SAND2009-3005P

# Impacts of Integrating Renewable Energies into the Electrical Grid

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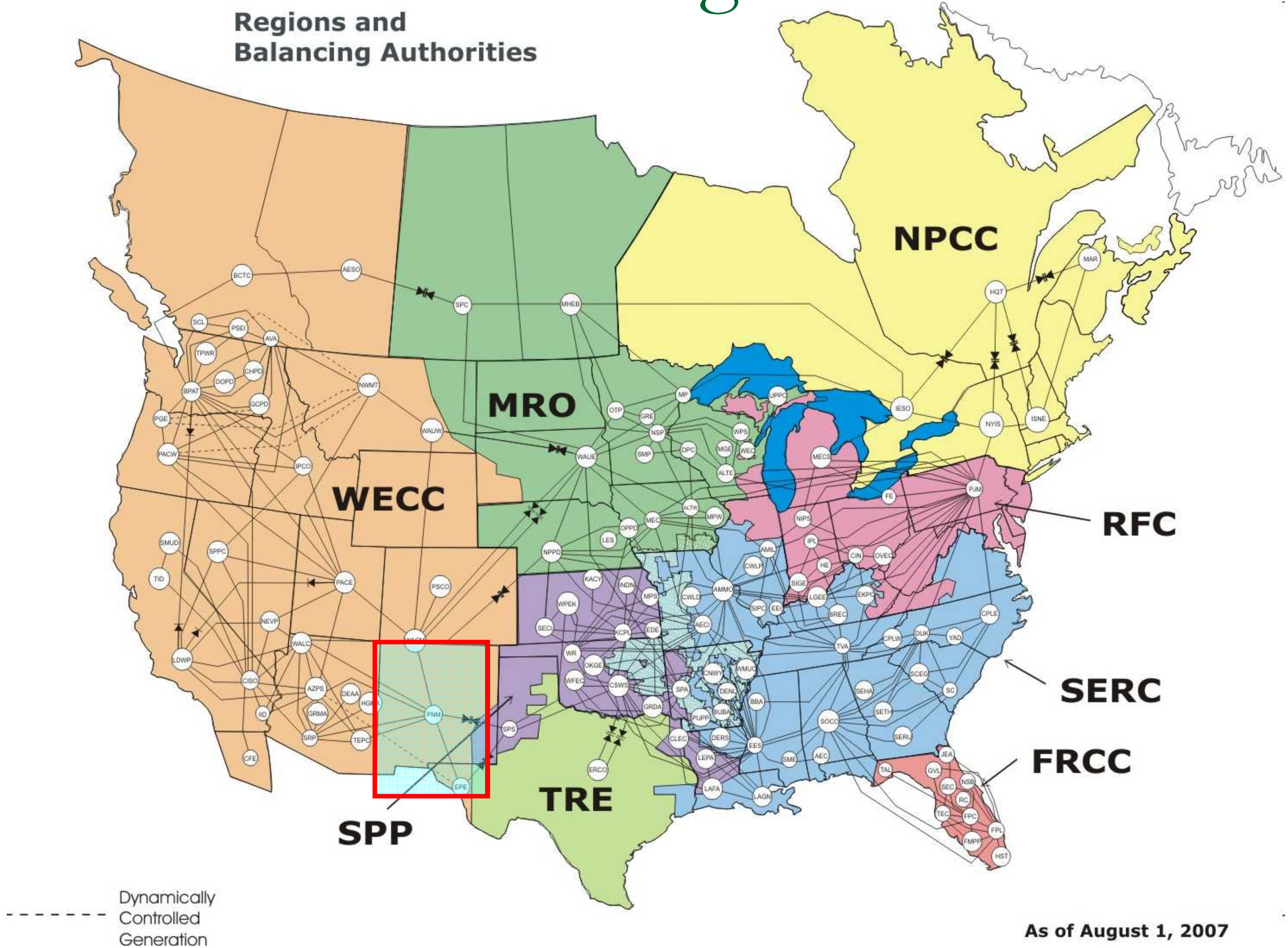
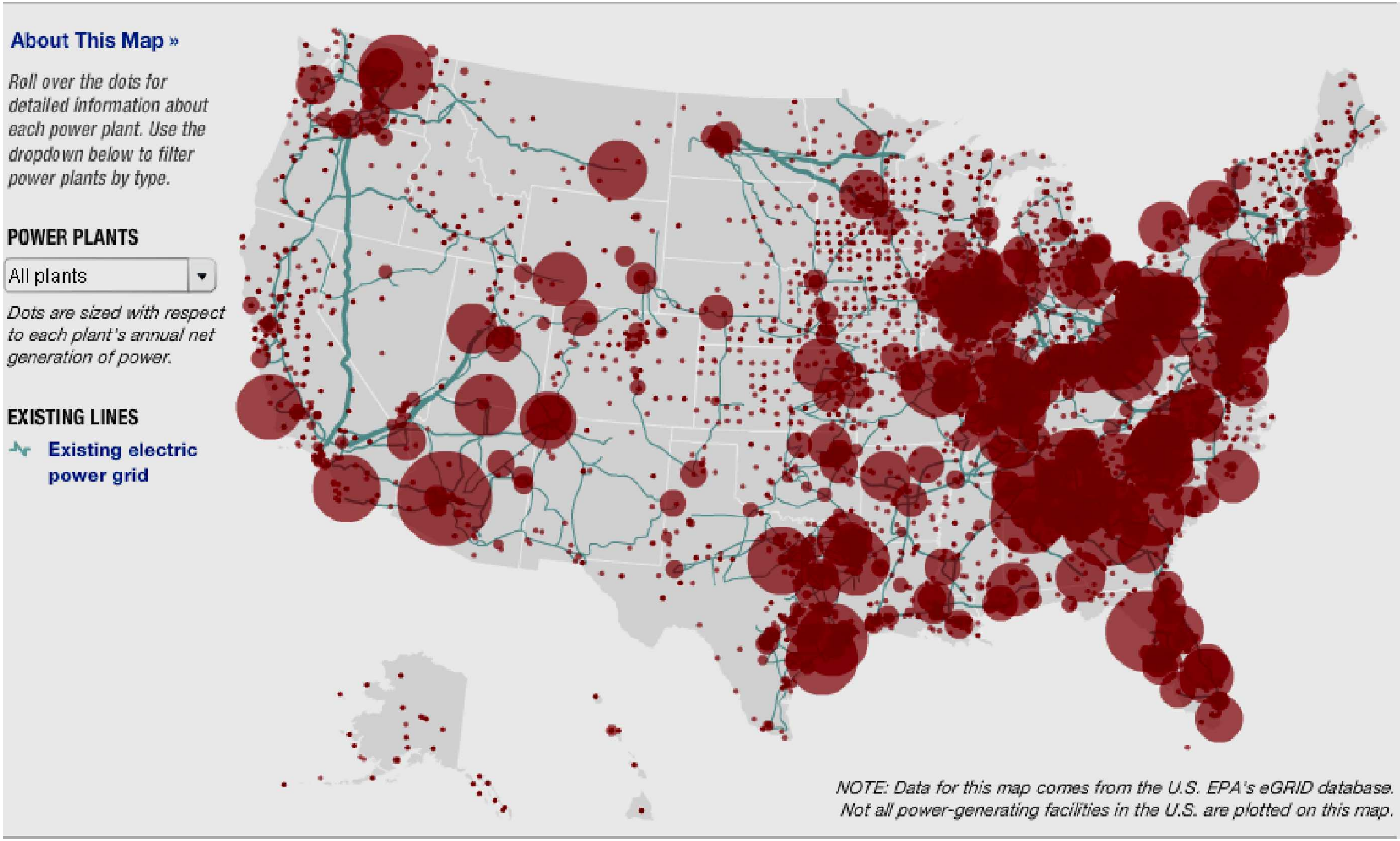
**ENG300 Course Project** **Spring 2009**

# US Electric Grid:  Regions & BAs



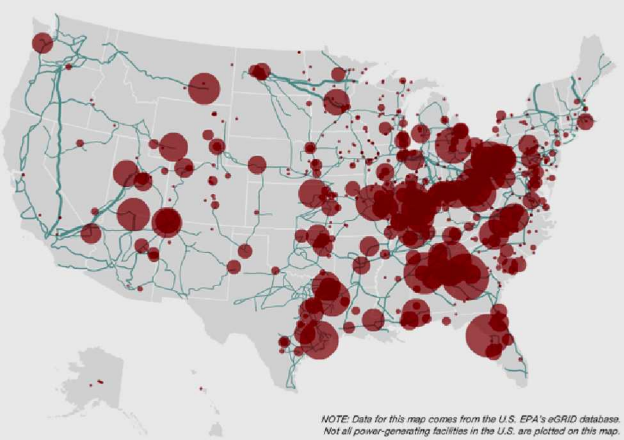

- Source: http://www.nerc.com/fileUploads/File/AboutNERC/maps/NERC_Regions_BA.jpg

# Electrical Power Plants: All

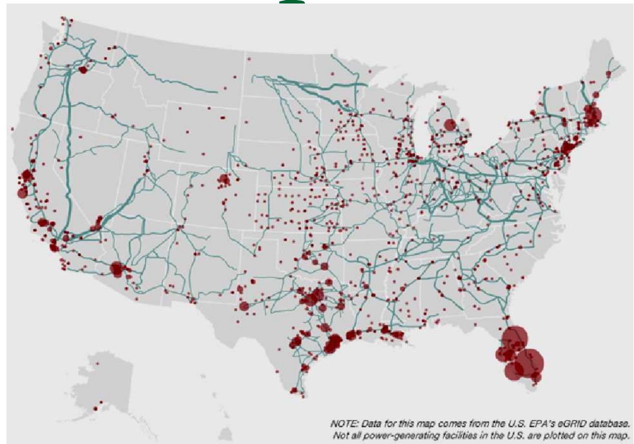



- Source: http://www.npr.org/news/graphics/2009/apr/electric-grid/

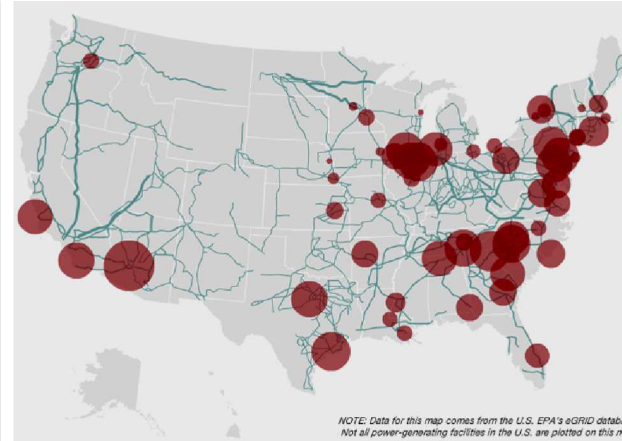
# Power Plants: Dispatchable



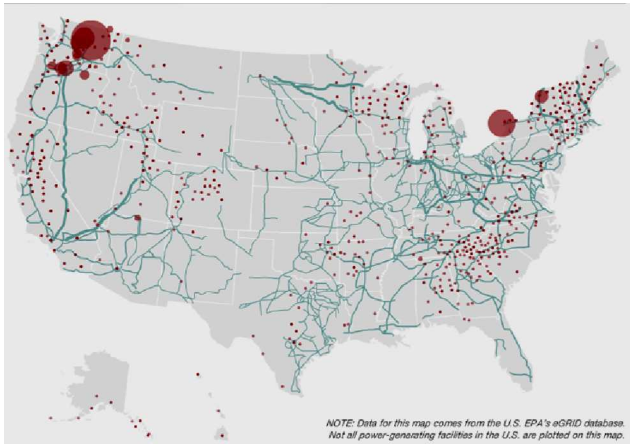

- Coal



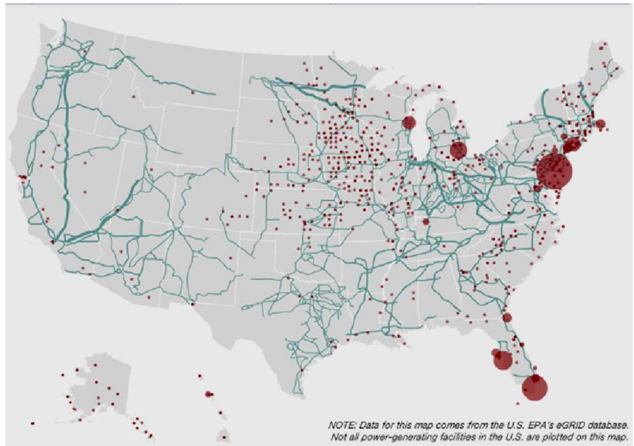

- Natural Gas



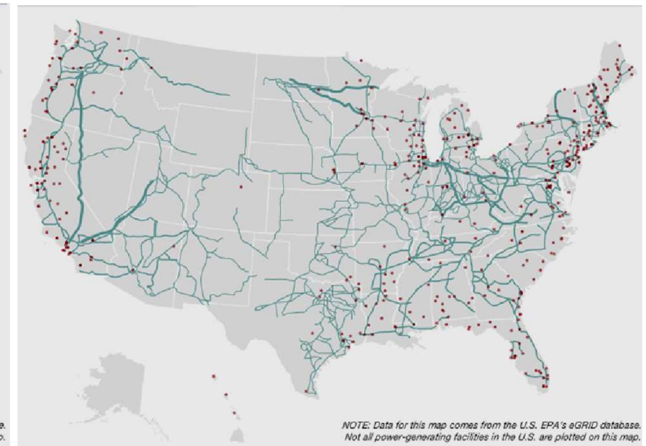

- Nuclear




- Hydro




- Oil

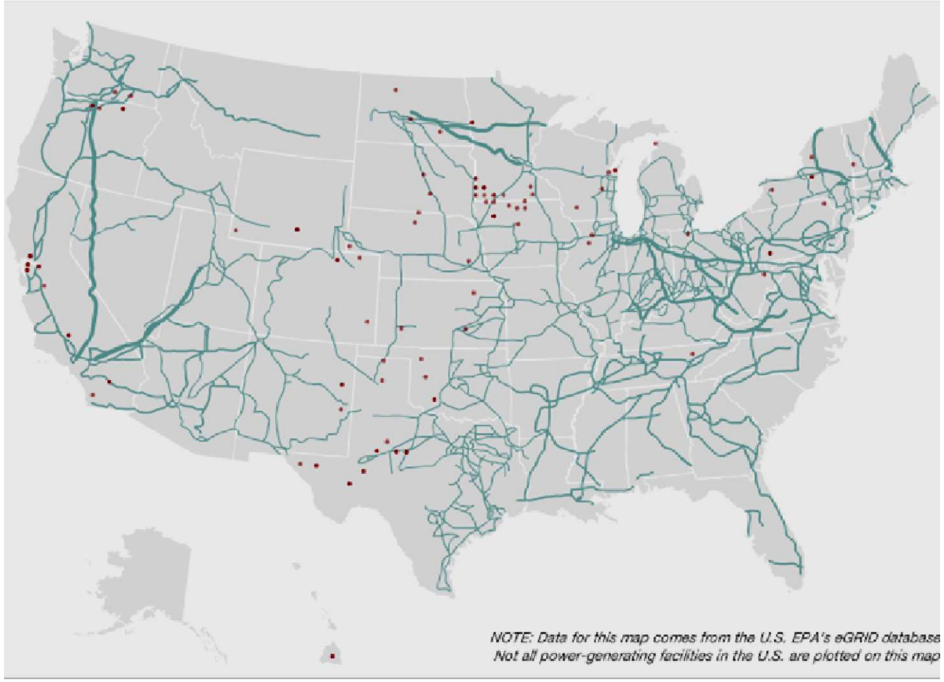



- Biomass

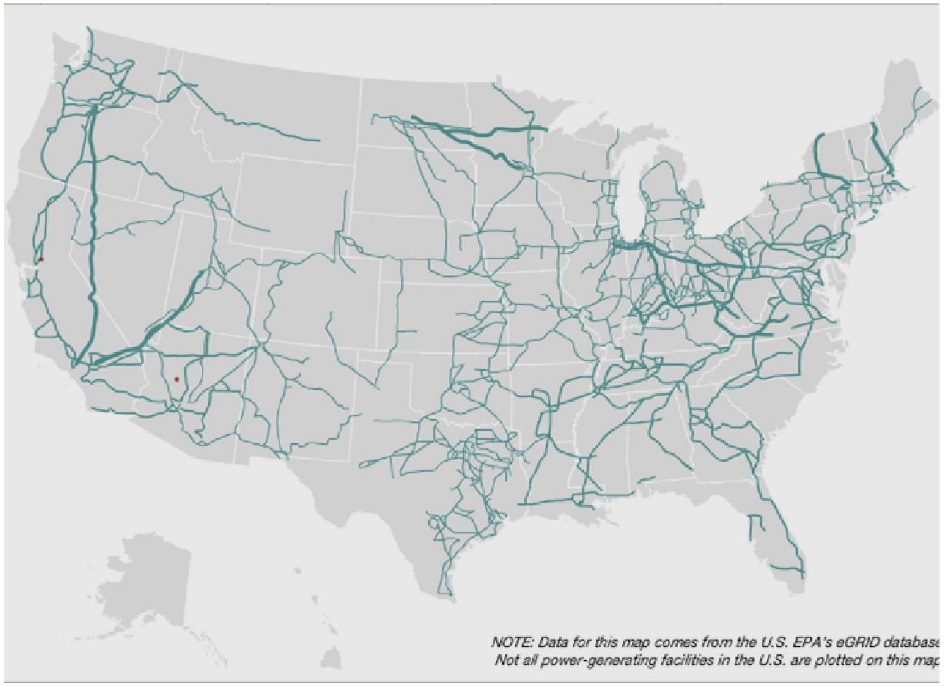
- Dispatchable:
  - Can generate on-demand to meet load

- Source: http://www.npr.org/news/graphics/2009/apr/electric-grid/

# Power Plants:  Nondispatchable




- Wind

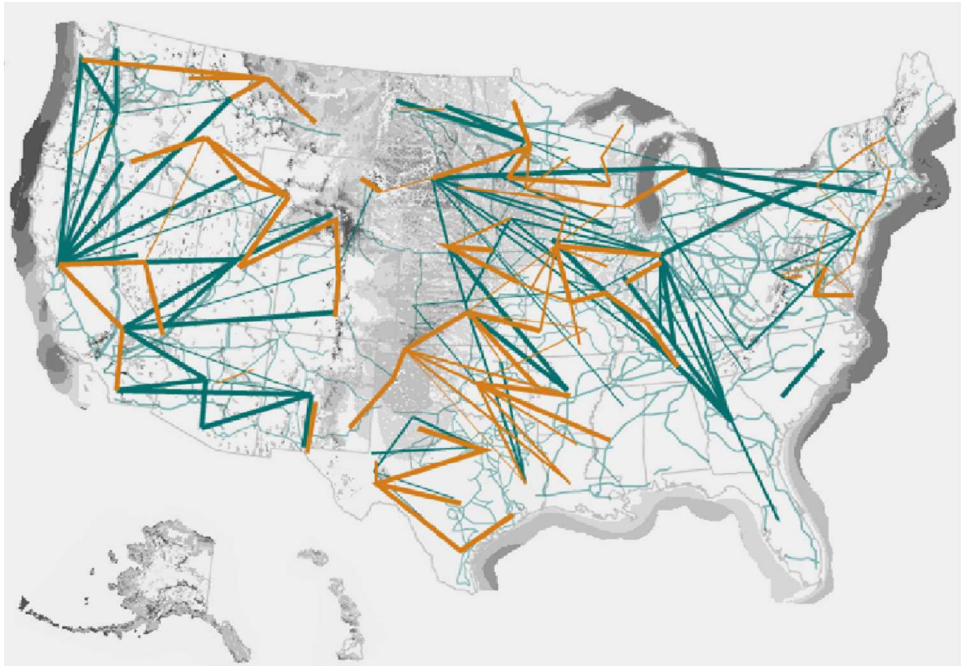


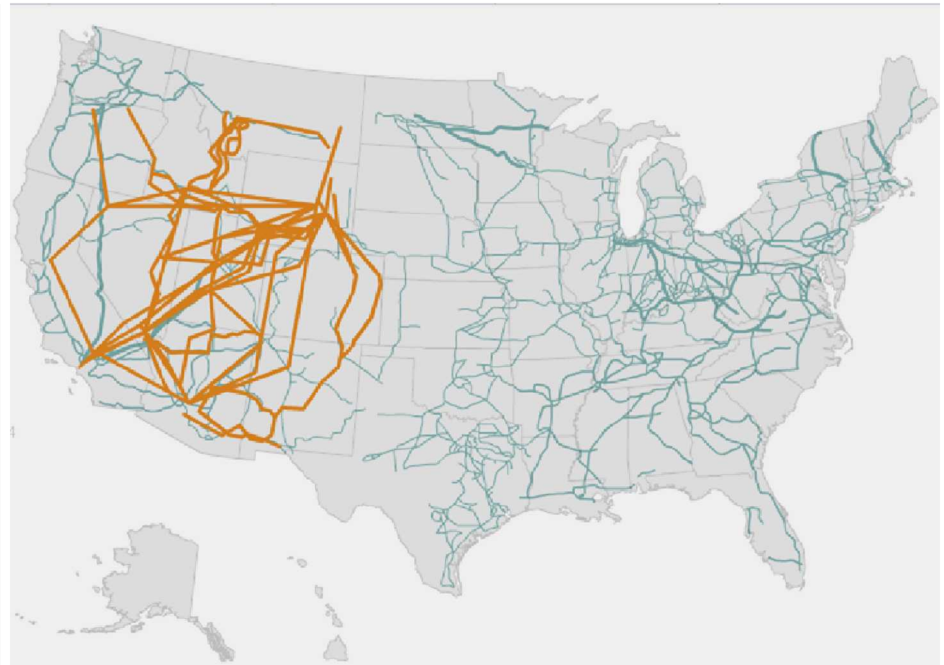

- Solar

- Nondispatchable:
  - Can NOT generate on-demand to meet load

- Source: http://www.npr.org/news/graphics/2009/apr/electric-grid/

# Electric Grid:  Future Renewables





EXISTING LINES

Existing electric power grid

PROPOSED LINES

Wind power transmission lines in 2030

New wind power transmission lines projected after 2030

EXISTING CAPACITY

Wind speed

*At 50m (164 ft), in mph*

- Superb: 19.7-24.8
- Outstanding: 17.9-19.7
- Excellent: 16.8-17.9
- Good: 15.7-16.8
- Fair: 14.3-15.7

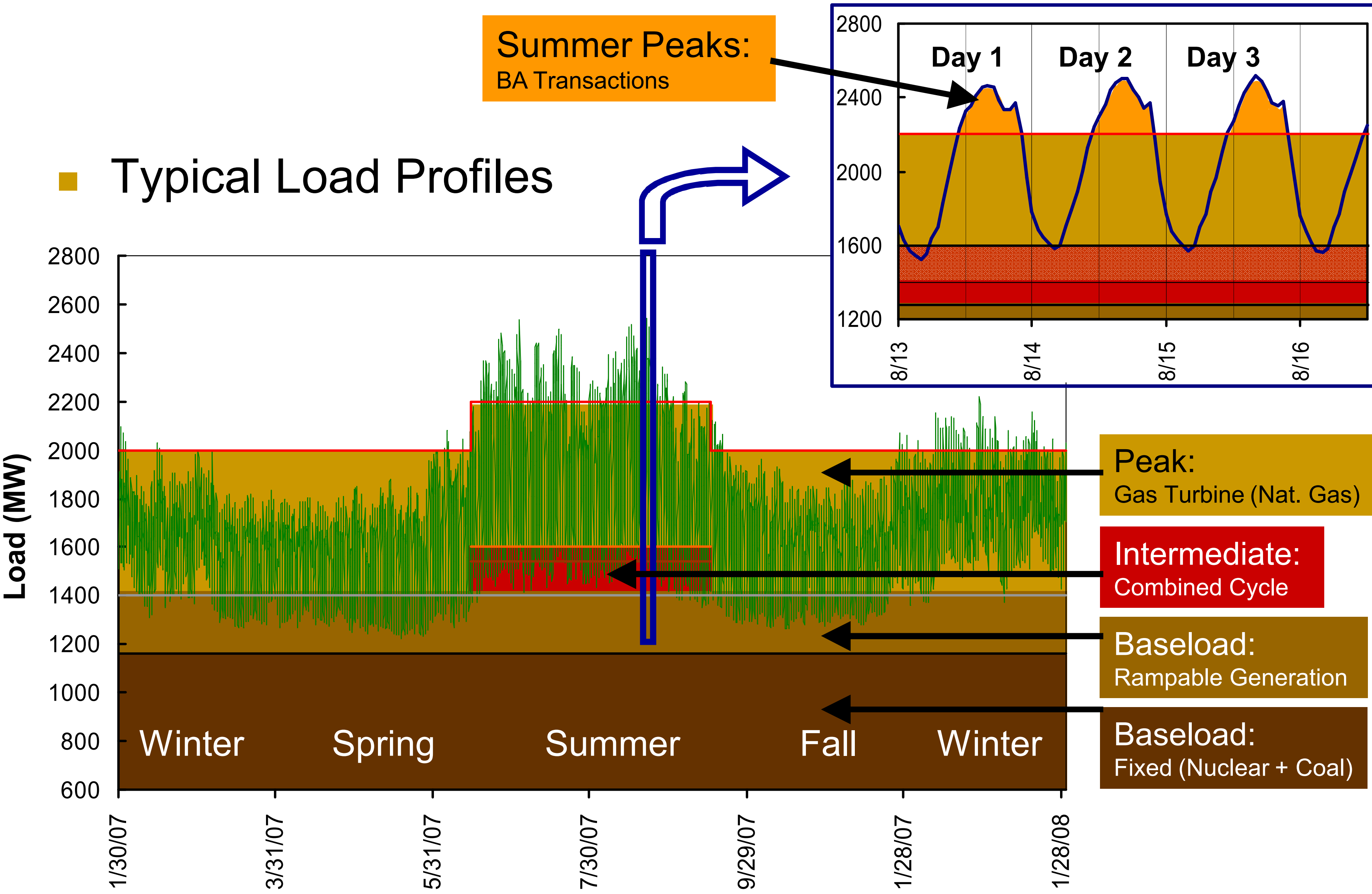
- Wind energy transmission

- Solar energy transmission

Source: http://www.npr.org/news/graphics/2009/apr/electric-grid/

# New Mexico BA: Load & Generators

- Typical Load Profiles



# New Mexico BA: Generator Types

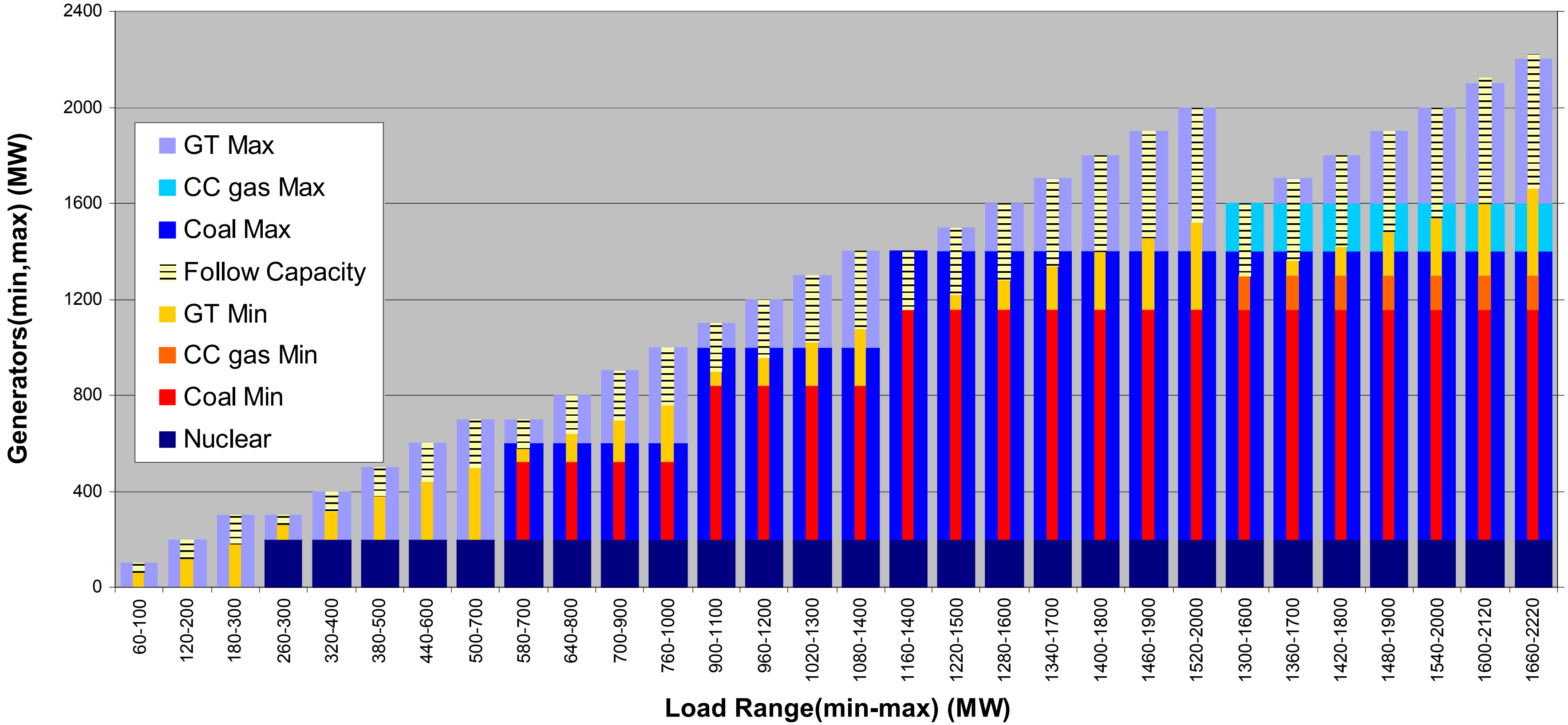
| NM Balance Area: Generator Type Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Generator** (Type) | **Unit size** (MW) | **Units/ plant** (#) | **Load Regulation** (% available) | **Min-Max Energy** (MW/unit) | **Stop-start** (hours) | **Startup** (hours) | **Ramp Rate** (MW/min/unit) |
| **Nuclear** | 1000 | 1 | 0 | 200 | n/a | n/a | 0 |
| **Coal** | 400 | 3 | 20 | 320-400 | 180 | 8 | 10 |
| **CC Gas** | 200 | 1 | 30 | 140-200 | 180 | 2 | 20 |
| **Gas Turbine** | 100 | 6 | 40 | 60-100 | 2 | 0.33 | 30 |
| **Wind 1** | 204* | 1 | n/a | 0-204 | 2 | n/a | n/a |
| **Wind 2** | 90* | 1 | n/a | 0-90 | 2 | n/a | n/a |

* 2007 wind farms modeled, current NM wind capacity is 496 MW

Legend:

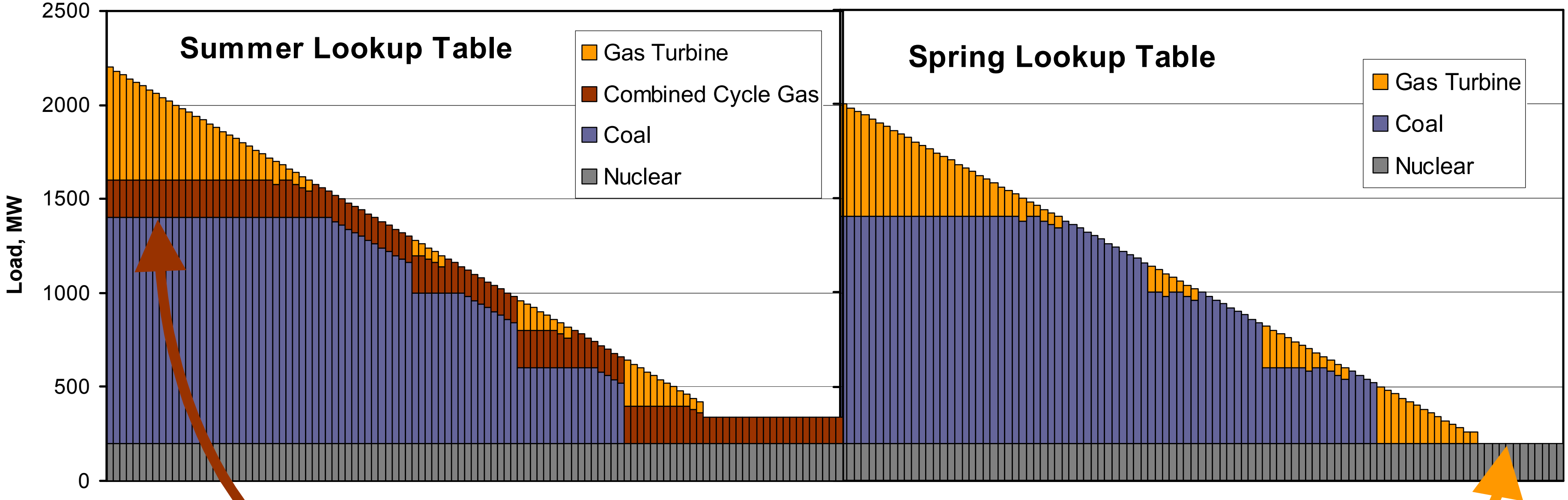
- Always on
- Seasonal
- Baseload (minimal on/off)
- Peak Load Follow
- Intermittent

# New Mexico BA: Generators & Load




- Load-matching & Generator Differences:
  - Unit capacities
  - Unit ramp rates
  - Unit shut-down/restart limitations
- As load increases, follow capacity increases

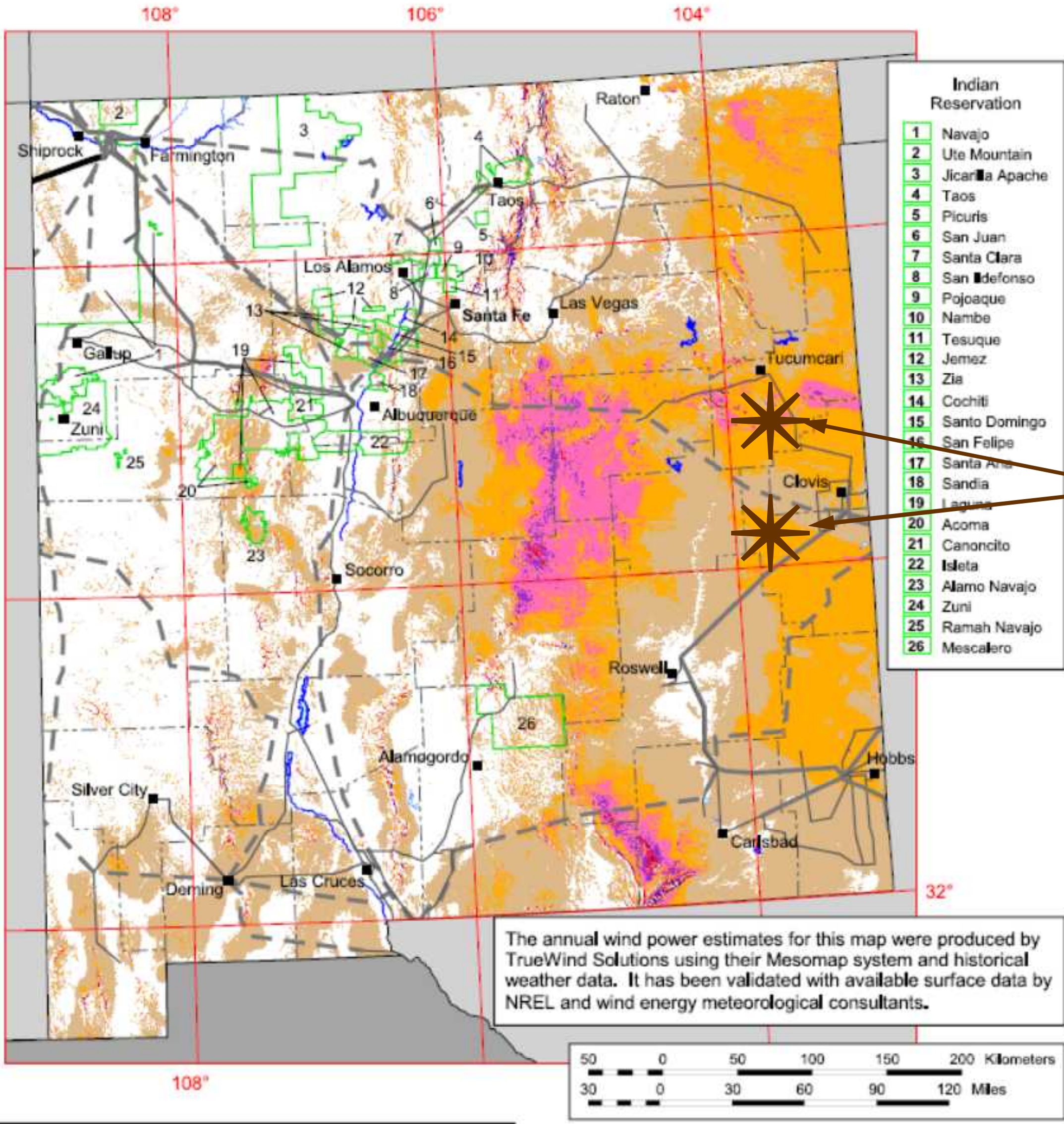
# New Mexico BA: Generators & Load




- Load-matching & Model Lookup Tables:
  - Summer: include CC Gas
  - Spring: no CC Gas
  - All seasons: Coal units shutdown/startup
    - Problematic condition

# New Mexico BA:  Wind

New Mexico - Wind Resource at 50 m




Wind Resources in NM:

- two wind farms in 2007
  - 2007 capacity ~294 MW
- current utility wind ~496 MW

2007 wind farms

Transmission Line*
Voltage (kV)
115 - 138
230
345
500

* Source: POWERmap, ©2002 Platts, a Division of the McGraw-Hill Companies

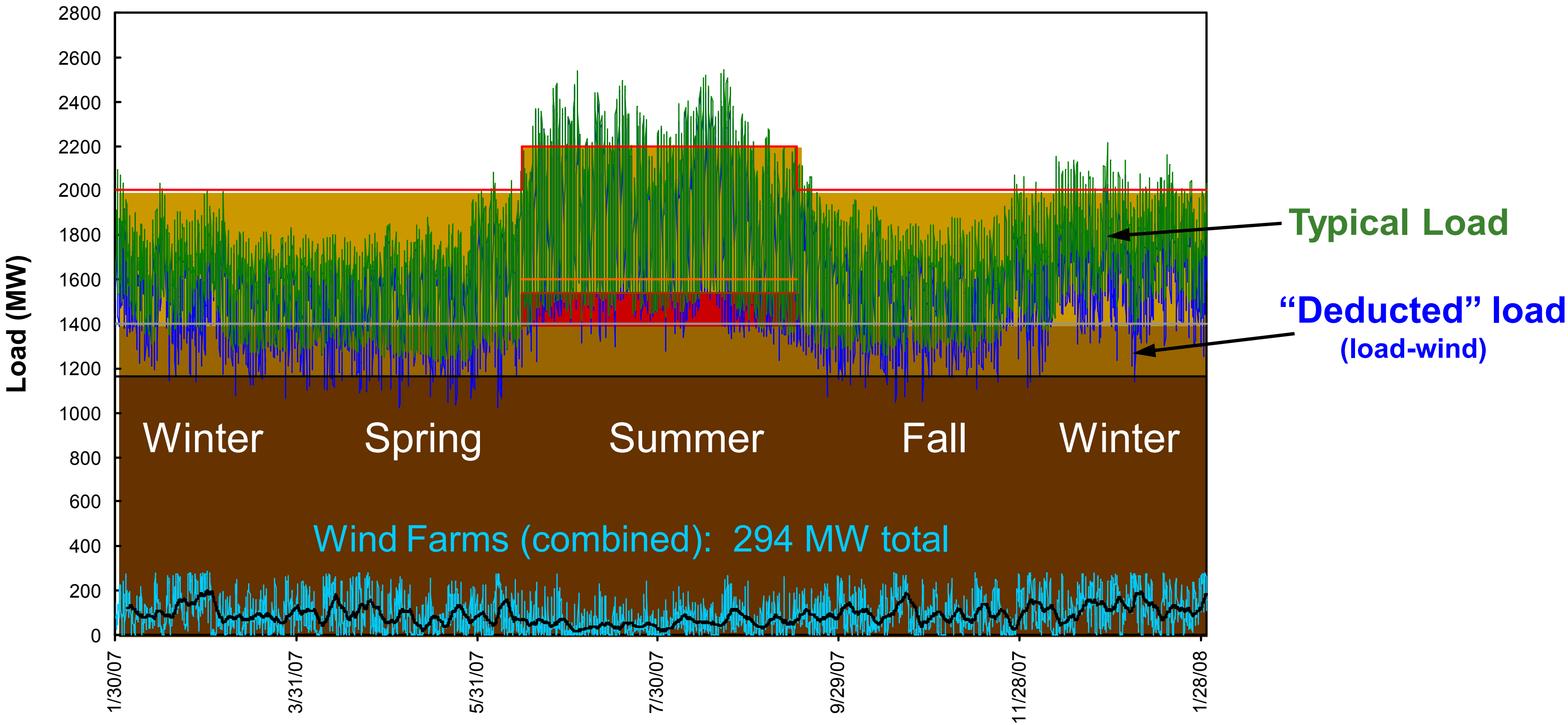
Wind Power Classification

| Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m $^2$ | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph |
|---|---|---|---|---|
| 1 | Poor | 0 - 200 | 0.0 - 5.9 | 0.0 - 13.2 |
| 2 | Marginal | 200 - 300 | 5.9 - 6.7 | 13.2 - 15.0 |
| 3 | Fair | 300 - 400 | 6.7 - 7.4 | 15.0 - 16.6 |
| 4 | Good | 400 - 500 | 7.4 - 7.9 | 16.6 - 17.7 |
| 5 | Excellent | 500 - 600 | 7.9 - 8.4 | 17.7 - 18.8 |
| 6 | Outstanding | 600 - 800 | 8.4 - 9.3 | 18.8 - 20.8 |
| 7 | Superb | > 800 | > 9.3 | > 20.8 |

[a] Wind speeds are based on a Weibull k of 2.0 at 1500 m elevation.

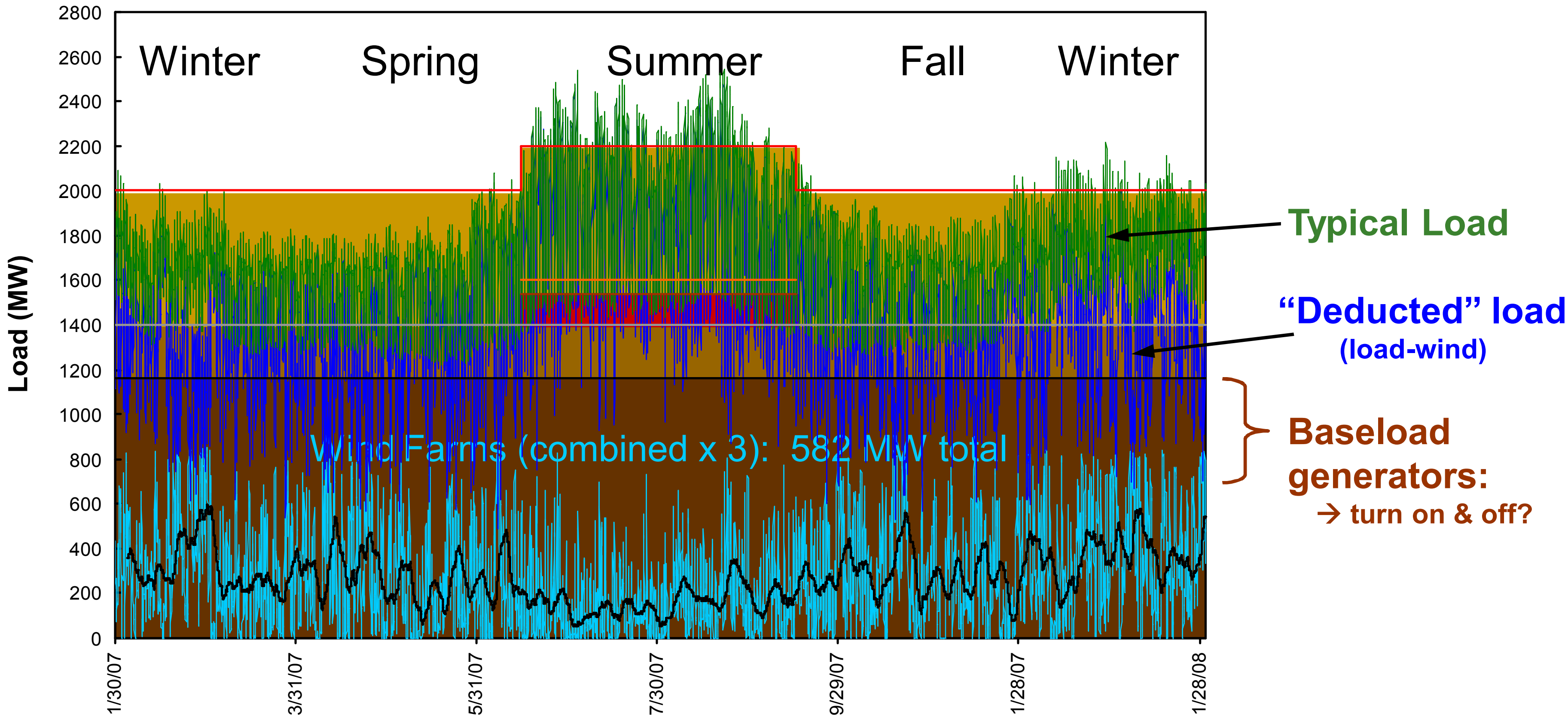
- Source: http://www.windpoweringamerica.gov/pdfs/wind_maps/nm_50m.pdf

# New Mexico BA: Wind Vs Load




- Wind generators are never turned off:
  - satisfy mandated renewable energy portfolios
  - model can consider this as “**deducted load**”
- Result is too much generation (where load penetrates baseload region)

# New Mexico BA: Wind Vs Load



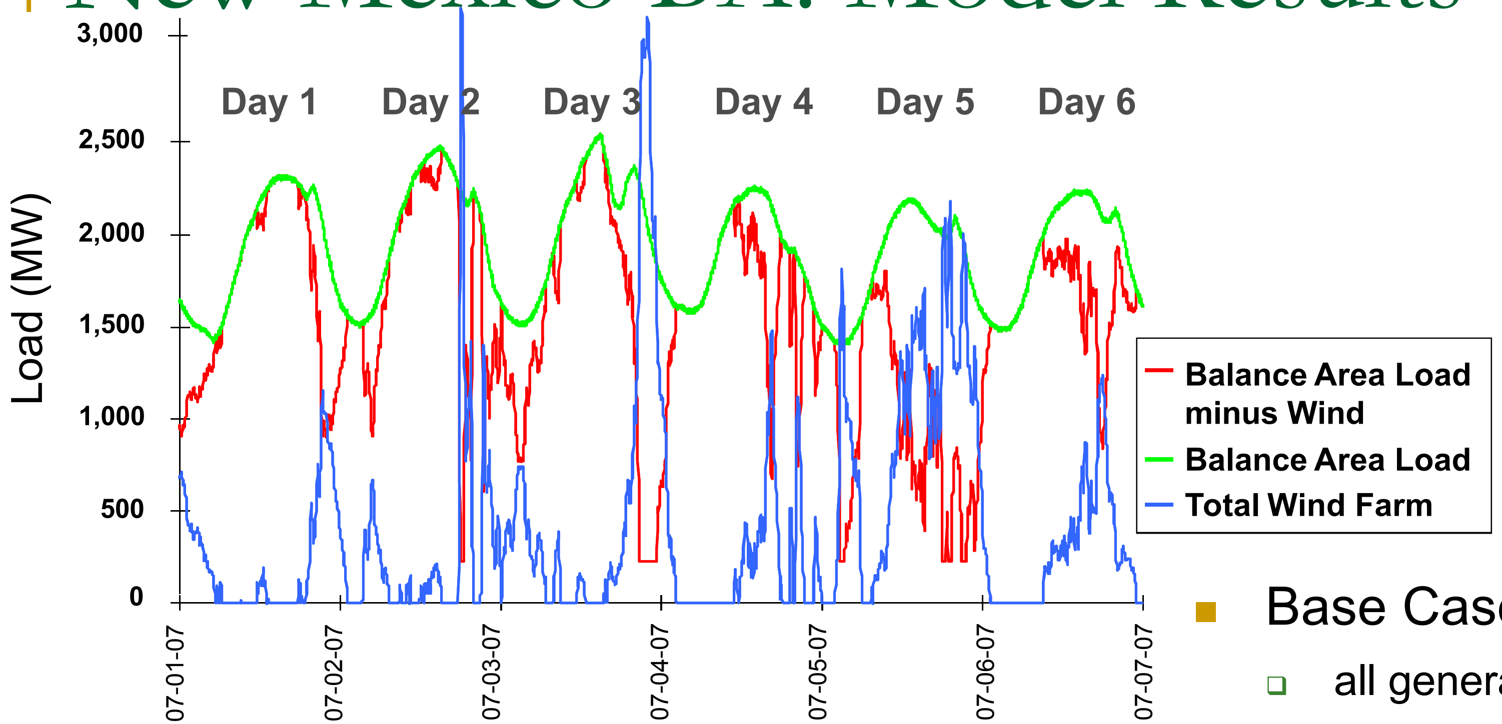

- Consider 3x 2007 wind generators (never turned off):
  - greater penetration into **baseload region**,
  - greater range of load change (min vs max load)
    - need **more generator ramping capacity** at **lower loads**
  - **wind generation** peaks and **load peaks** do not match

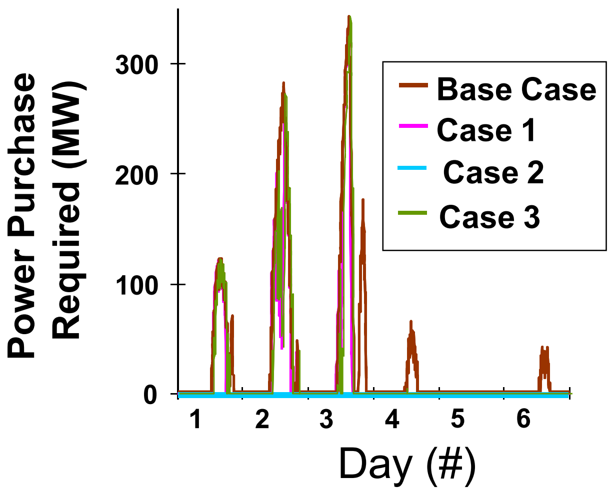
# New Mexico BA:  Model Structure

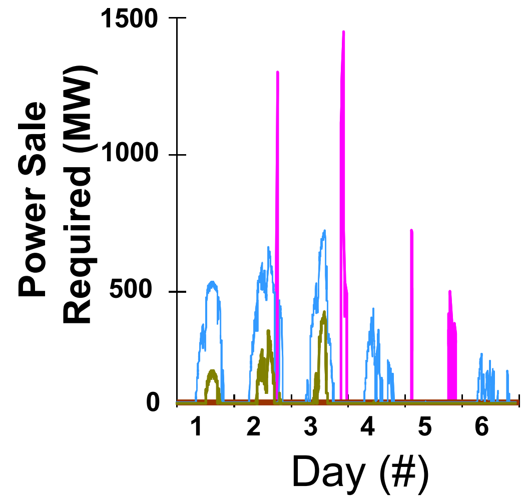
- Based on existing infrastructure of transmission and balance areas, what are considerations regarding multiple generator types/sources?

- Model stuff…
  - Model Graphic/diagram/flowchart
  - Model description

# New Mexico BA: Model Results

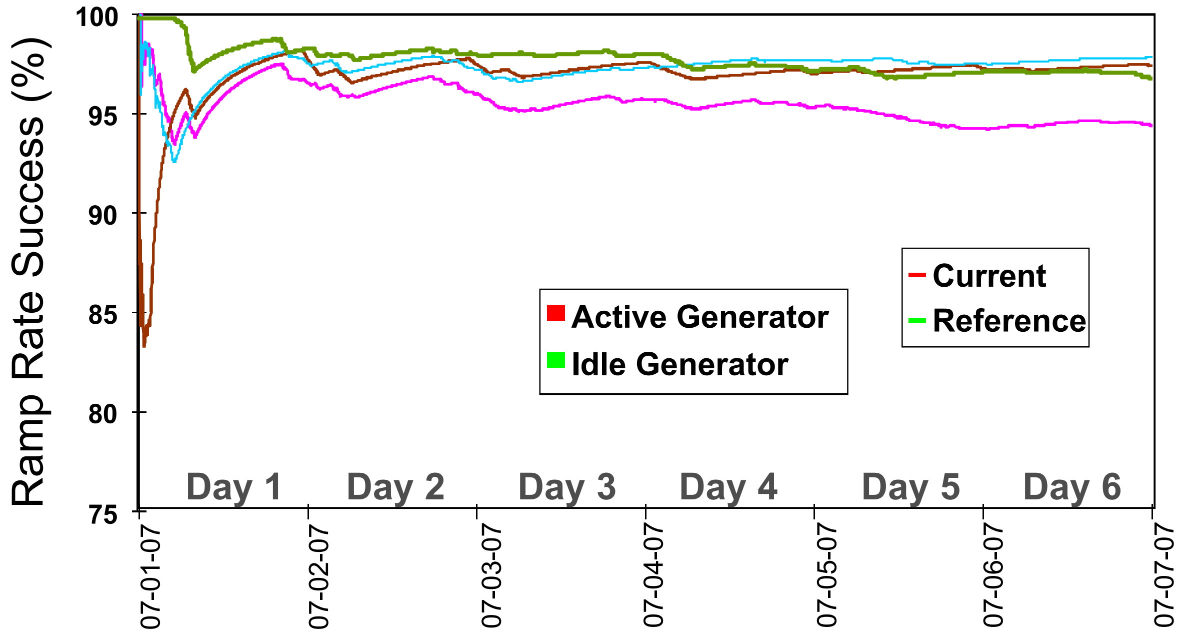



- Base Case (Summer):
  - all generators, **no wind**
- Case 1 model:
  - all generators **+ 10x wind**
- Case 2 model:
  - all generators **minus 1 coal unit + 10x wind**
- Case 3 model:
  - **Case 1, no ramping**

# New Mexico BA: Model Results

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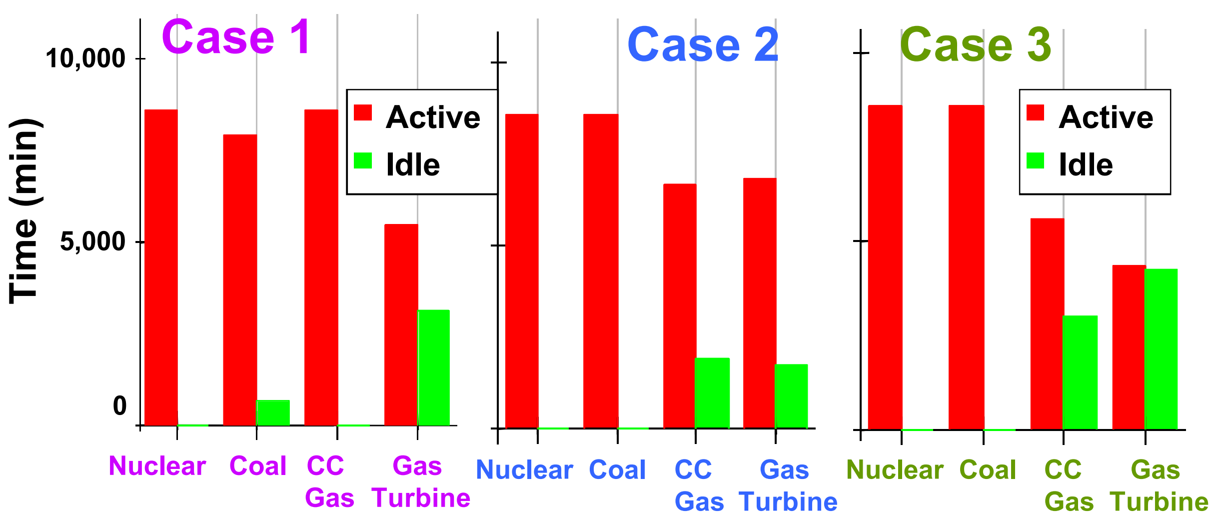


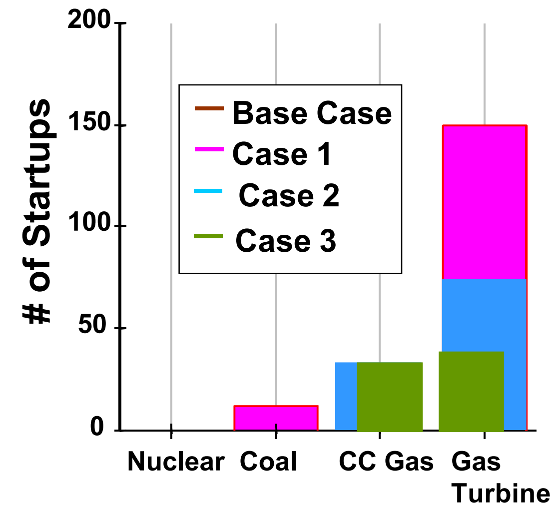

# Renewable Generators: Intermittent!

- Model Limitations:
  - Generators
    - (solar absent, ramp rates, start lag, off-line intervals, etc.)
  - Regulation (ACE, market economics)
  - 24-hr forecasting (1-hr forecasting modeled)
  - Storage systems
  - Metrics (costs, GHG emissions, water use, etc.)
- Penetration remedies:
  - Storage (long term solution)
    - pumped hydro, compressed gas, batteries, solar thermal, fuel cells, flywheels, capacitors, etc.
  - Improved renewable systems (intermediate term solution)
  - Grid integration across sectors (long/intermediate solution)
    - better load matching from more renewable generators
    - more acceptance of 1-hr forecasting
  - Shut down wind when loads low (short term solution)
    - use wind for peak loads only

# Electrical Grid Storage: Types

| **Electrical Grid Storage Options:** | | | | | (conversion) Power | (total) Energy | | Energy | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Type/description** | **Capacity (MWhrs)** | **Charge Rate (MW)** | **Discharge Rate (MW)** | **Min Charge State(%Capty)** | **Efficiency (%)** | **Efficiency (%)** | **Response time(cycle)** | **Cost ($/MWh)** | **Notes/comments** | **References** |
| **Battery Systems** | | | | | | | | | | |
| > Lead-acid | 5-160 | | 0.001-50.0 | 40-50 | 85 | 75-80 | <1/4 | 0.15-0.27 | Poor energy density, short cycle life, high maintenance, toxic materials. Most cost-effective electrical storage known, most mature. Float charging = constant voltage applied to fully-charged battery, to counter self-discharge, ensures fully charged when needed. In 1999, 93.3% of battery lead recycled, and large % of plastic battery case. | (SandRprt-4247,2008) (Kaldellis,Energy,2007) (SandRprt-0765,2001) (Dufo-Lopez,EP,2009) |
| > VRLA/OPZS batteries | 3 | 1.75-6 hrs | | 20 | | | | 0.2 | | (SandRprt-4247,2008) (Dufo-Lopez,EP,2009) (Hund-Testing,2008) |
| > Ni-Cd | 7 | | 0.001-25.0 | | | 70-90 | | 0.60 | Deep discharge reduces life | (SandRprt-4247,2008) (Kaldellis,Energy,2007) (McDowall,JPS,2006) |
| > Na-S | 1-7 | recharge: 5-10hrs for Hi-pulse 2x30sec dischrge/hr, or Hi-pulse 5min discharge/12hr | 0.05-6.0 | 1-40 (10 typ) | 86-90 | 75-85 | | 0.17-0.35 | High energy density (3x lead-acid), long life w/ deep discharge, most suitable economically for energy management. Environmentally benign, sealed, no emissions, >99% recyclable, inexpensive. Total capital cost for 10MW system = $3.1-3.4/MW. | (SandRprt-4247,2008) (Kaldellis,Energy,2007) (SandRprt-0765,2001) (Dufo-Lopez,EP,2009) (Oshima,ACT,2004) (EPRI-DOE,2003) |
| > Ni-MH | | | | | | | | 0.35 | | (SandRprt-4247,2008) |
| > Na-NiCl (ZEBRA) | 0.01-10 | recharge: 1 hr (20kWh cell) | | 0 | 100 | | | 0.15 | Related to Na-S batteries. High power density with repeated heavy discharges, long life. Batteries stored fully charged indefinitely, no maintenance. Suitable for load leveling, peak storing, power conditioning at 0.1-10MWh. | (SandRprt-4247,2008) (BetaRsrch-App,2005) (Tilley,EVS-18,2001) |
| > Li-Ion | | | | | | | | 0.78 | | (SandRprt-4247,2008) |
| > flow batteries (Zn-Br, Vanadium redox, polysulfide-Br) | 0.02-100 | recharge: 4hrs | 0.02-100.0 | 1 | 75-85 | 60-70 | <1/4 | 0.24-1.5 | Total capital cost for 10MW system (Vanadium redox)= $4.3-4.5/MW. | (Kaldellis,Energy,2007) (McDowall,JPS,2006) (SandRprt-4247,2008) (SandRprt-0765,2001) |
| **Capacitors** | | | | | | | | | High-power, short-duration: capable of deep discharge and virtually unlimited cycle life. | (SandRprt-4247,2008) |
| > Electrochemical | | | | | | | | 0.25 | Short-term (seconds duration), costs thus in $/MW instead of $/MWh. | (SandRprt-4247,2008) |
| > Ultracapacitors | 0.0001 | same | 0.01-1.0 | | | 95 | <1/4 | 82 | Short term (seconds duration) | (Kaldellis,Energy,2007) (SandRprt-0765,2001) (McDowall,JPS,2006) |
| > Lead-carbon (hybrid) | | 1.2 hrs (3x lead-acid rate) - 20hrs | | 0.1 | 95 | 90-95 | | 0.24 | Stores energy both chemically (battery) and statically (capacitor). | (SandRprt-4247,2008) (AxionPwr-Tech,2004) (Lam,JPS,2006) |
| **Pumped Hydro** | 5,000-50,000 | | 100-1000 | 5 | 85 | 65-80 | minutes | 0.02-2.0 | Large storage can provide up to 1GW power for days. 22 GW at 150 facilities in 19 states -- almost exclusively utility-owned/operated, size up to 2.1 GW. Total capital cost for 1GW system = $0.98/MW. | (Kaldellis,Energy,2007) (SandRprt-0765,2001) (EPRI-DOE,2003) |
| **Flywheels** | | | 0.01-2 | | | | | | Short term (10-30secs duration), one type up to 3hr duration | (Kaldellis,Energy,2007) (EPRI-DOE,2003) |
| > Low-speed | 0.01-0.6 | 10sec-2.5min | 0.1-2 | | | | | 0.3 | Short term (10-15sec). | (SandRprt-4247,2008) (SandRprt-0765,2001) (McDowall,JPS,2006) |
| > High-speed | <0.05 | 15sec-2.5hr | 0.01-0.7 | | | 90 | | 0.35-25 | Short/med term (15sec-3hrs). | (SandRprt-4247,2008) (SandRprt-0765,2001) (McDowall,JPS,2006) |
| **Compressed Air (CAES)** | 4000 | | 25-350 | 30-45 | 80-85 | 70-80 | | | Large storage can provide up to 1GW for up to days. Total capital cost for 300MW system = $0.65/MW | (Kaldellis,Energy,2007) (EPRI-DOE,2003) |
| > aquifer | 10,000 | 12hr full recharge | 350 | | | | | 0.002 | | (SandRprt-0765,2001) |
| > pressure vesssels | 200-400 | | 25-100 | | | | | 0.4-0.8 | | (SandRprt-0765,2001) |
| **Hydrogen/Fuel Cells** | 0.1-24 | | 0.05-5.0 | 10 | 40-70 | 25-45 | seconds | 0.4-1.33 | | (Kaldellis,Energy,2007) (SandRprt-0765,2001) (Dufo-Lopez,EP,2009) |
| **SMES:** superconducting magnetic energy storage | 1-5000 | | 1-1000 | | | | <1/4 | | Short term (seconds duration) | (Kaldellis,Energy,2007) (SandRprt-0765,2001) (EPRI-DOE,2003) |

# Acknowledgements:

- Abraham Ellis
  - Grid operations information
  - Data for load and generators
  - Model development feedback
- Georgianne Peek
  - Electrical storage technologies
- Abas Akhil
  - Grid operations information
- Dan Riley
  - Solar generation data

- **Take Home Message:**
  - Introduction of intermittent supply generators (wind, solar, tidal/ocean) results in significant (and sometimes rapid) imbalances in grid unless remedied.
  - More imbalances → more disruption of grid

# Thank You!