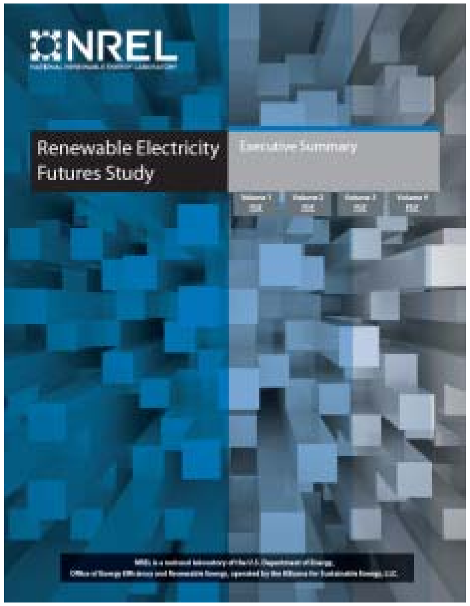
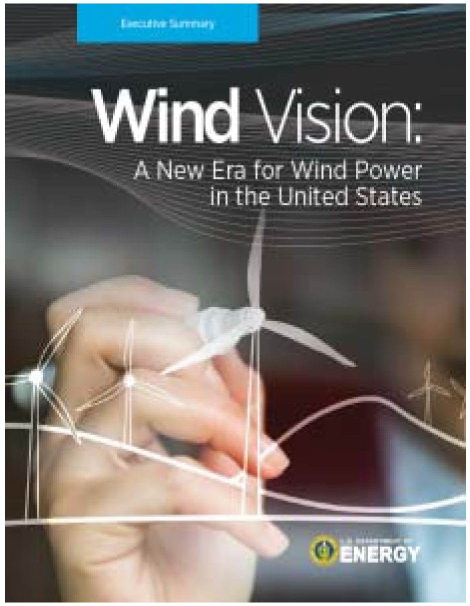
High Renewable Electricity Scenarios

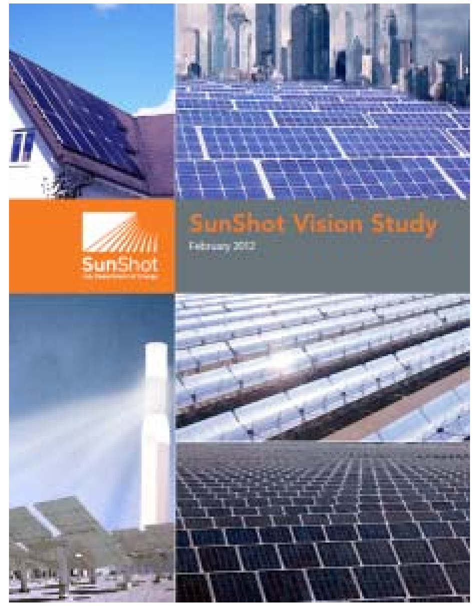
Trieu Mai and Doug Arent

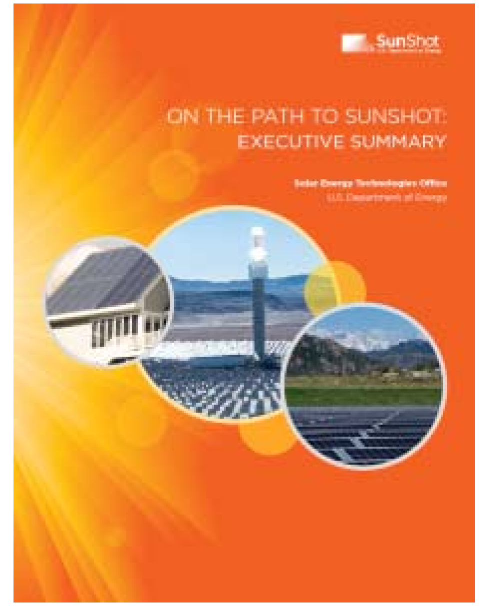
EPRI & IEA Workshop: Renewables and Clean Energy for Industries
Washington DC; November 29-30, 2016

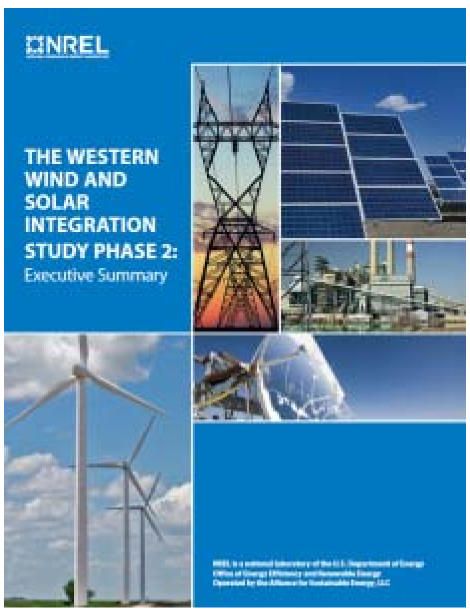
NREL/DOE Renewable Energy Vision & Integration Studies

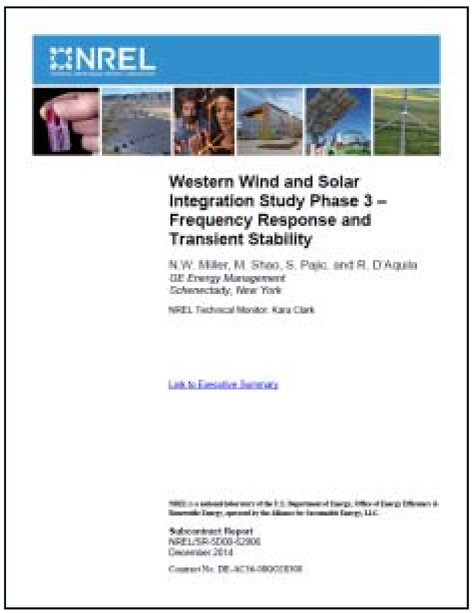


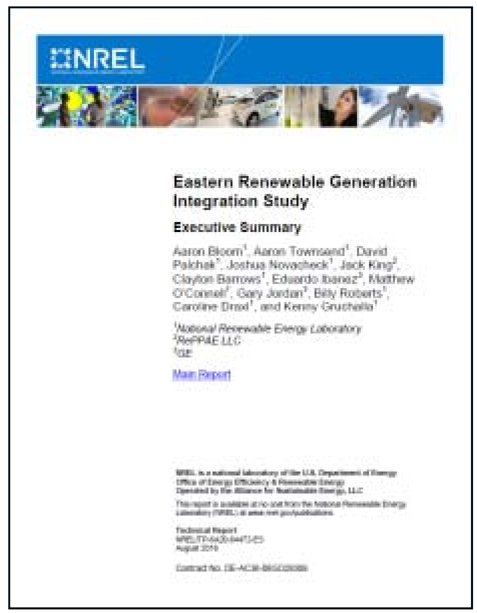


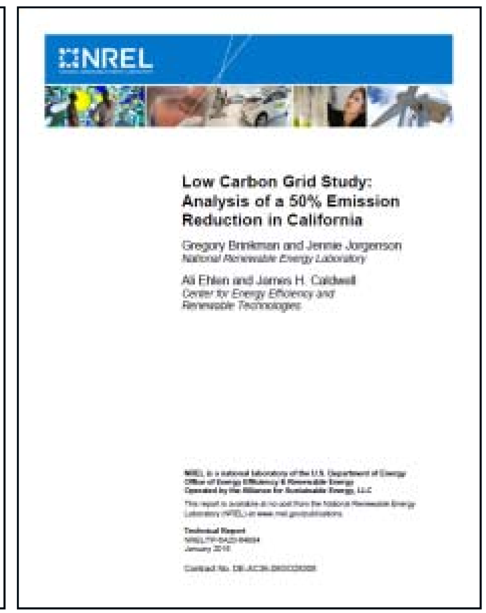




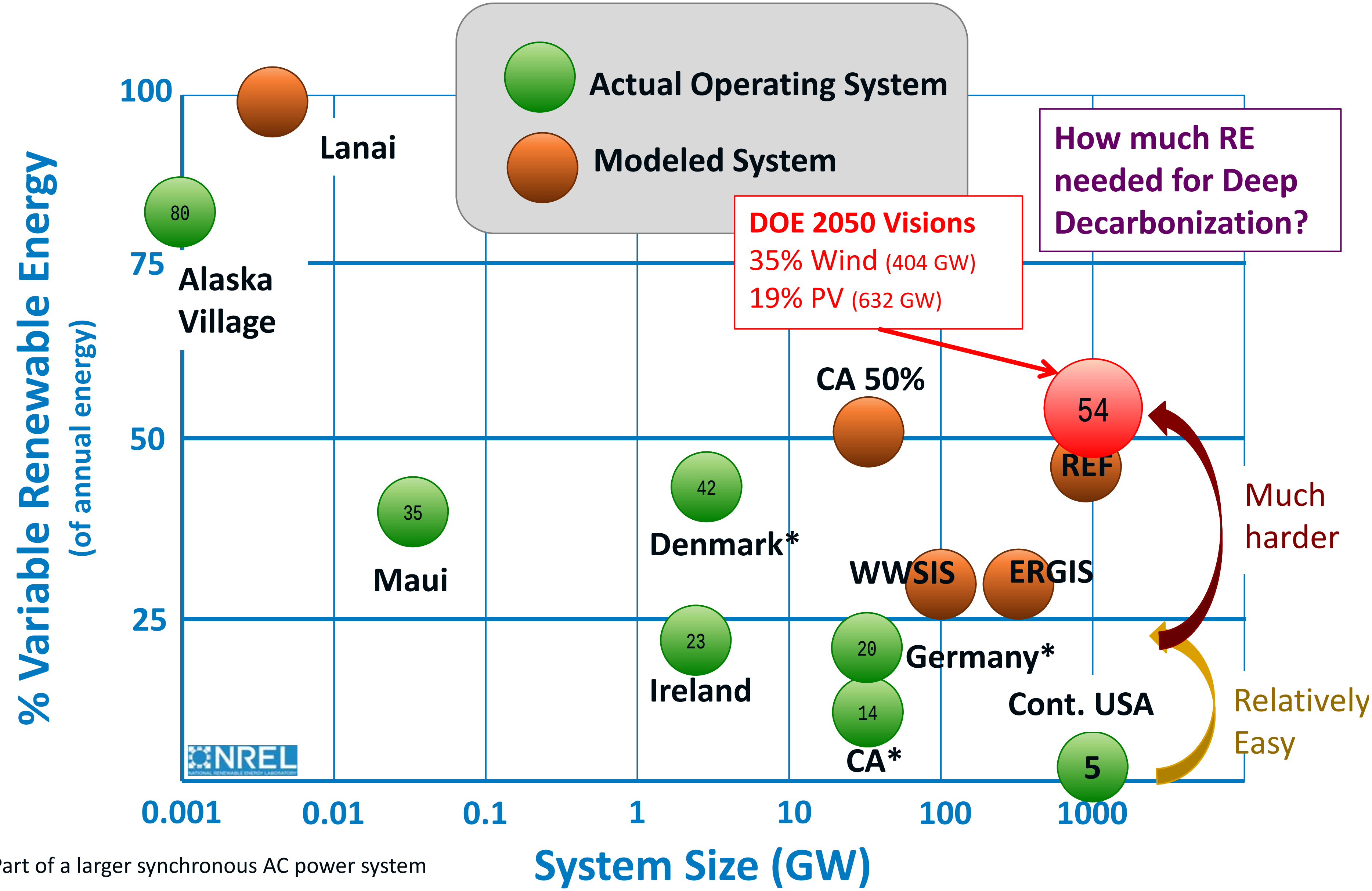






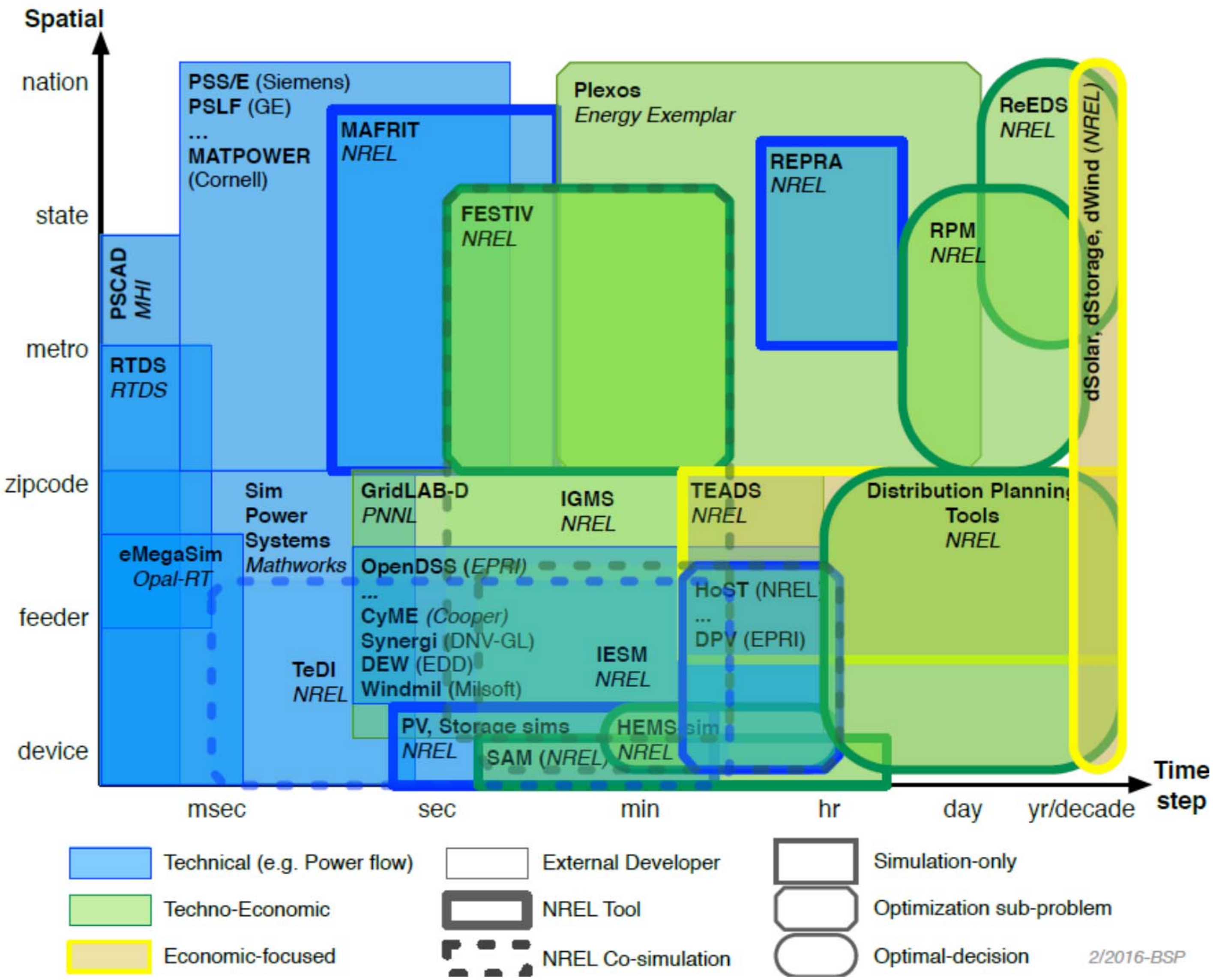


Current VRE Penetrations vs. System Size



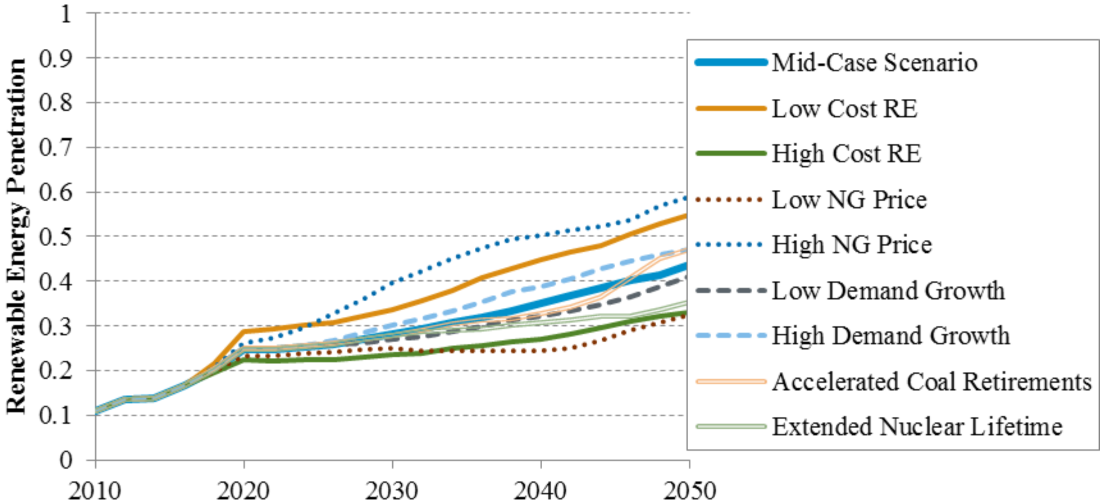
* Part of a larger synchronous AC power system

Current Power System Model Map

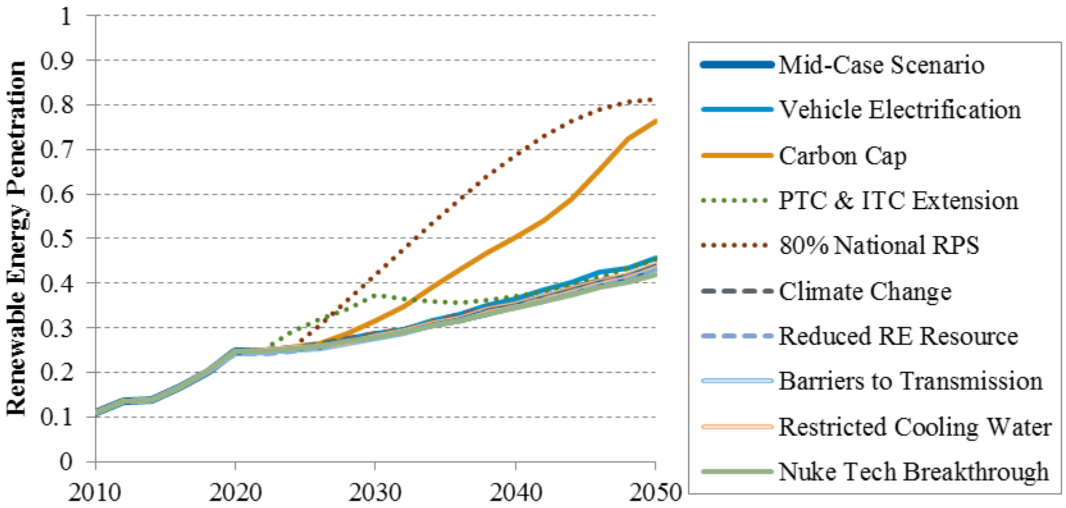


Things we think we know about integrating high RE shares (and some things we don't know)

RE shares will likely grow over time, particularly under decarbonized futures



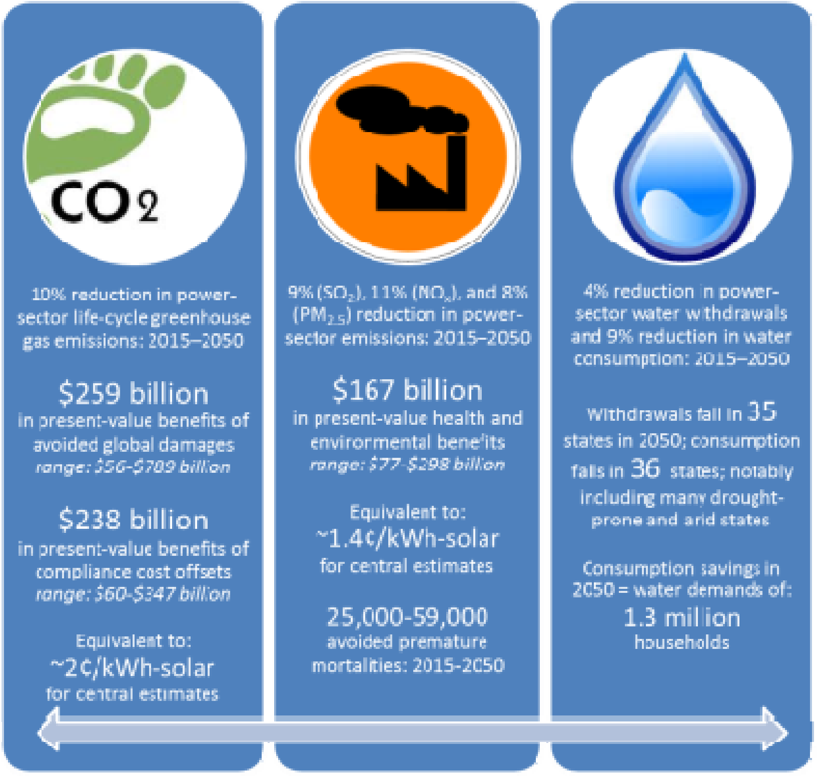
Source: NREL 2016 Standard Scenarios Report



Unknowns

- Future conditions w.r.t. RE cost reductions, NG prices, and policies will ultimately determine the achieved RE penetration
- Under a carbon-constrained future, RE growth will also be determined by future of nuclear and CCS
- Significant growth in wind and solar PV anticipated, but ultimate RE composition still difficult to predict
  - Less research on economic potential of biopower, geothermal, hydropower, offshore wind, CSP, marine hydrokinetics
  - Utility-scale vs. distributed RE
- *Most research focuses on wind and solar*

Plentiful resources (in the U.S.) & benefits > costs



On the Path to SunShot
(27% solar by 2050)

Wind Vision
(35% wind by 2050)

The *Study Scenario* results in cumulative savings, benefits, and an array of additional impacts by 2050.

System Costs[1]	Benefits[1,2,3]		
$	GHG	Air Pollution	H_2O
$149 billion (3%) lower cumulative electric sector expenditures	14% reduction in cumulative GHG emissions (12.3 gigatonnes CO_2-equivalents), saving $400 billion in avoided global damages	$108 billion savings in avoided mortality, morbidity, and economic damages from cumulative reductions in emissions of SO_2, NO_x, and PM 22,000 premature deaths from air pollution avoided	23% less water consumption and 15% less water withdrawals for the electric power sector

Additional Impacts

Energy Diversity	Jobs	Local Revenues	Land Use	Public Acceptance and Wildlife
Increased wind power adds fuel diversity, making the overall electric sector 20% less sensitive to changes in fossil fuel costs. The predictable, long-term costs of wind power create downward price pressure on fossil fuels that can cumulatively save consumers $280 billion from lower natural gas prices outside the electric sector.	Approximately 600,000 wind related gross jobs spread across the nation.	$1 billion in annual land lease payments $440 million annual lease payments for offshore wind plants More than $3 billion in annual property tax payments	Less than 1.5% (106,000 km²) of contiguous land area of the U.S. occupied by wind power plants Less than 0.04% (3,300 km²) of contiguous U.S. land area impacted by turbine pads, roads, and other associated infrastructure	Careful siting, continued research, thoughtful public engagement, and an emphasis on optimizing coexistence can support continued responsible deployment that minimizes or eliminates negative impacts to wildlife and local communities

Note: Cumulative costs and benefits are reported on a Net Present Value basis for the period of 2013 through 2050 and reflect the difference in impacts between the *Central Study Scenario* and the *Baseline Scenario*. Results reported here reflect central estimates within a range; see Chapter 3 for additional detail.

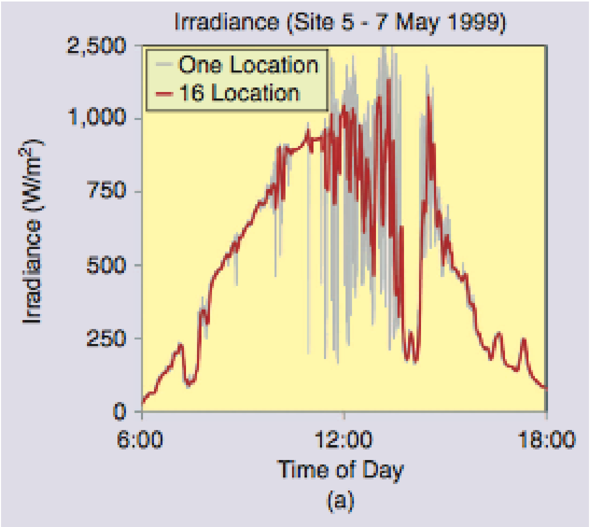
[1] Electric sector expenditures include capital, fuel, and O&M for transmission and generation of all technologies modeled, but excludes consideration of estimated benefits (e.g., GHG emissions).

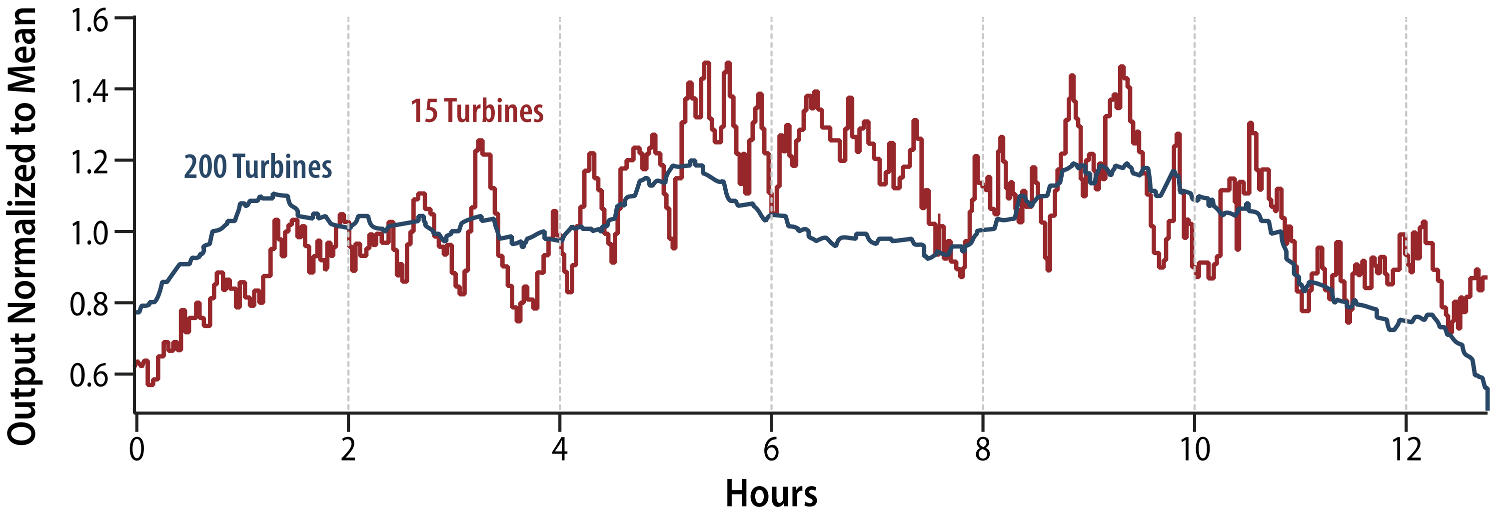
[2] Morbidity is the incidence of disease or rate of sickness in a population.

[3] Water consumption refers to water that is used and not returned to the source. Water withdrawals are eventually returned to the water source.

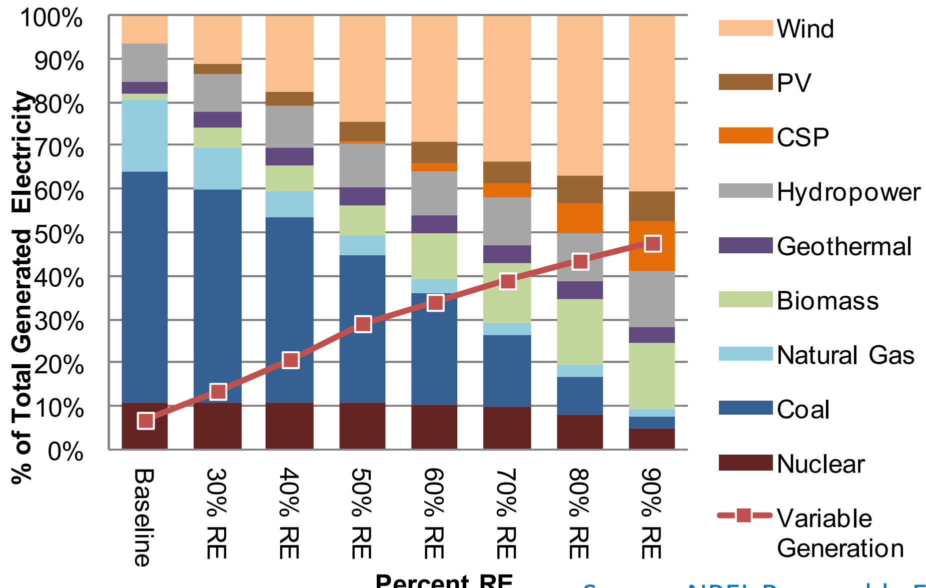
Integrating <35% wind and solar is doable with existing and known best practices

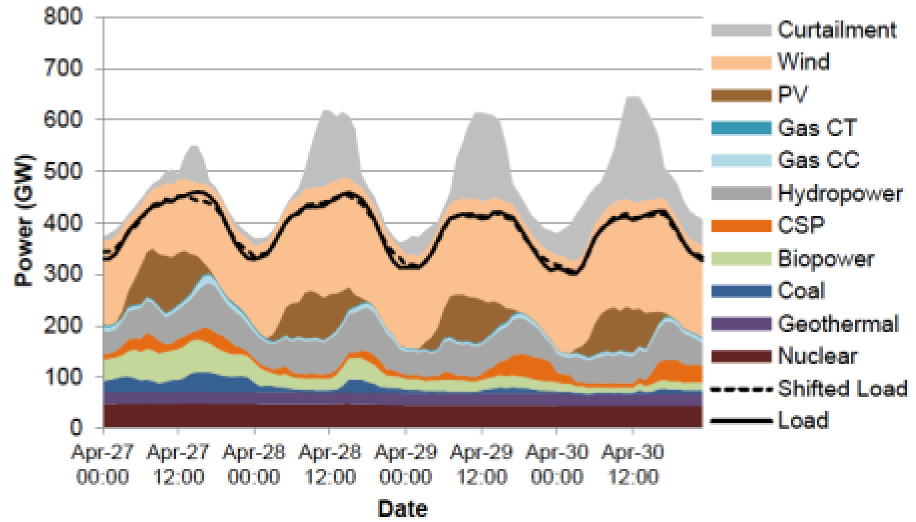
- "Integration costs" are small
- Faster dispatch schedule
- Improved wind and solar forecasting
- Ramping / cycling thermal generators
- Increase balancing area coordination
- Geographic diversity



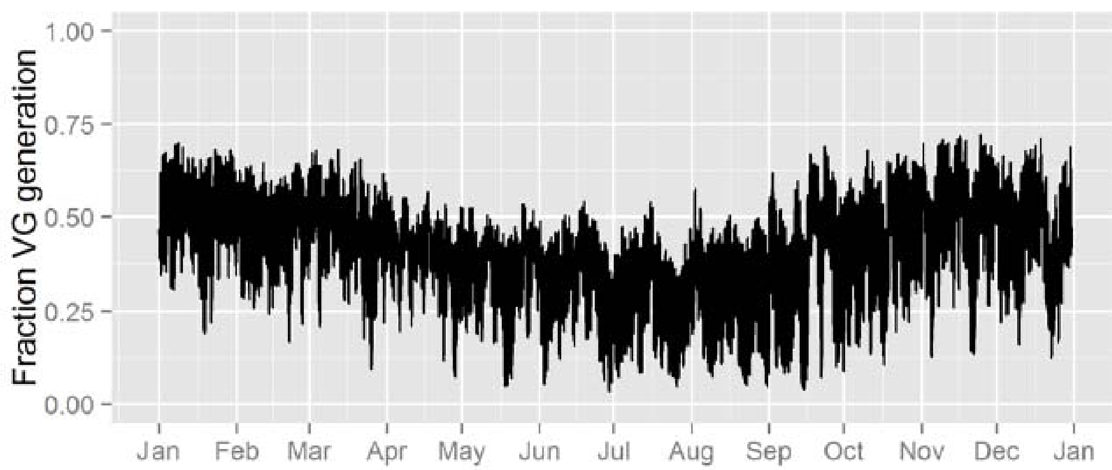


Fewer studies of large systems with **>35%** variable RE generation, but these studies suggest it can be done





Source: NREL Renewable Electricity Futures Study (2012)



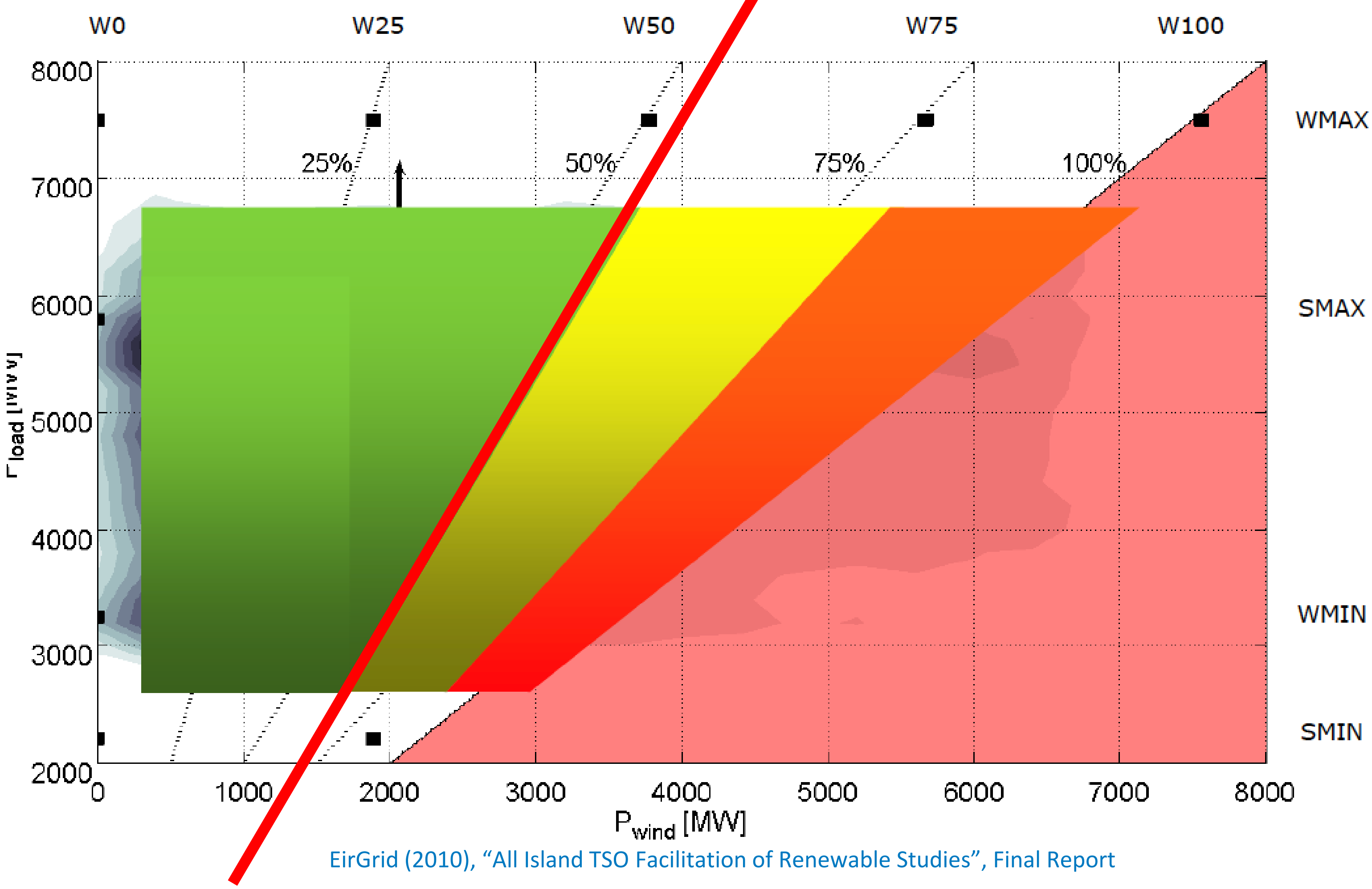
Source: Brinkman (2015): Renewable Electricity Futures: Operational Analysis of the Western Interconnection at Very High Renewable Penetrations

Engineering challenges: power system stability with high shares of non-synchronous generation

Ireland

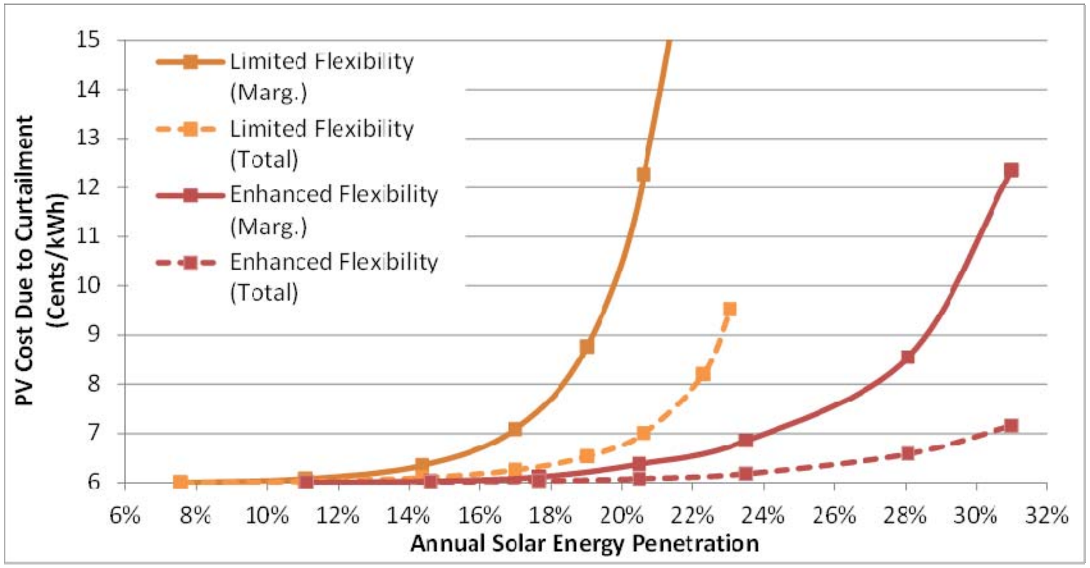
- **23% Wind on Annual Energy Basis** (2015)
- Island Power System (6.5GW peak)

Currently Limiting Grid to
55% instantaneous
Non-Synchronous Penetration



EirGrid (2010), "All Island TSO Facilitation of Renewable Studies", Final Report

Economic challenges: RE curtailment at very high penetrations and more(-expensive) sources of flexibility may be needed

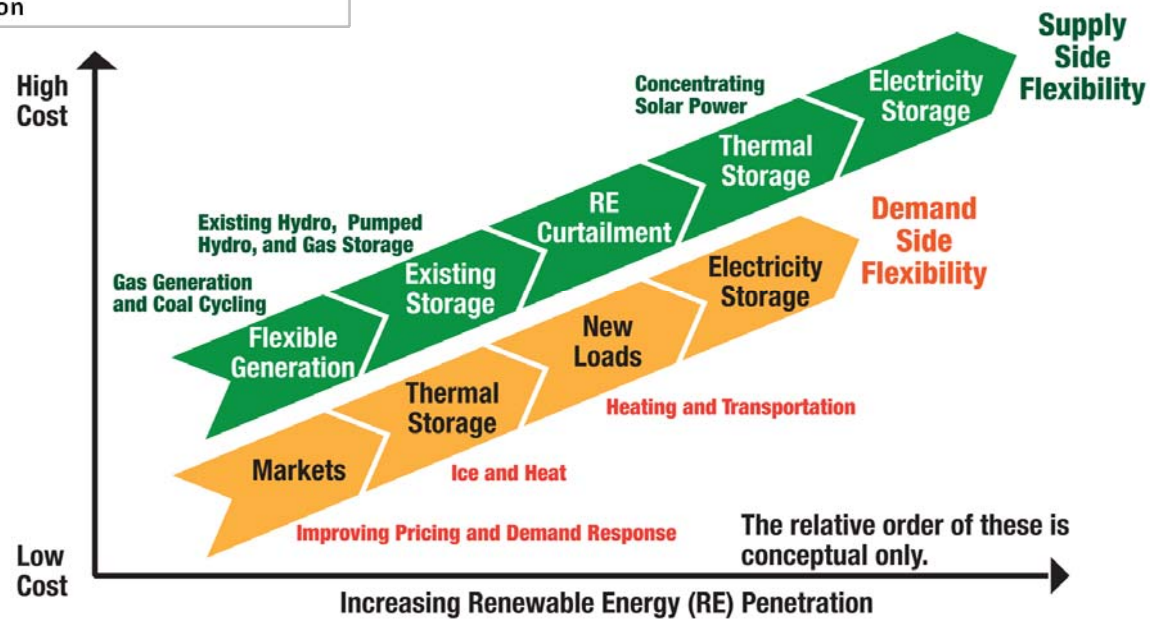


Source: On the Path to SunShot

At high penetrations, curtailment can cause significant declining value (and effectively increase RE costs)

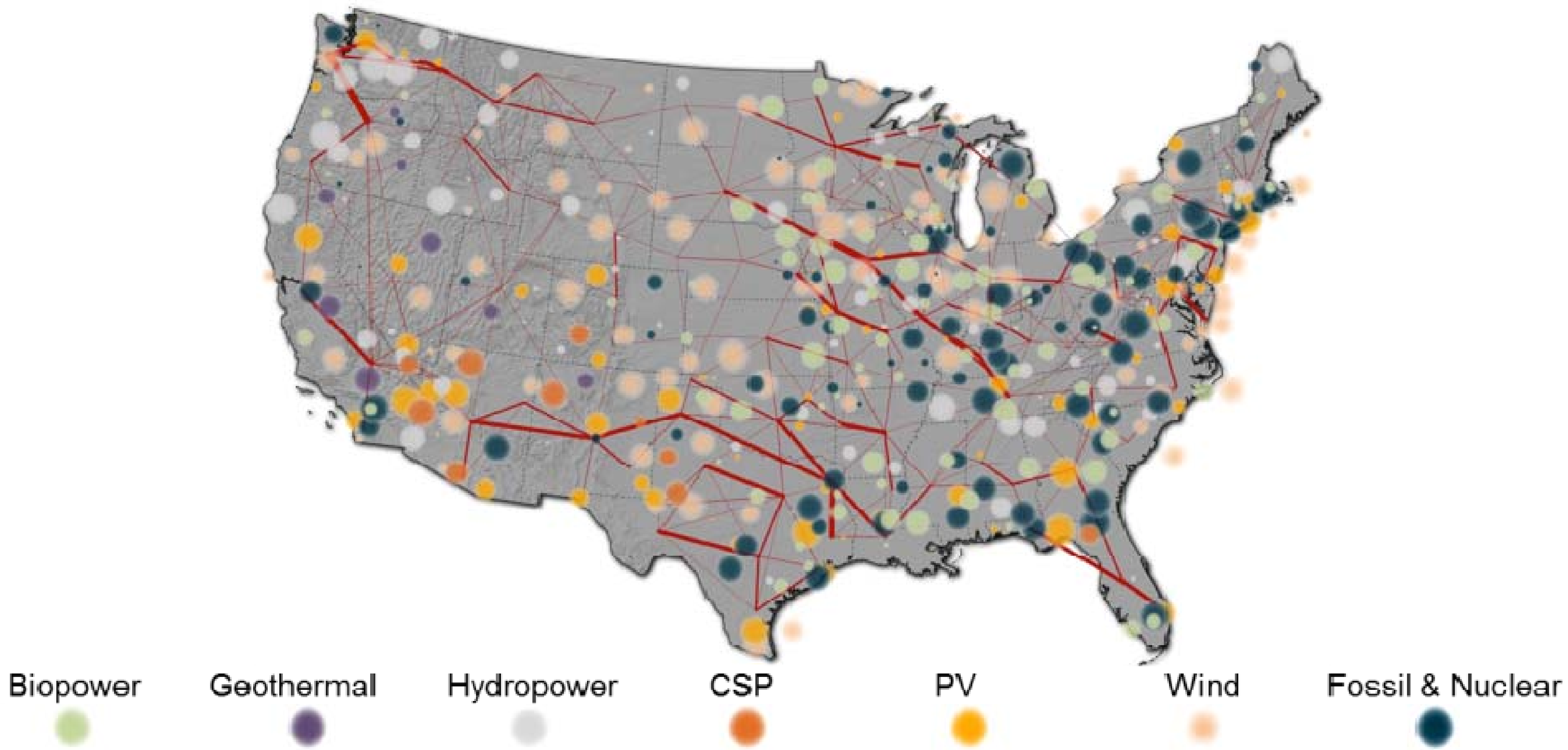
How actively will the demand-side participate in future power systems operations?

Can new loads help facilitate RE integration?



Source: Denholm et al. 2010

www.nrel.gov/analysis/re_futures

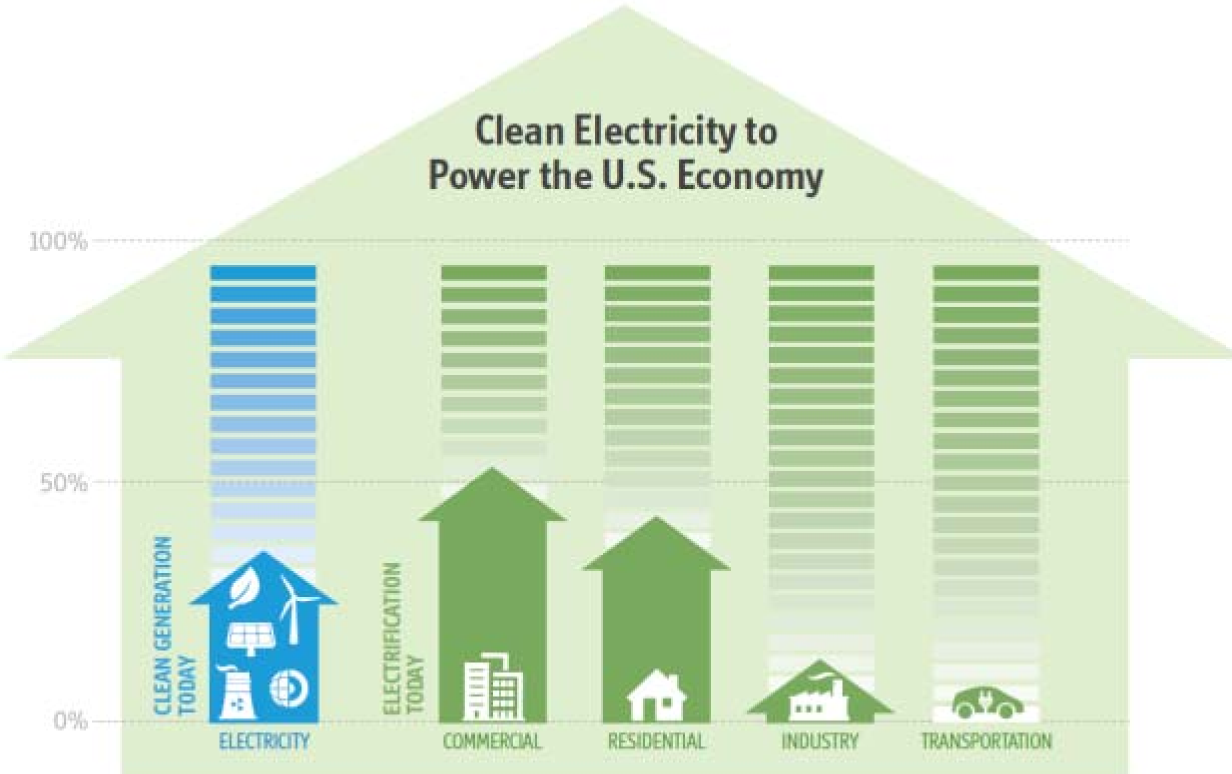


Source: Renewable Electricity Futures (2012)

A future U.S. electricity system that is largely powered by renewable sources is possible, and further work is warranted to investigate this clean generation pathway.

Future Work

Potential for Widespread Electrification to Reduce Unwanted Pollution (POWER-UP) Study – www.nrel.gov/analysis/power-up.html



1. What **end-use services** are the best candidates for **electrification** and how might adoption barriers be overcome?
2. How might mass electrification impact national and regional **electricity consumption and consumption patterns**?
3. How would the U.S. **electricity system transform** to meet the growing consumption needs from mass electrification and, at the same time, decarbonize?
4. How would a decarbonized grid operate to serve an electrified economy and what role might **demand-side flexibility** play to support reliable operations?
5. What impacts would this pathway have for GHG emissions, consumer costs, and other environmental, public health, and social implications?

Thank You.

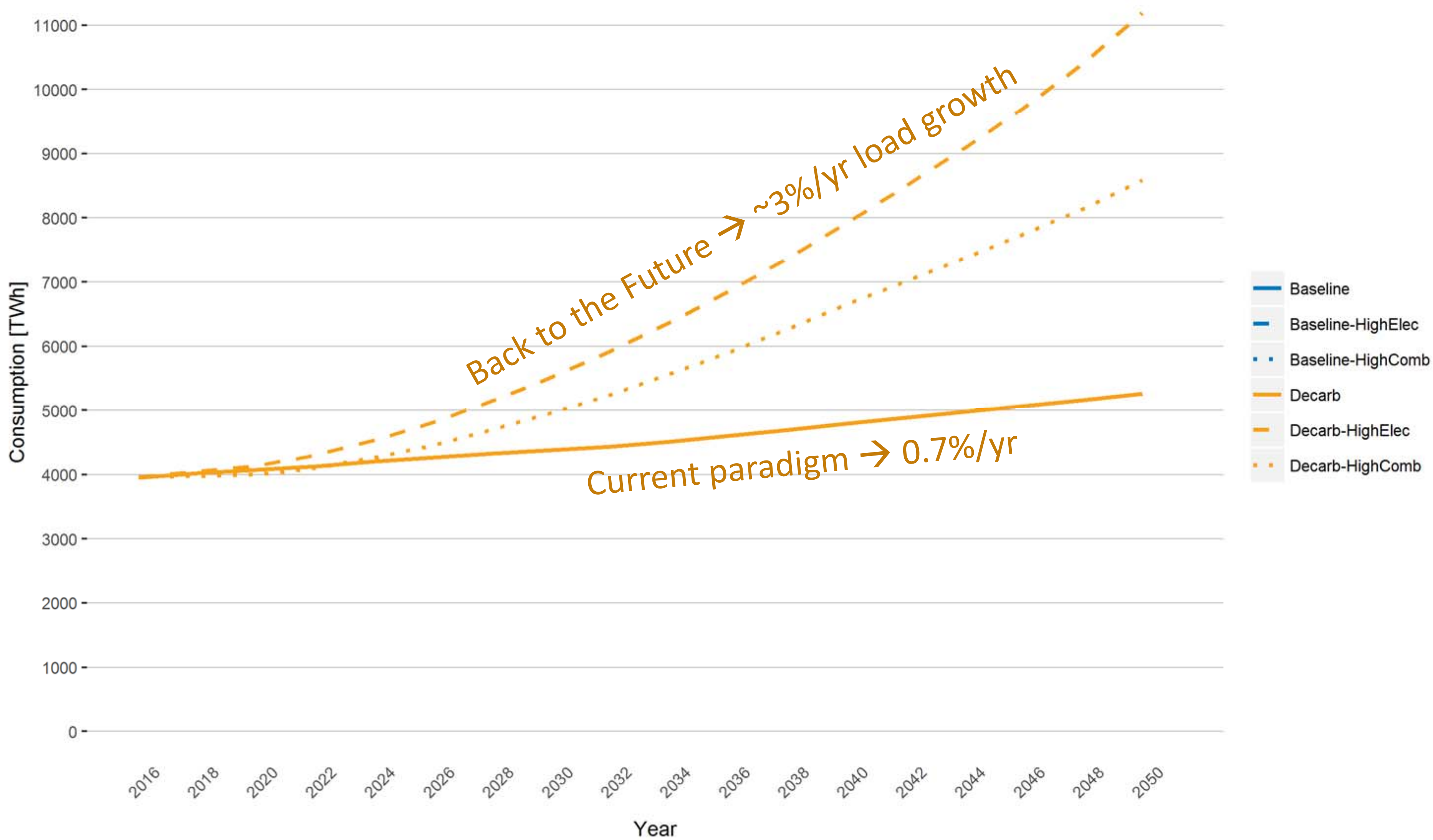
Trieu.mai@nrel.gov
Doug.arent@nrel.gov

www.nrel.gov

NATIONAL RENEWABLE ENERGY LABORATORY

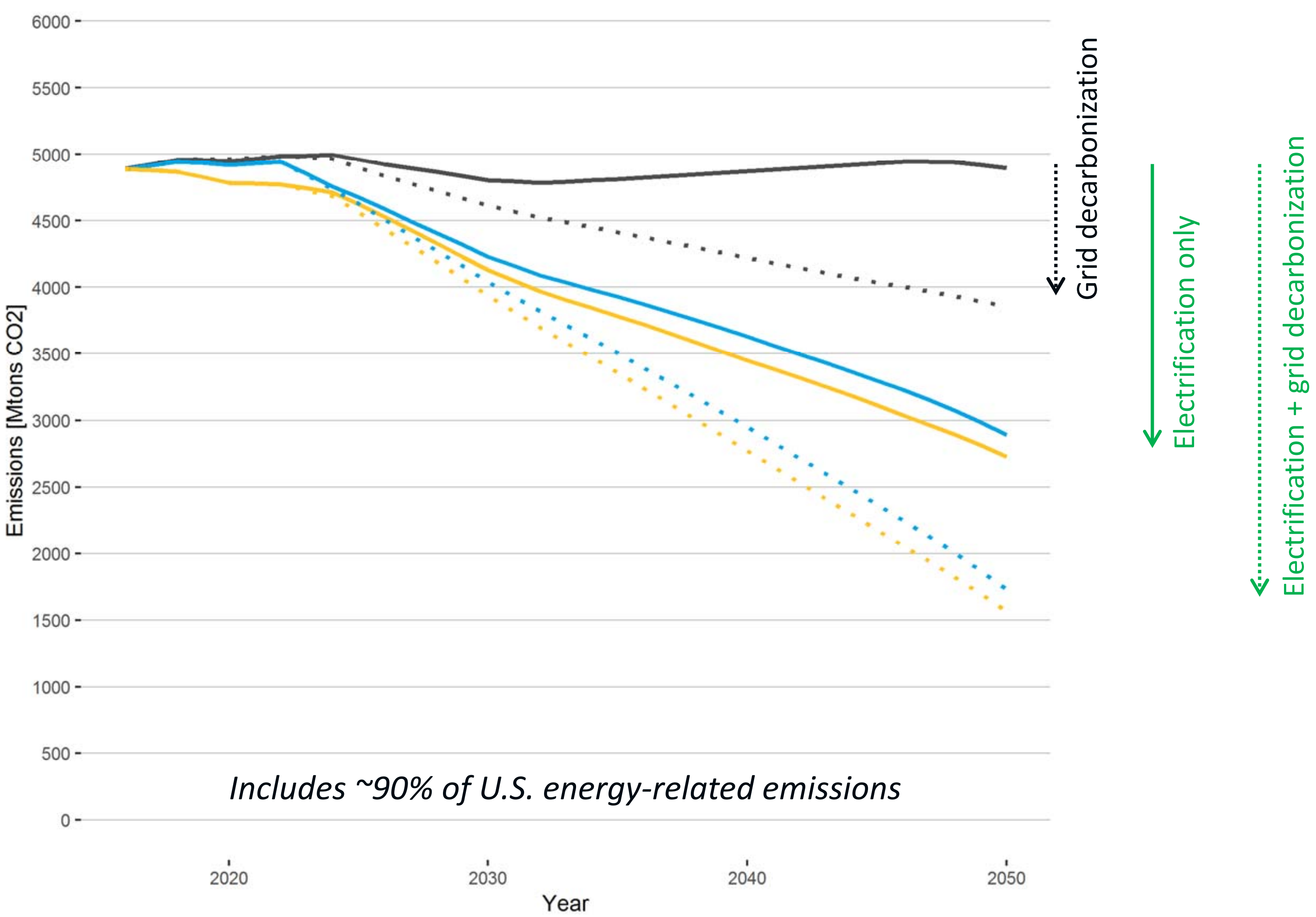
Electrification Technical Potential Analysis: Electricity Consumption

Preliminary Results Only - Do Not Distribute or Cite

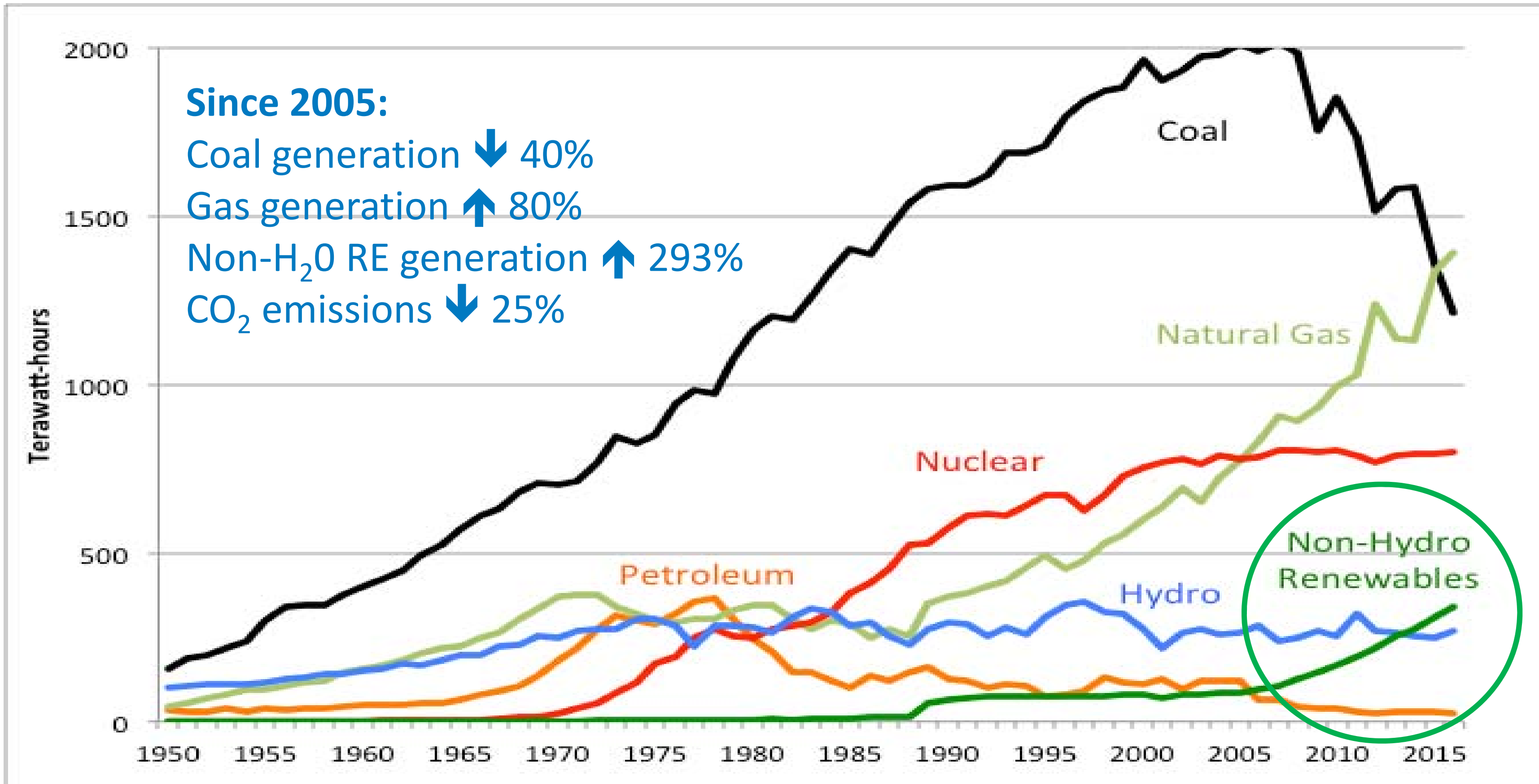


Electrification Technical Potential Analysis: GHG Emissions

Preliminary Results Only - Do Not Distribute or Cite



The U.S. electricity system is undergoing a transformation



- Currently, U.S. RE electricity comprises about 14% of total generation with about 5% from wind and solar
- Basic questions: **How much RE can be integrated in the U.S. power system? What are the impacts to power system reliability, consumer costs, and to the environment?**