National Renewable Energy Laboratory
*Innovation for Our Energy Future*

# Flexibility Options for VG Integration- Lessons from High Resolution Operational and Capacity Expansion Models

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**July 22, 2013**

# Renewable Backup?

- Backup is a poorly defined term
  - **Is dedicated backup required for nuclear power plant re-fueling outages?**
- My working definition -When you add renewables to the grid do you need to add additional thermal capacity?
- **Starting point - you adding renewables to an already reliable grid**
  - **If you replace your incandescent light bulb with a LED is backup needed?**

# Renewable Backup?

Additional reliable capacity (or flexibility resources) are needed if:

1. Load growth exceeds the reliable capacity provided by new renewable resources
2. Retirements exceeds the reliable capacity provided by new renewable resources
3. Additional system flexibility is needed to effectively incorporate RE
   – Reserves provision
   – Supply/Demand coincidence and minimum generation problems

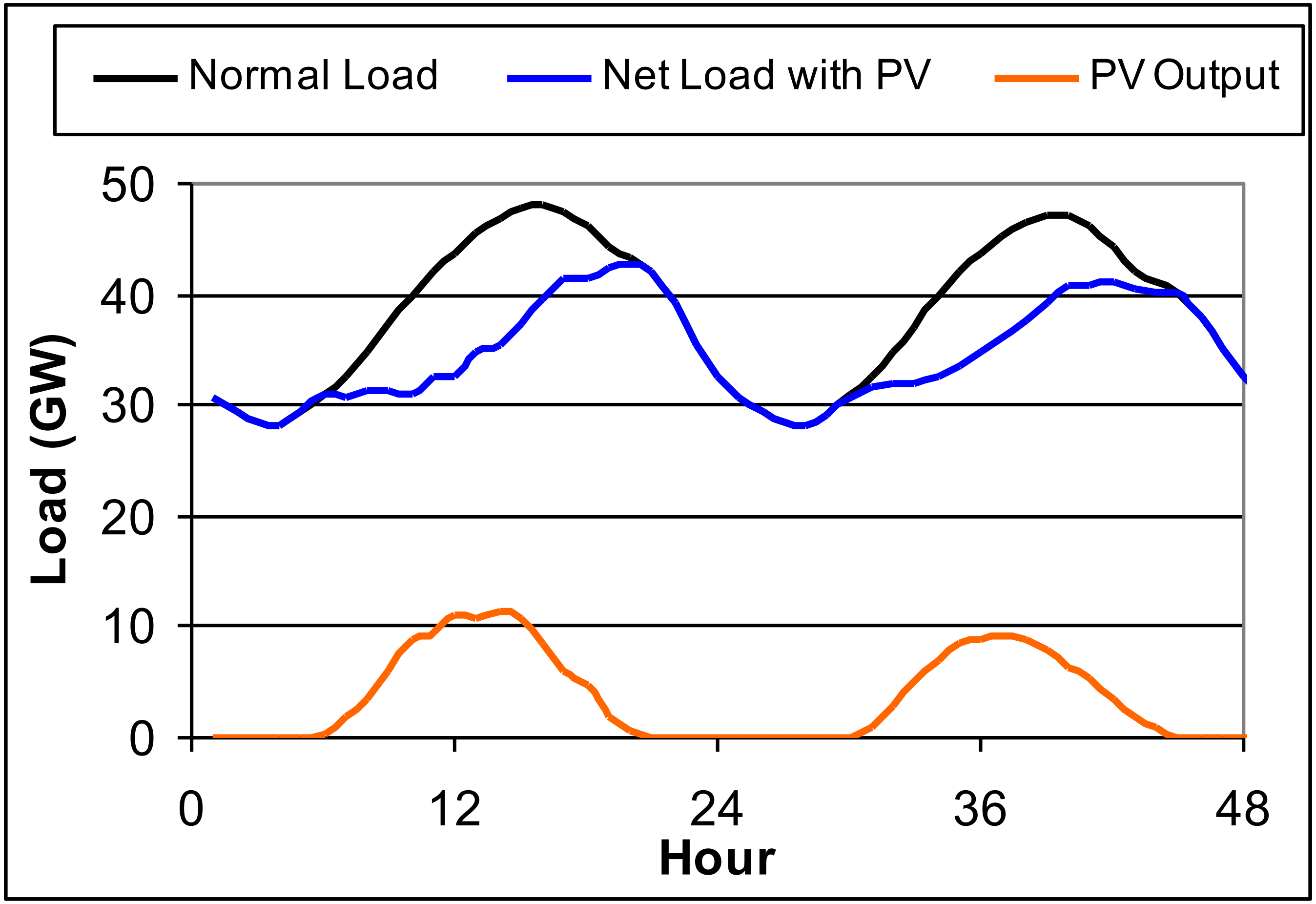
# High Resolution Modeling

- Chronological models to simulate grid operations in specific scenarios
- High(ish) resolution capacity expansion model to explore possible cost-optimal scenarios

# Net Load Duration Curves

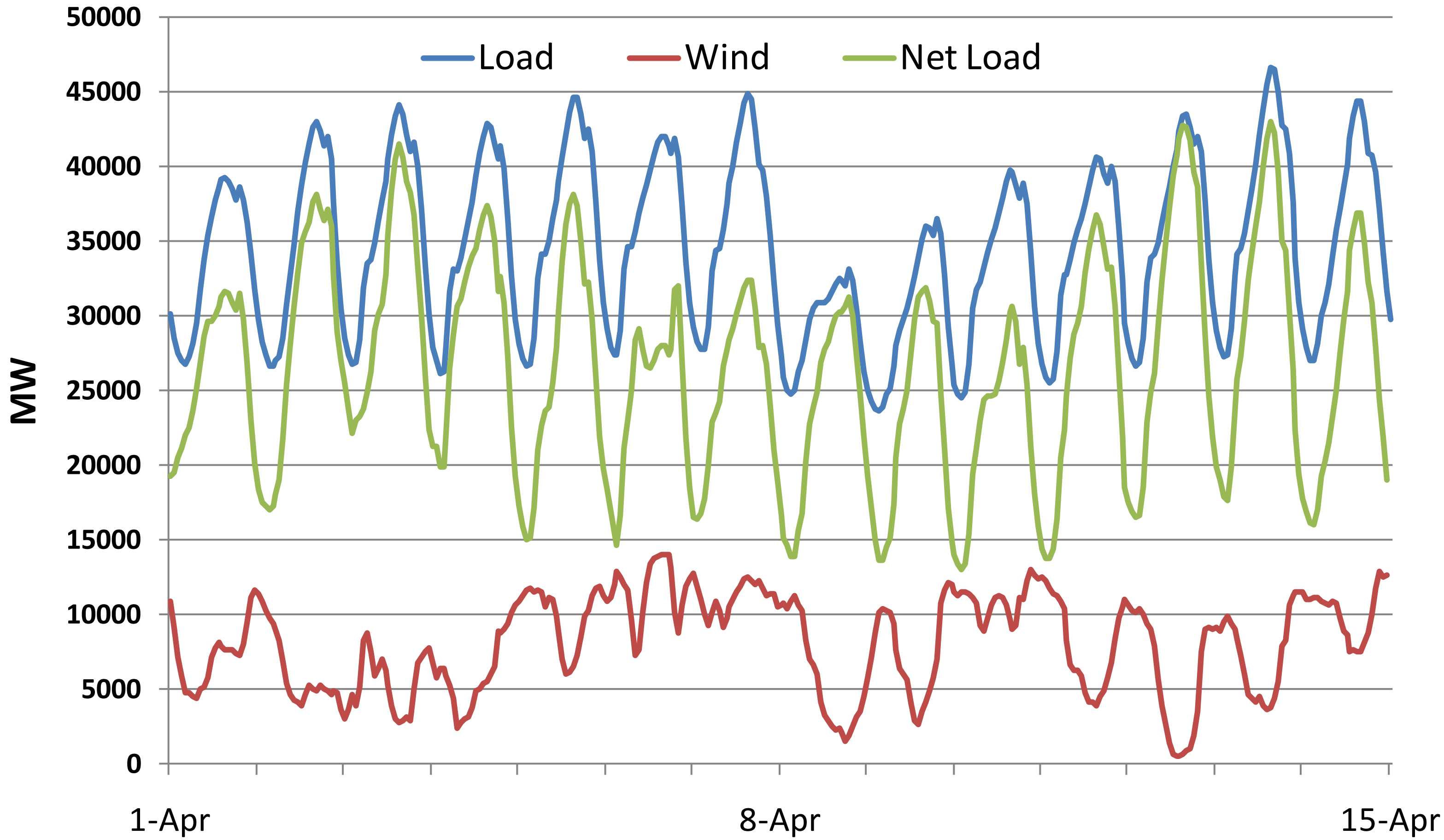
- Net load duration curves provide insights into the value of renewables and determine when flexibility measures must be added.
- Net load = Normal Load - VG

# Net Load with PV

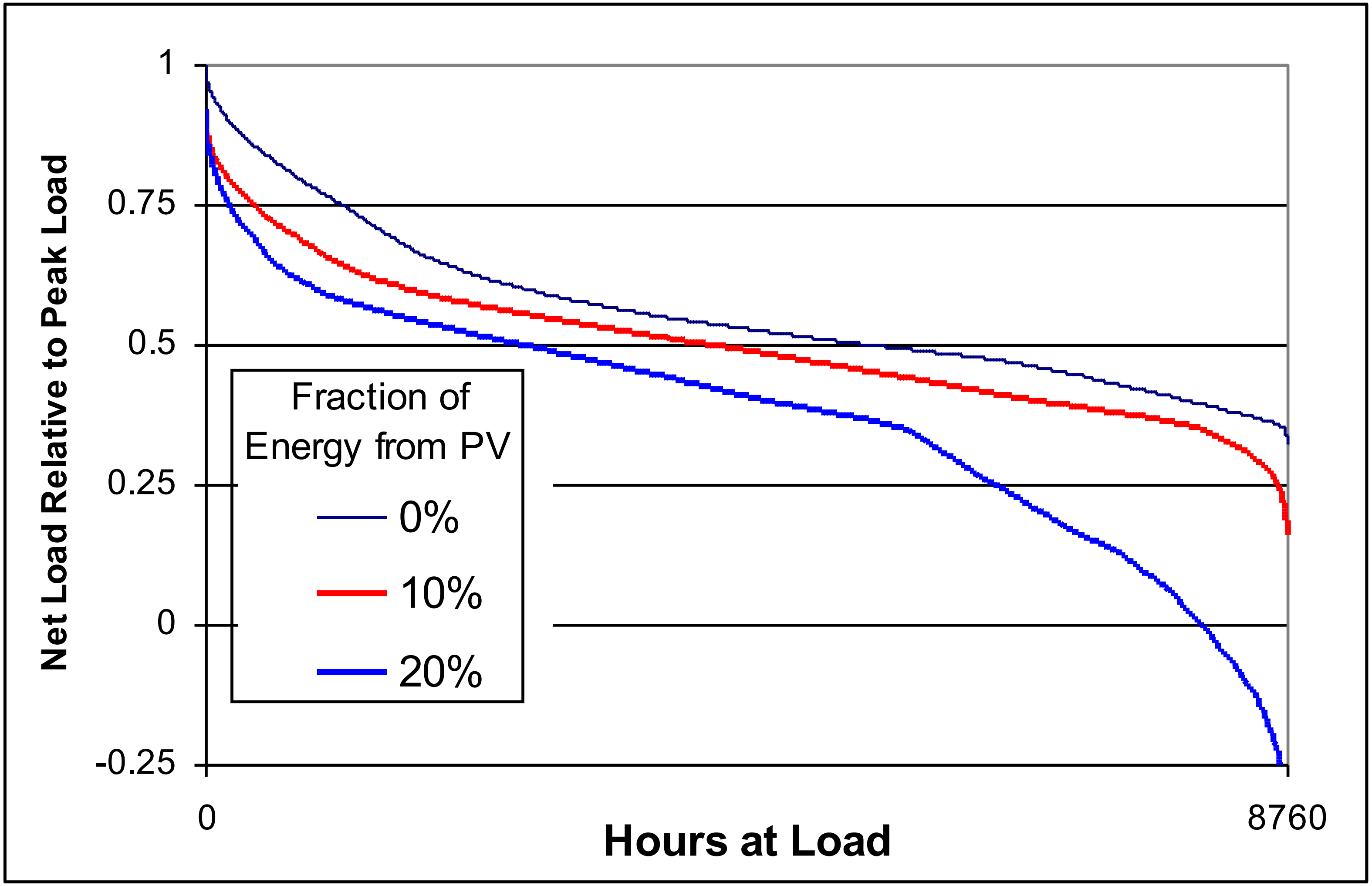



16 GW simulated PV system providing 11% of system's energy

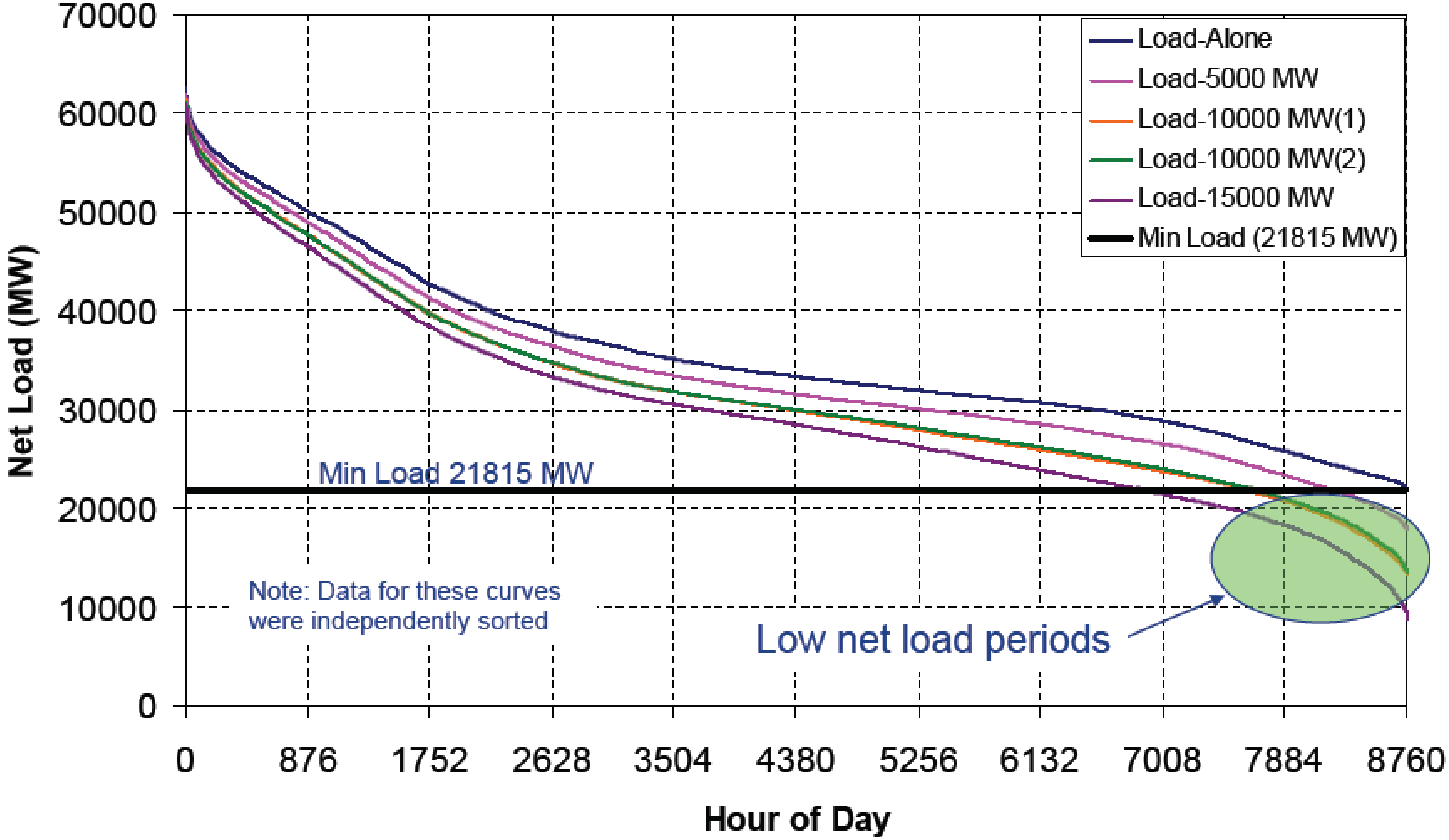
# Net load with wind



# Net LDC with PV

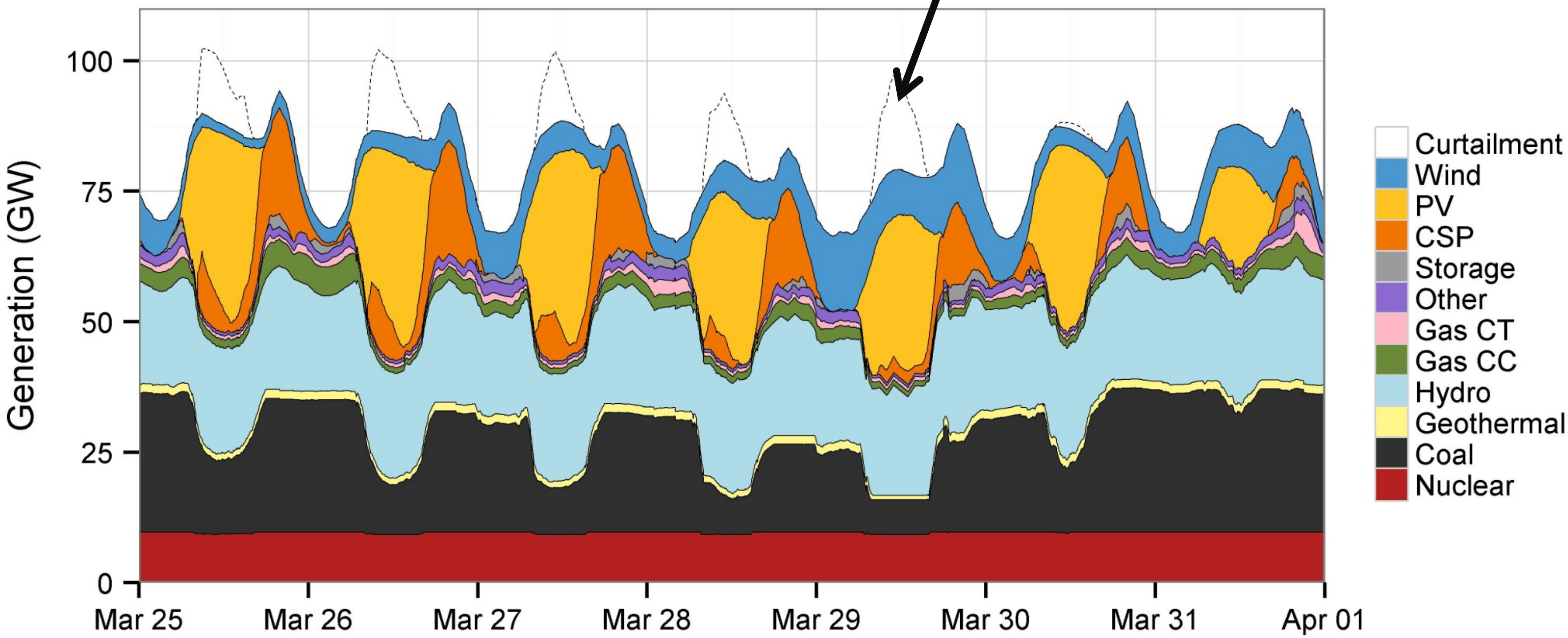


# Net LDC with wind



# Flexibility Challenge

This is a problem

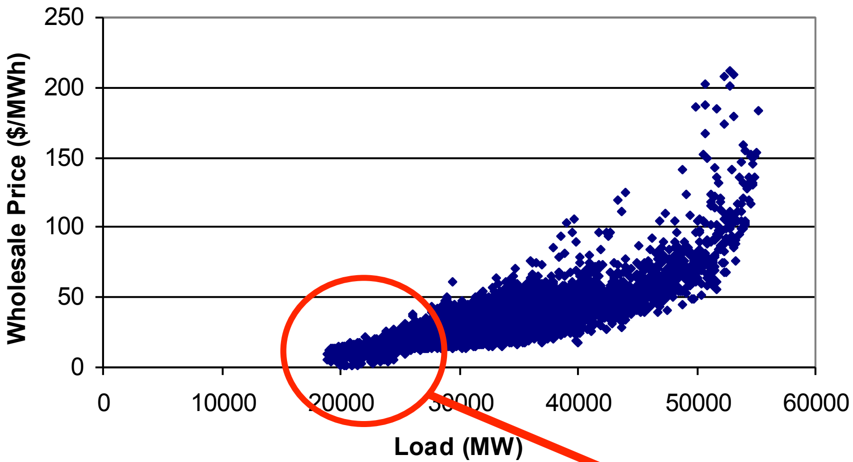



WWSIS II High Solar Scenario (25% solar, 8% wind)

Solar is 60% PV and 40% Concentrating Solar Power with 6 hours thermal storage

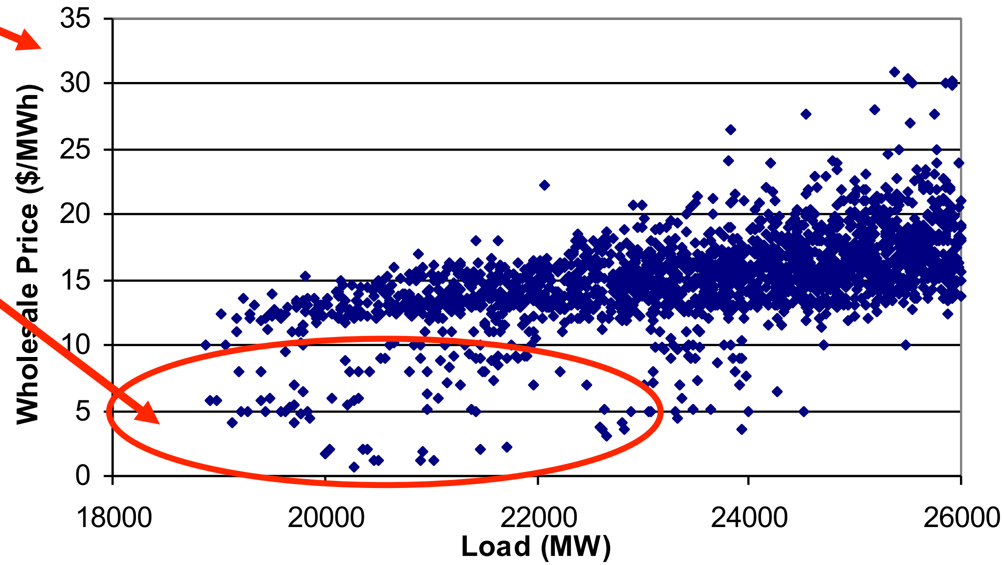
# Current System Flexibility

## Limited by Baseload Capacity



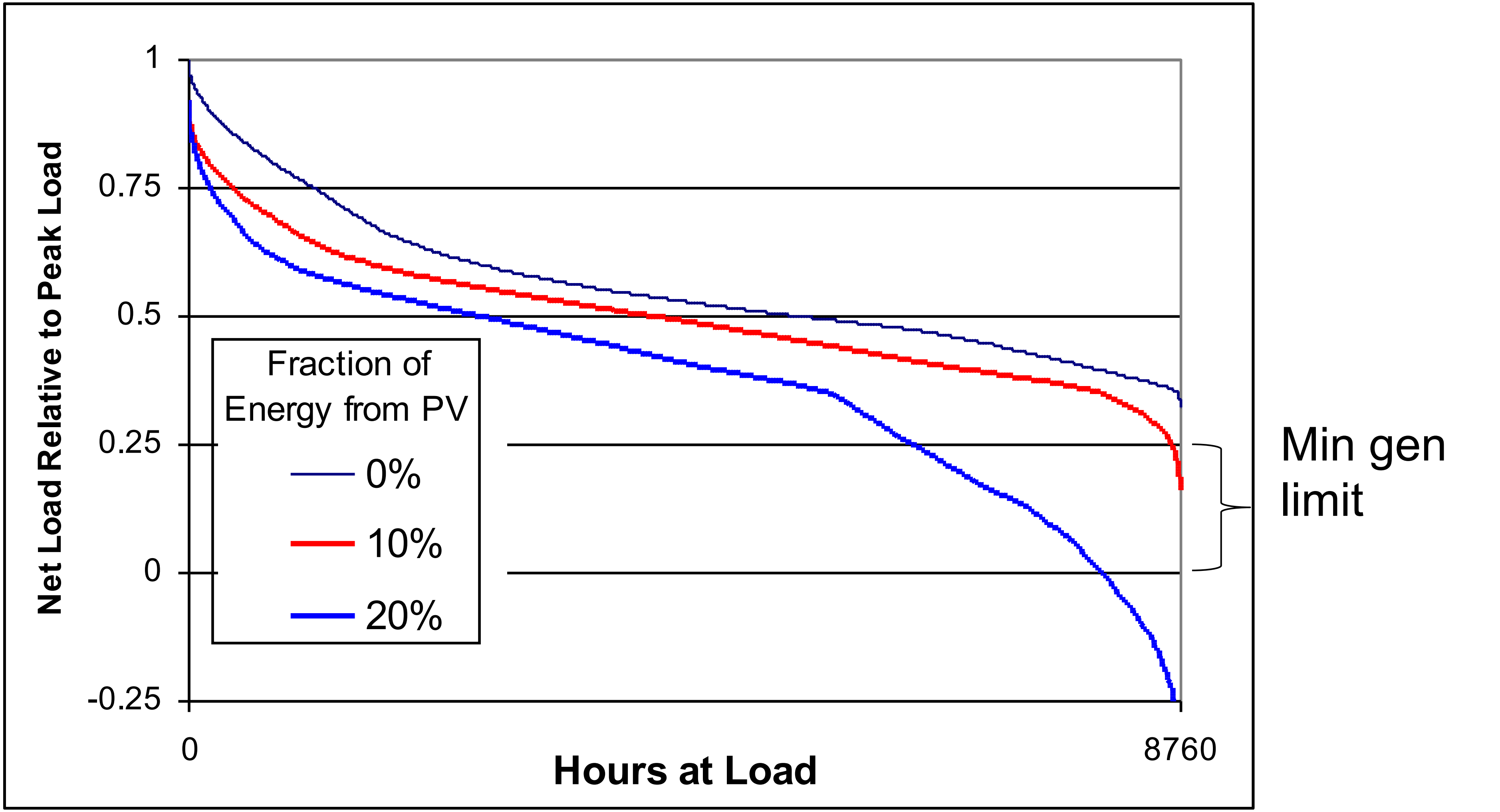

Price/Load
Relationship in PJM

Below Cost Bids




Plant operators would rather sell energy at a loss than incur a costly shutdown. Wind and solar may be curtailed under these conditions.

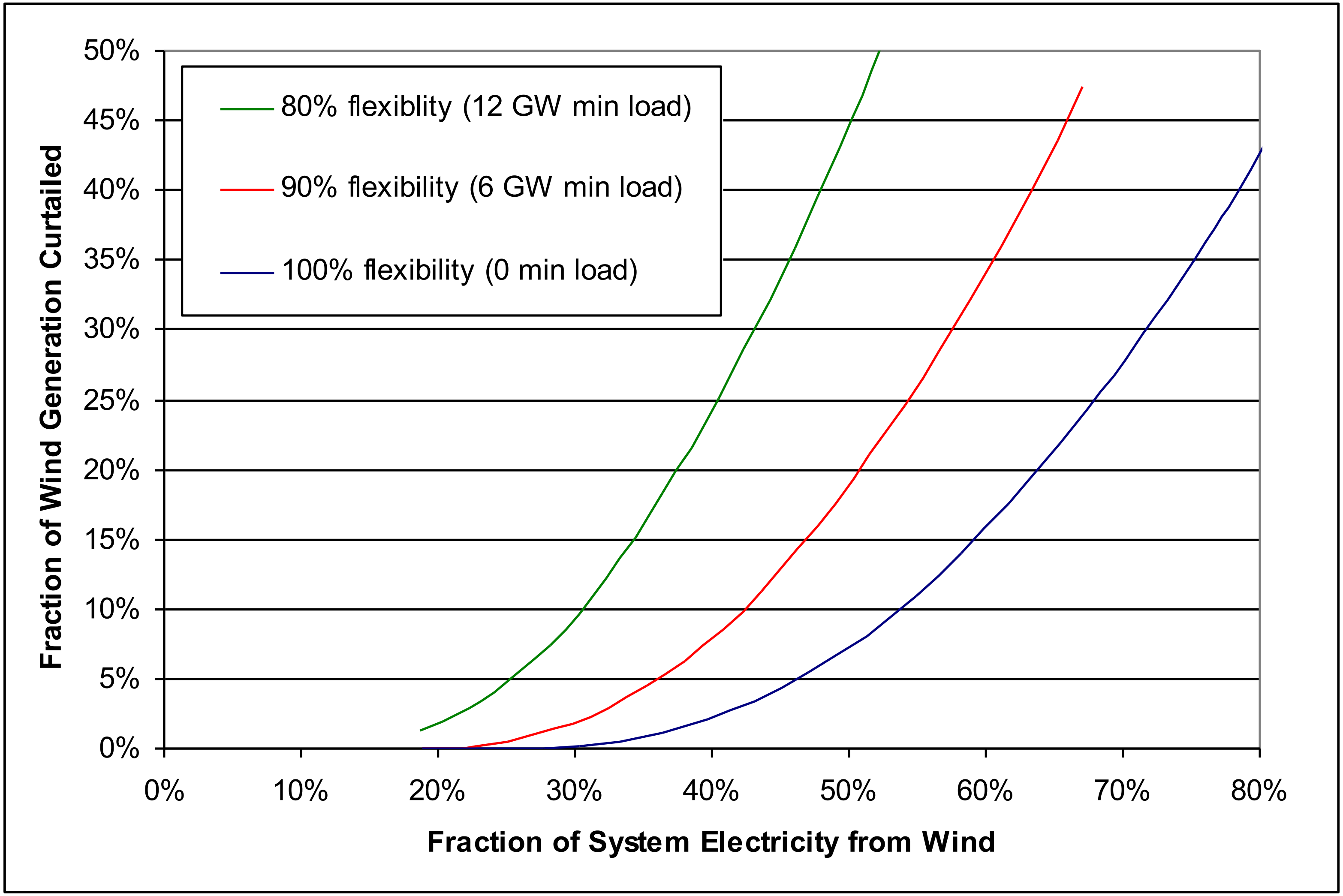
# Net PV Curtailment



# Limits to VG Penetration - Curtailment

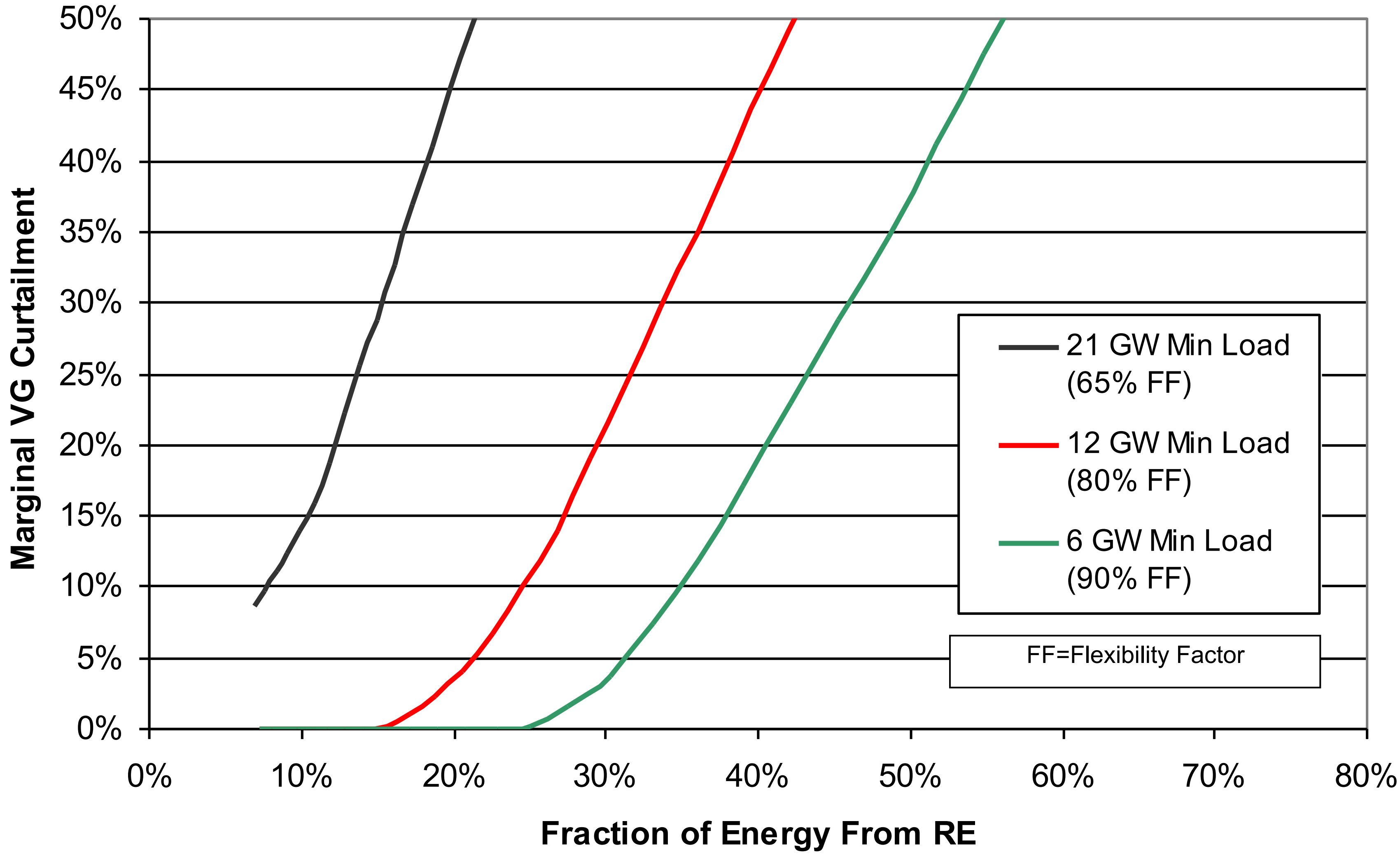
- At high penetration, economic limits will be due to curtailment
  - Limited coincidence of VG supply and normal demand
  - Minimum load constraints on thermal generators
  - Thermal generators kept online for operating reserves
  - Transmission constraints

# Curtailment as a Function of Flexibility

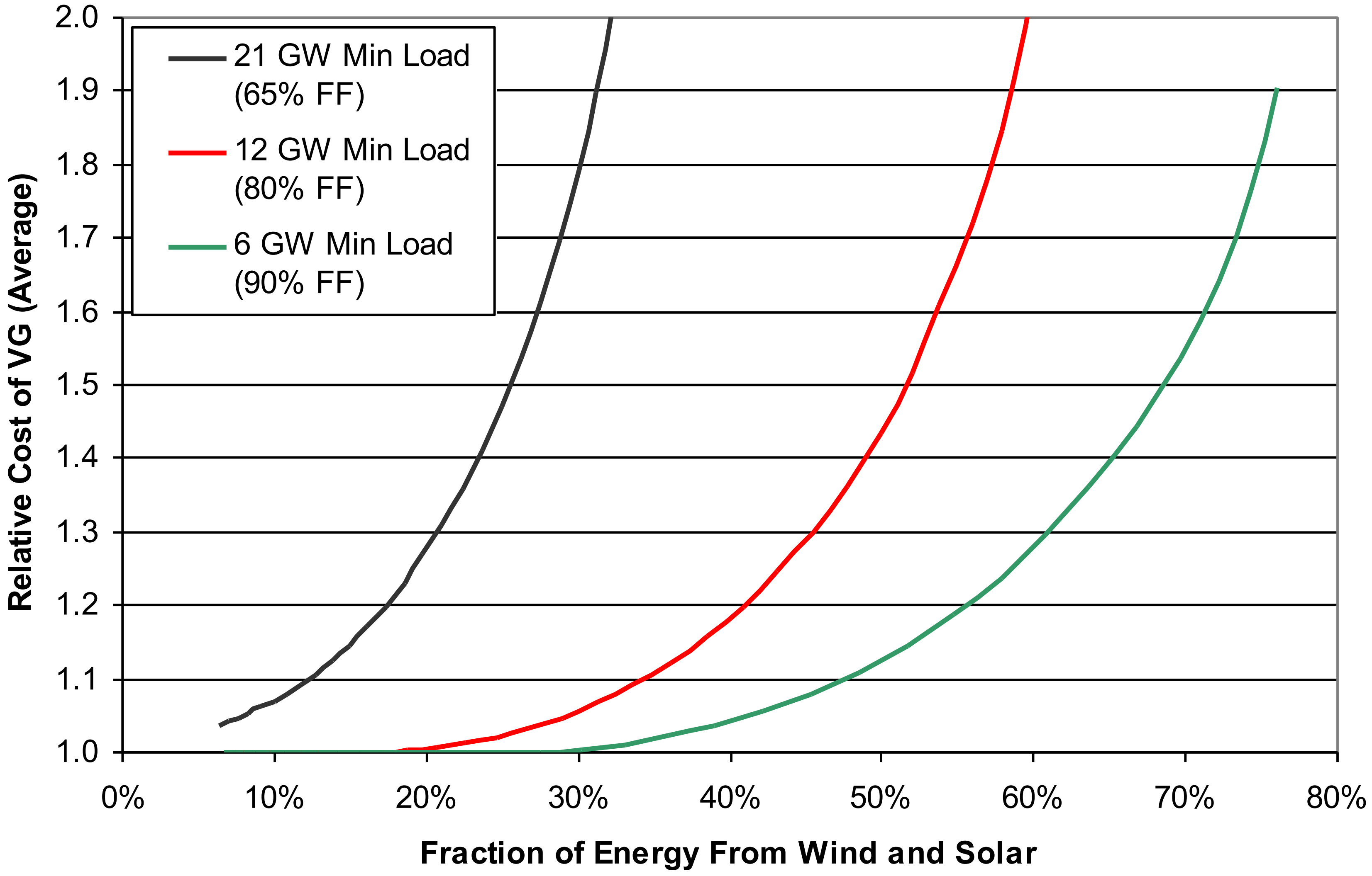



Average curtailment rate as a function of VG penetration for different flexibilities in ERCOT

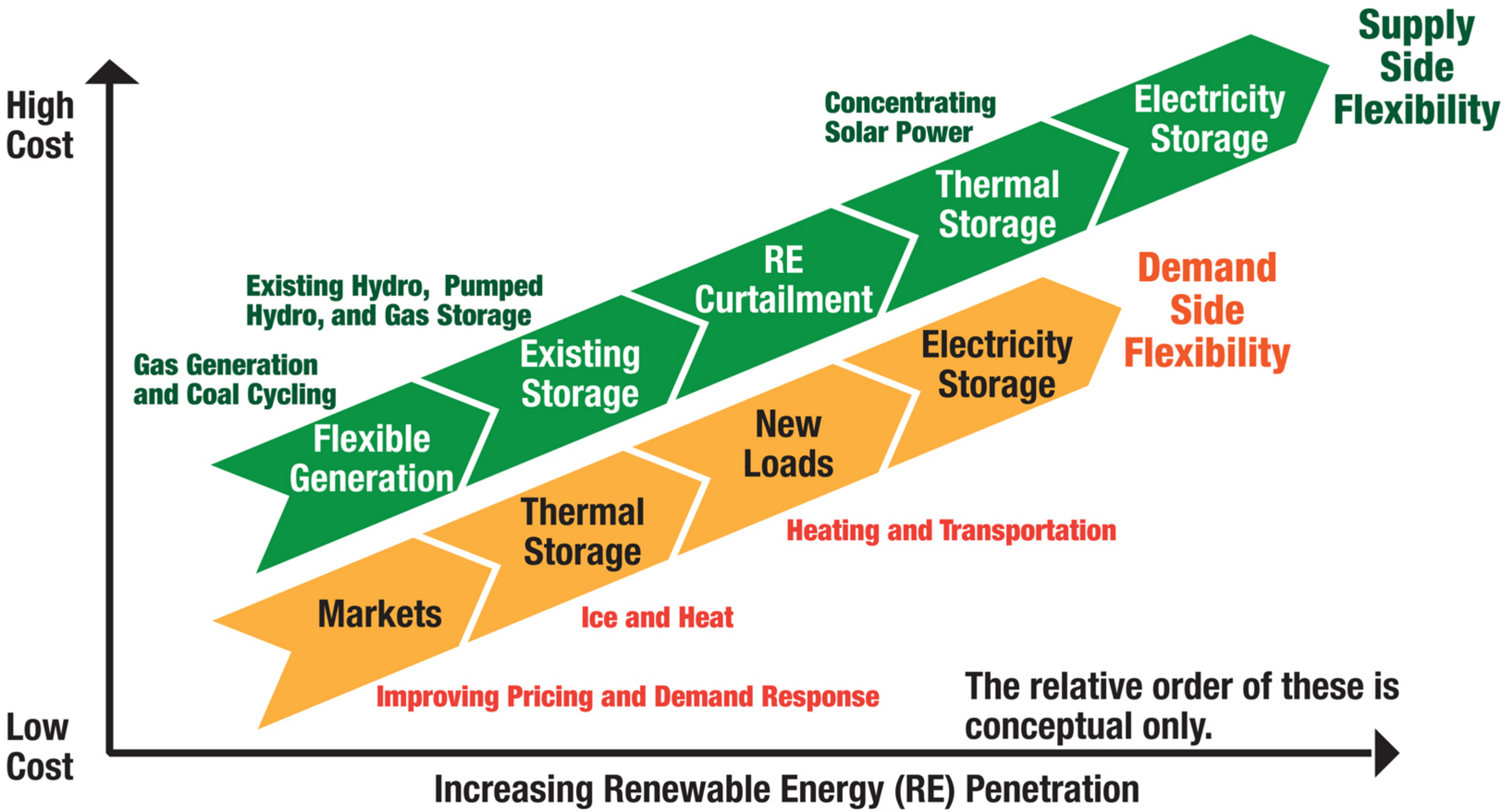
# Marginal Curtailment Rates



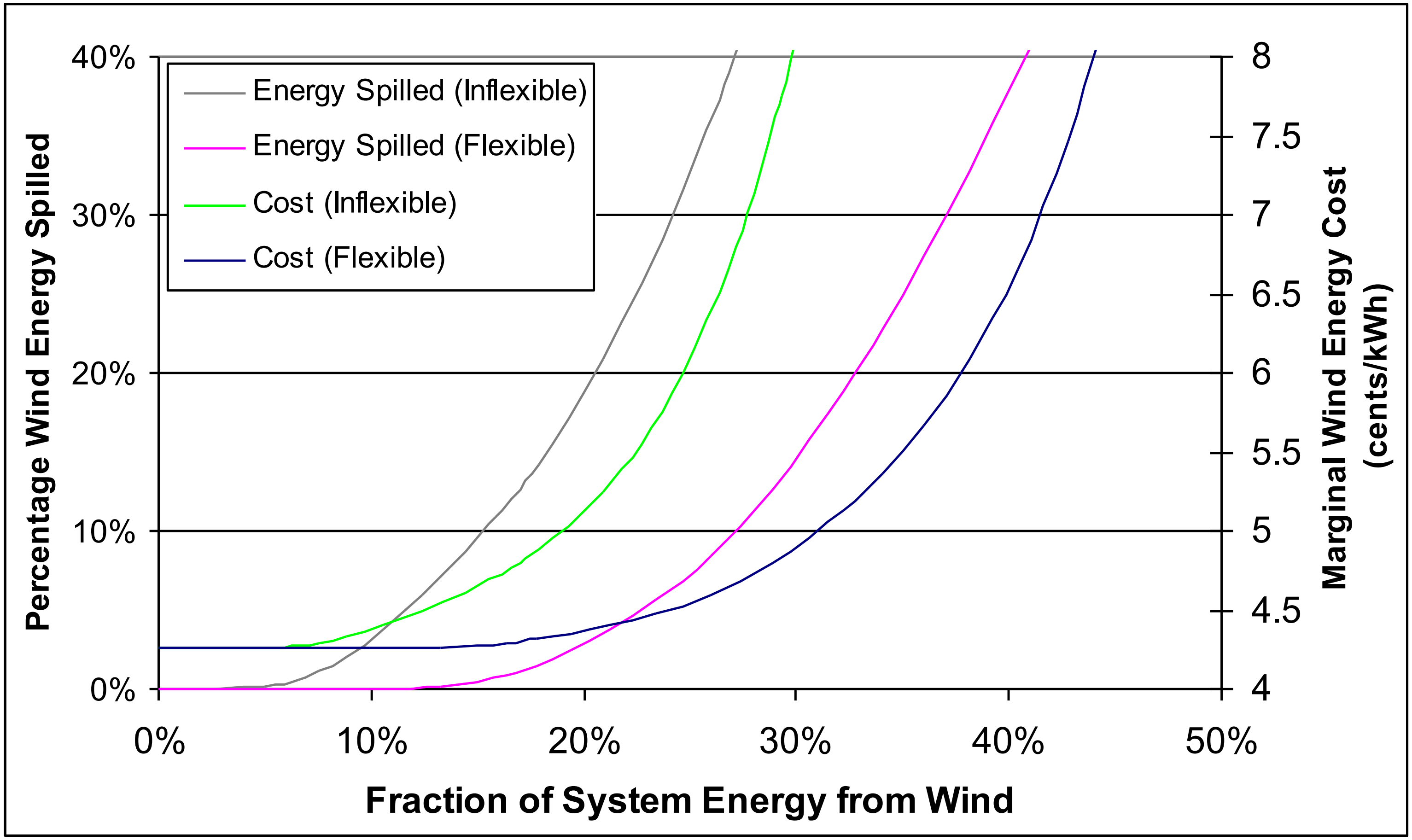
# Cost of Curtailment



# Flexiblity Supply Curve

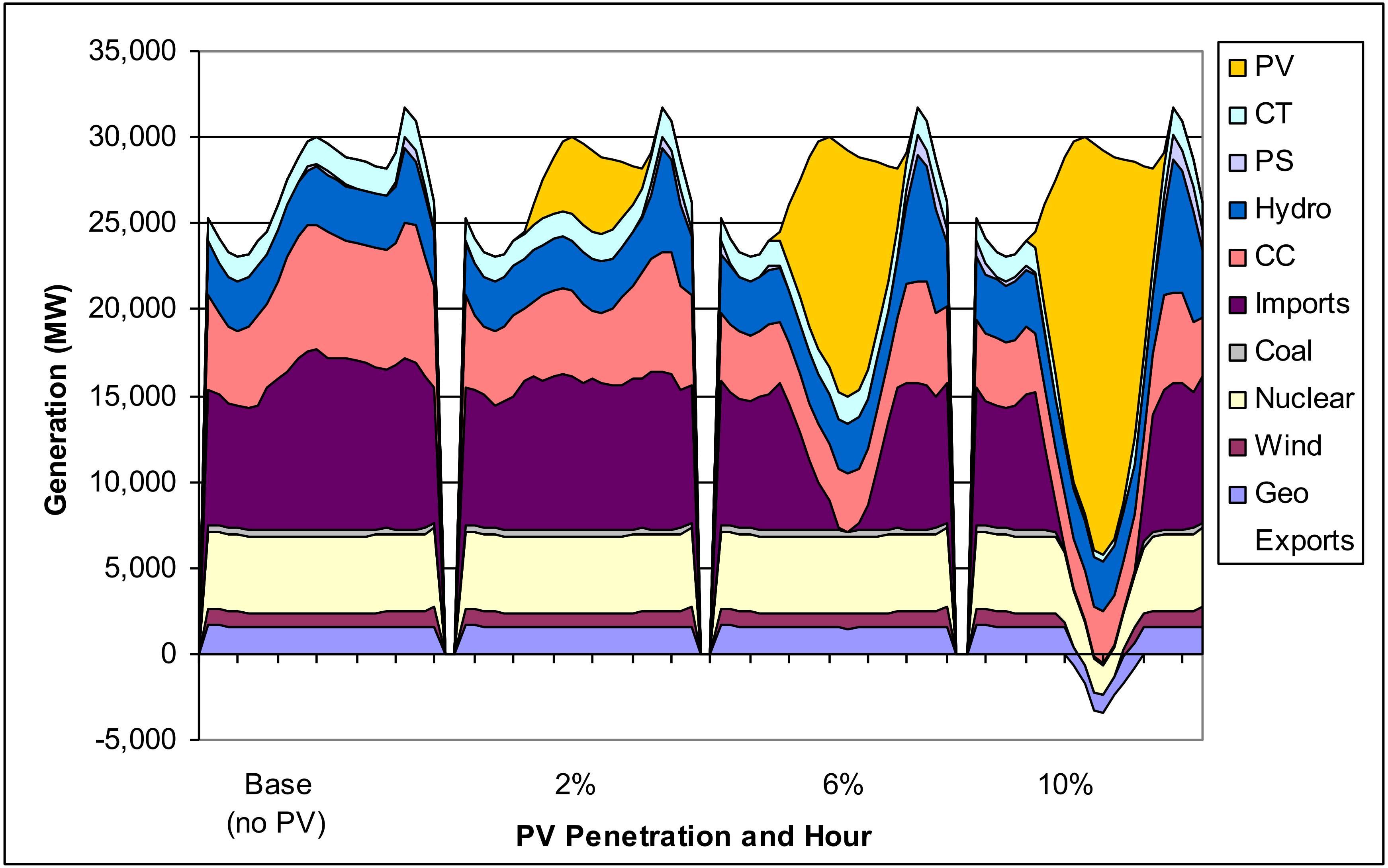


# Spatial Diversity

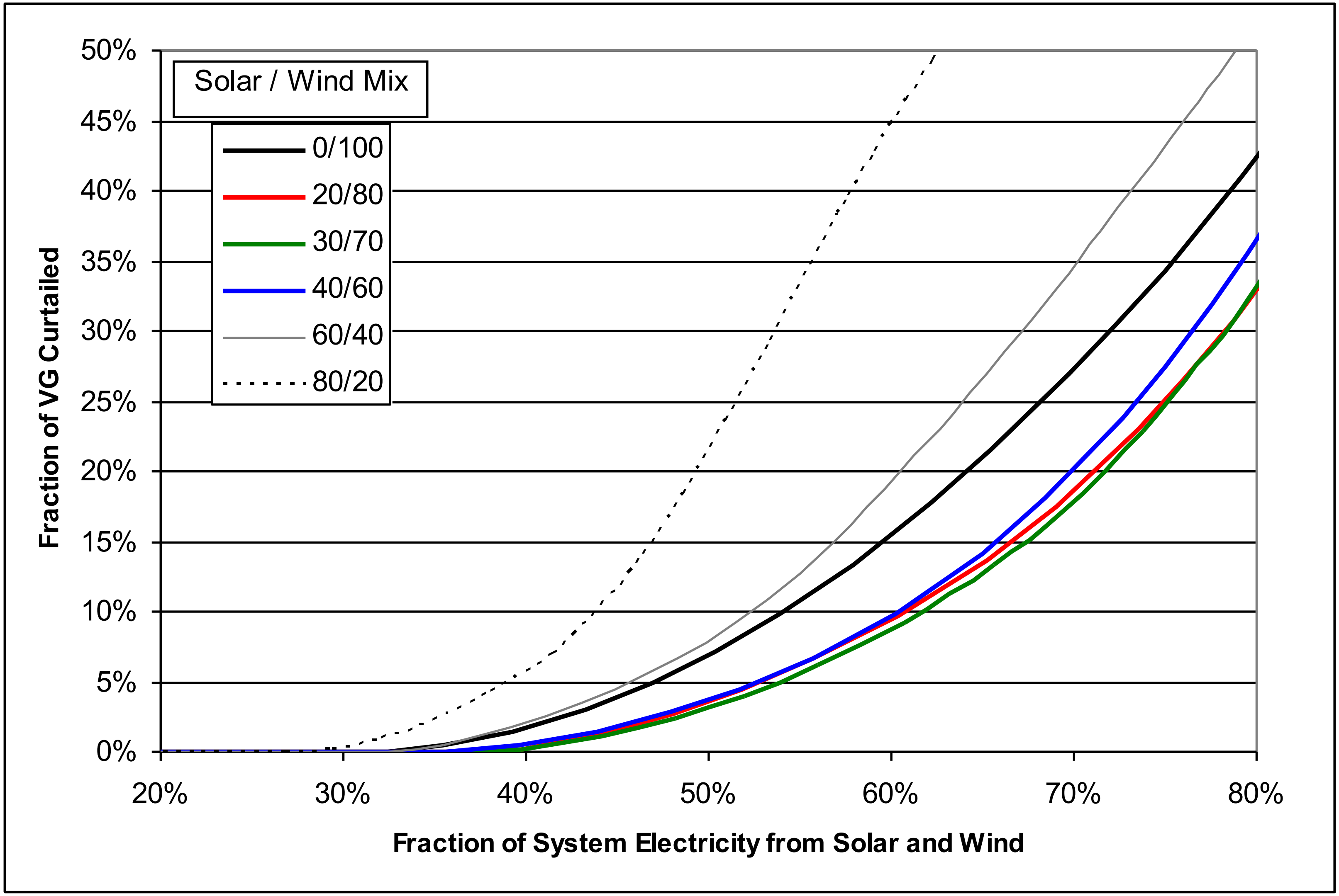



Very small BA with a single wind resource. This is an example of how NOT to evaluate the impact of wind (or pick chart colors) (Denholm 2004)

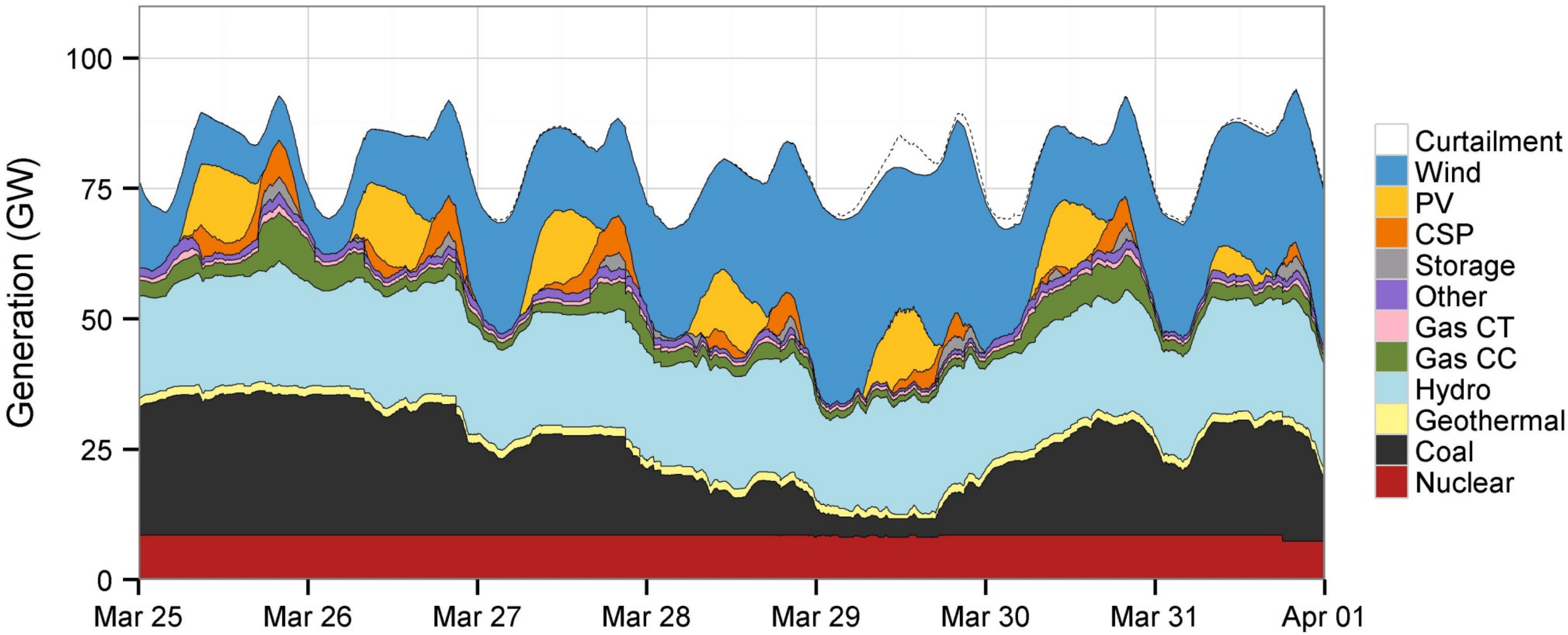
# BA Cooperation



# Different RE Mixes Improves Supply/Demand Coincidence

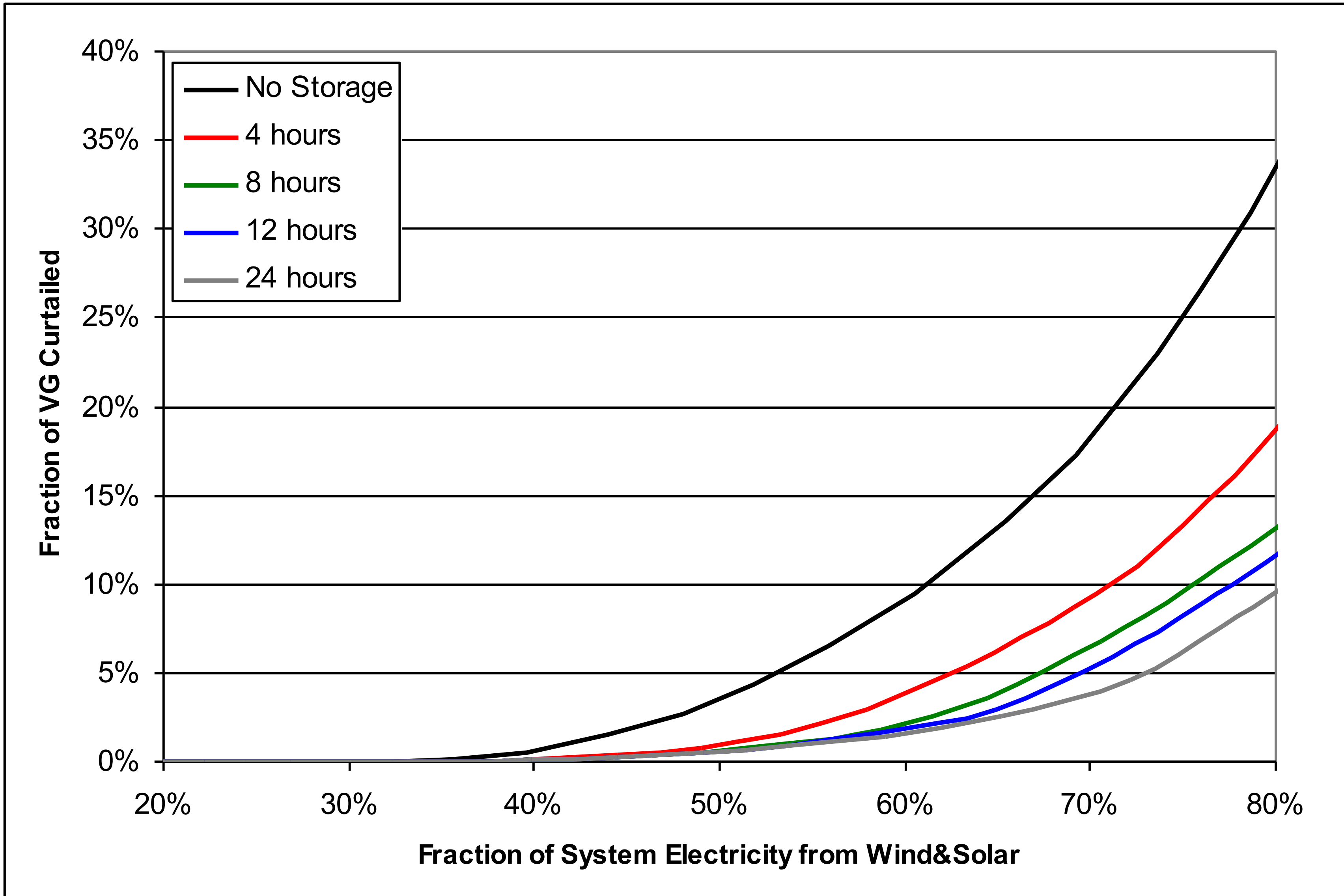


# WWSIS II High Wind Case (8% solar, 25% wind)

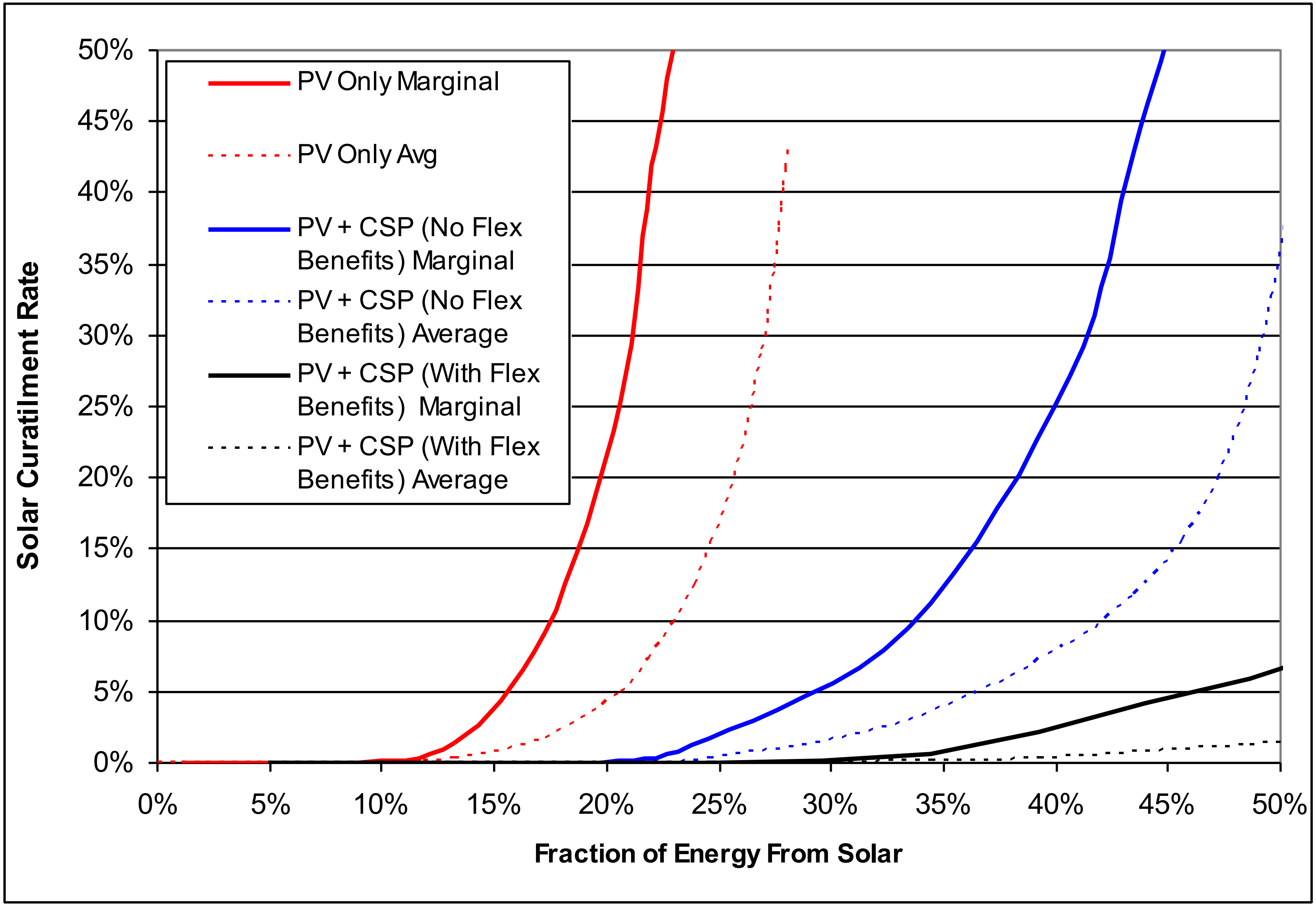



http://www.nrel.gov/electricity/transmission/western_wind.html

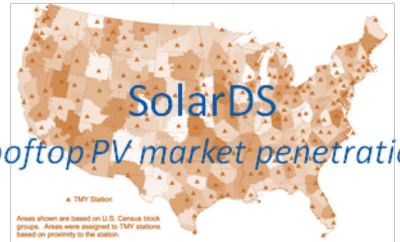
# Energy Storage Can Reduce VG Curtailment



# CSP as a Source of Flexibility



# Renewable Electricity Futures





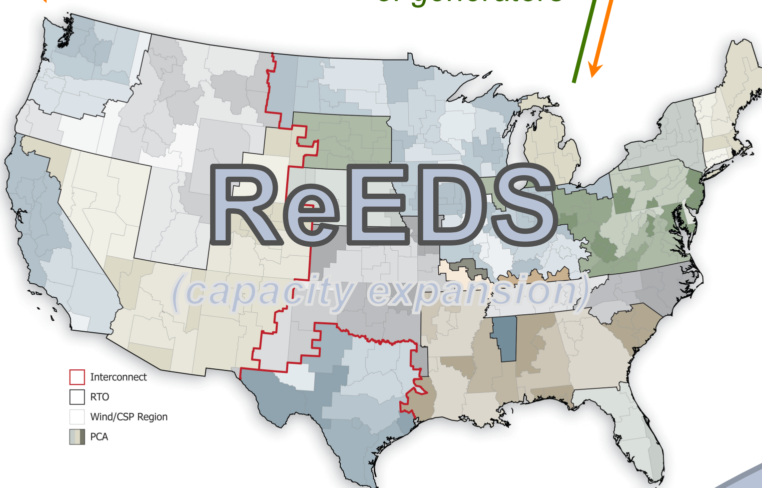
*rooftop PV penetration*

*2050 mix of generators*

*does it balance hourly?*

Black & Veatch
Technology Teams
Flexible Resources
End-Use Electricity
System Operations
Transmission

*Technology cost & performance*
*Resource availability*
*Demand projection*
*Demand-side technologies*
*Grid operations*
*Transmission costs*

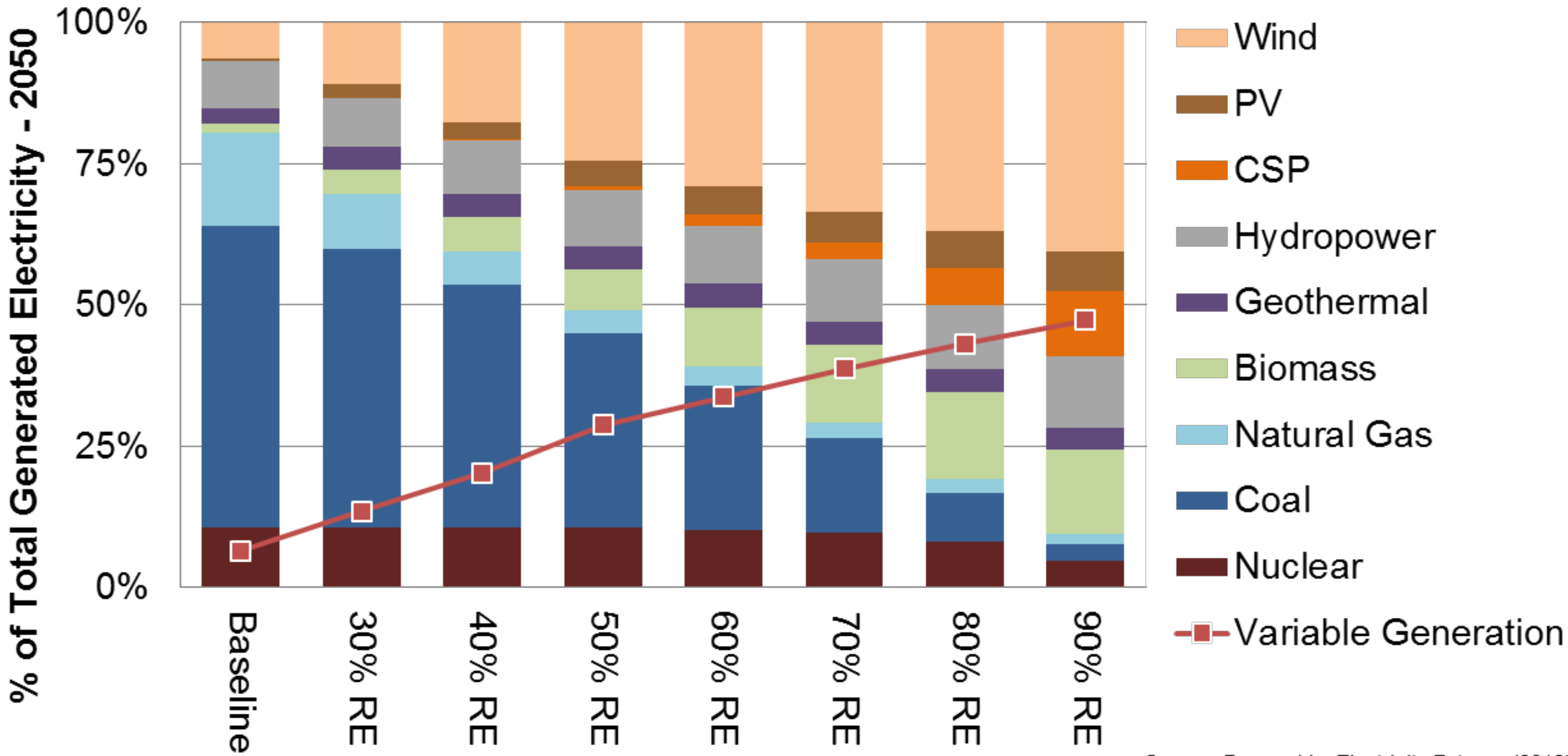



High resolution modeling using **134 nodes & hourly time steps**

**Implications**
GHG Emissions
Water Use
Land Use
Direct Costs

***Capacity & Generation 2010-2050***

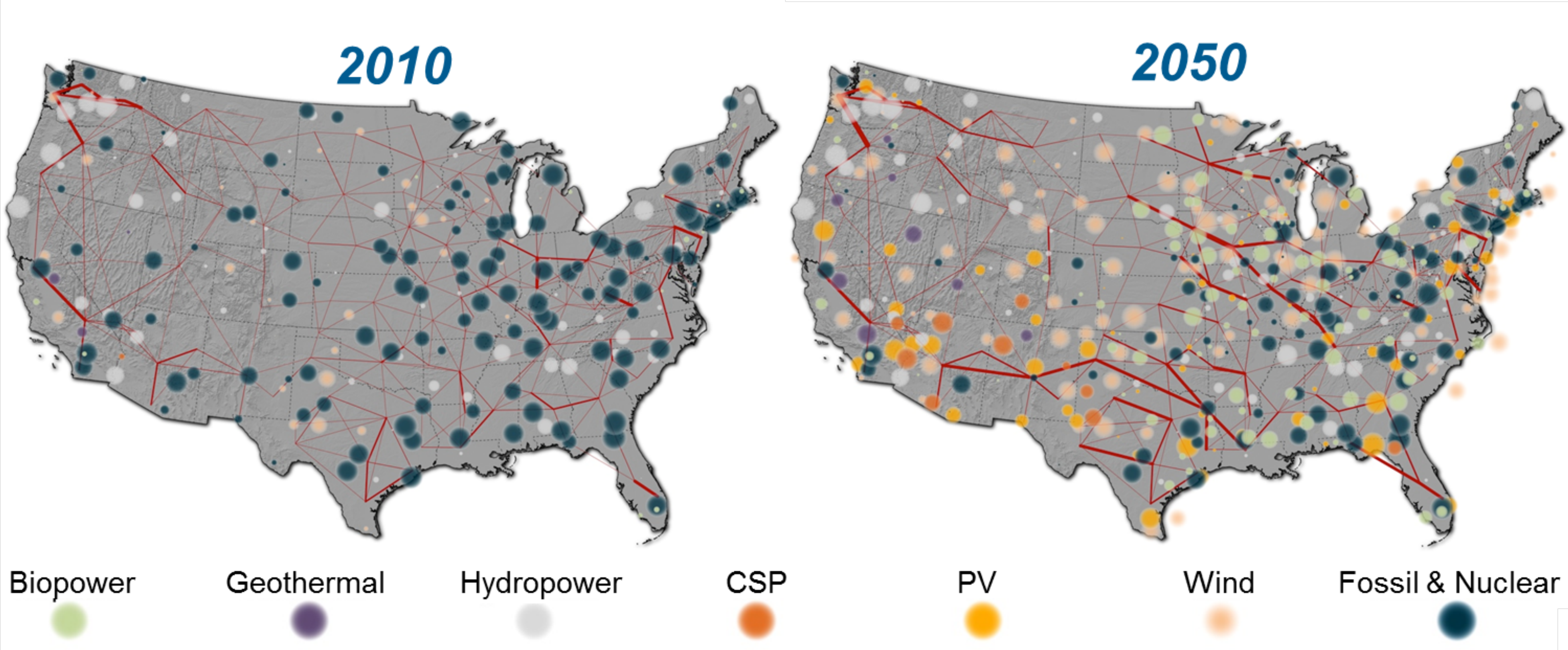
# RE Resource Supply from 30% - 90% Electricity




Source: Renewable Electricity Futures (2012)

**Additional variability challenges system operations, but can be addressed through increased use of supply- and demand-side flexibility options and new transmission.**

# How Does RE Futures Achieve 80% RE?

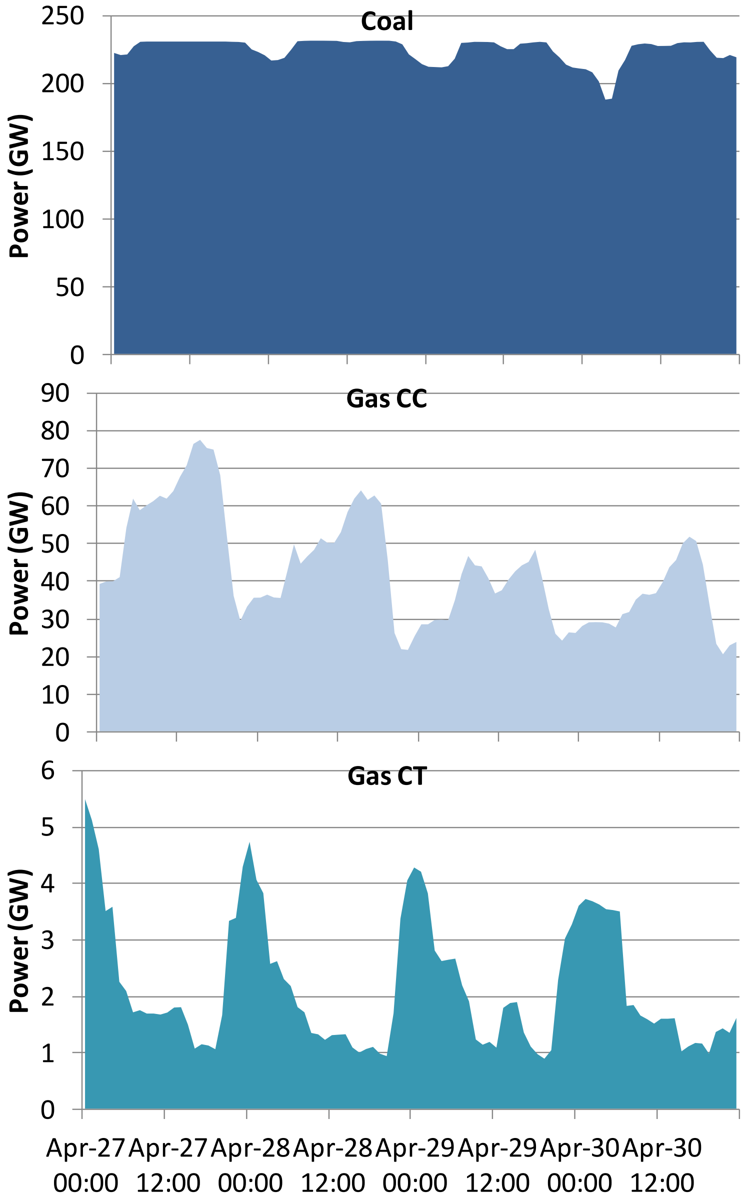



Source: Renewable Electricity Futures (2012)

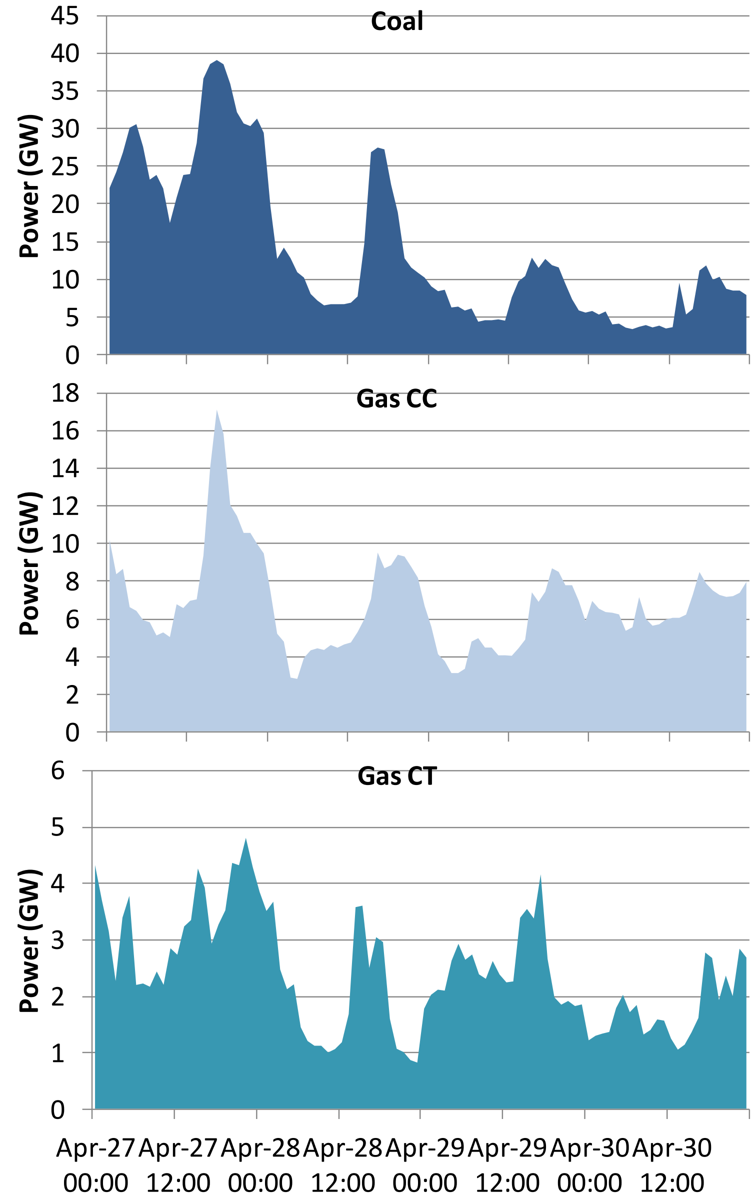
**RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050—while meeting electricity demand on an hourly basis in every region of the country.**

# 1) Cycle Generators

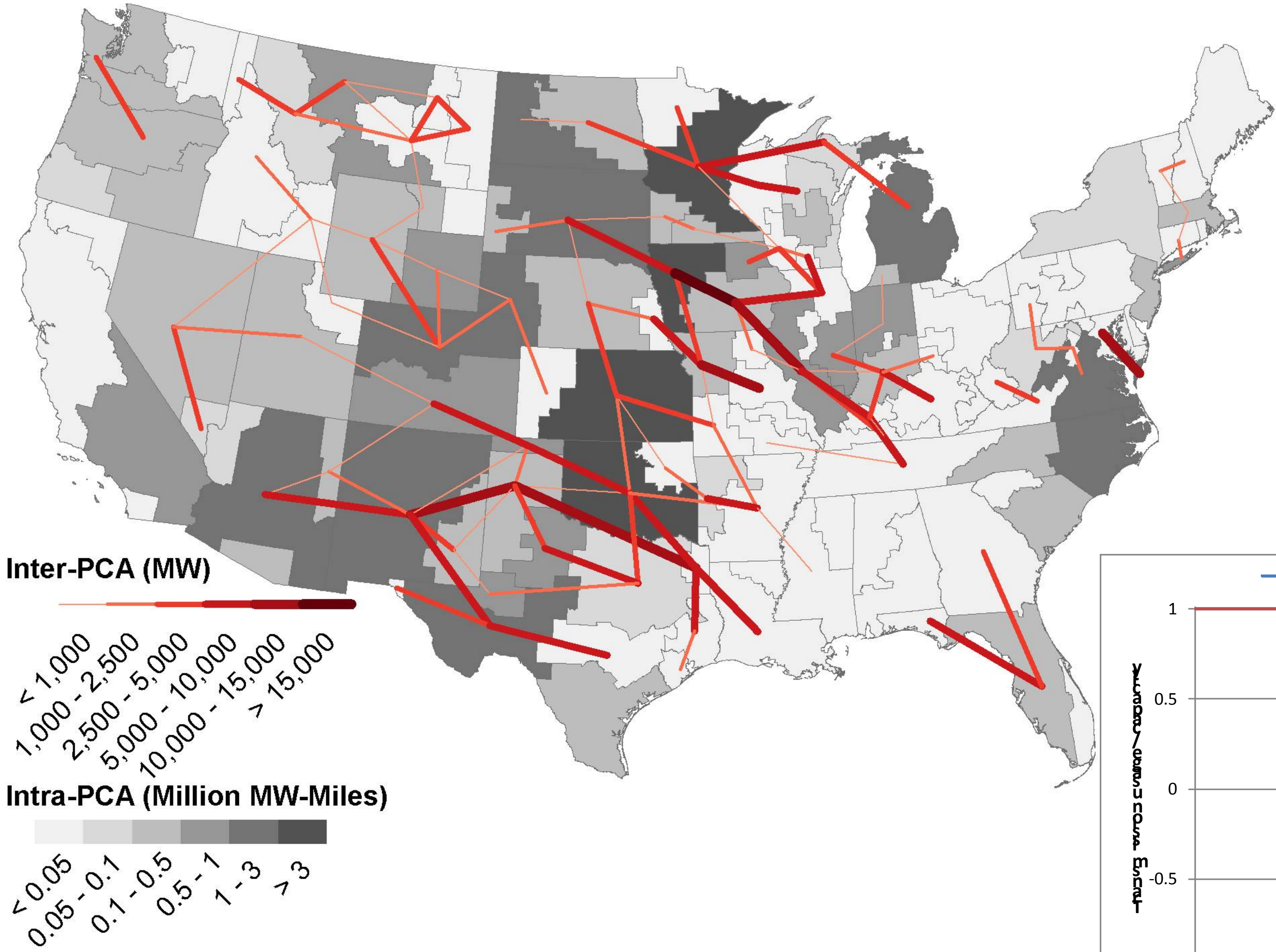
*Baseline scenario*

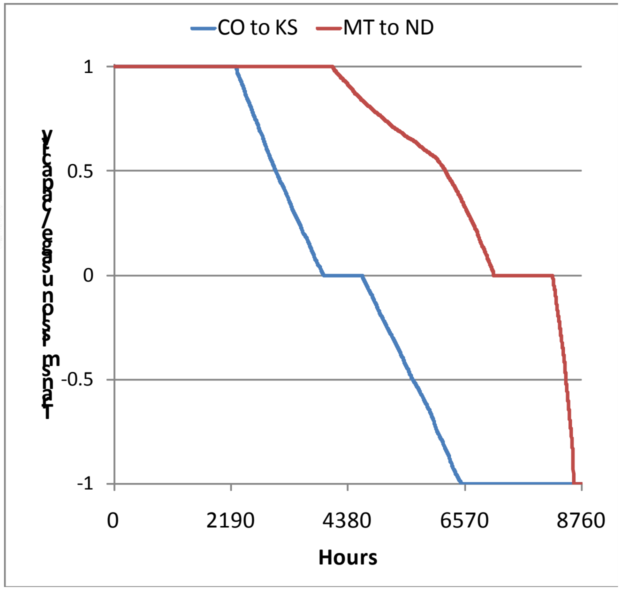



*80% RE-ITI scenario*

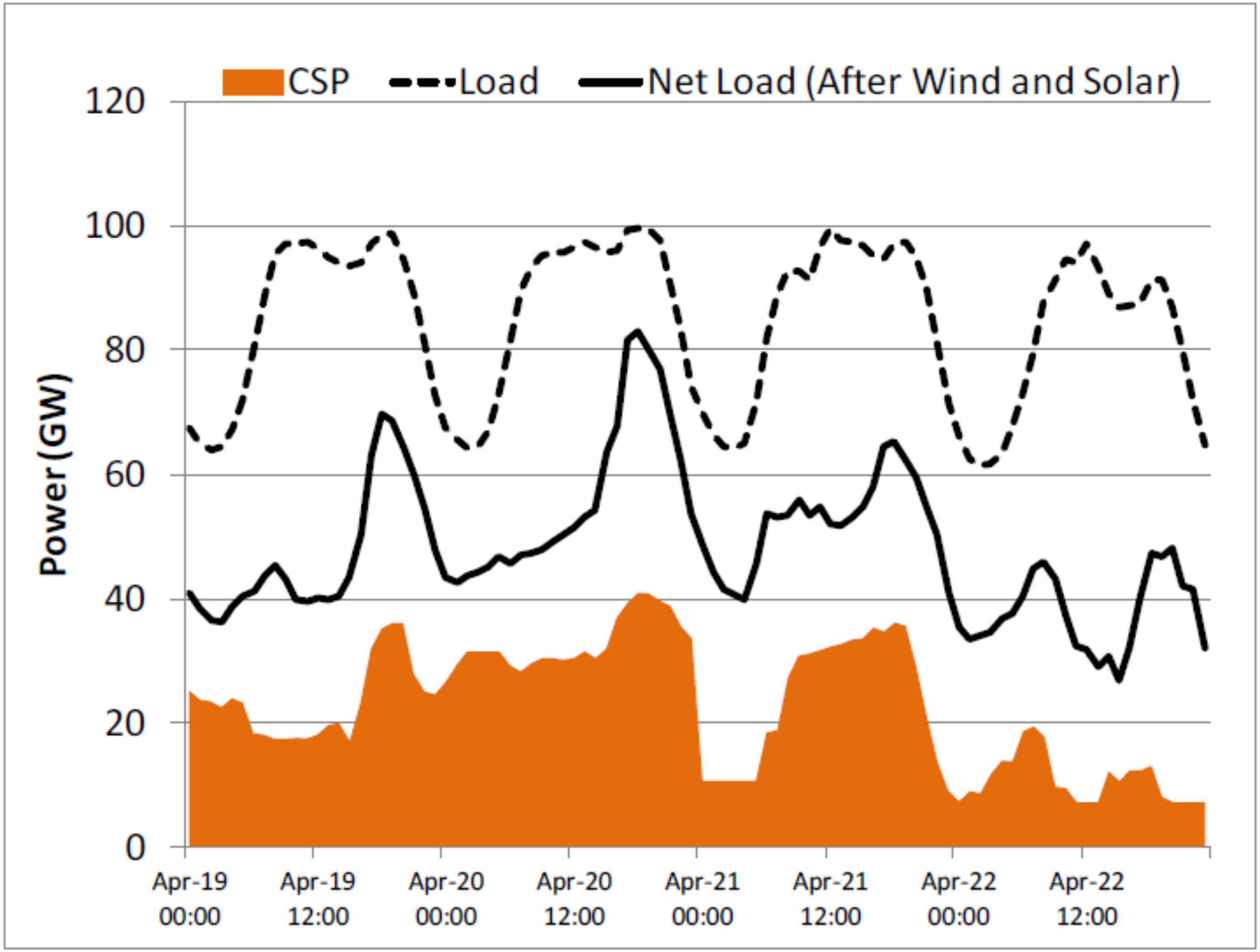


# 2) Build New Transmission



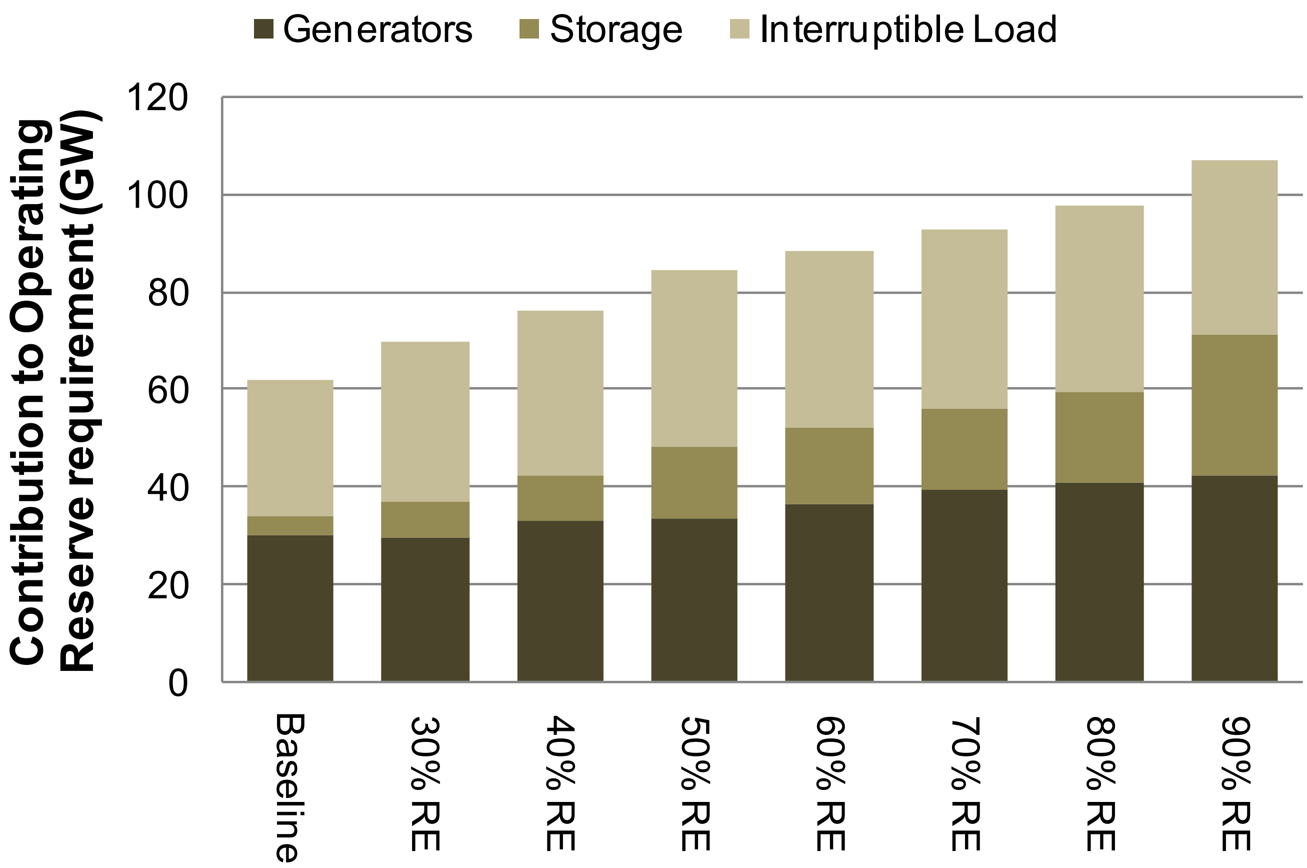



# 3) Deploy Dispatchable Renewables

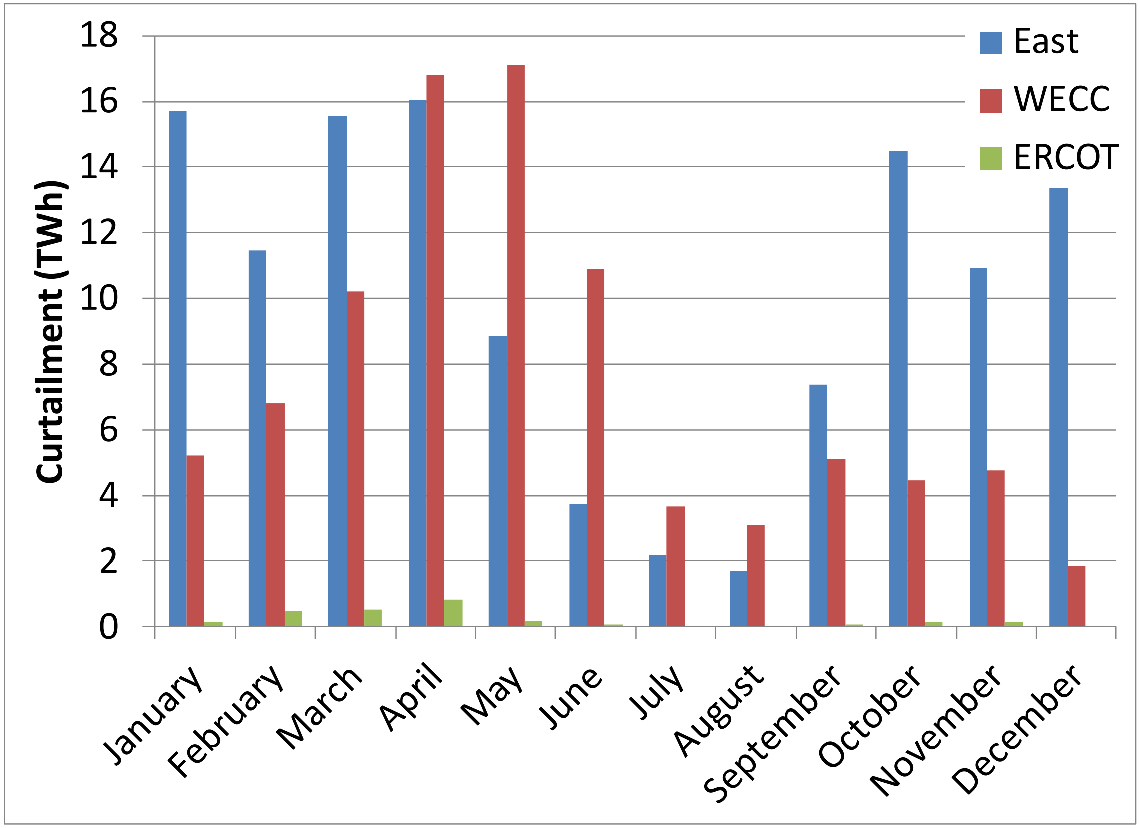



*Source: Denholm et al (2012)*

# 4) Harness Responsive Demand (smart grid?)

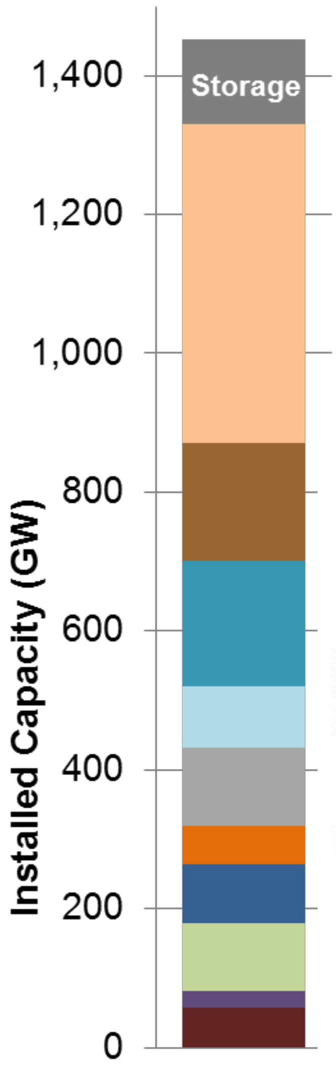


# 5) Accept inevitable curtailment in the spring.

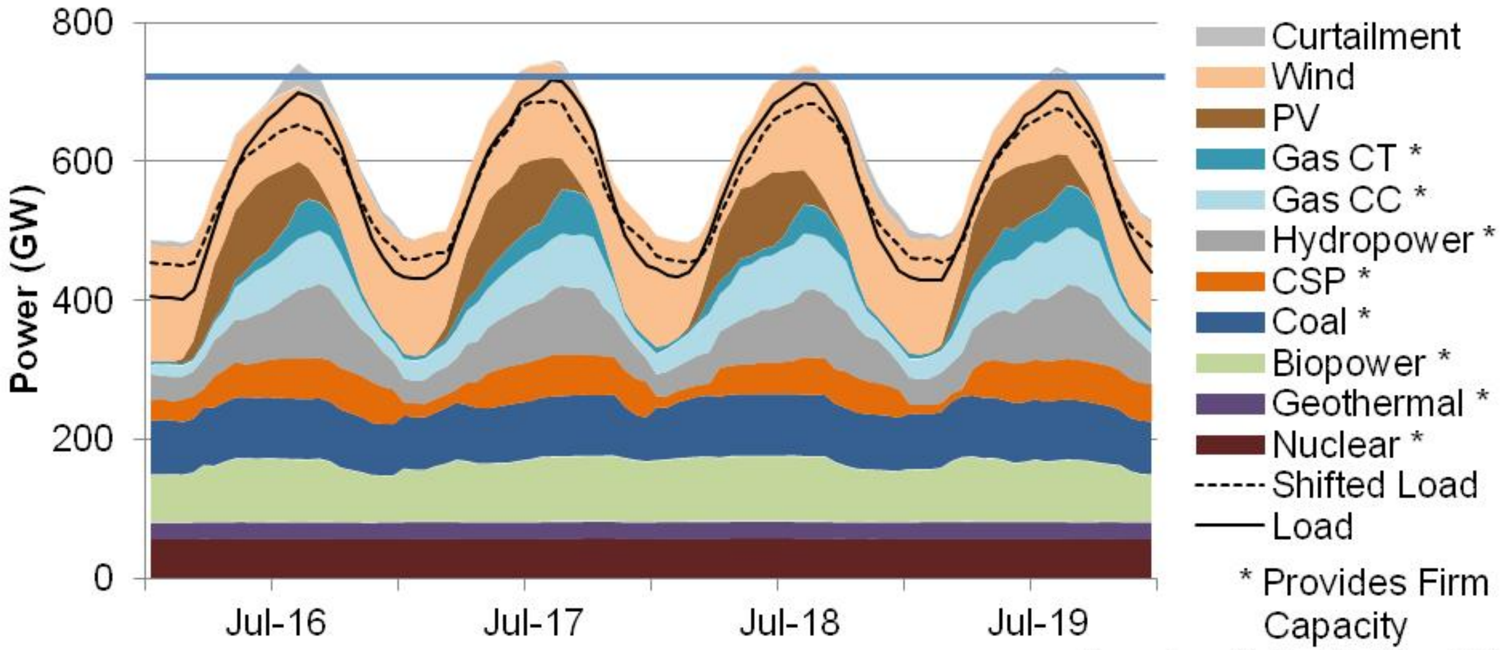



8-10% of wind, solar, hydropower curtailed in 2050 under 80% RE scenarios

# 6) And develop new storage

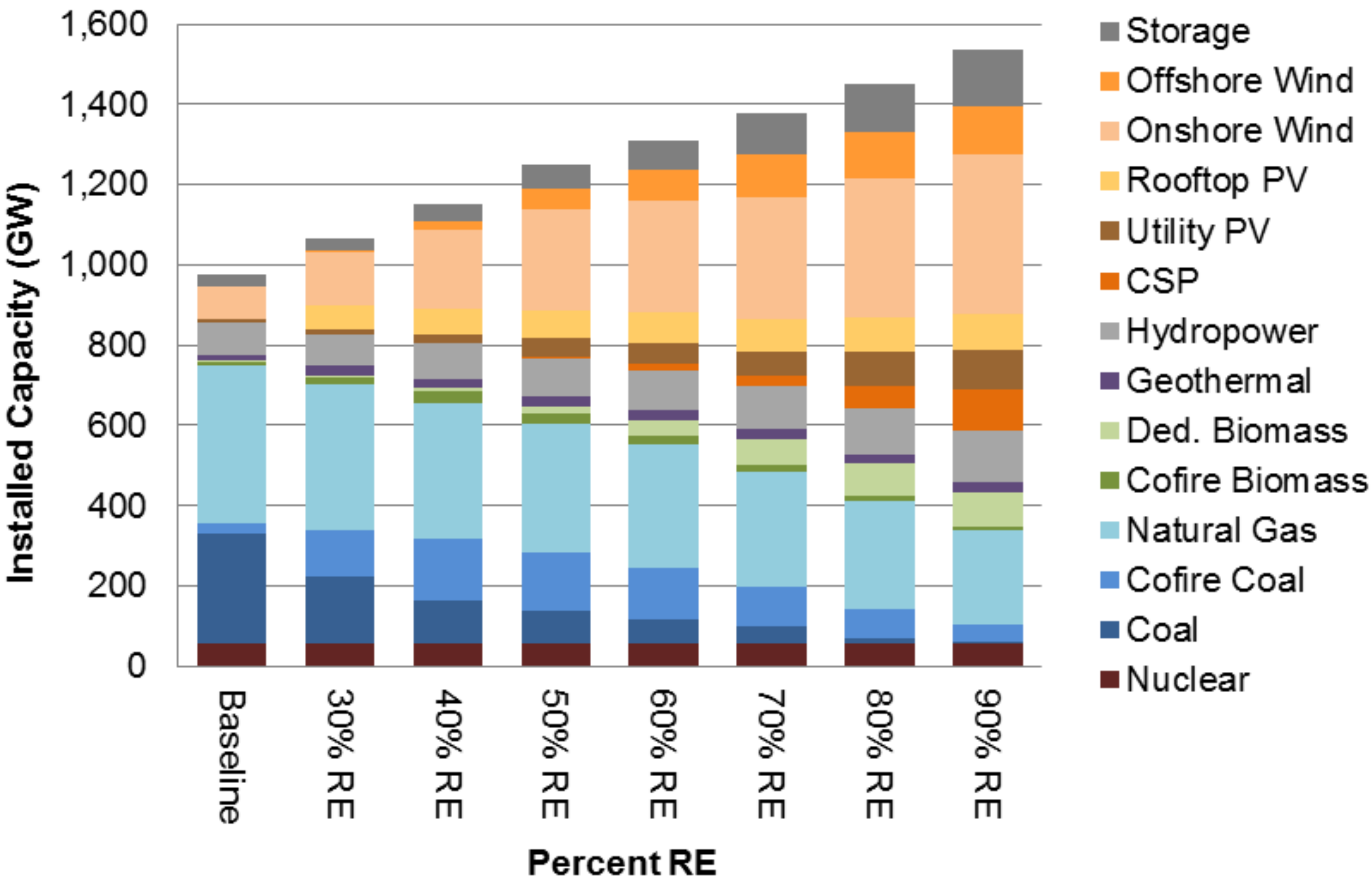



**Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves supplying firm capacity.**




Source: Renewable Electricity Futures (2012)

# Storage is not deployed in significant amounts before 50% VG and beyond




***RE-ITI scenarios***

# Instead of Conclusions, My Opinions

- Backup is not a well defined concept in resource planning (it is a co-optimization problem, not a "backup problem")
- Dedicated (1:1) flexibility resources are typically non-optimal
- The limits to RE deployment are based on the economics of curtailment driven by system flexibility and supply demand coincidence
- There are many sources of flexibility which will be deployed, many (most?) of which are cheaper than energy storage
- At ultra-high penetration of VG, storage will likely be important

# Questions?

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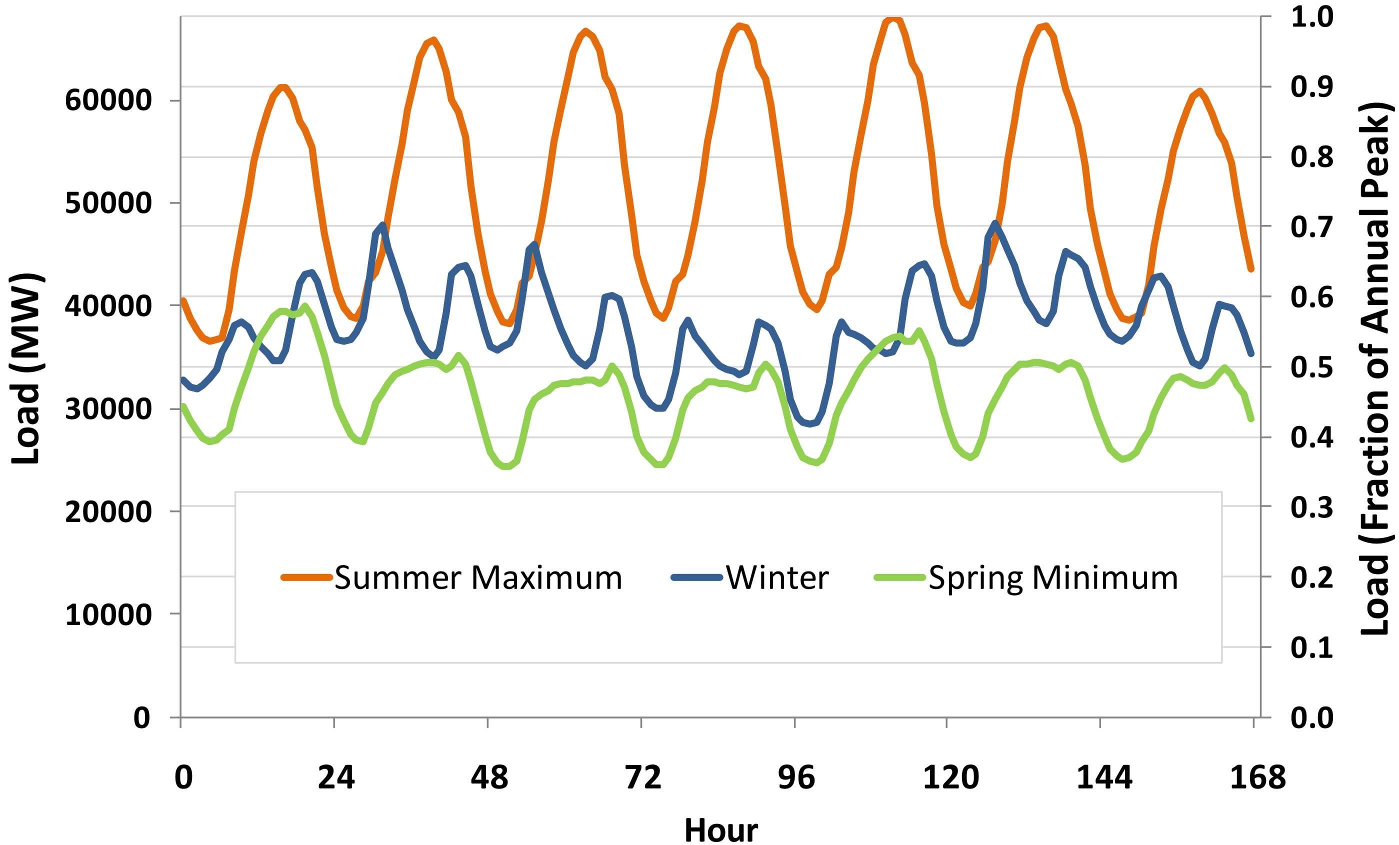
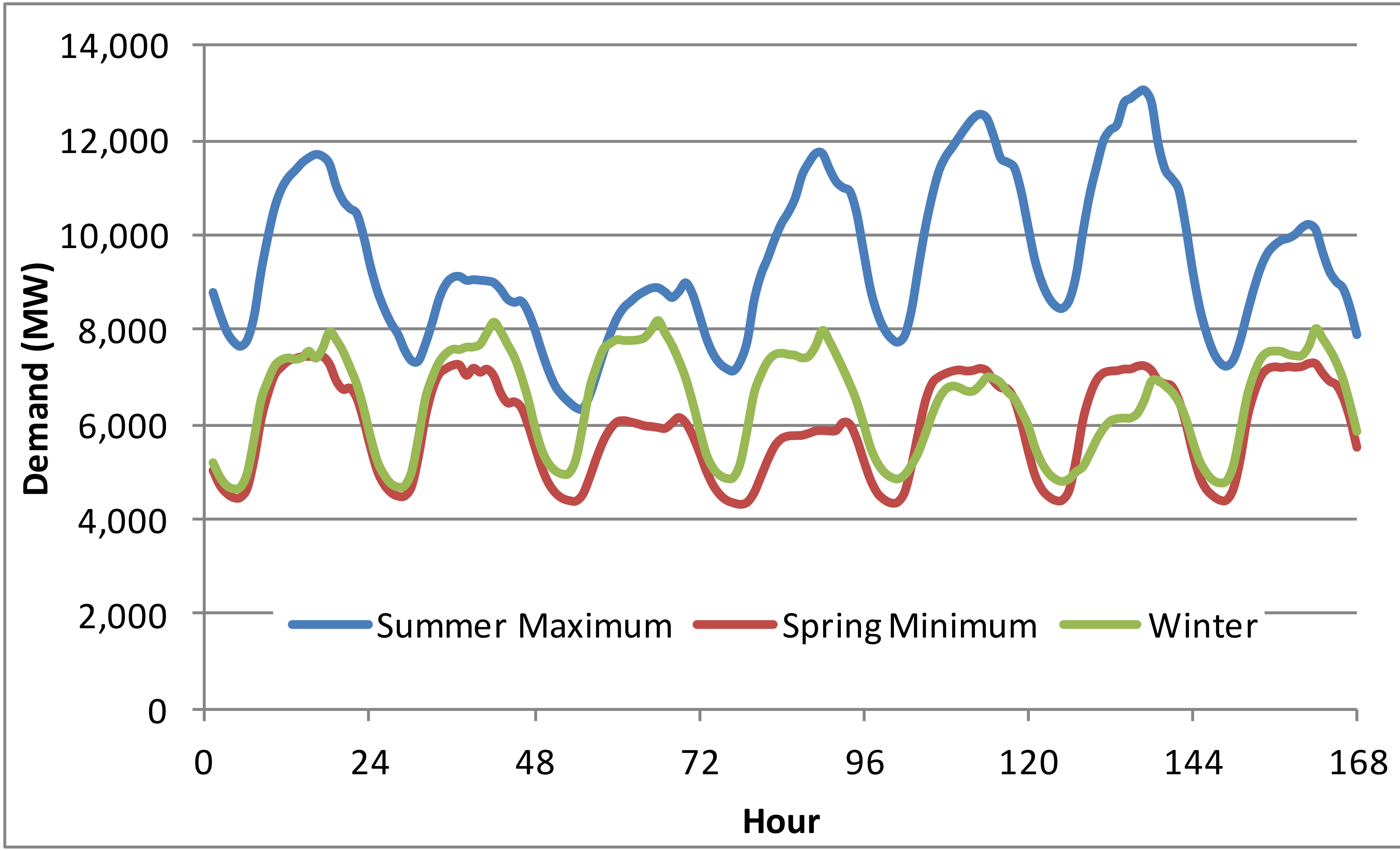
# Demand patterns are similar for much of the U.S.



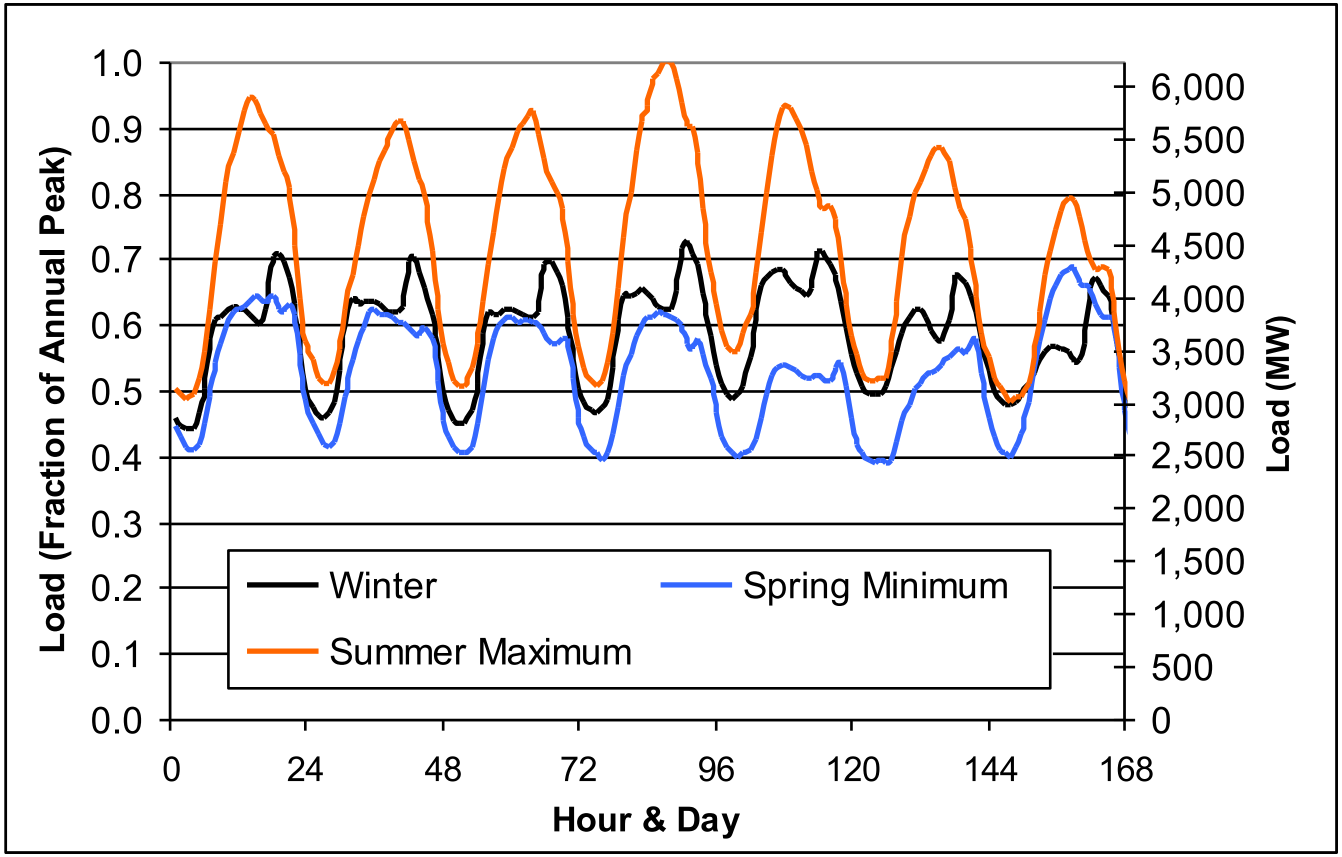

Hourly electricity demand for three weeks in the ERCOT (Texas) Grid in 2005

# New York City



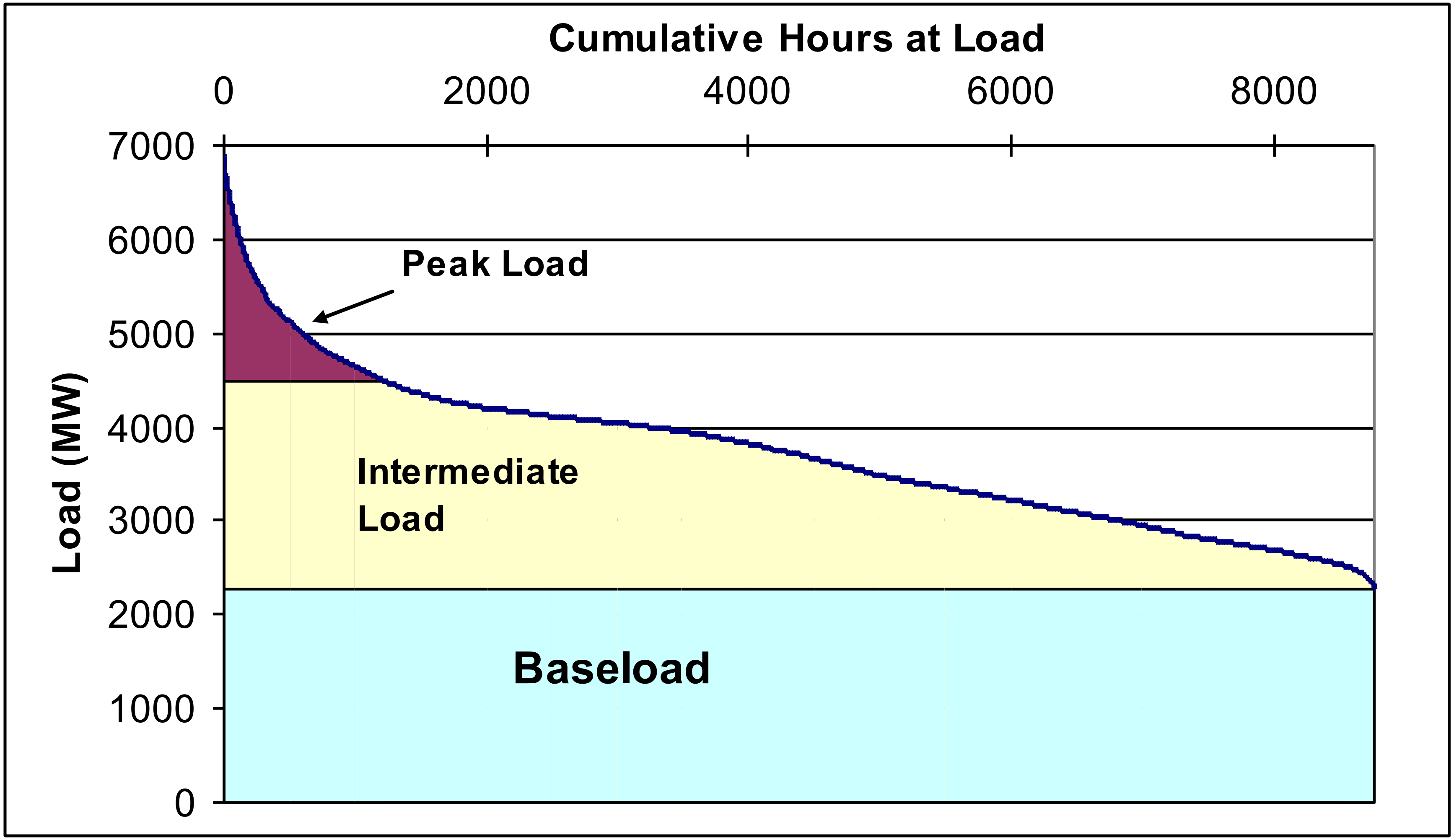

NYC (Con Ed) Demand in 2005

# Colorado



Load (Fraction of Annual Peak)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Load (MW)
Winter
Spring Minimum
Summer Maximum
0
24
48
72
96
120
144
168
Hour & Day

# Traditional LDC–Based Planning




Load Duration Curve

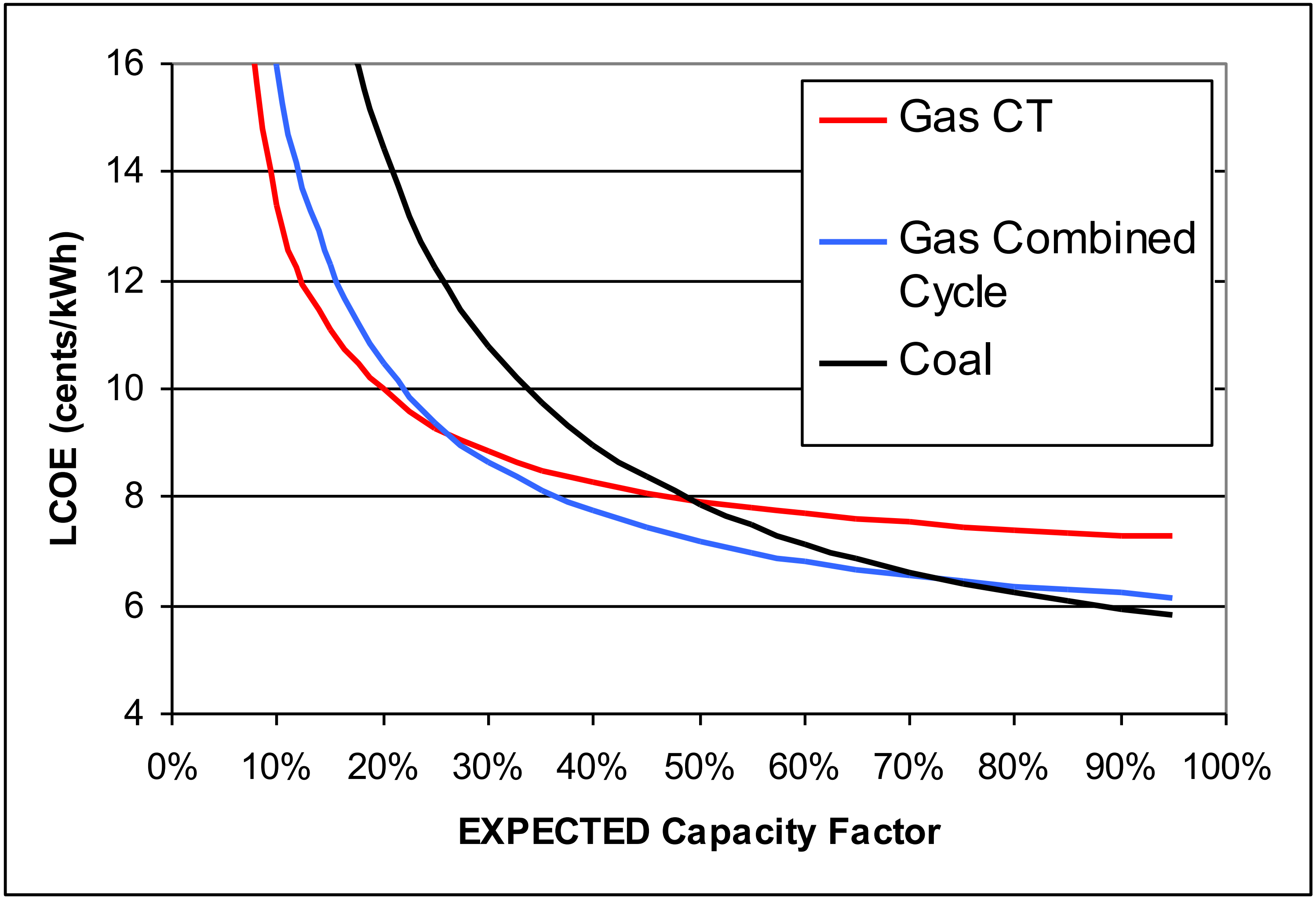
# Simple Capacity Expansion Problem

Calculate the "Levelized Cost of Energy" for several plant types and the resulting optimal mix

LCOE = Fixed Cost + Variable Oper. & Maint. + Fuel

$$\text{Fixed Cost} = \frac{\text{Capital Cost} * \text{Capital Charge Rate}}{\text{Capacity Factor} * 8760}$$

# LCOE Determines the Mix of Generators



# Simple Solution