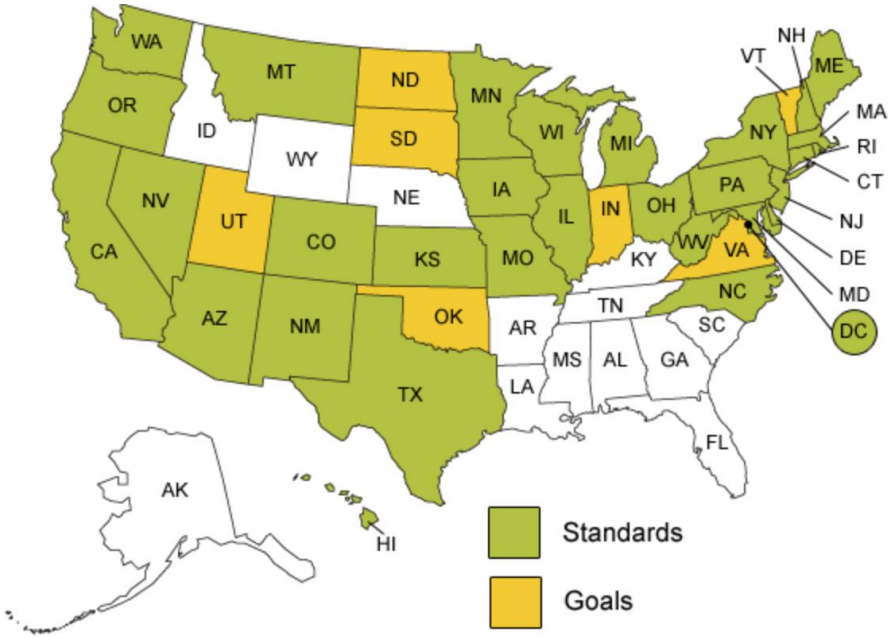

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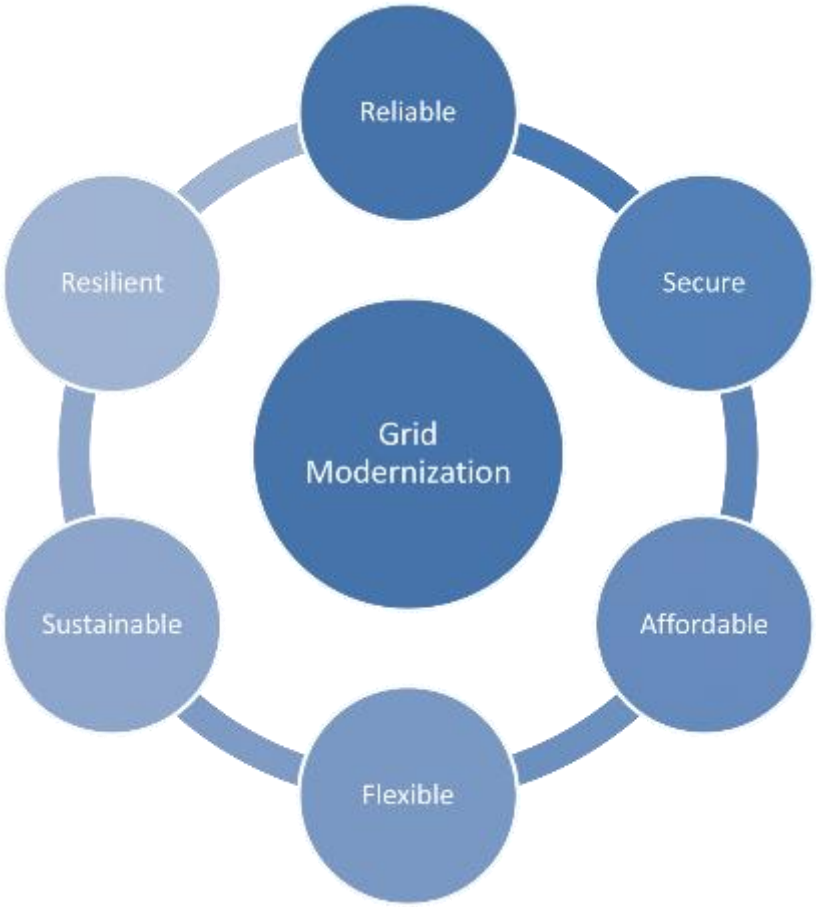
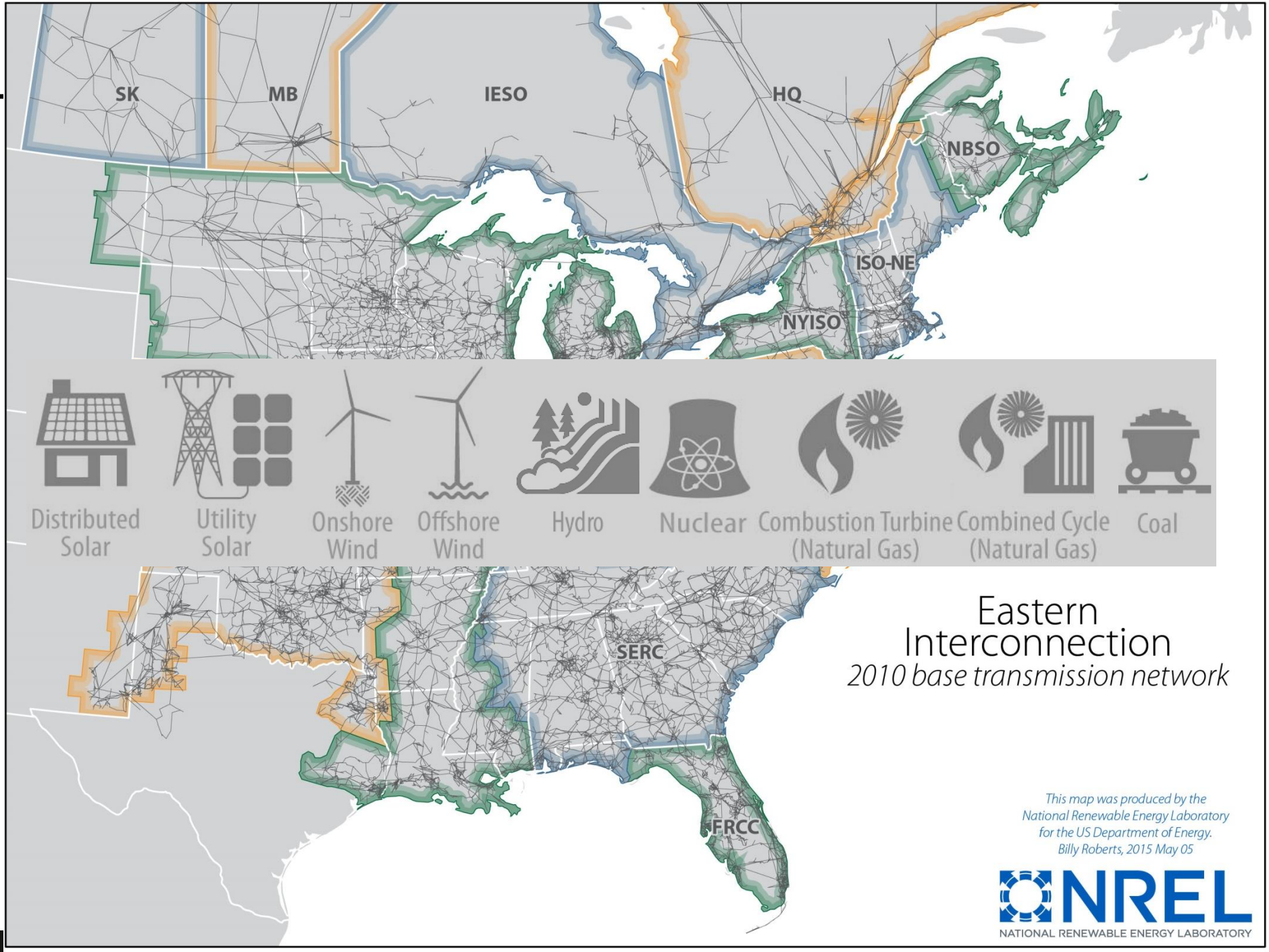
DOE GRID MODERNIZATION INITIATIVE

The vision of DOE's Grid Modernization Initiative is a future grid that:

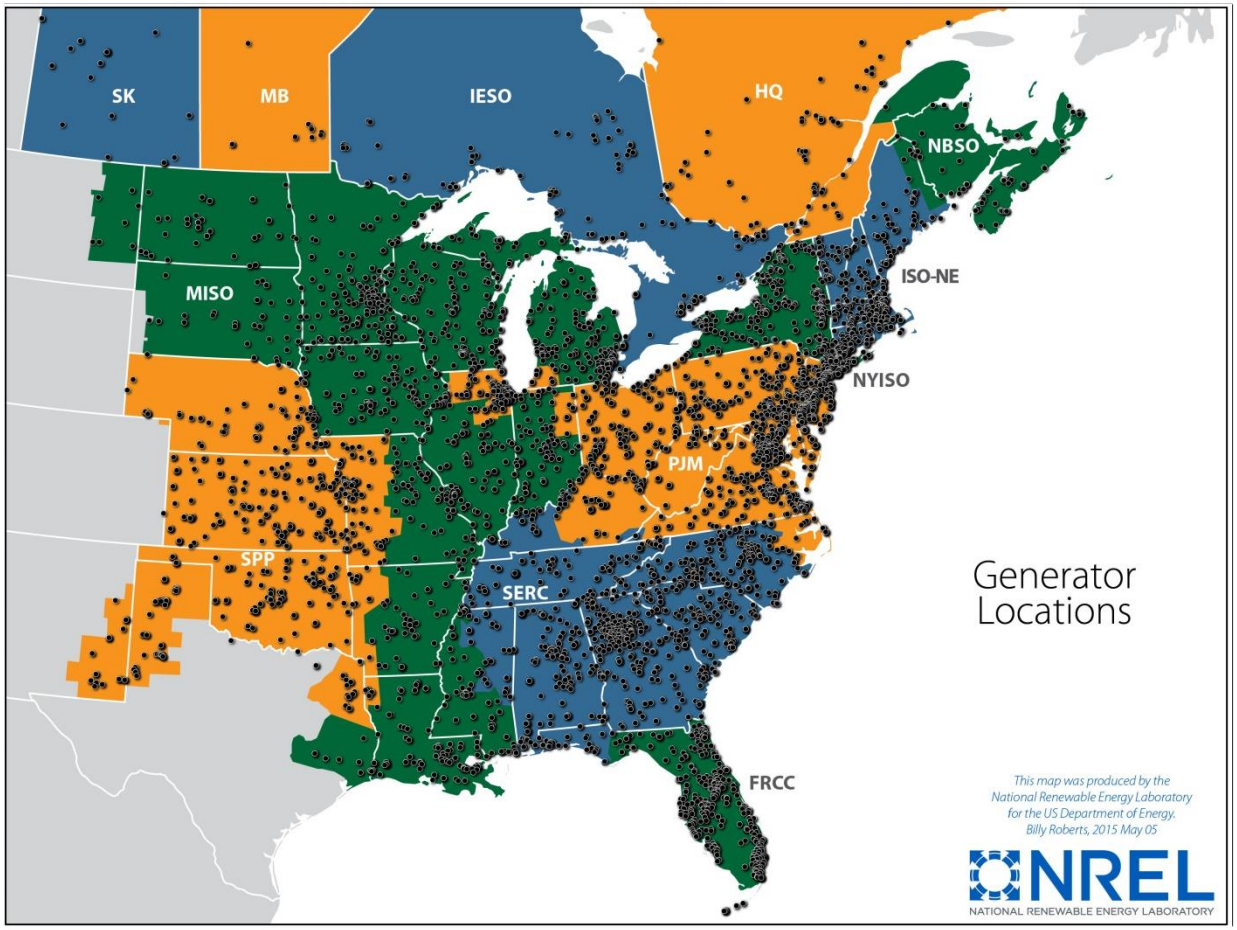
- **Seamlessly integrates conventional and renewable sources, storage, and central and distributed generation.**
- **Serves as a critical platform for prosperity, competitiveness, and innovation in a global clean energy economy.**
- **Delivers resilient, reliable, flexible, secure, sustainable, and affordable electricity to consumers where they want it, when they want it, how they want it.**



http://energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf


SK
MB
IESO
HQ
NBSO
ISO-NE
NYISO
SERC
FRCC
Distributed Solar
Utility Solar
Onshore Wind
Offshore Wind
Hydro
Nuclear
Combustion Turbine (Natural Gas)
Combined Cycle (Natural Gas)
Coal
Eastern Interconnection
2010 base transmission network
This map was produced by the National Renewable Energy Laboratory for the US Department of Energy.
Billy Roberts, 2015 May 05
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Eastern Interconnection



- 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

Scenarios

Generator Type	Installed Capacity (GW)				
	2010	LowVG	RTx10	RTx30	ITx30
Wind	7	24	104	183	222
PV	0	1	5	219	110
Nuclear	105	102			
Coal	298	230			
Gas CC	165	173			
CT/Gas Boiler	166	148			
Hydro	85	87			
Other	55	22			

Non-wind and solar fleet remains constant

Low VG

- Renewables in service in 2010, modest transmission upgrades

RTx10

- Regional Transmission, 10% VG penetration, mostly wind.

RTx30

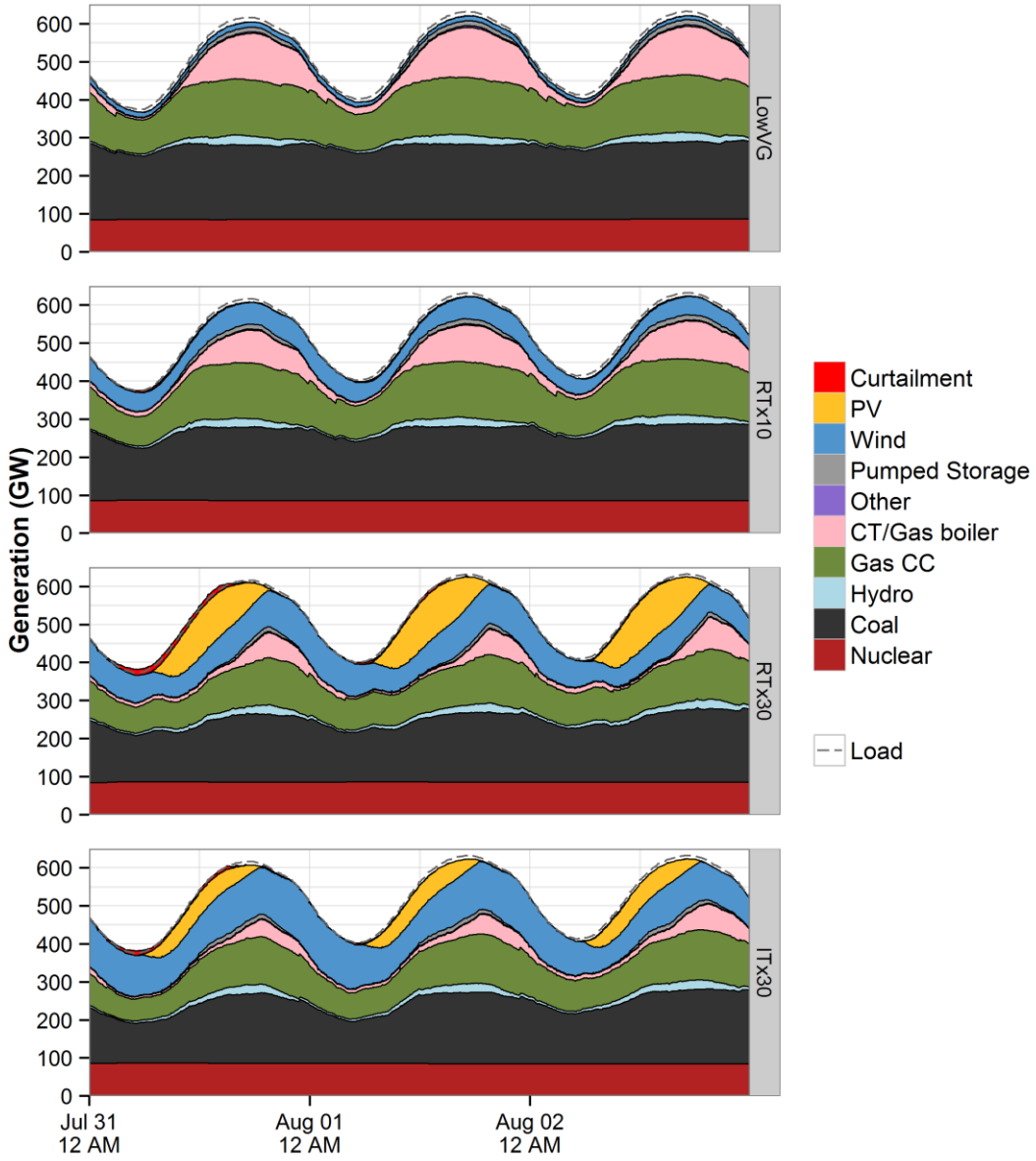
- Regional Transmission, 30% penetration, 20% wind, 10% solar

ITx30

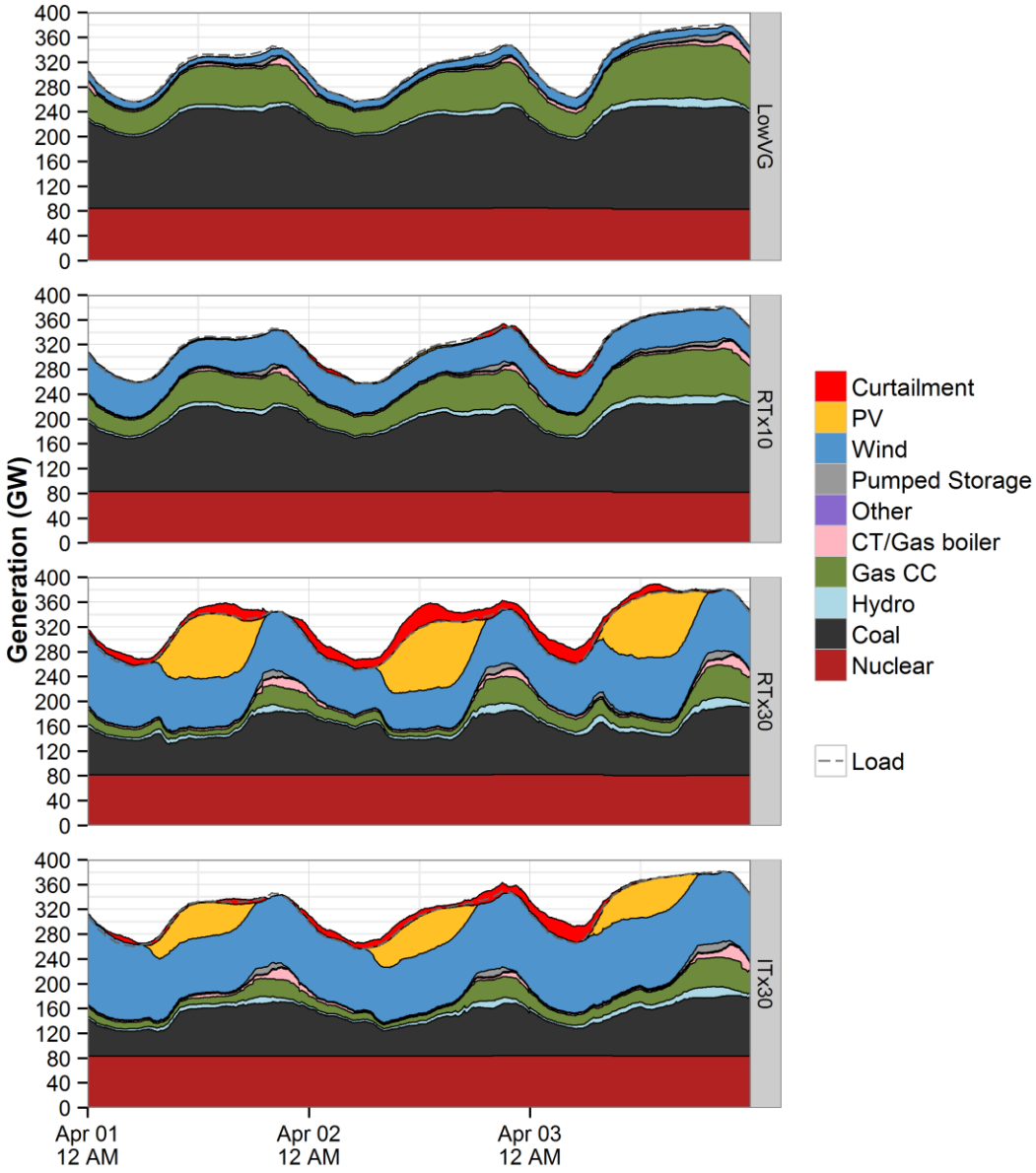
- Inter-regional Transmission, 30% penetration, 25% wind, 5% solar

Transmission Expansions are from EIPC

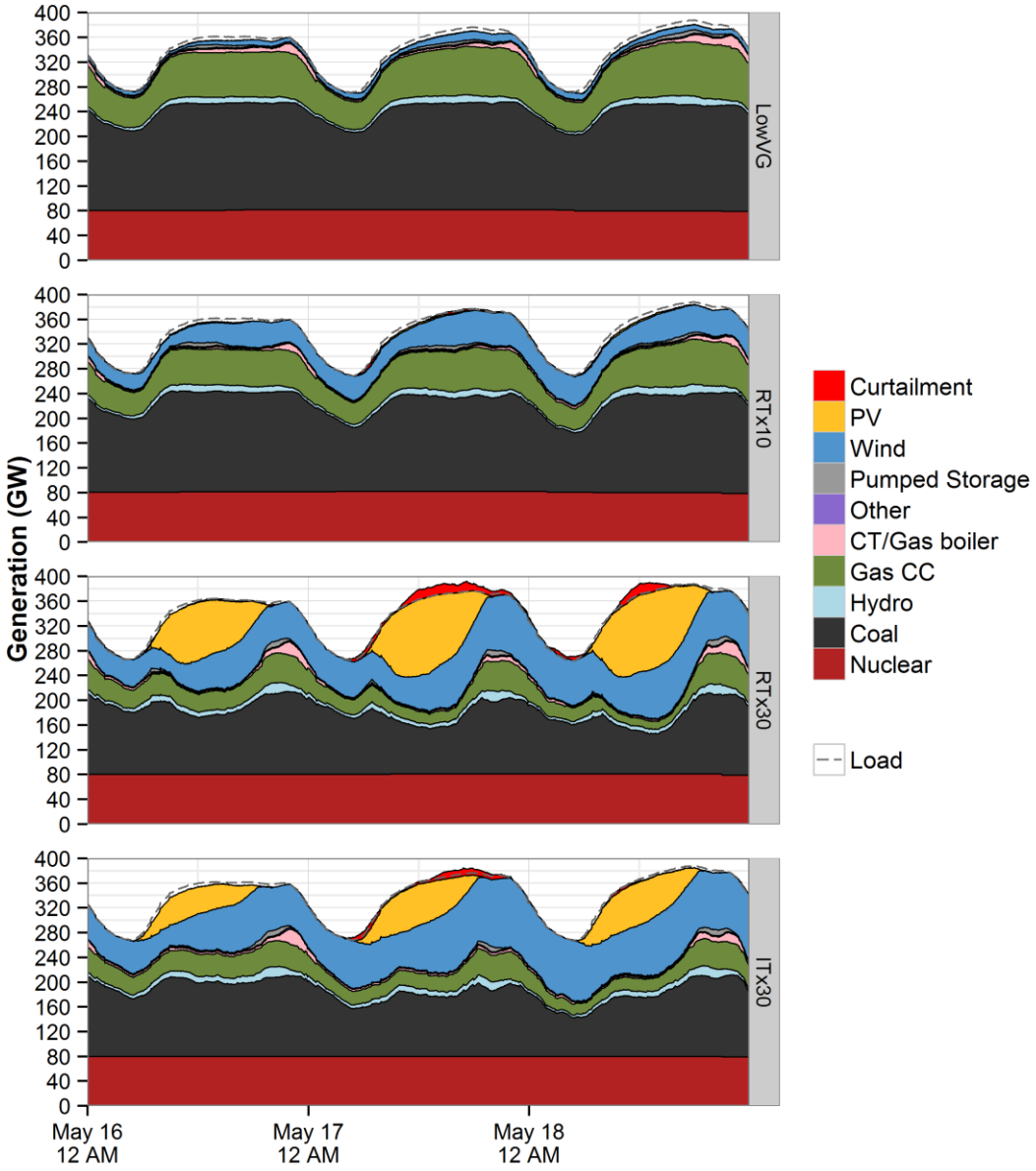
Peak Load for the Eastern Interconnection



High Wind for the Eastern Interconnection



High Solar for the Eastern Interconnection



NREL RESEARCH AREAS

Design & Studies

Operations & Controls

Sensing, Measurements, and Forecasting

Integrated Devices and Systems

Reliability and Markets

Operations & Controls

Design & Studies

Resource Measurements

Grid Sensors

Forecasting

Solar

EVs

Wind

Loads

Power Electronics

Energy Storage

Characterization

Interoperability

Interconnection

Physical and Cyber Security

Institutional Support

ENERGY SYSTEMS INTEGRATION FACILITY (ESIF)

NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

Unique Capabilities

- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale HPC and data mgmt system in showcase energy efficient data center
- MW-scale Power hardware-in-the-loop (PHIL) simulation capability to test grid scenarios with high penetrations of clean energy technologies

ESIF LABORATORIES

Rooftop PV

Energy Storage -
Residential, Community & Grid Scale Storage

Smart buildings & controllable loads

HPC & Data Center

Energy Systems Integration
Fuel Cells, Electrolyzers

Power Systems Integration
Grid Simulators - Microgrids

Outdoor Test Areas
EVs, Transformers, Cap Banks, Regulators

Advanced Distribution Management Systems

PV INTEGRATION IN HAWAII

TECHNOLOGY ADDRESSED

Interconnection challenges when connecting distributed PV at high penetration into the electrical distribution grid such as in Hawaii.

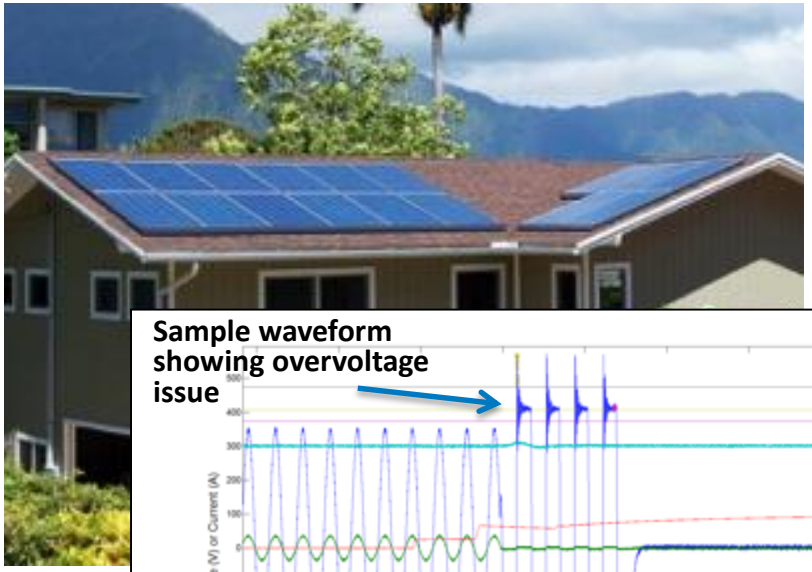
R&D STRATEGY

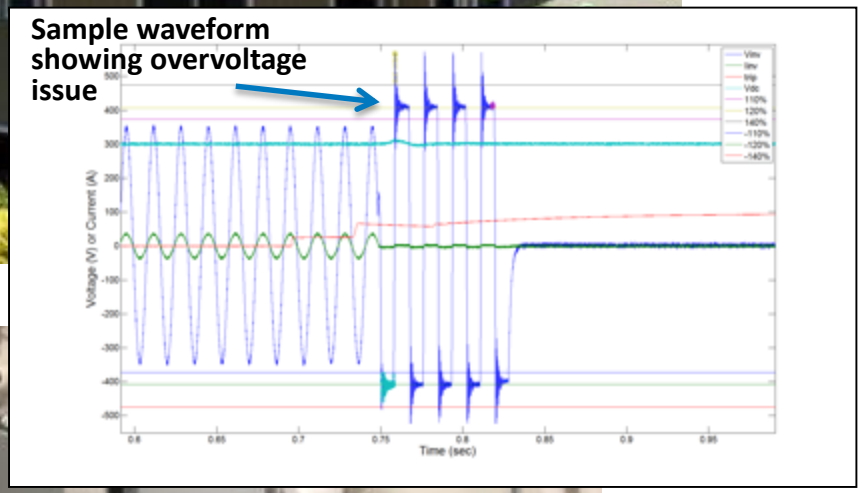
Test solar inverters from various manufacturers for their ability to mitigate transient overvoltage impacts

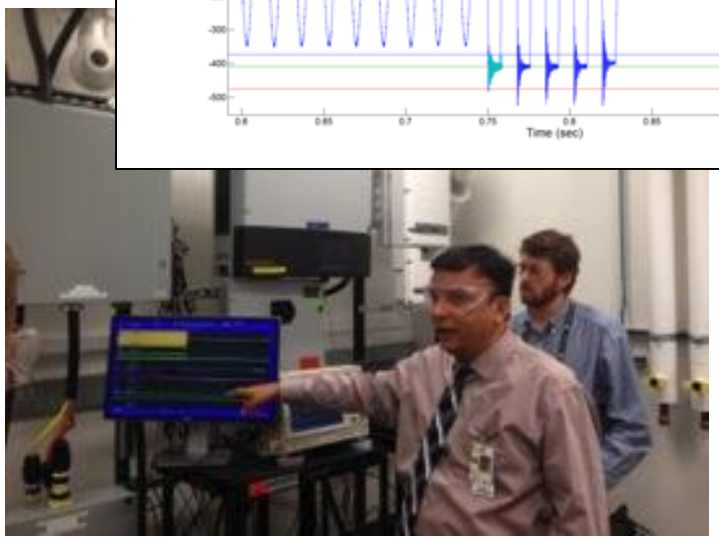
IMPACT

HECO filed with the PUC to modify their interconnection policies to allow siting of PV systems with advanced inverters on neighborhood distribution circuits up to 250% of minimum daytime load (MDL).

http://www.nrel.gov/docs/fy15osti/64173.pdf





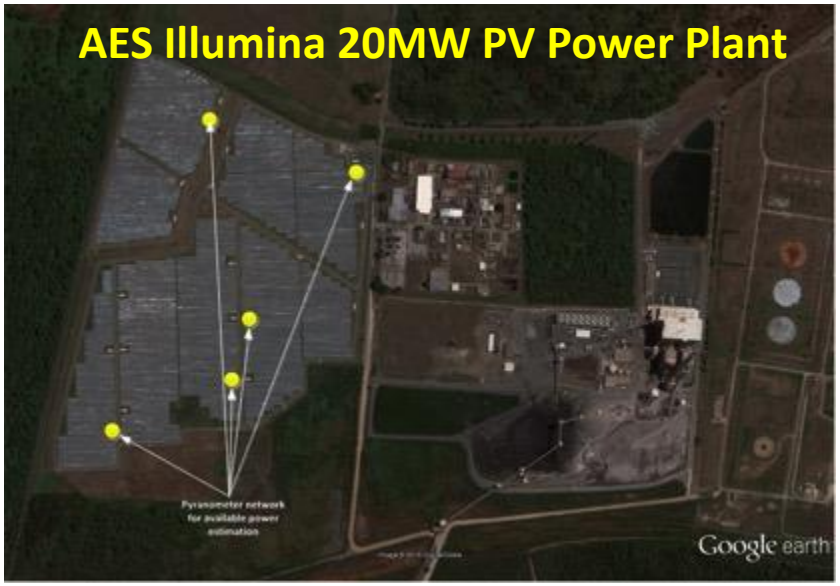


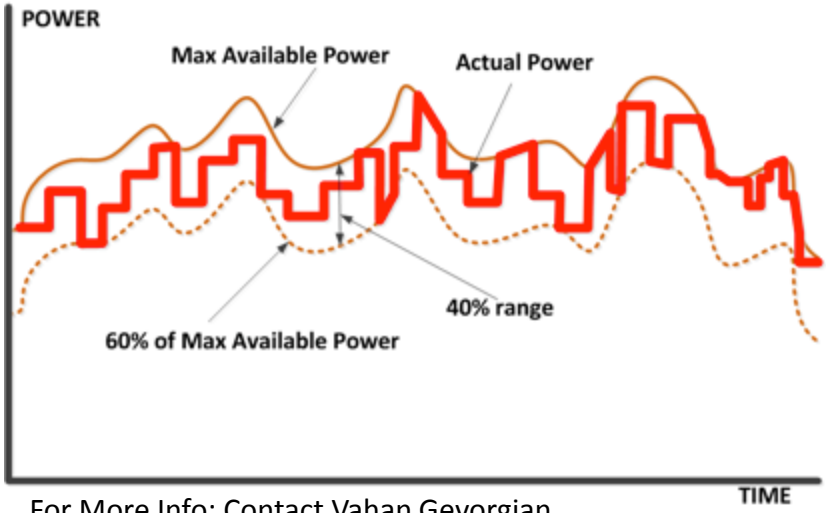
For More Info: Contact
Sudipta Chakraborty
Sudipta.Chakraborty @ nrel.gov

PV PROVIDES GRID SERVICES FOR PUERTO RICO

- **PV participated in Automatic Generation Control (AGC)**
  - Follow PREPA AGC signal within 40% of available power
- **PV provided frequency droop response**
  - Both up and down-regulation
  - 5% and 3% symmetric droop
- **Fast Frequency Response (FFR) tests**
  - Test plant's ability to deploy all reserve within 500 ms
  - Three new controls were implemented and validated

Impact
First of a kind real-world experiment using PV systems to maintain large grid stability

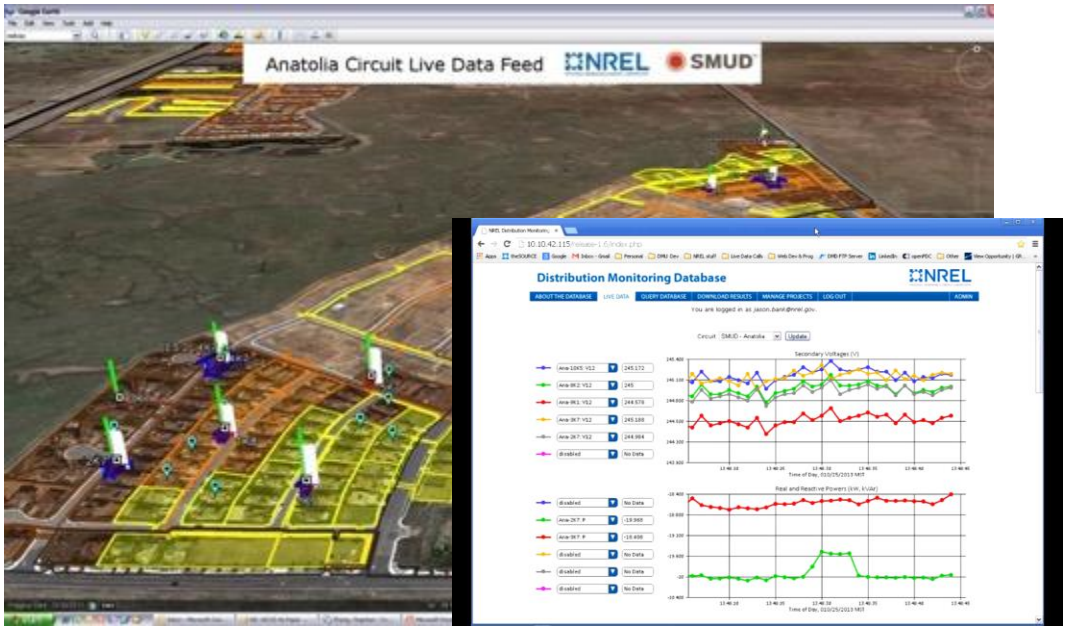


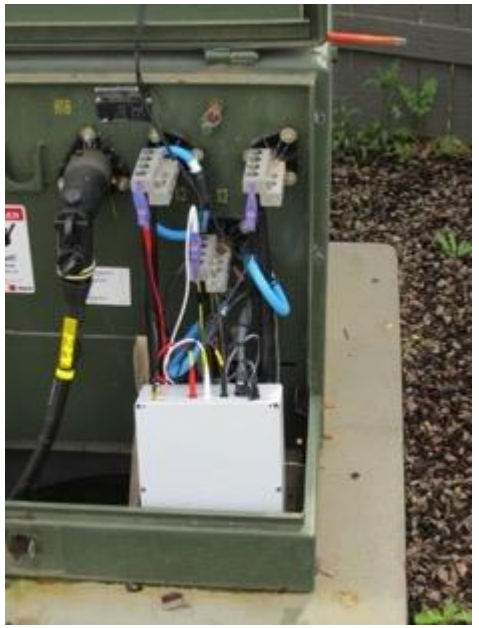


For More Info: Contact Vahan Gevorgian
Vahan.Gevorgian @ nrel.gov

http://www.nrel.gov/docs/fy16osti/65368.pdf

SMUD HIGH-PEN PV/ENERGY STORAGE PROJECT





- Focus – model and demonstrate the value of energy storage at the customer and community level in a high-penetration PV scenario
- A real-time network of distribution level PMUs was developed and deployed to quantify PV and energy storage impacts/mitigation of impacts

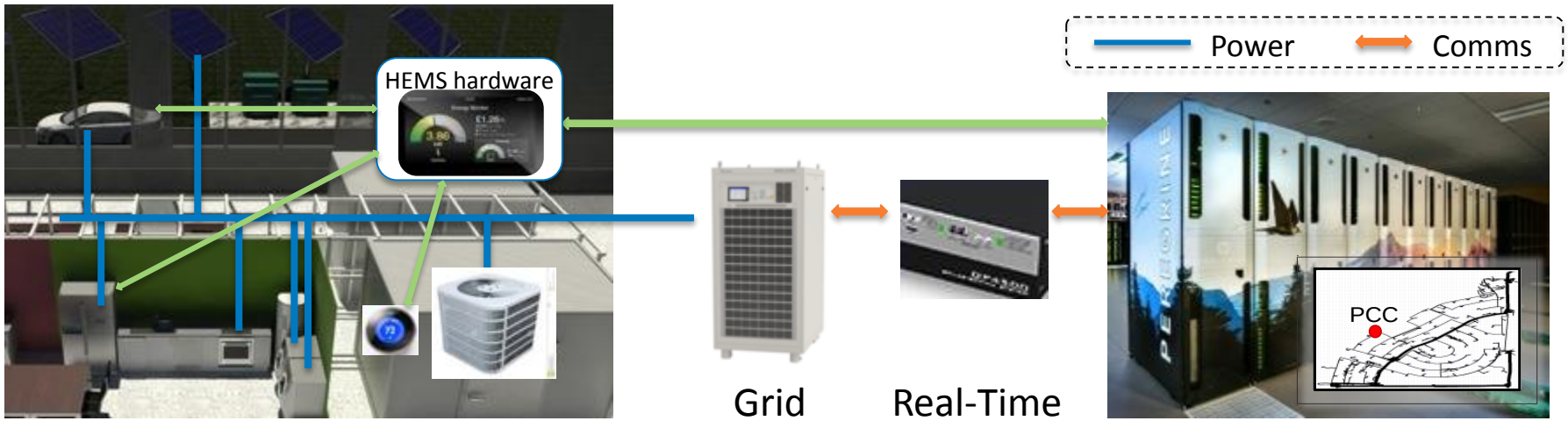
HOME ENERGY MANAGEMENT SYSTEM RESEARCH

Capabilities

- Smart Home Hardware-in-the-loop – includes appliances, HVAC, PV, EV
- Centralized optimization (within home/buildings) based on Model Predictive Controls (MPC)
- Simulation of aggregated homes with distribution systems – including market signals

IMPACT
Provide a test bed that allows complete system optimization from appliances to aggregators to system operations

For More Info: Contact Annabell Pratt
Annabell.Pratt @ nrel.gov



DER, appliances and HEMS in SPL

Grid Simulator

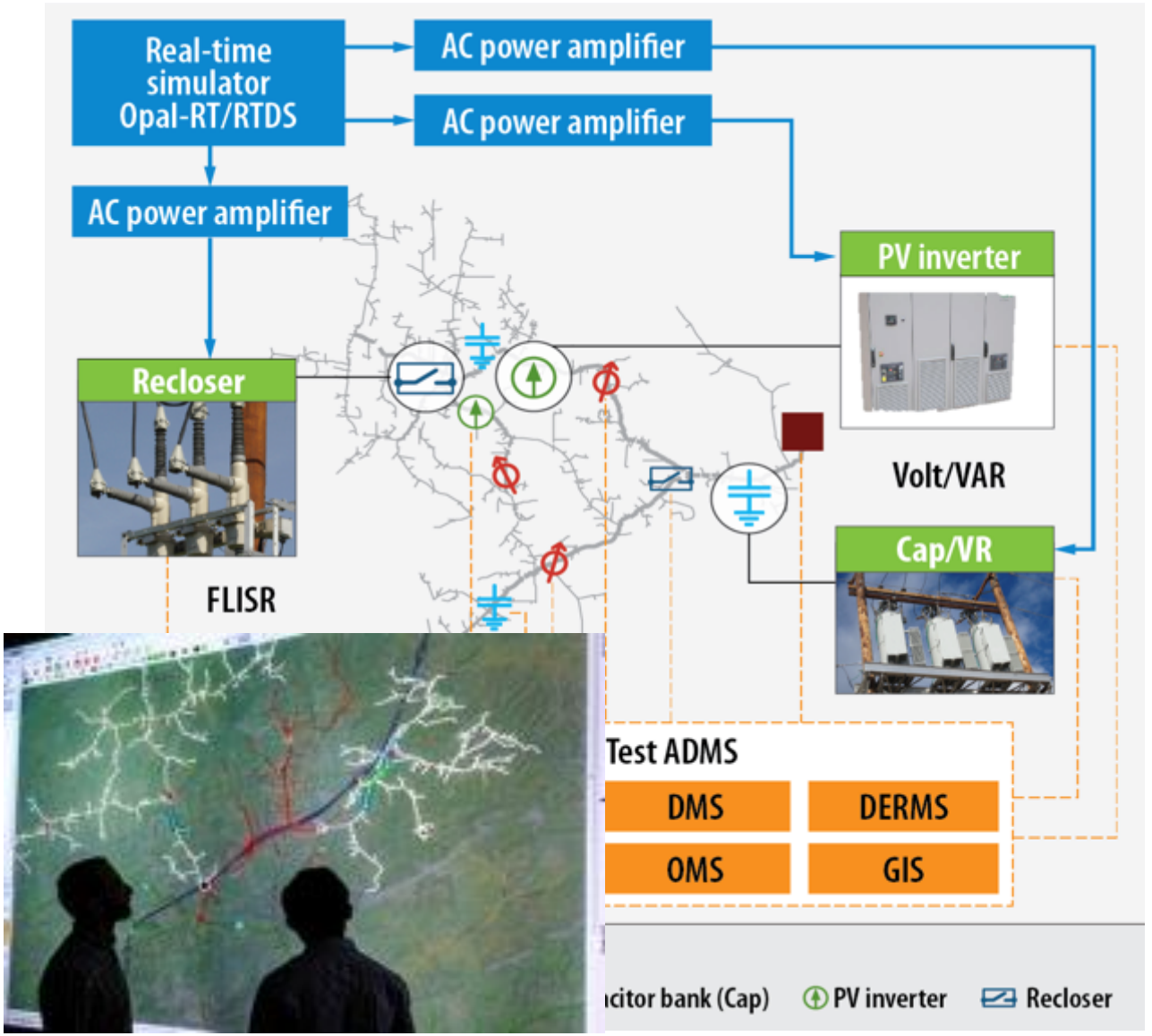
Real-Time Simulator

Simulation on Peregrine

http://www.nrel.gov/docs/fy15osti/64365.pdf

NREL ADMS TESTBED

- NREL is establishing a **national, vendor-neutral** Advanced Distribution Management System (ADMS) testbed to **accelerate industry development and adoption of ADMS capabilities**
- Enable utility partners, vendors, and researchers to evaluate existing and future ADMS use cases and integrate with HIL equipment

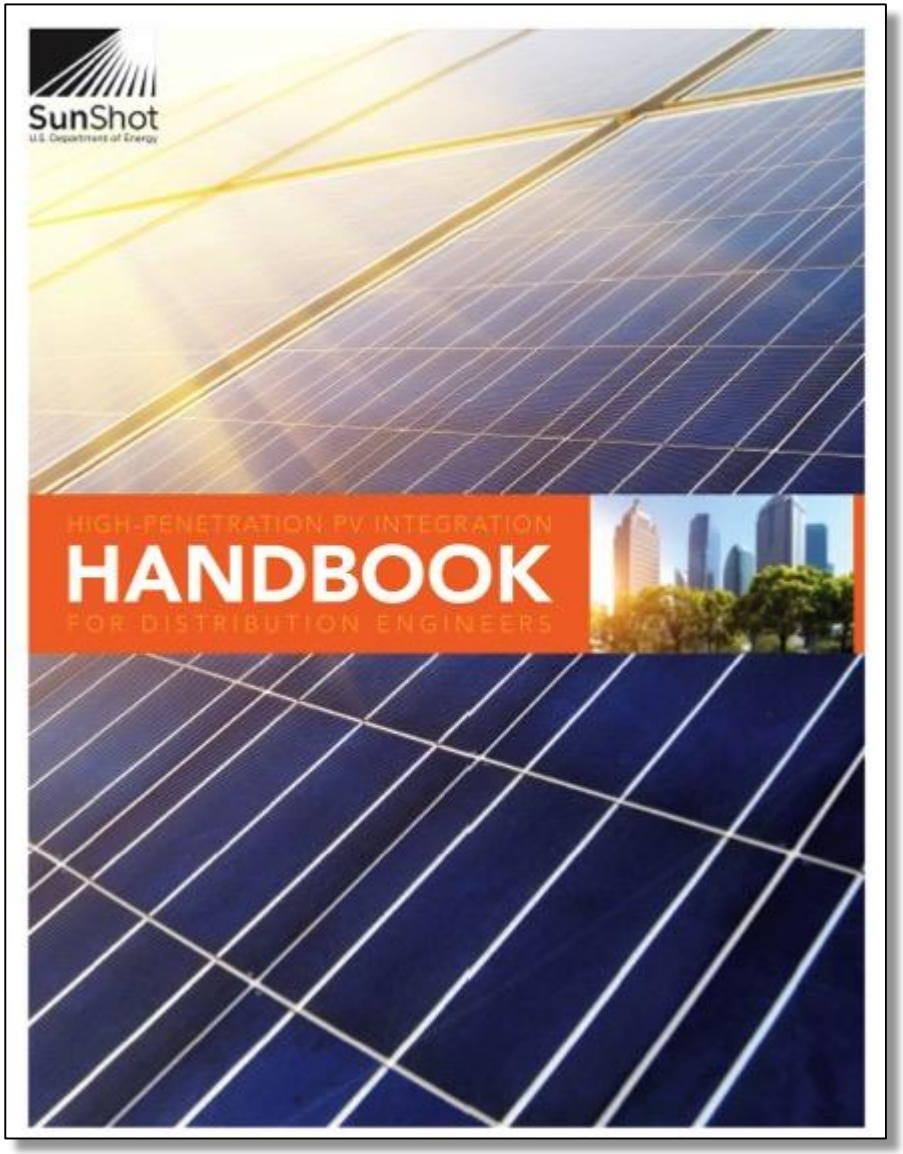


For More Info: Contact Murali Baggu Murali.Baggu @ nrel.gov

HANDBOOK FOR DISTRIBUTION ENGINEERS

- NREL/SCE High-Penetration PV Integration Project findings were turned into a handbook (100+ pages) to help distribution engineers analyze the impacts of high-penetration levels of photovoltaic (PV) systems interconnected in electrical distribution system.

- Project partners were: The National Renewable Energy Laboratory (NREL), Southern California Edison (SCE), Quanta Technology, Satcon Technology Corporation, Electrical Distribution Design (EDD), and Clean Power Research (CPR)



http://www.nrel.gov/docs/fy16osti/63114.pdf

For More Info: Contact Barry Mather Barry.Mather @ nrel.gov

INTEGRATED T&D GRID MODELING SYSTEM (IGMS)

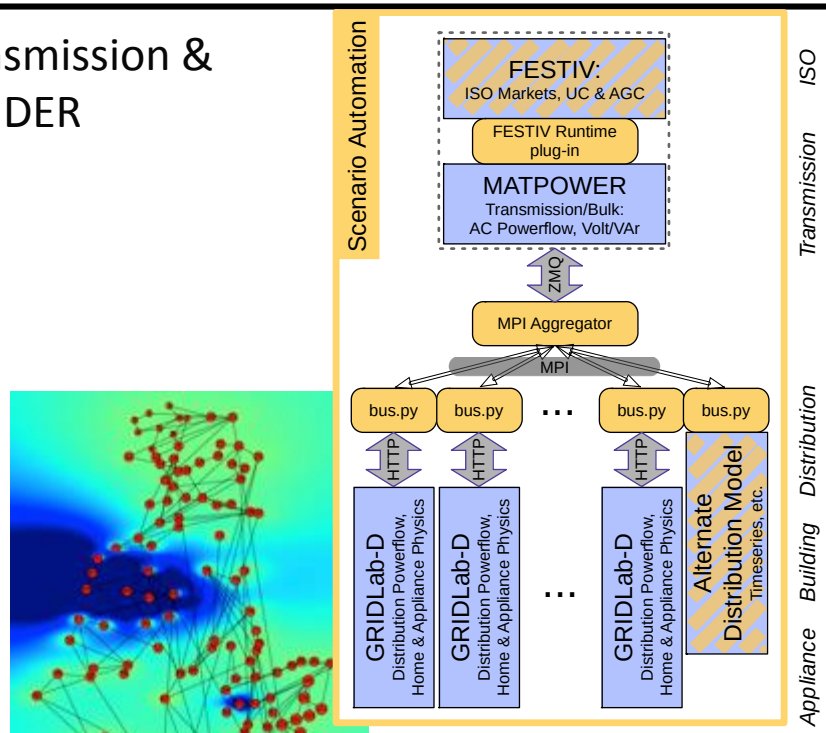
Next-generation analysis framework for full-scale transmission & distribution modeling that supports millions of highly DER

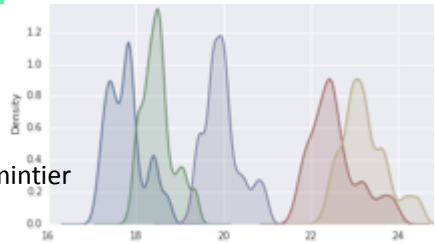
End-to-End T&D Modeling Capability

- detailed multi-period wholesale markets (including LMPs)
- generator/reserve dispatch (AGC)
- AC Powerflow (bulk transmission)
- Full unbalanced 3-ph power flow for 100s-1000s of distribution feeders
- Physics based end-use models of buildings and end-use loads.

Example Applications

- **Successful Medium Scale Run(s): 118 Transmission buses, 743 Distribution Feeders, >1M total buses, >600k homes**
- **Future:**
  - Simulate smart grid storage, PV, and demand response
  - Simulate alternative market and service architectures
  - Co-simulation with Hardware via PHIL
  - Connect to Advanced DMS/EMS systems

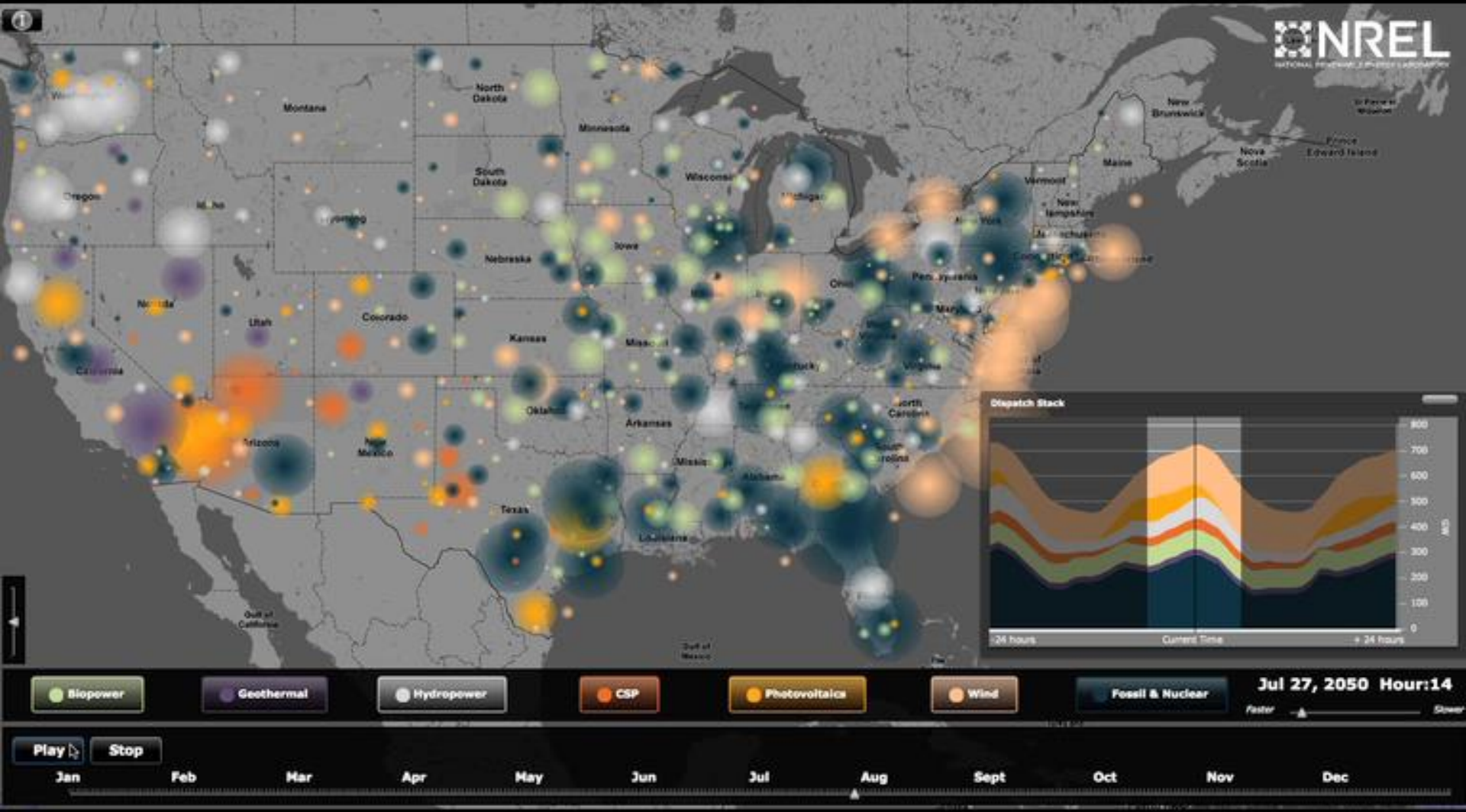




For More Info: Contact Bryan Palmintier
Bryan.Palmintier @ nrel.gov

IMPACT
Provides a first-of-a-kind co-simulation with transmission-level markets, 1000s of distribution feeders, and millions of DERs

http://www.nrel.gov/docs/fy16osti/65552.pdf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North Carolina
South Carolina
Vermont
New Hampshire
Maine
New Brunswick
Nova Scotia
Prince Edward Island
Dispatch Stack
24 hours
Current Time
+ 24 hours
GW
800
700
600
500
400
300
200
100
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Biopower
Geothermal
Hydropower
CSP
Photovoltaics
Wind
Fossil & Nuclear
Jul 27, 2050 Hour:14
Faster
Slower
Play
Stop
Jan
Feb
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Dec

Summary and Takeaways

- RE in the U.S. is experiencing robust growth
- Market expansion has been driven by state-level portfolio standards and the federal investment tax credit along with net metering policies
- Recent surge has been enabled by innovative financing options and falling systems prices
- Significant barriers and opportunities remain
  - Strong growth projected over the next two years, but:
  - Policy patchwork remains across the U.S. creating an inefficient business environment
  - Soft costs remain high
  - Uncertainties in utility business models could impact PV
  - Technical integration challenges remain

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Thanks for the Opportunity to Share NREL's Research!




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