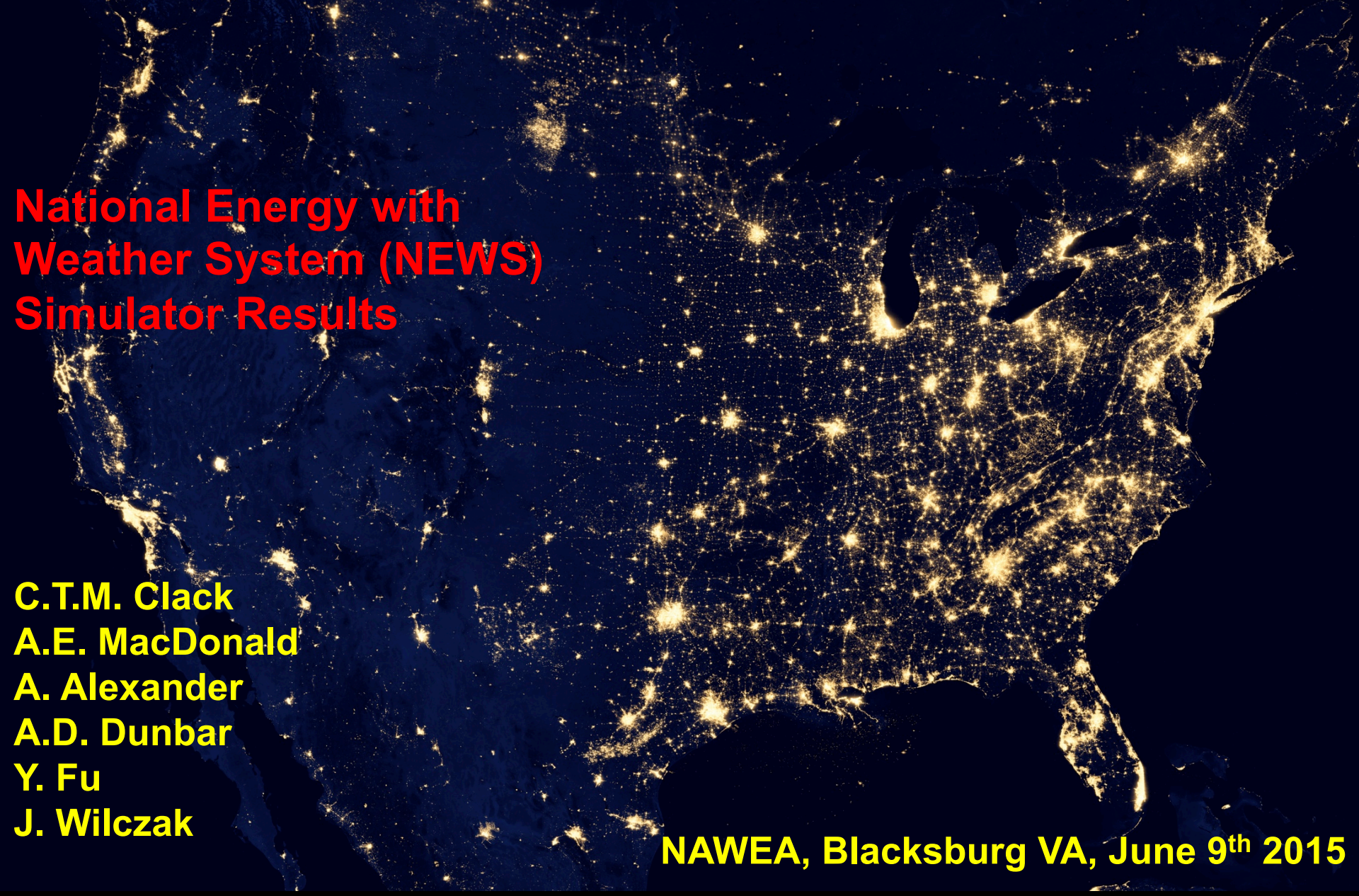

National Energy with Weather System (NEWS) Simulator Results

C.T.M. Clack
A.E. MacDonald
A. Alexander
A.D. Dunbar
Y. Fu
J. Wilczak

NAWEA, Blacksburg VA, June 9th 2015

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UNIVERSITY OF COLORADO **BOULDER** and **NOAA**

Post Industrial Carbon Dioxide Rise

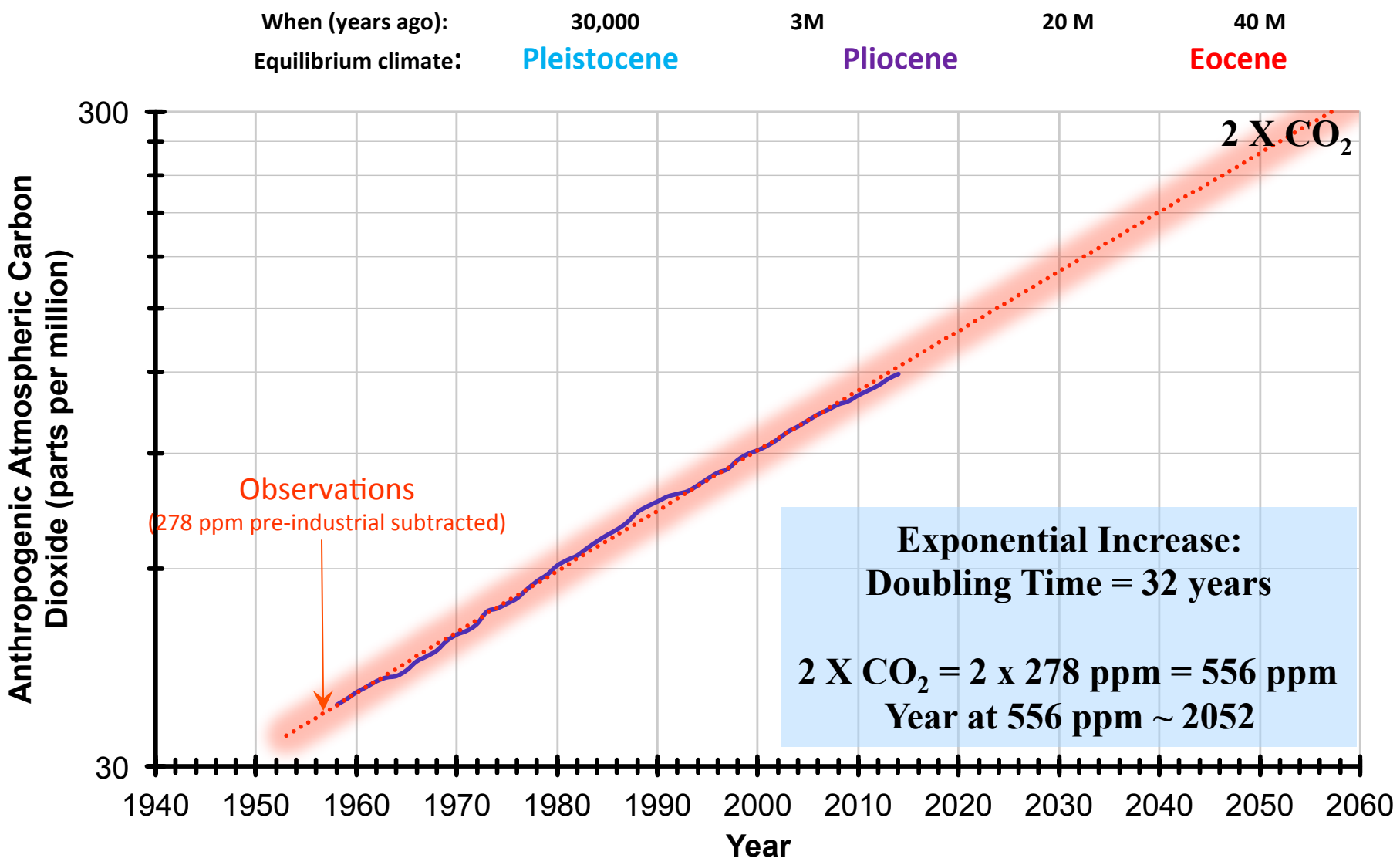

Image update and adapted from PNAS paper, Hofmann, et al; Solomon et al, Irreversible Climate Change, February 2009; Beerling & Royer, Convergent Cenezoic CO2, Nature Geoscience, July 2011

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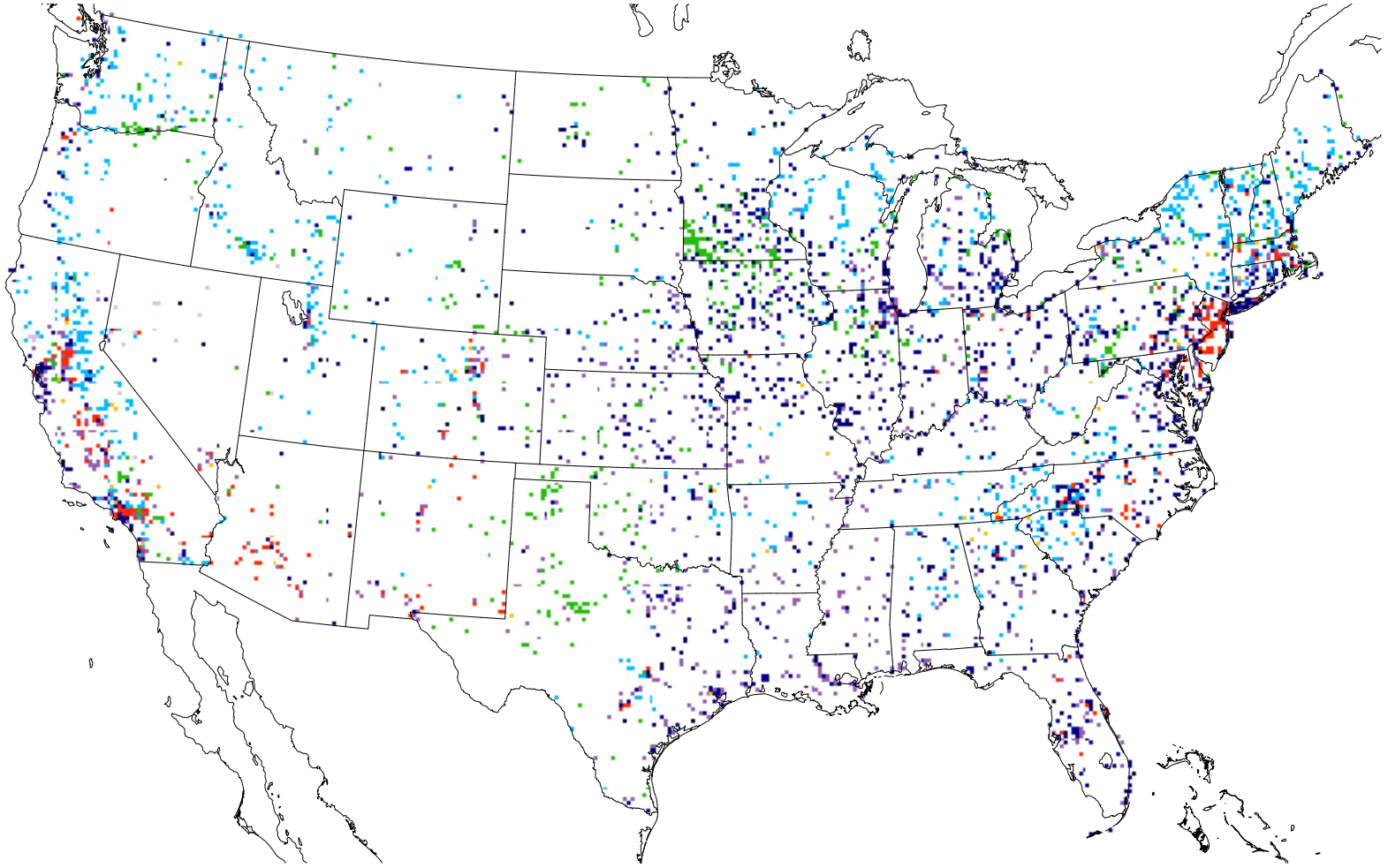
Take Away Messages

- The US can produce up to **80% of its electricity** from carbon free sources by 2030 at costs similar to those today.
- The US **needs a national high-voltage direct-current transmission system** and it should be co-optimized with generation.
- The US should move away from a localized systems to a large-scale system.
- Current technologies **without storage** can do the job if HVDC is expanded, reducing overall costs of the system.
- Other technologies **can incorporate** into a national electric system.
- HVDC **improves the efficiency of the electric sector**, regardless of generation mix (although the biggest impact is with variable generation).
- If a national HVDC system is introduced other sectors **can be shifted** to electrical energy. For example; water heaters, heat pumps, electric vehicles, power-to-gas, etc.

The Electric Power System in 2012



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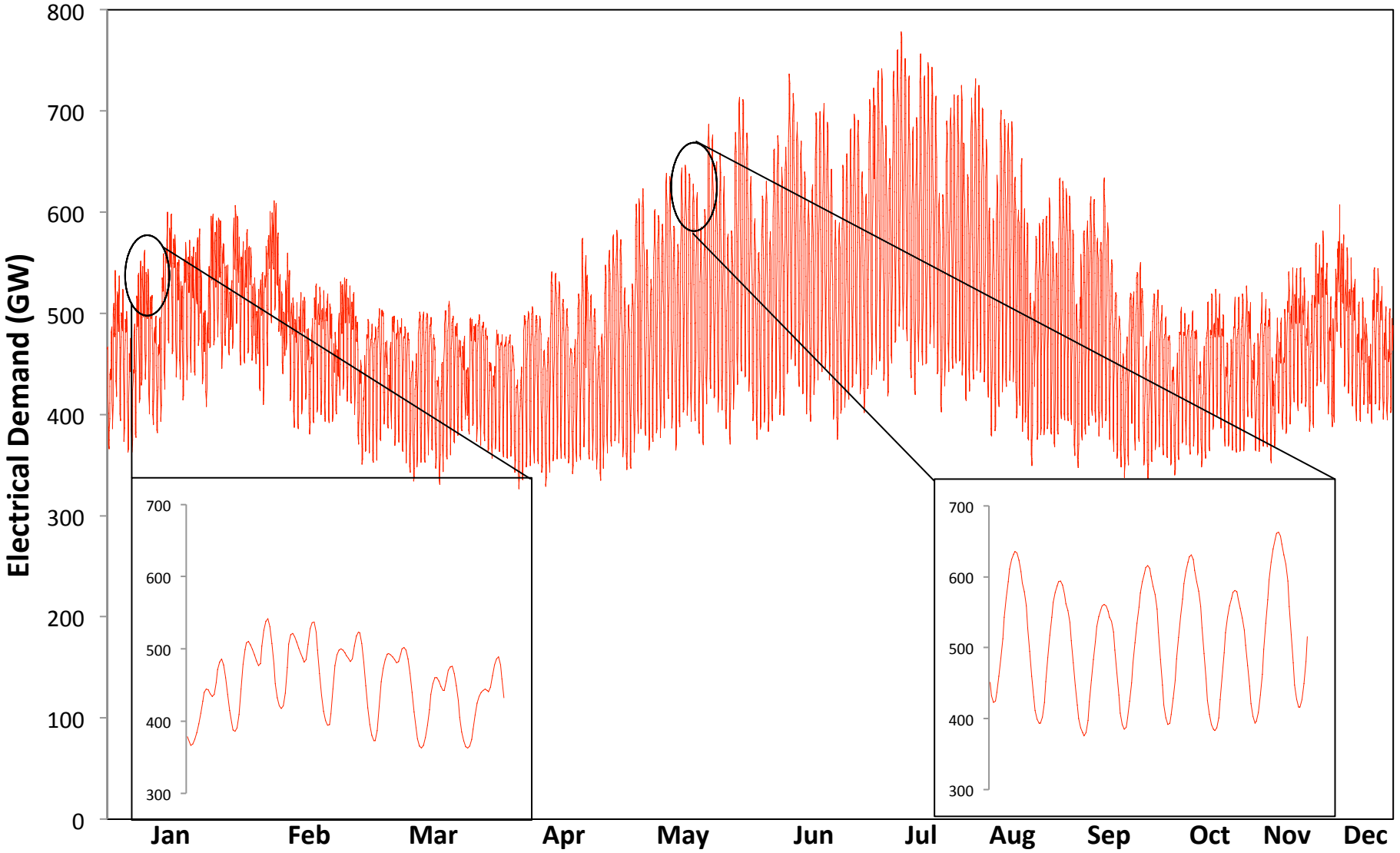
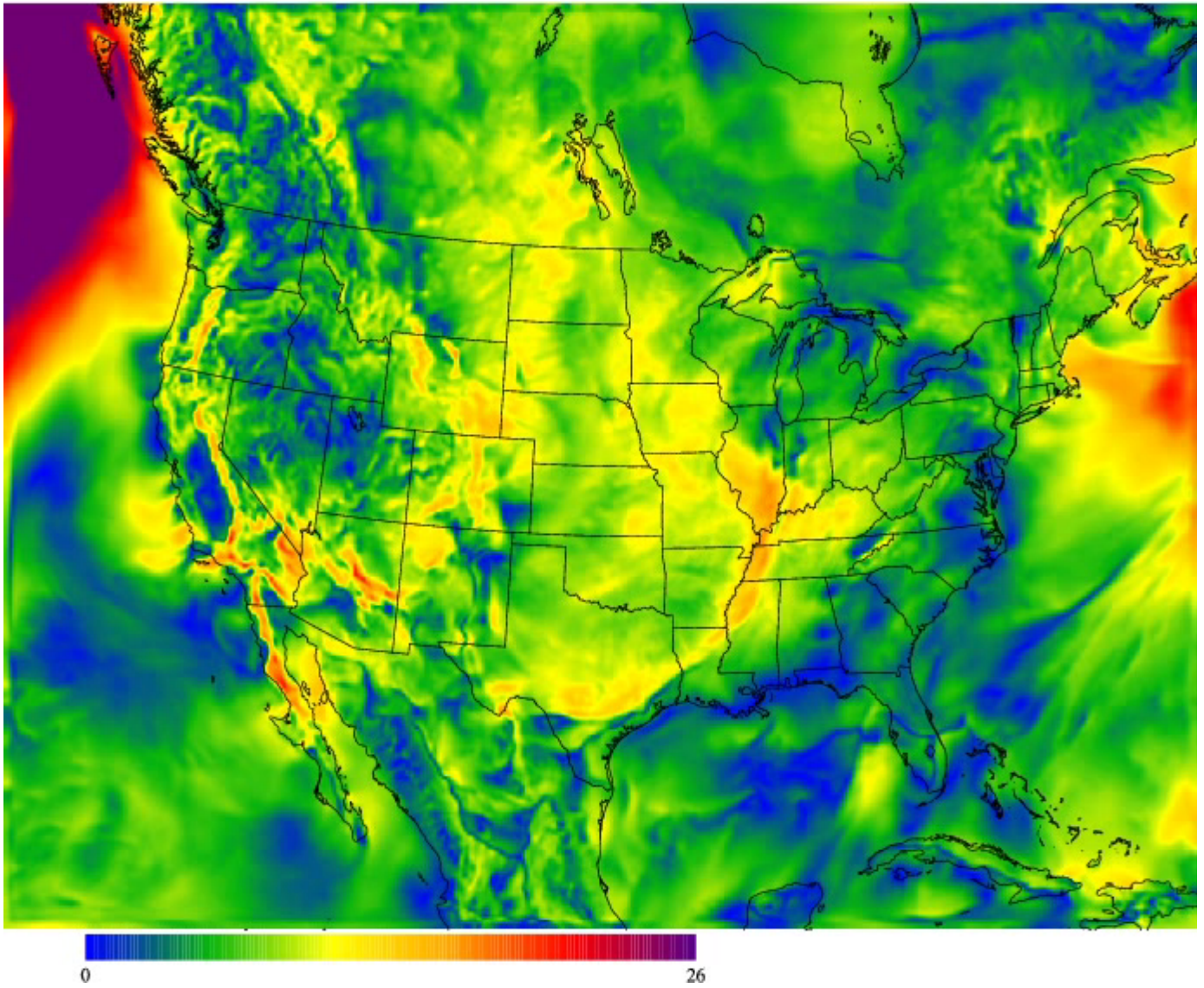
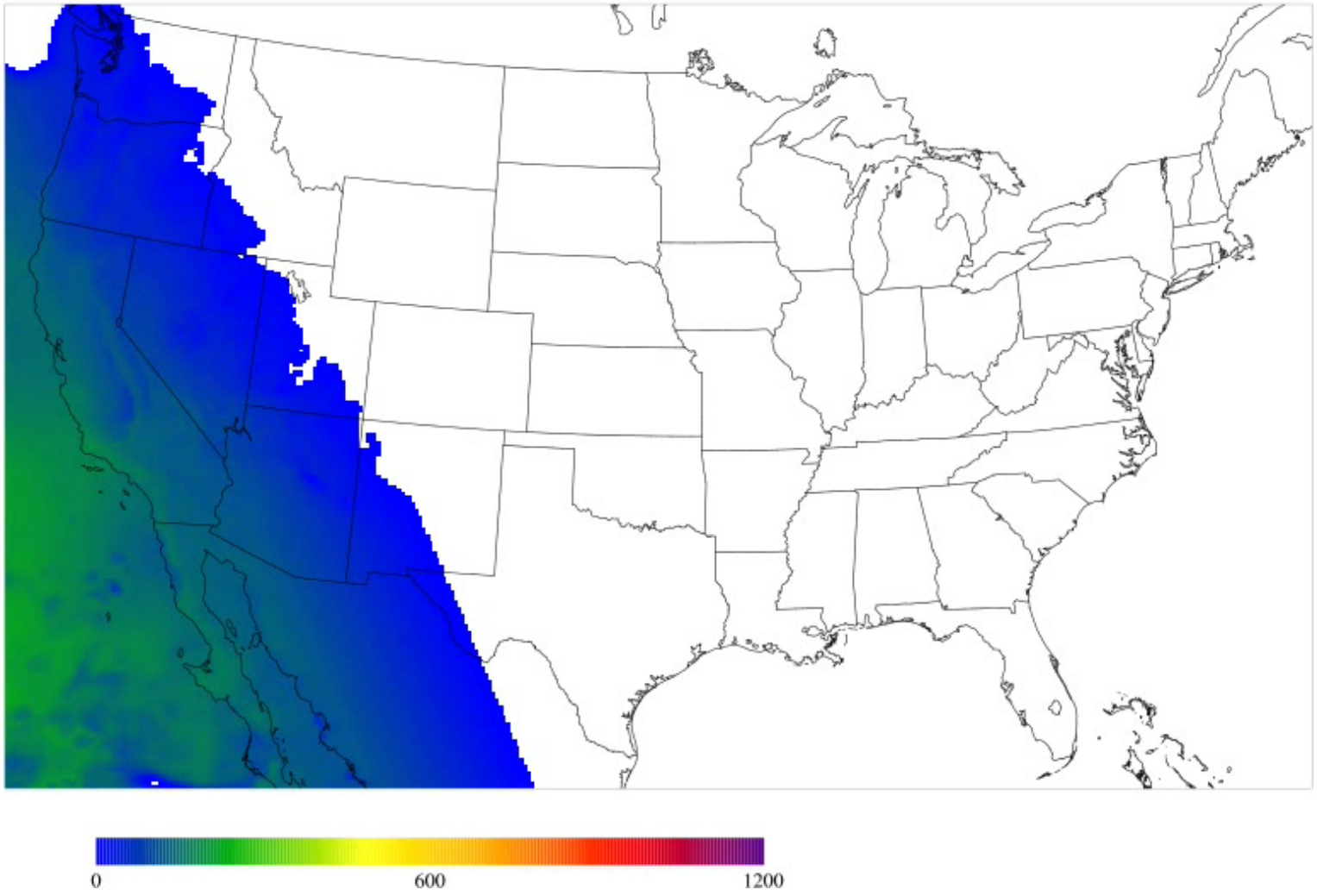
US Aggregated Electric Demand



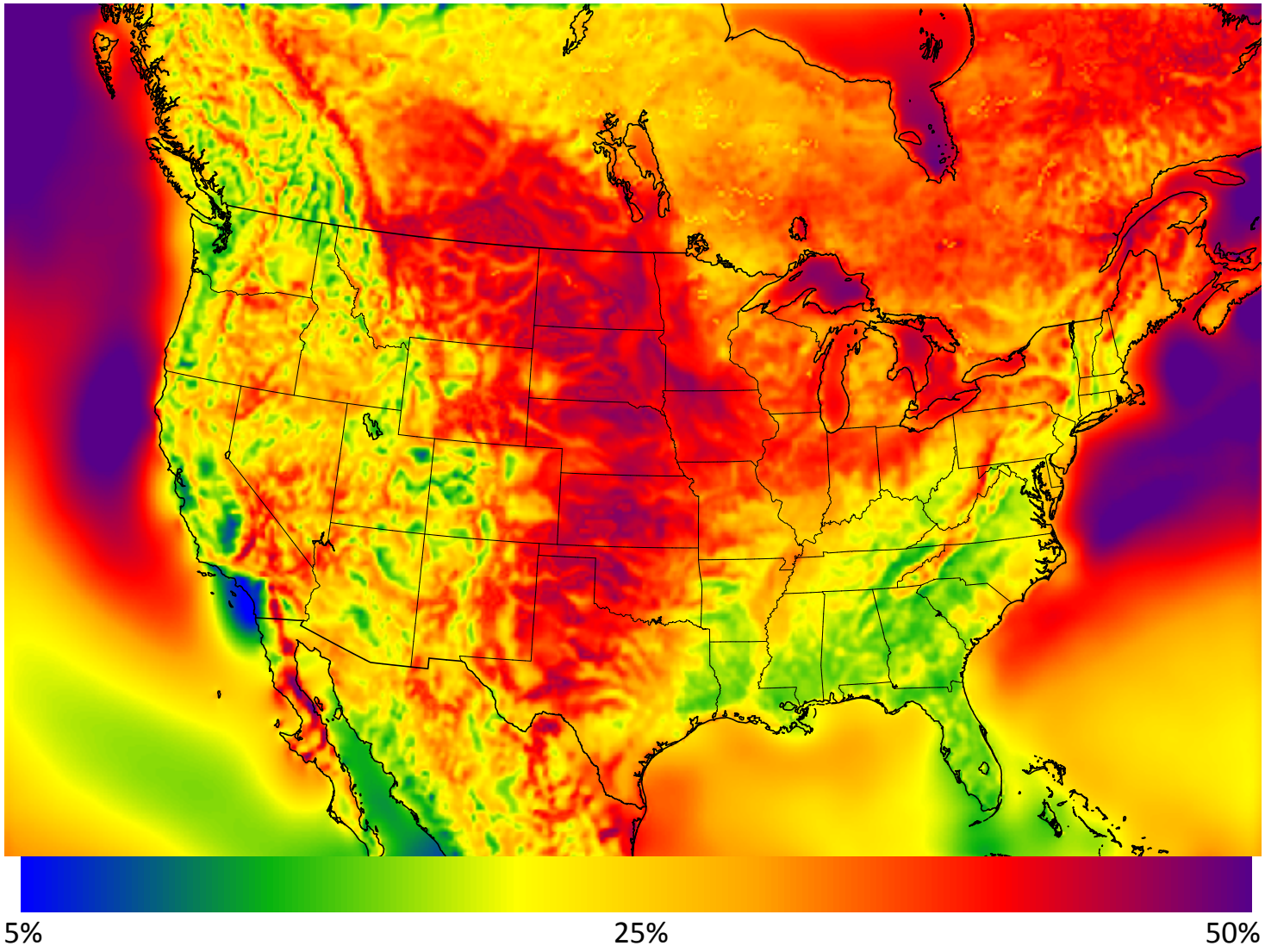
Wind Speed Video (m/s)



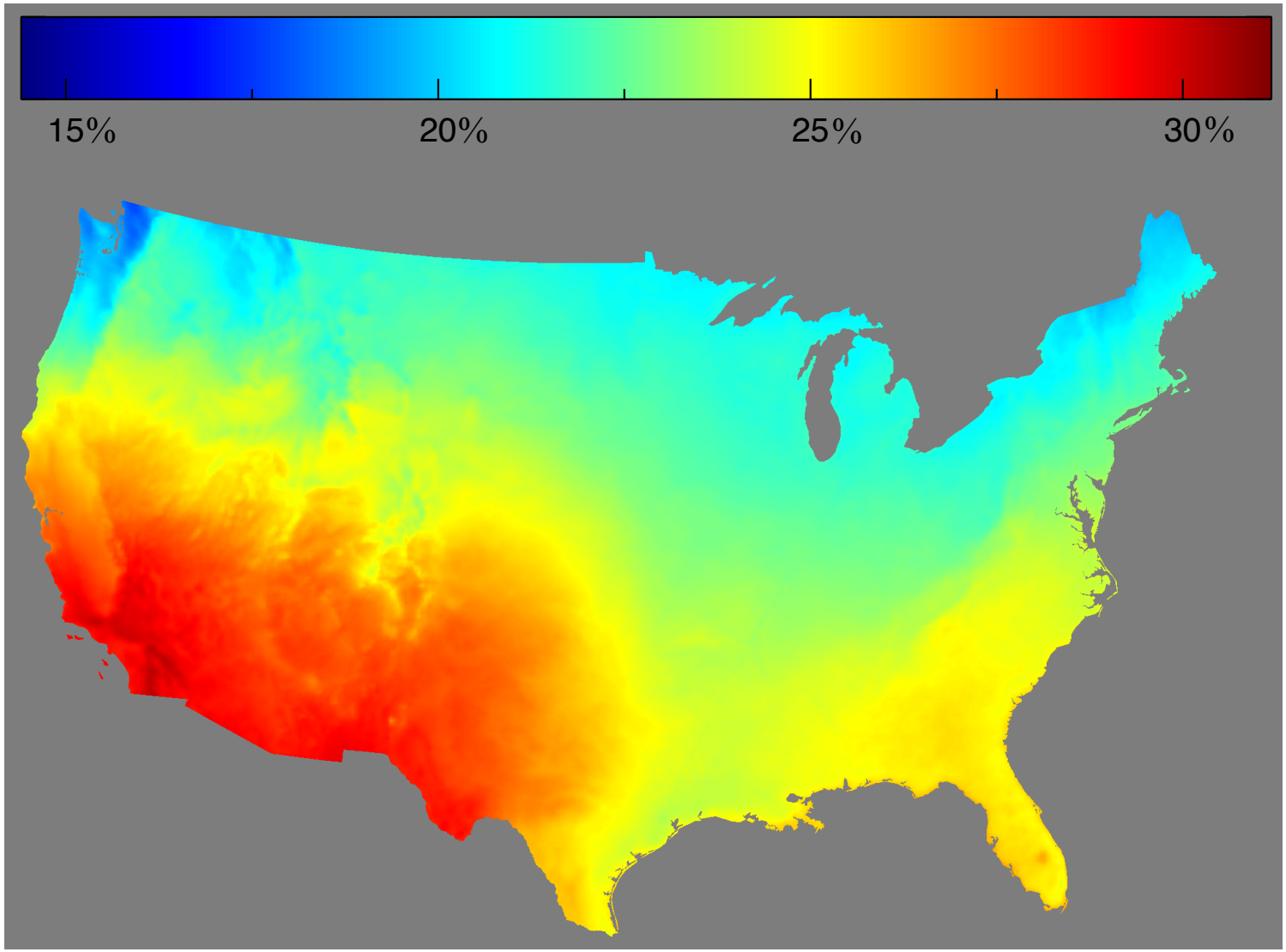
Solar Irradiance Video (W/m^2)



Wind Capacity Factor Map

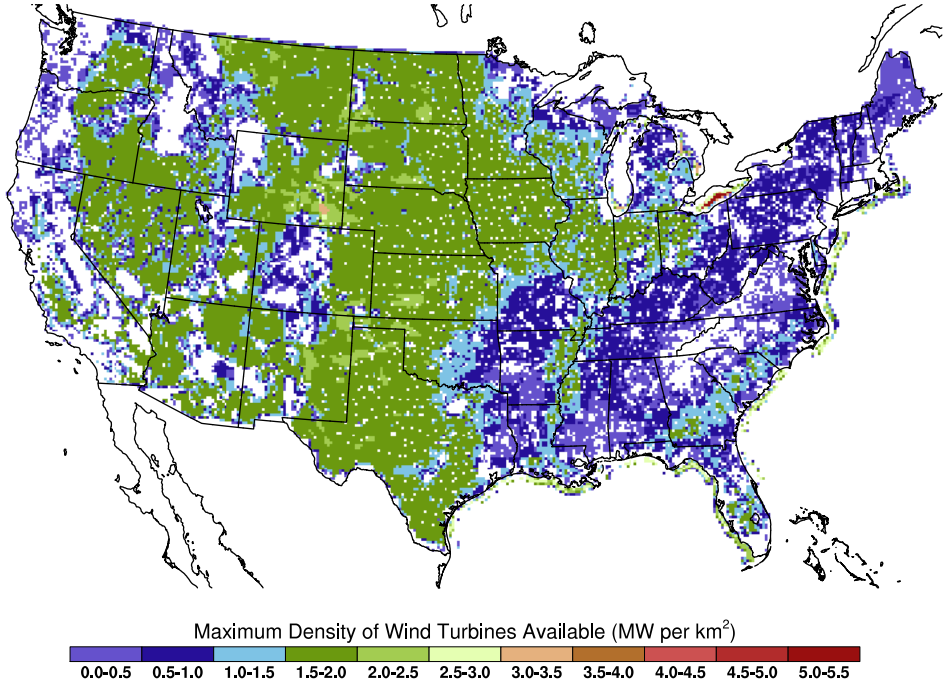


Solar PV Capacity Factor Map

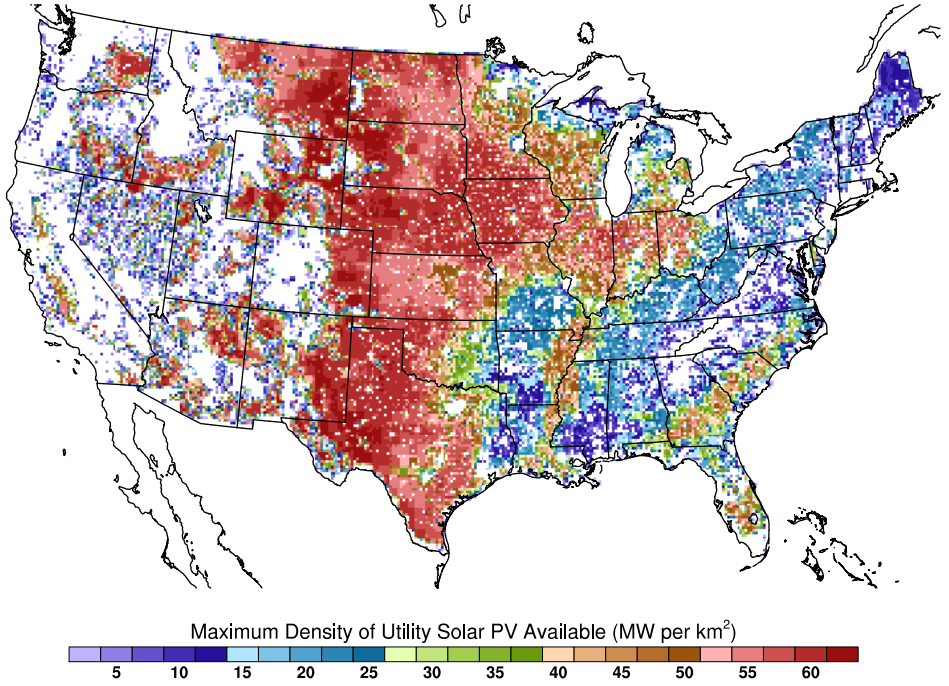


Land Use Constraints

Wind

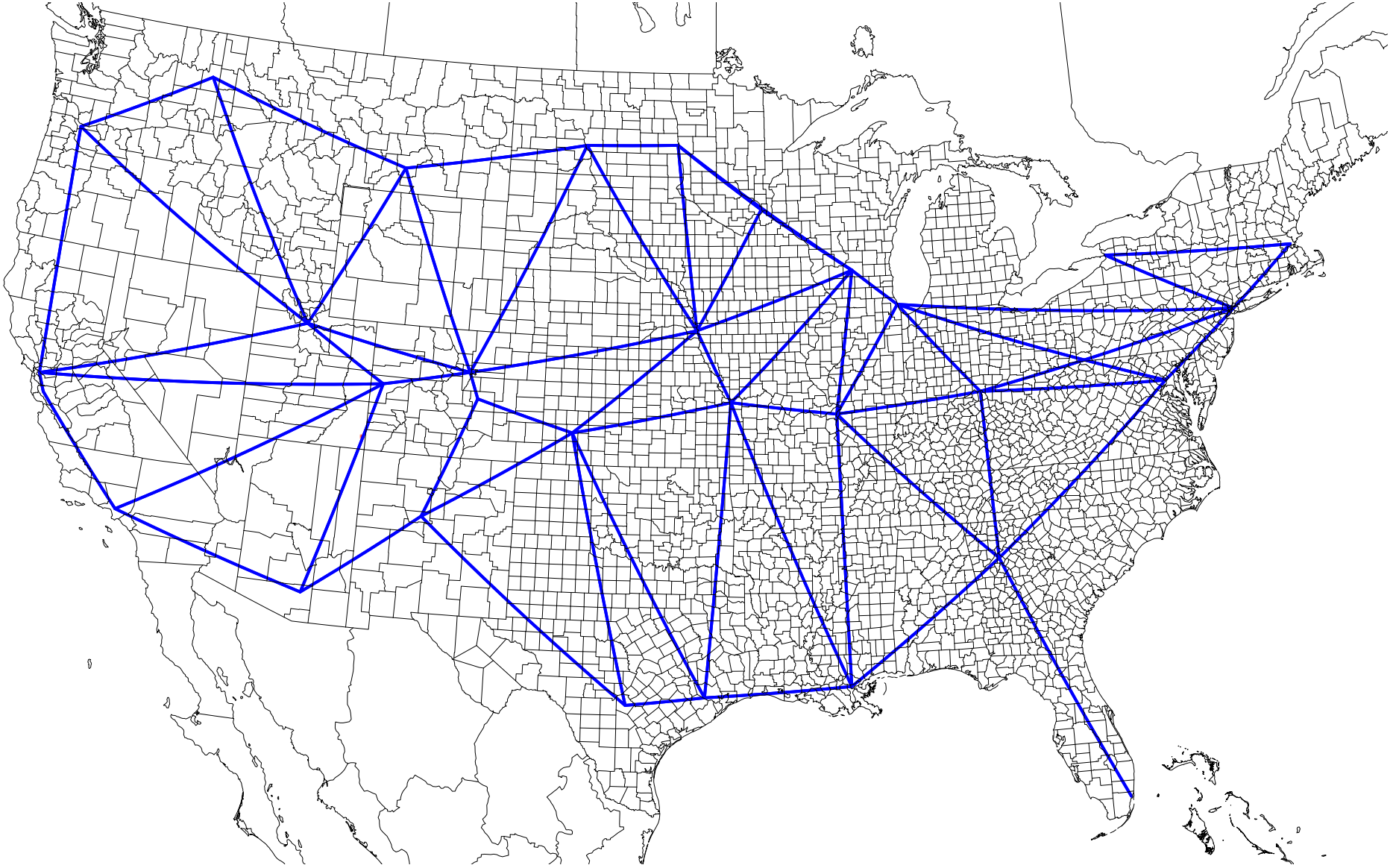


Solar PV



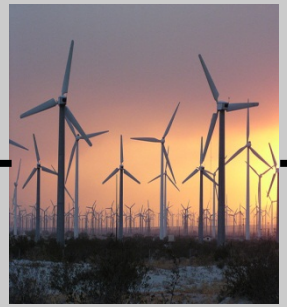
- The type and amount of electricity generation installed in each RUC cell is constrained by:
  - **Spacing between facilities**
  - **Topography of the land**
  - **Land Use (residential, commercial, protected lands, etc…)**

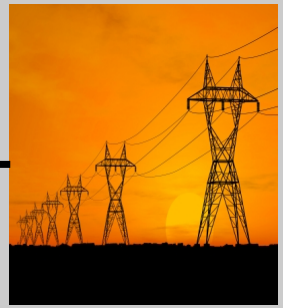
HVDC Transmission Overlay



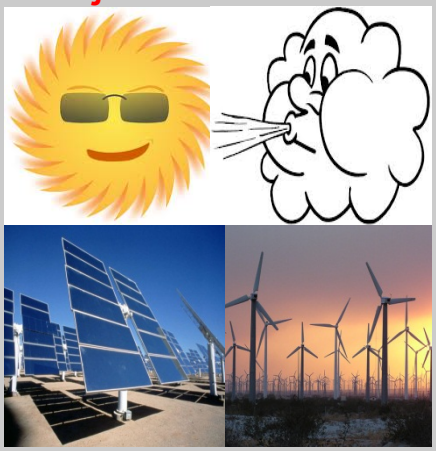
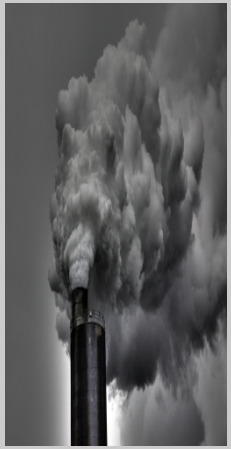
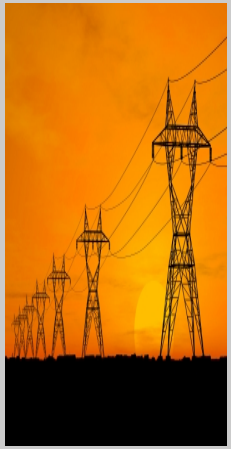
Mathematical Optimization

Minimize:





Subject to:

ALL OTHER EQUATIONS CONSTRAIN THE MAGNITUDE OF ANY OF THE TERMS

Peer reviewed description of the linear programming optimization techniques used.

Electrical Power and Energy Systems 68 (2015) 103–114

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Linear programming techniques for developing an optimal electrical system including high-voltage direct-current transmission and storage

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ABSTRACT

The planning and design of an electric power system, including high-voltage direct-current transmission, is a complex optimization problem. The optimization must integrate and model the engineering requirements and limitations of the generation, while simultaneously balancing the system electric load at all times. The problem is made more difficult with the introduction of variable generators, such as wind and solar photovoltaics. In the present paper, we introduce two comprehensive linear programming techniques to solve these problems. Linear programming is intentionally chosen to keep the problems tractable in terms of time and computational resources. The first is an optimization that minimizes the deviation from the electric load requirements. The procedure includes variable generators, conventional generators, transmission, and storage, along with their most salient engineering requirements. In addition, the optimization includes some basic electric power system requirements. The second optimization is one that minimizes the overall system costs per annum while taking into consideration all the aspects of the first optimization. We discuss the benefits and disadvantages of the proposed approaches. We show that the cost optimization, although computationally more expensive, is superior in terms of optimizing a real-world electric power system. The present paper shows that linear programming techniques can represent an electrical power system from a high-level without undue complication brought on by moving to mixed integer or nonlinear programming. In addition, the optimizations can be implemented in the future in planning tools.

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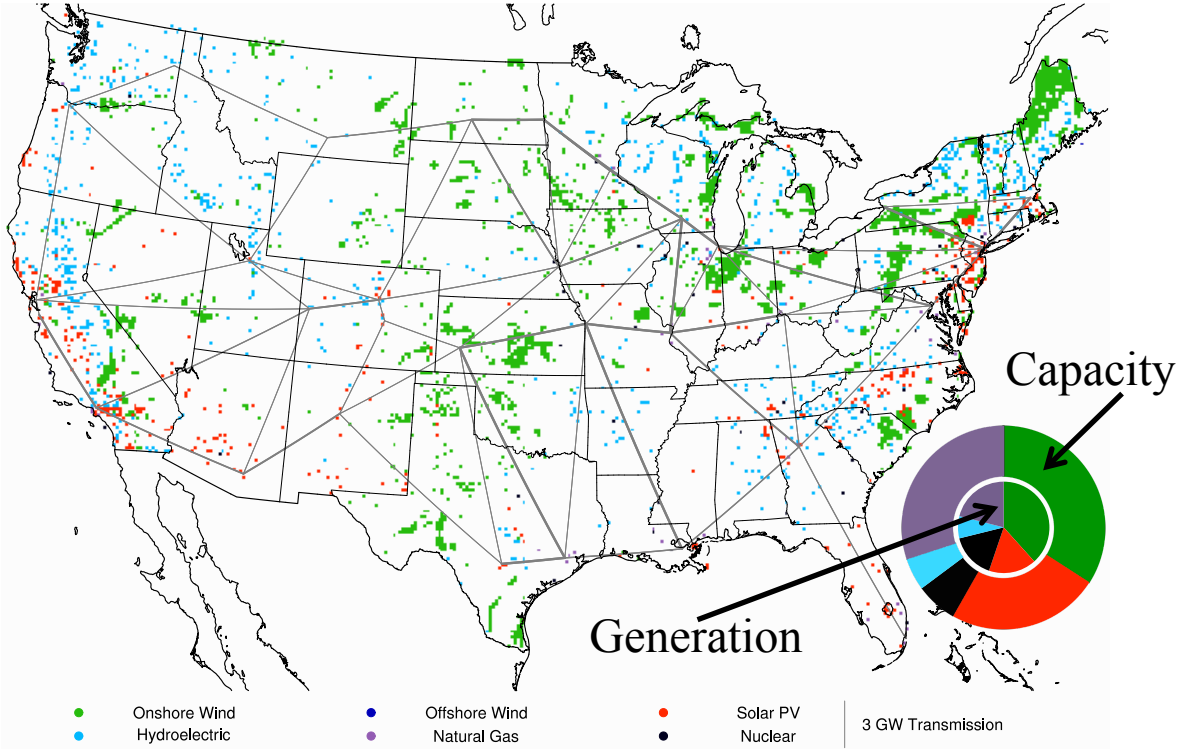
1. Introduction

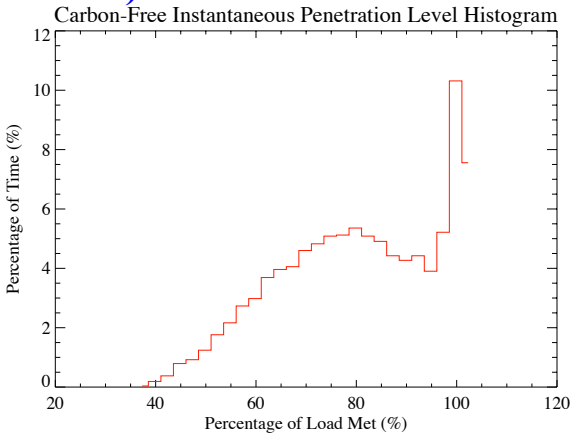
An electric power system is a complex web of power generators, transmission and distribution lines, a small amount of storage, and power consumers, which must be kept in dynamic equilibrium. The electric power generated on the system at any one instance must be consumed somewhere at the same instant. The historical design of electric power systems is an ad hoc method of addition as needed. A description of electric power systems can be found in, e.g., [1,2]. The ad hoc nature of electric power system growth and regeneration can lead to system weaknesses, which can hamper further growth of new generation and transmission. The electof asset scheduling to power flow optimization across a network, for a selection of related optimizations and overviews see, e.g., [3–6].

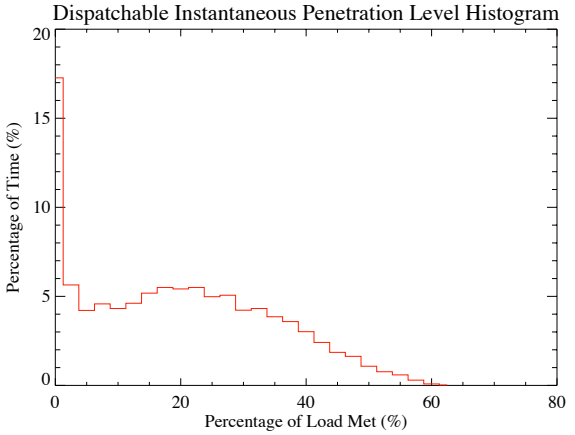
The optimization of electric power systems becomes even more difficult with the addition of renewable generators, such as wind turbines and solar photovoltaic (PV) cells. The optimization must take into consideration the variable nature of these relatively new forms of power. In recent years, the optimization of wind, solar, and conventional generator systems has attracted strong research. Much of the attention in the research has been to consider high penetration levels of wind and solar PV deployment in the electrical power system, see e.g., [7–11], which is what we con-

NEWS Result: Single US 48 States Electric Power System

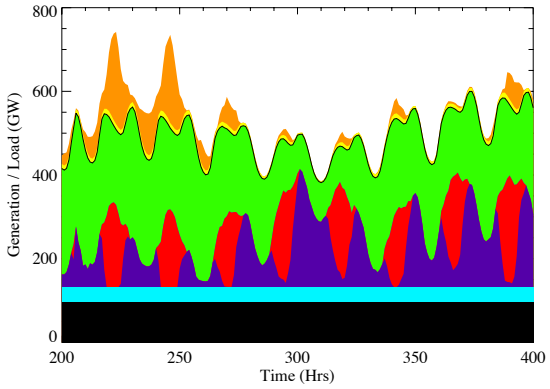
(Low Cost Renewables, High Cost Natural Gas)

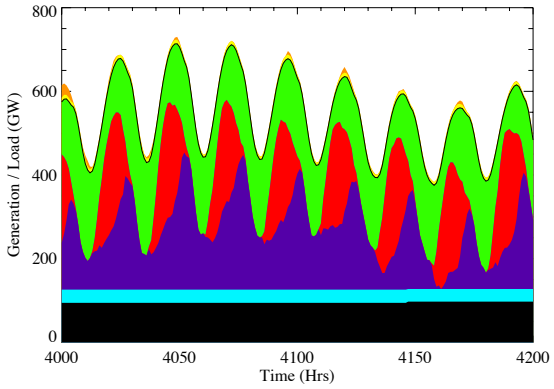


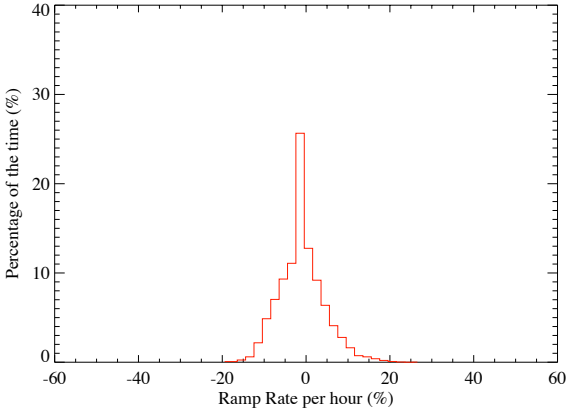




- Uses Low Cost Renewables and High Cost Natural Gas Fuel

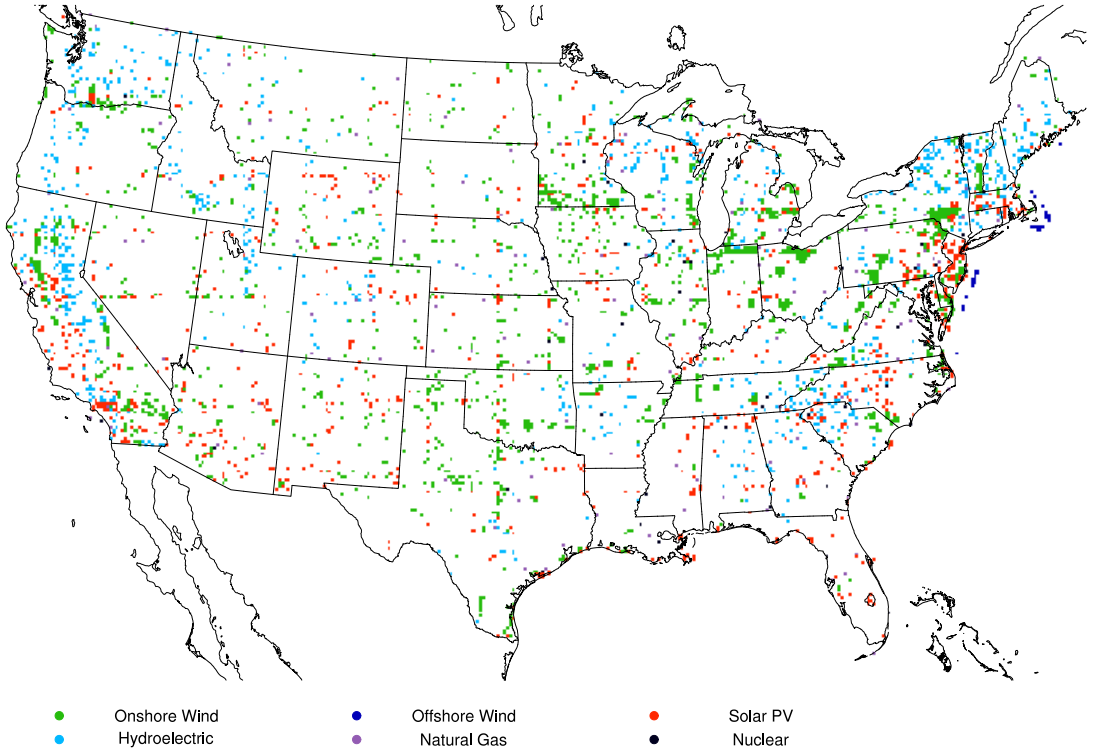


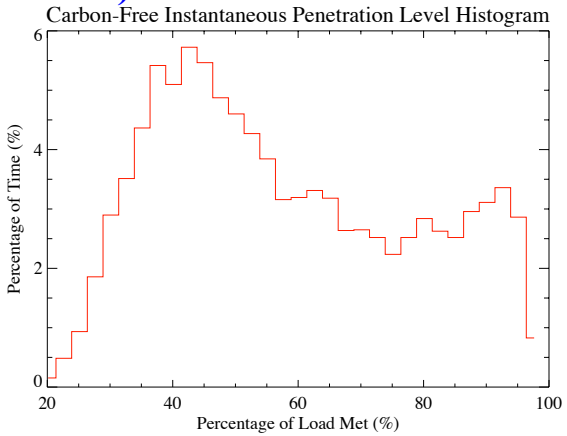


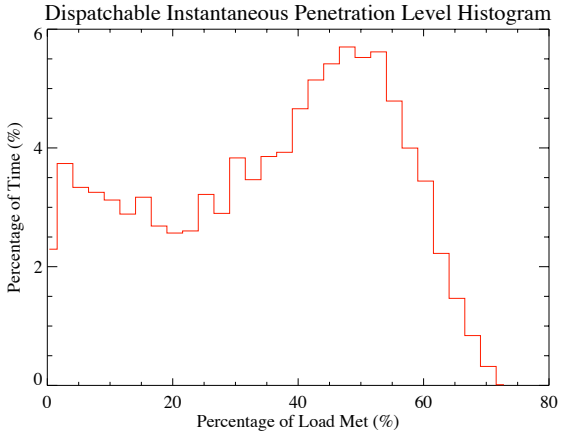


NEWS Result: 128 Independent Electric Power Systems

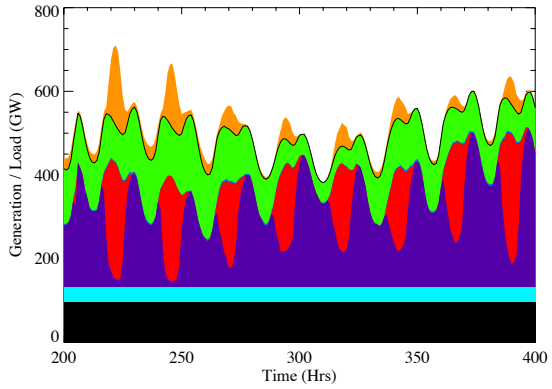
(Low Cost Renewables, High Cost Natural Gas)

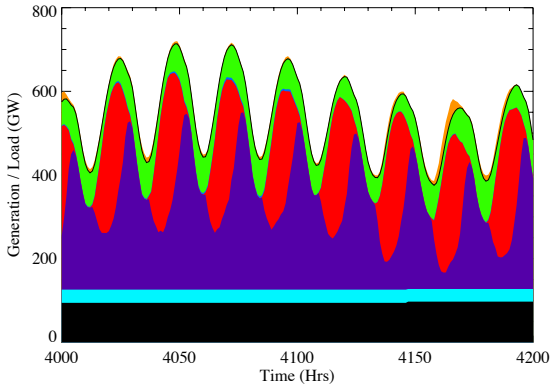


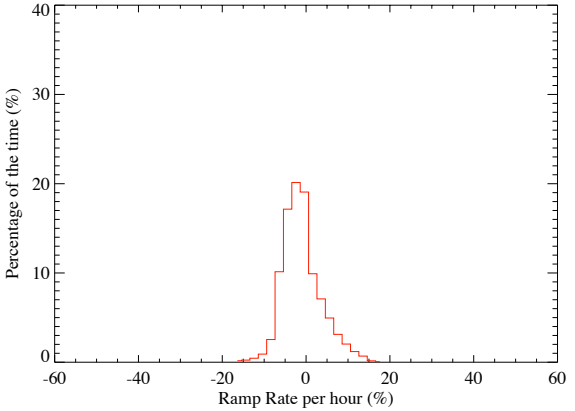




- Uses Low Cost Renewables and High Cost Natural Gas Fuel

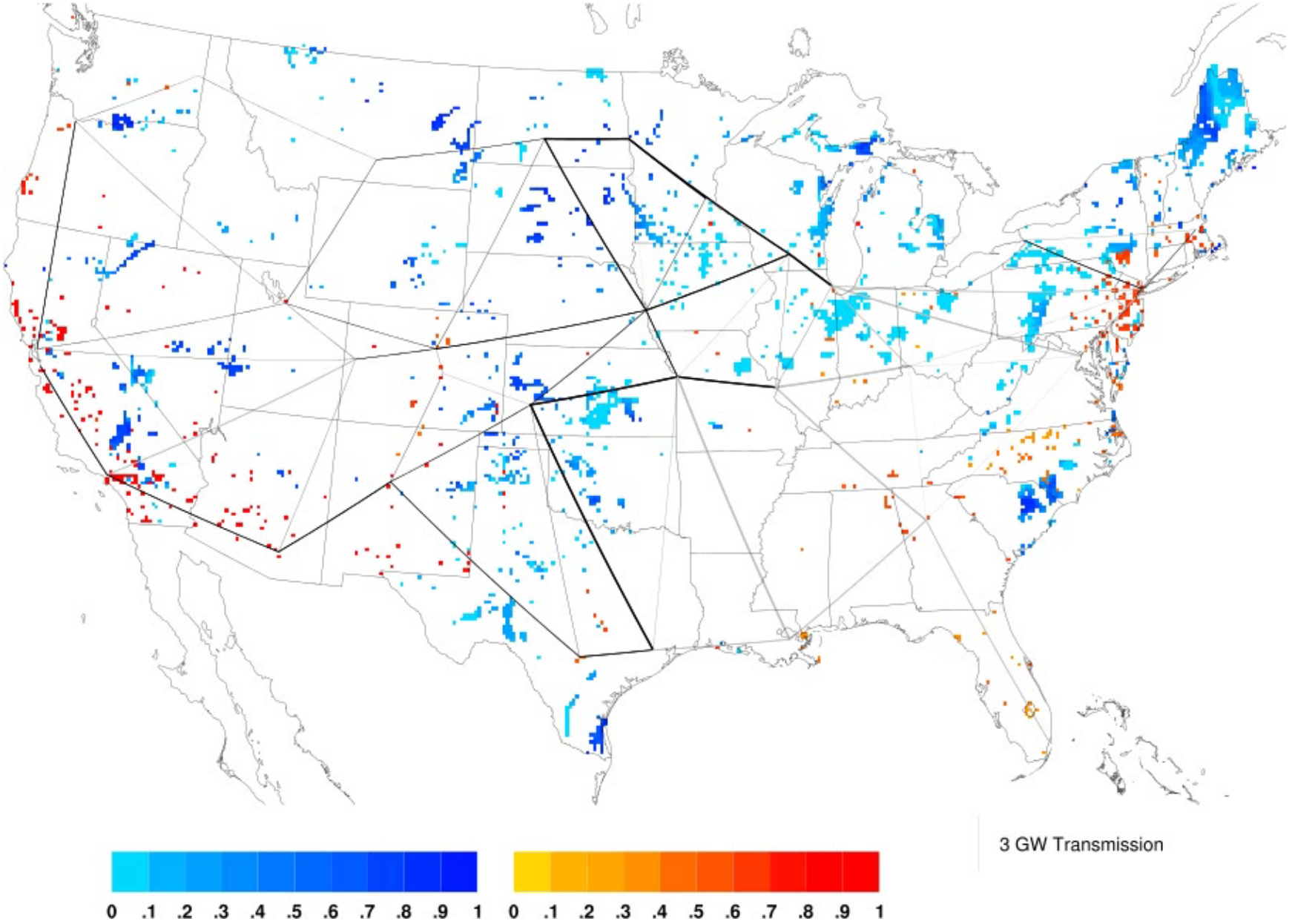




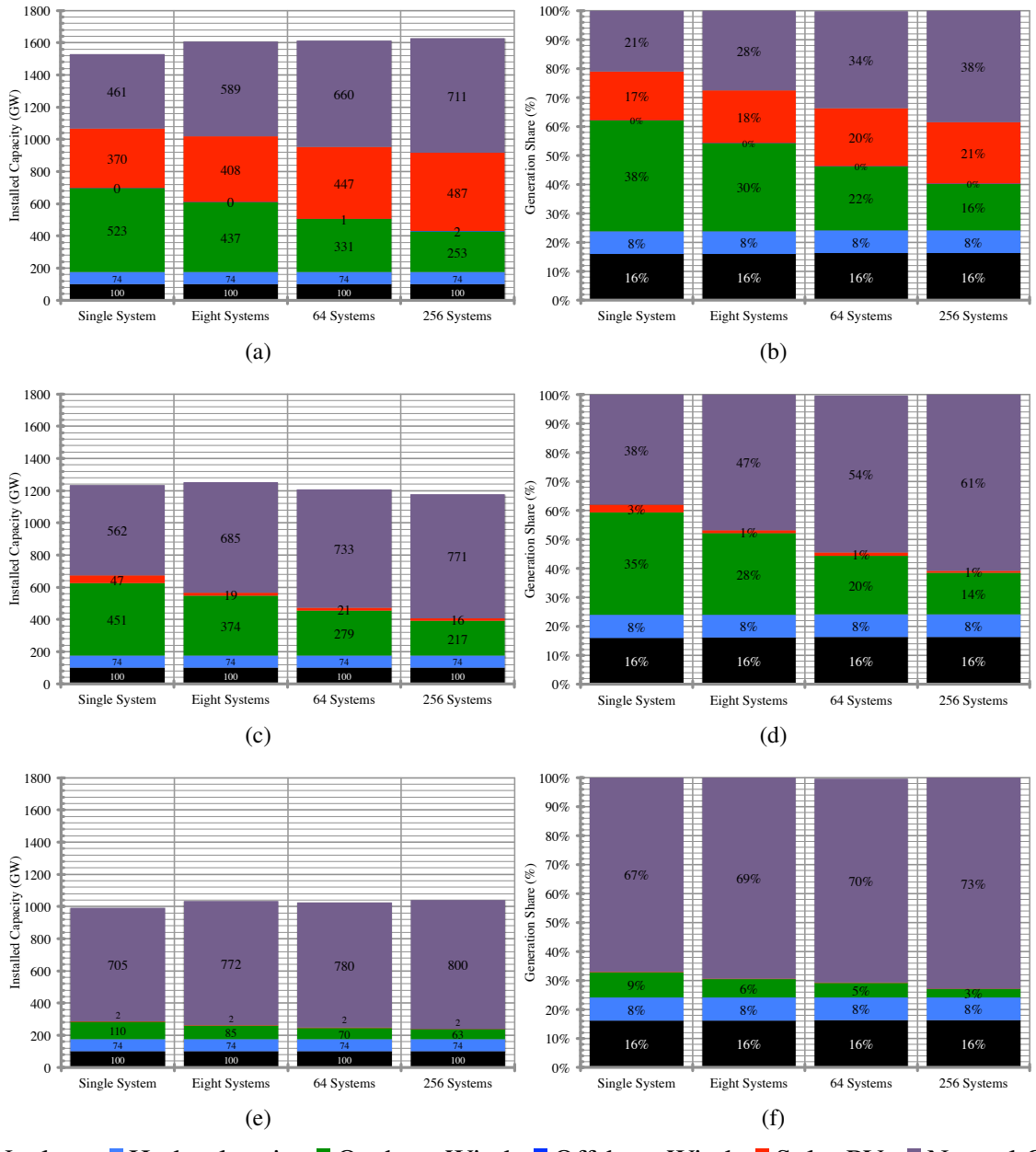


Dispatch of wind and solar PV within the simulation

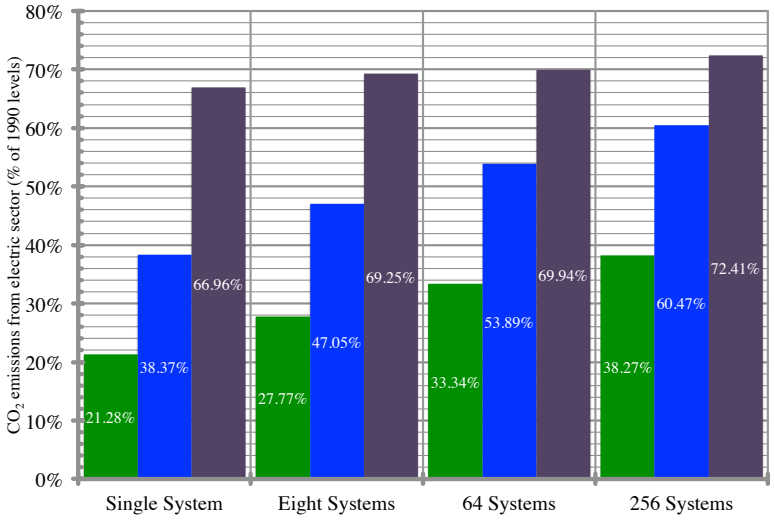
(Low Cost Renewables, High Cost Natural Gas)



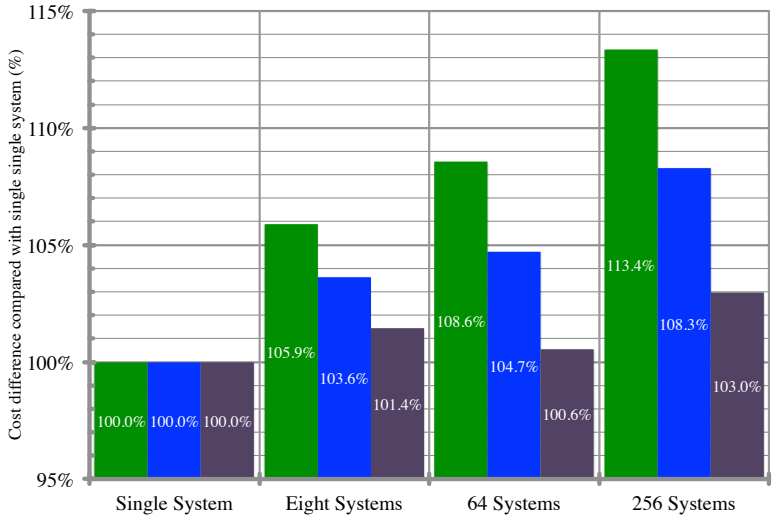
NEWS Result: Geographic Scale and Cost of Technology



NEWS Result: Geographic Scale and Cost of Technology



(a)



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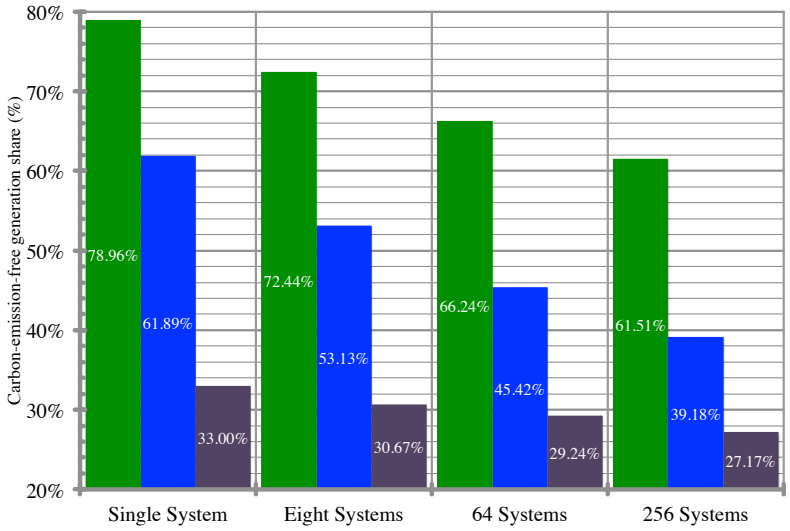
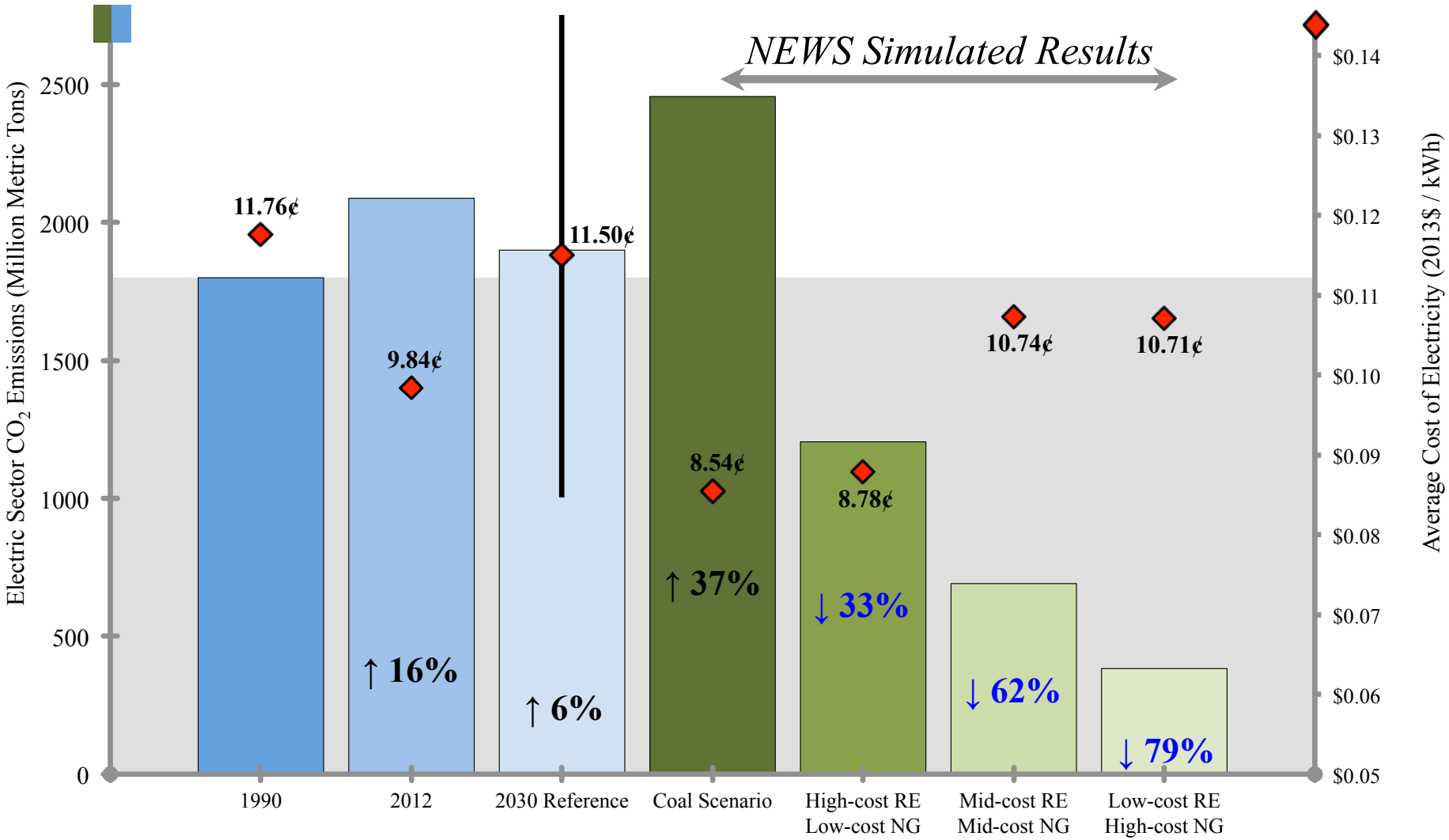


(c)

Low-cost RE High-cost NG Mid-cost RE Mid-cost NG High-cost RE Low-cost NG

What can the US achieve and what will it cost?*



* Without storage and with current technologies

Take Away Messages

- The US can produce up to **80% of its electricity** from carbon free sources by 2030 at costs similar to those today.
- The US **needs a national high-voltage direct-current transmission system** and it should be co-optimized with generation.
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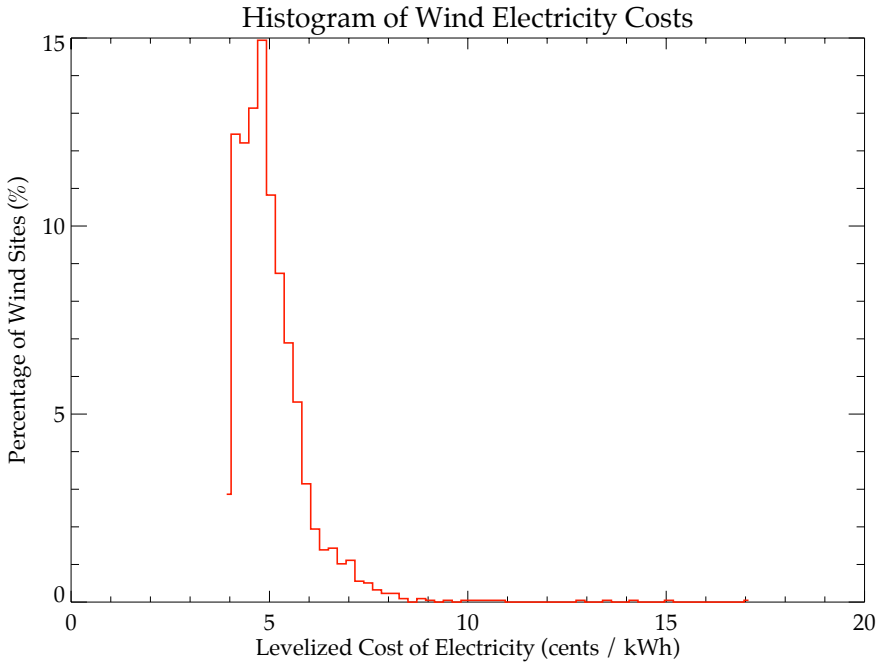
- Other technologies **can incorporate** into a national electric system.
- HVDC **improves the efficiency of the electric sector**, regardless of generation mix (although the biggest impact is with variable generation).
- If a national HVDC system is introduced other sectors **can be shifted** to electrical energy. For example; water heaters, heat pumps, electric vehicles, power-to-gas, etc.

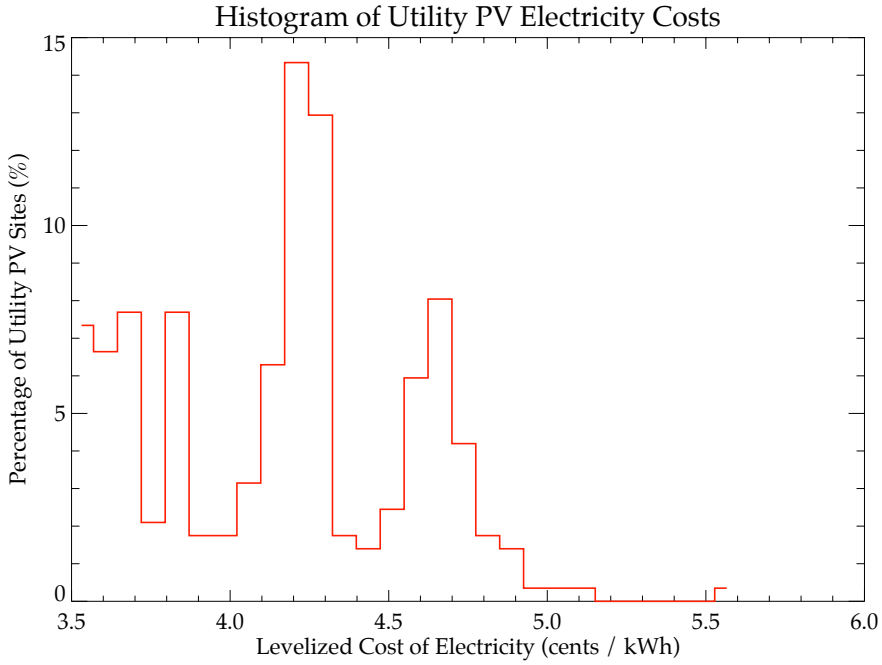
NEWS Result: Back-ups

Distribution of Levelized Cost of Electricity

- System uses only ~ **205,000** 3MW wind turbines
- Approximately **460 km^2** of land taken out of current use
- Wholesale cost of wind power **5.2¢ / kWh**
- A share of **38.4%** of electricity generation



- System uses only ~ **18,500** 20MW solar PV plants
- Approximately **6,110 km^2** of land taken out of current use
- Wholesale cost of solar power **4.6¢ / kWh**
- A share of **16.7%** of electricity generation

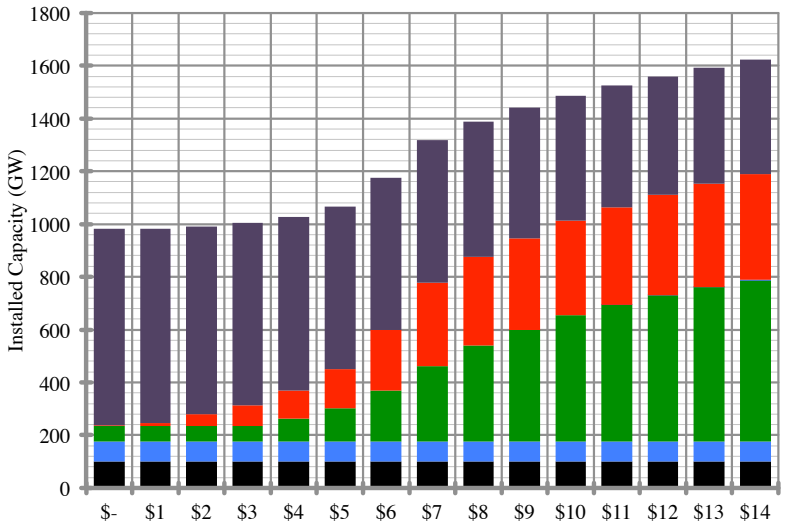


Wholesale cost of natural gas power **12.3 ¢ / kWh**

Average retail cost of electricity for the entire system **10.7¢ / kWh**

NEWS Result: Sensitivity to Natural Gas

NEWS Result: Sensitivity to Natural Gas



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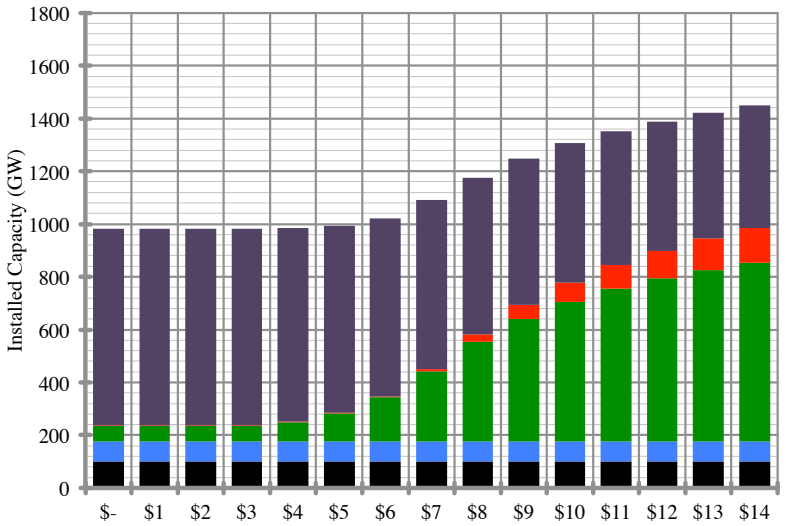

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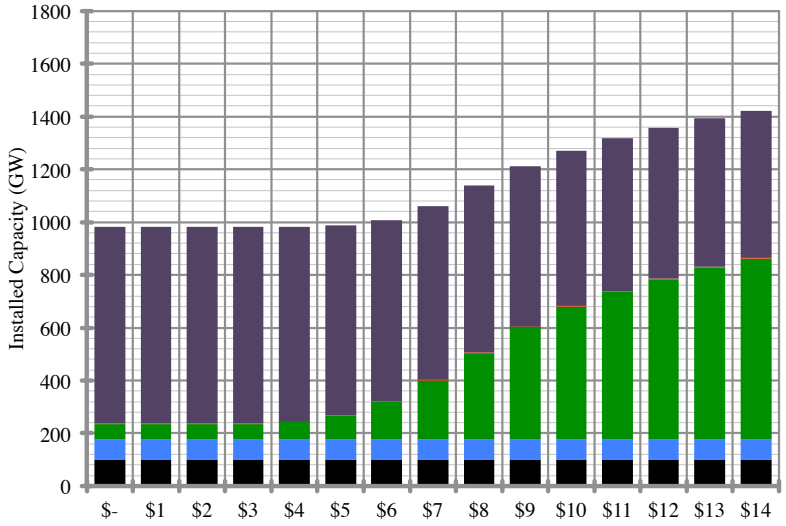
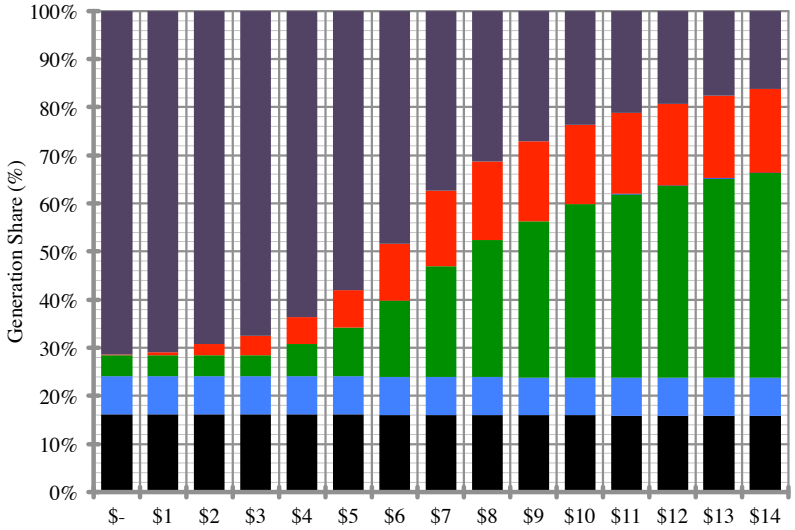


(c)

Nuclear Hydroelectric Onshore Wind Offshore Wind Solar PV Natural Gas

NEWS Result: Sensitivity to Natural Gas



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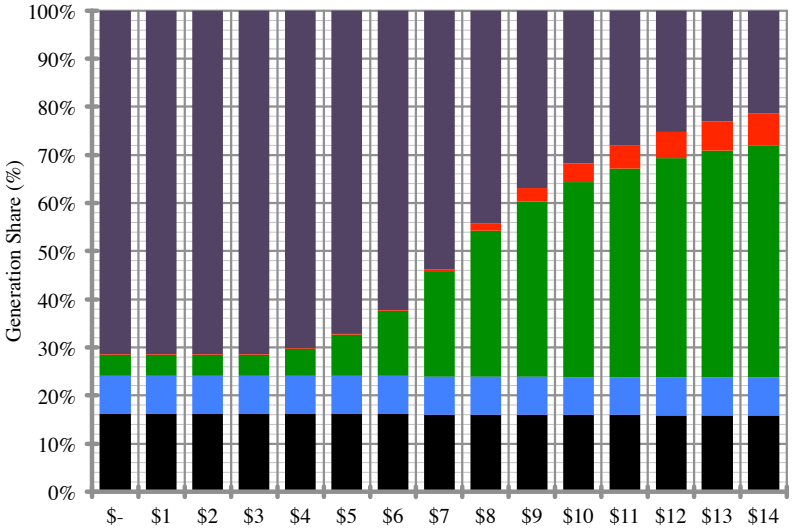

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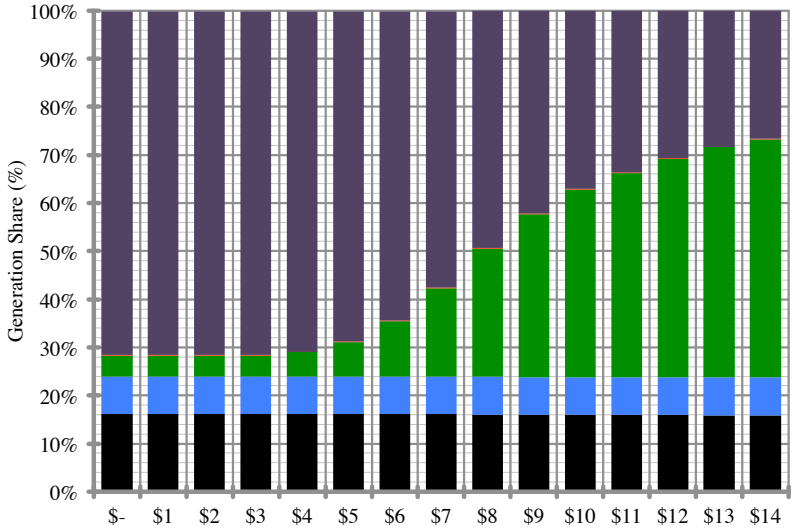
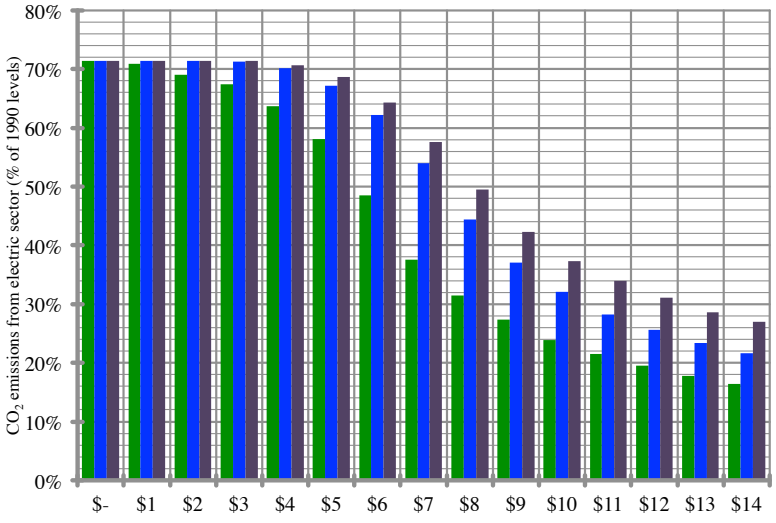


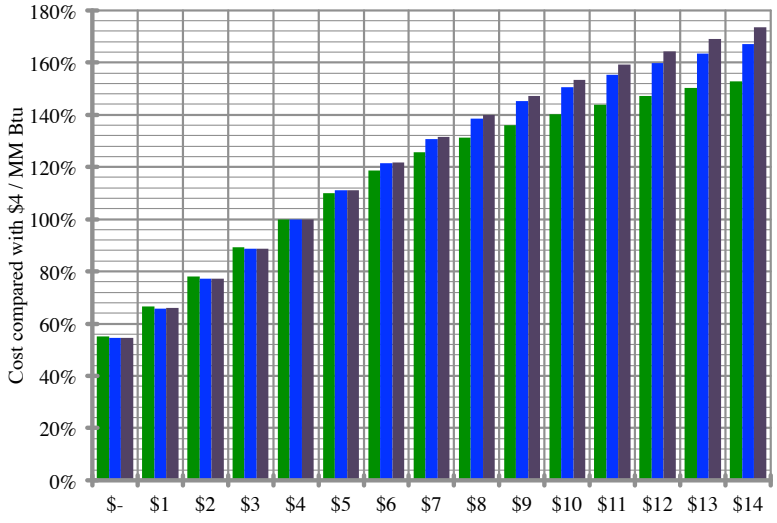
(c)

Nuclear Hydroelectric Onshore Wind Offshore Wind Solar PV Natural Gas

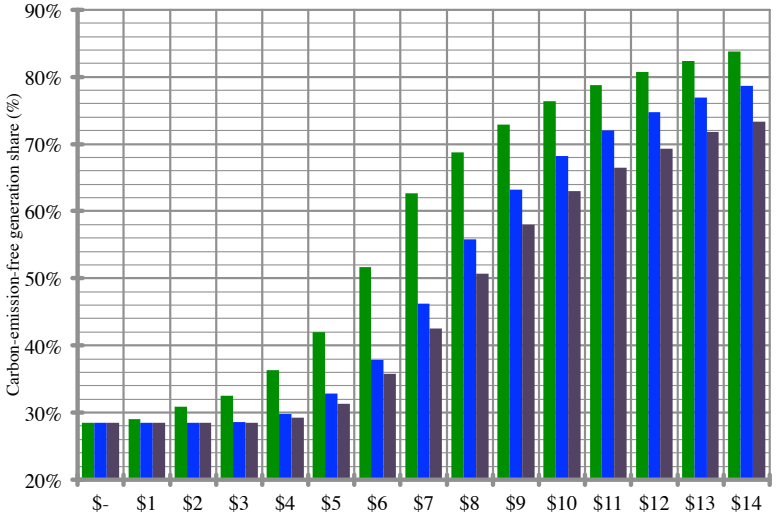
NEWS Result: Sensitivity to Natural Gas



(a)



(b)



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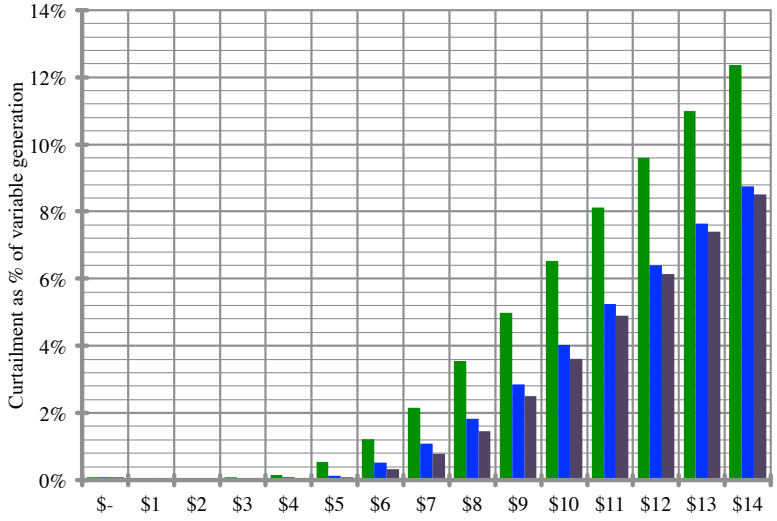

(d)

Low-cost Renewable Mid-cost Renewable High-cost Renewable

NEWS Result: The Effect of Coal and EPA CAA 111(d)

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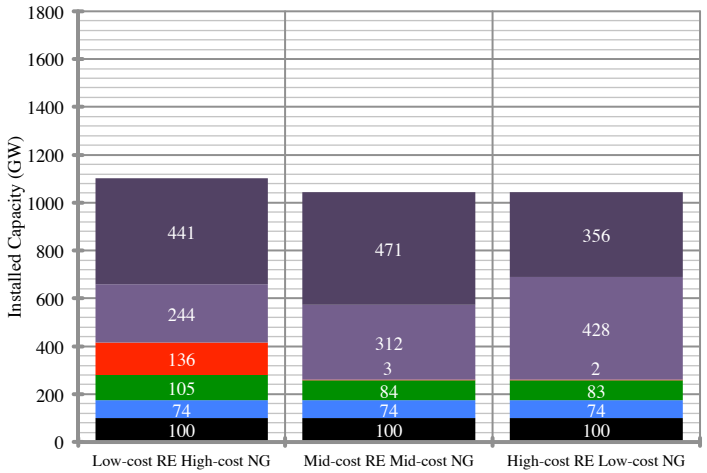
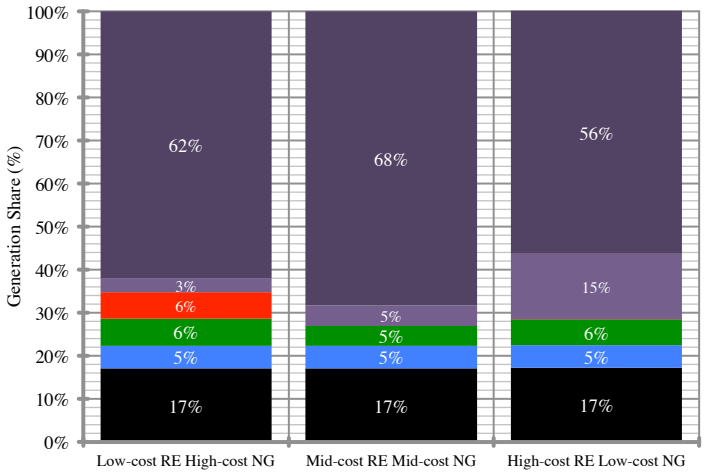
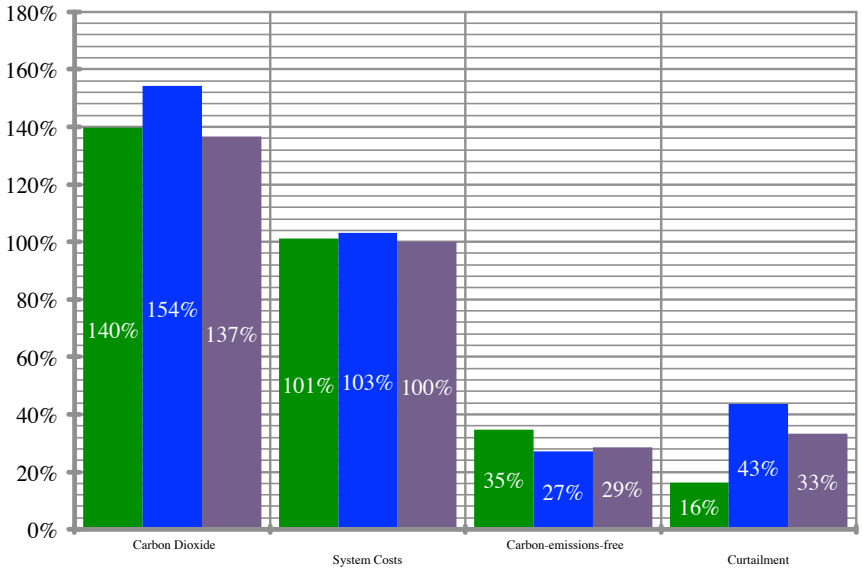


(a)



(b)

■ Nuclear ■ Hydroelectric ■ Onshore Wind ■ Offshore Wind ■ Solar PV ■ Natural Gas ■ Coal



■ Low-cost RE High-cost NG ■ Mid-cost RE Mid-cost NG ■ High-cost RE Low-cost NG