CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Mapping Energy Futures:

Overlay of an Environmental Transmission Model on the Super OPF to Simultaneously Account for Air Quality, Locational Reliability and Price

Richard Schuler,
William Schulze, John Taber, Ray Zimmerman,, Max Zhang, Jubo Yan, Charles Marquet, Kale Smith (Cornell)
Dan Shawhan, Andy Kindle (RPI)
Dan Tylavsky, Di Shi (Arizona State University)

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Why a Planning Tool?

- A planning tool that optimizes investment in generation is needed because the electric power industry faces the possibility of
  - Increased loads consistent with the goal of energy independence (e.g., plug-in hybrids).
  - Increased loads from other energy users trying to find less CO_2 emitting sources of energy under threat of regulation
  - Restrictive caps or regulations on CO_2 emissions from generation
  - Possible regulations on the emissions of fine particulates

- As well as the need to maintain reliability

- The artificial $1000 cap on offer prices in electricity markets prevents a free market solution for optimal investment that requires planning.

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Importance of a Network

Outcomes depend on the transmission constraints in the system

Cannot necessarily use the cheapest or least polluting power

Most planning models (EPA IPM, RFF Haiku) ignore full transmission details, use “bubbles and pipes”

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

No model of the national electric power system exists that includes a sufficiently detailed specification of the electricity network, power generation, and air and environmental quality, to allow optimal investment in response to incentives or regulation.

We have just completed such a model and have stress tested it for the Northeastern US with plans to expand to the entire nation with a much more detailed network model.

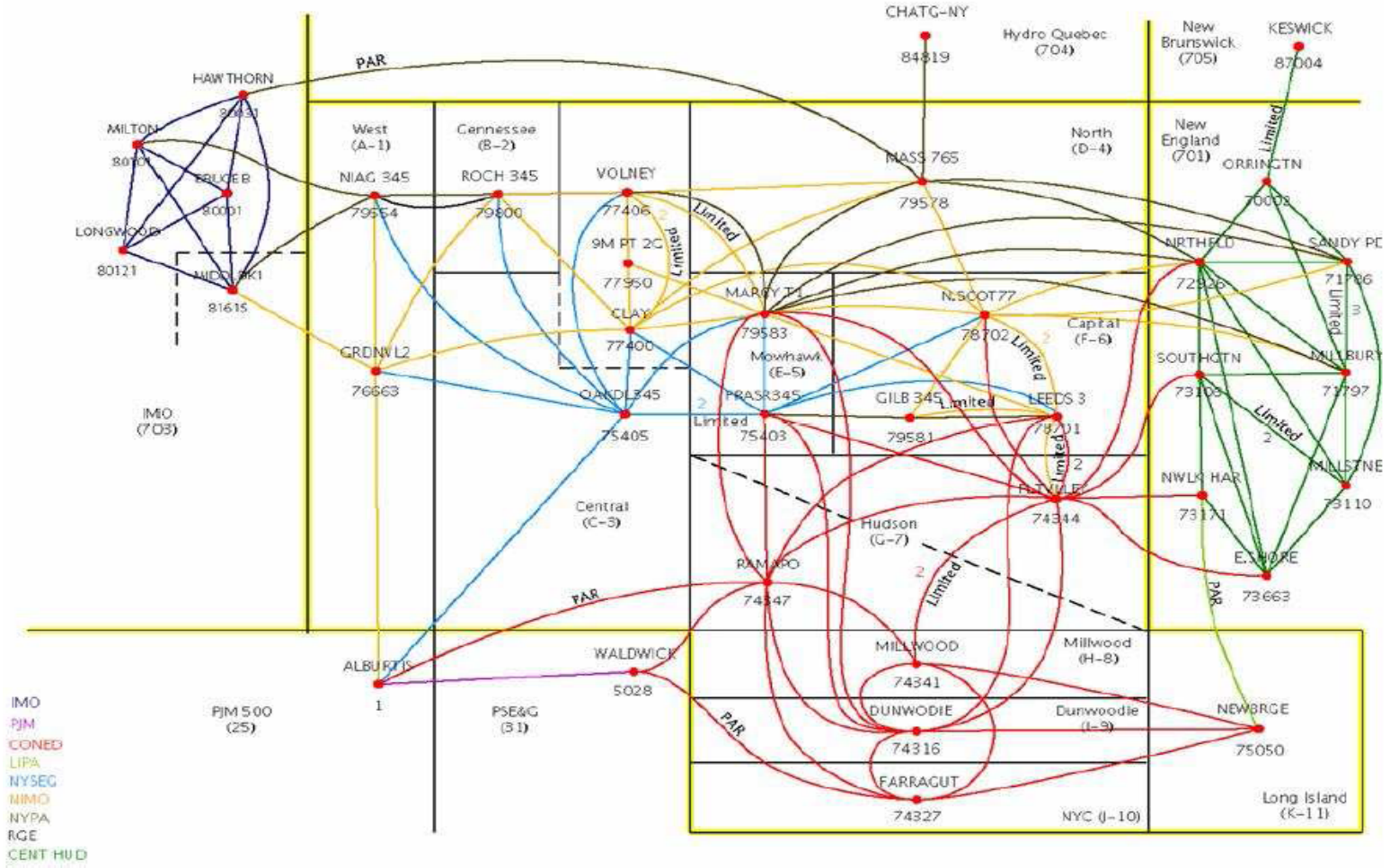
This model is adapted from the SuperOPF next generation real time optimal power flow software under development at Cornell. Some features are not used such as co-optimization, non-linear AC power flow modeling (DC modeling is used), etc., to allow reasonable solution times with the additional complexity of optimal investment over multiple hour types.

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

Model of the Northeast

PSERC



Eric Allen, Jeffrey Lang, and Marija Ilic, "A Combined Equivalenced-Electric, Economic & Market Representation of the Northeastern Power Coordinating Council (NPCC) US Electric Power System," IEEE Transactions on Power Systems, Vol. 3, Issue 3, 2008

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Model of the Northeast

	Capacity of NPCC	Capacity of US	Generation of NPCC	Generation of US
Coal	20%	31%	27%	44%
Natural Gas	32%	39%	20%	23%
Oil	13%	6%	1%	1%
Nuclear	25%	10%	35%	20%
Hydro	10%	8%	15%	6%
Wind	<1%	3%	<1%	2%

Looks like future direction for the United States?

The Northeast is more geared towards low-carbon electricity generation

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Model Information

- Generation unit data: Energy Visuals; EPA; and Allen, Lang and Ilic data sets matched up
- Base year is 2012. Investment allowed in 2022 and 2032. New plants must pay for capital.
- Underused plants are retired.
- Note that old plants must only cover variable costs and taxes while new plants must additionally cover investment costs. If old plants go bankrupt, they are sold at a discount, and keep generating.
- Sixteen hour types represent the year. Vary in terms of unit availability (from NERC) and load (from all ISOs).
- Load grows at 0.59% per year (before long run demand response) per NYISO projections

http://www.nyiso.com/public/webdocs/newsroom/press_releases/2009/NYISO_2009_Summer_Outlook__05212009_(2).pdf

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

New Power Plant and Fuel Costs

PSERC

Fuel Type	Capital Recovery $/ MW/Year	Total Fixed Costs ($/MW)	Total Variable Cost $/MWh (in 2012)	Total Possible Capacity Additions
Coal (Dual Unit Advanced PC)	$497,201	$35,255	$29.05	10 GW
Natural Gas (Advanced NGCC)	$181,824	$20,661	$39.05	30 GW
Wind*	$392,322	$30,710	$0	3.5 GW
Nuclear	$1,141,454	$95,571	$2.04	5 GW

*Excluding incentives for wind generation (included in one model run)

$/MBTU	2012	2022	2032
Coal	$1.68	$1.65	$1.71
Natural Gas	$4.50	$5.39	$6.62

Updated Capital Cost Estimates for Electricity Generation Plants
November 2010, U.S. Energy Information Administration,
Office of Energy Analysis

Annual Energy Outlook 2011
April 26, 2011, U.S. Energy Information Administration

Cornell University

Long Run Demand Response (Conservation)

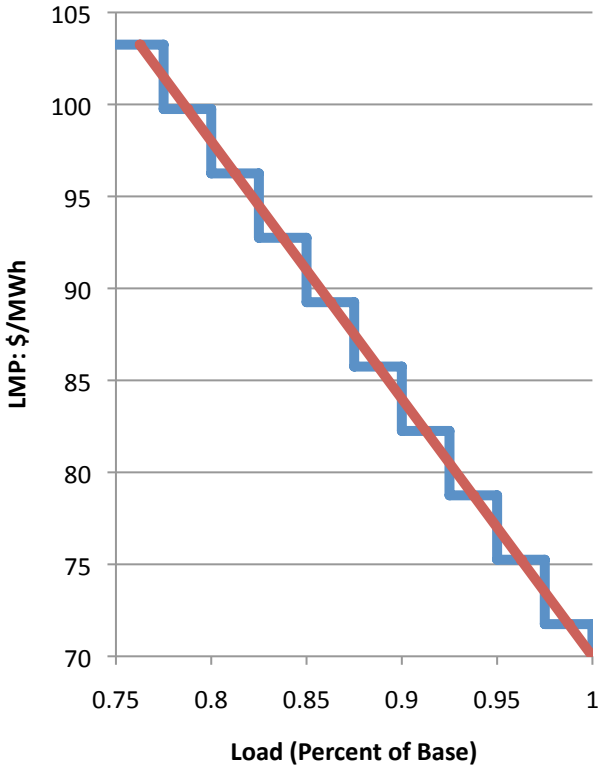
Actual Demand Response (Red)
Modeled Demand Response (Blue)

25% total demand response

10 blocks, each 2.5% of load

Effective price is at the midpoint of each interval

Consistent with piecewise-linear benefits function



In the long run, the elasticity of demand for electricity is -1. (1)

Surprisingly, in the short run, a new estimate of elasticity (assuming that consumers respond to monthly bills) is -0.982. (2)

The delivered price equals the LMP for each bus, for each representative hour in 2012, plus estimated distribution costs ($70/MWh)

1. Dahl, Carol. "A Survey of Energy Demand Elasticities in Support of the Development of the NEMS." ftp://ftp.eia.doe.gov/pub/oiaf/elasticitysurvey/elasticitysurvey_dahl.pdf
2. Fell, Harrison, Shanjun Li, Anthony Paul. "A New Approach to Estimate Residential Electricity Demand Using Household Expenditure Data."

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Model Runs for Stress Testing

- Base Case: No Regulations
- Kerry-Lieberman CO_2
- Nuclear Retired in 2022, No Regulations
- Nuclear Retired in 2022, Kerry-Lieberman CO_2
- Marginal Damages Charged for SO_2 and NOx Emissions (Starting in 2022) based on NRC, *Hidden Costs of Energy*
- PHEV Load Filling in 2022 and 2032
- Wind Incentives in place

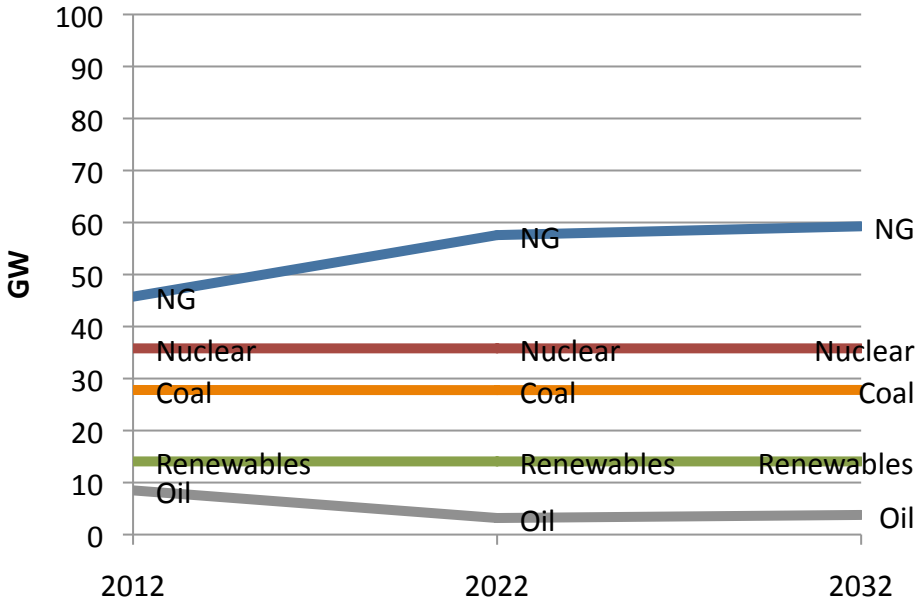
Cornell University

Base Case: No New Regulation

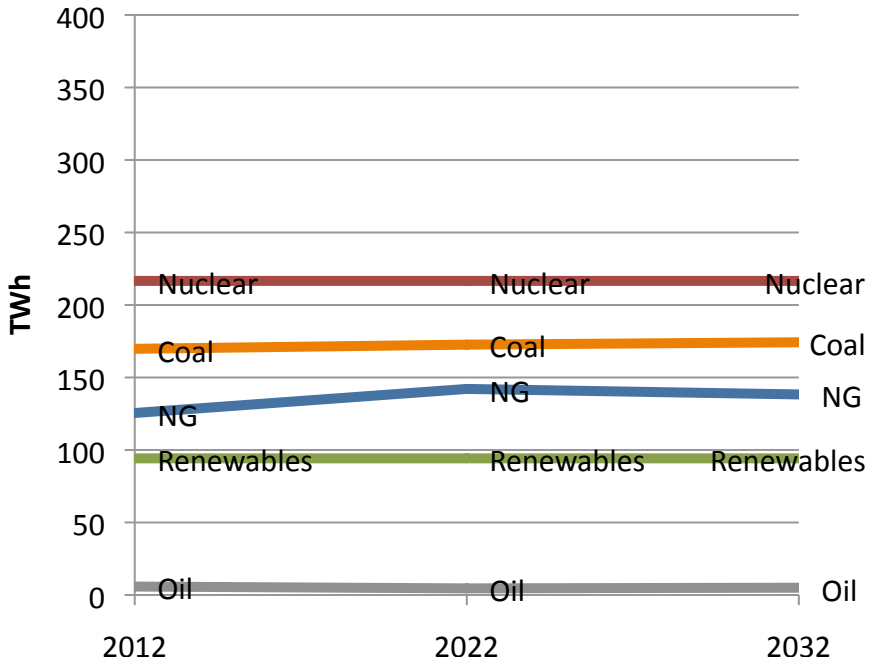
CERTS Consortium for Electric Reliability Technology Solutions

PSERC

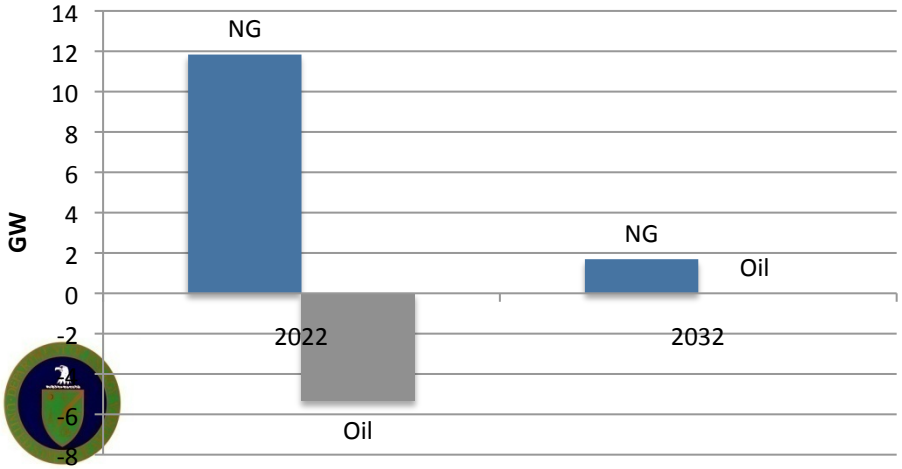
Capacity



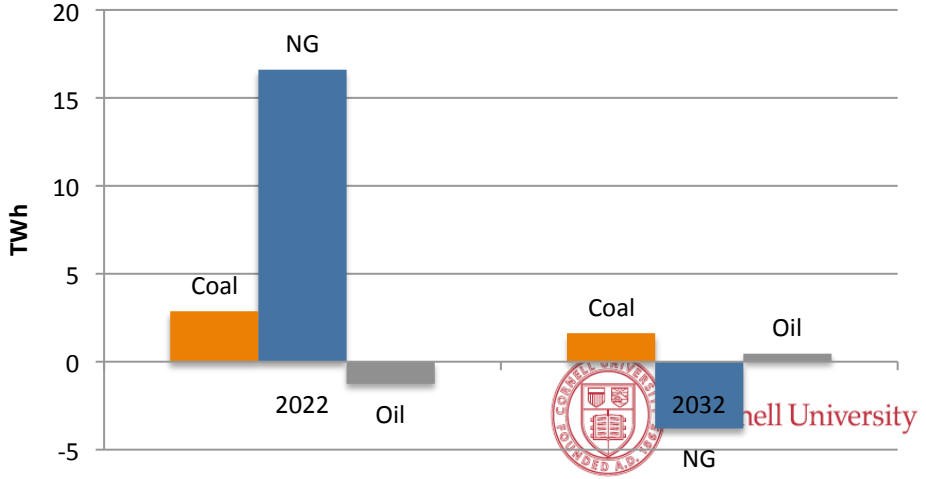
Generation



Capacity Changes



Generation Changes



Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

Proposed Legislation: Kerry-Lieberman

PSERC

- Why look at dead legislation?
  - Unresolved debate over cost
  - Industry has seen many policy reversals
  - Demonstrate what the model can do
  - Will combine with No Nuclear case for extreme stress test
- Proposal Features
  - Cap and Trade auction begins in 2012
  - Cap starts at 2005 level
  - Reduction of 17% by 2020
  - Reduction of 42% by 2030
  - Floor and Ceiling for prices (Price collar)
  - Floor starts at $12, increases by 3% annually
  - Ceiling starts at $25, increases by 5% annually

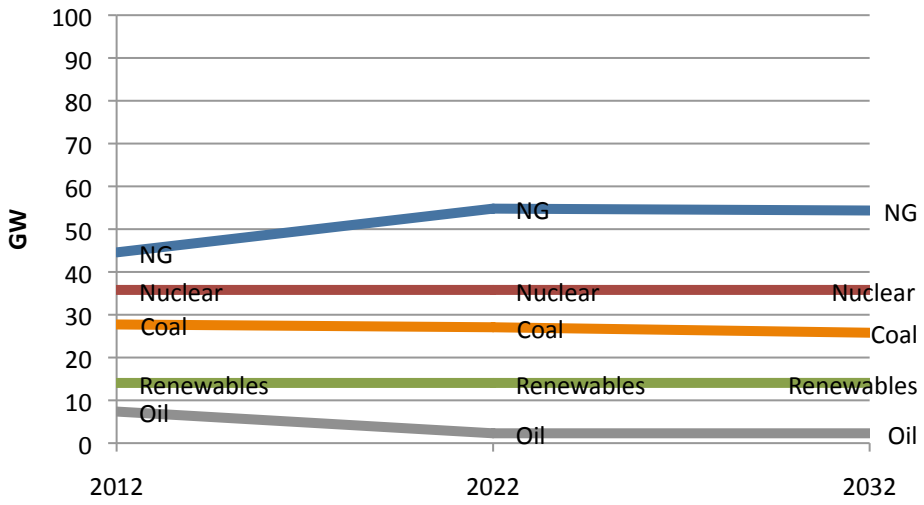
Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

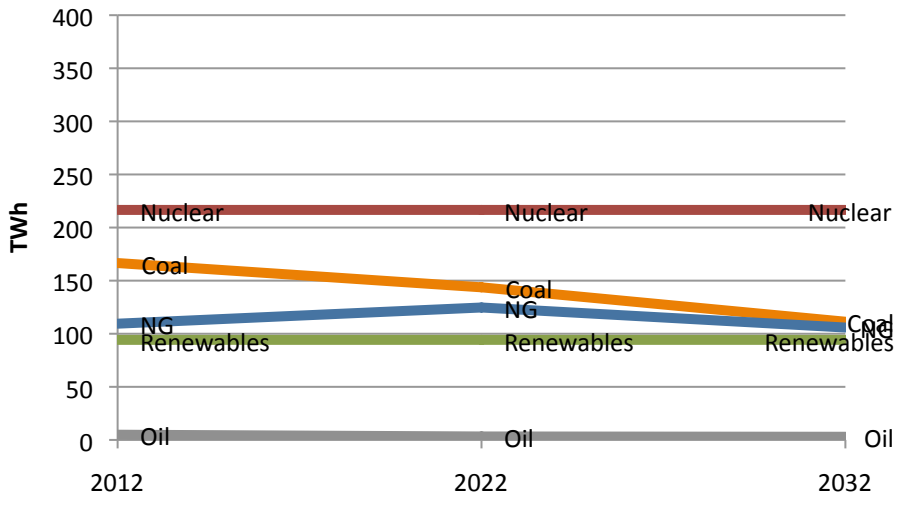
K-L CO2 Results

PSERC

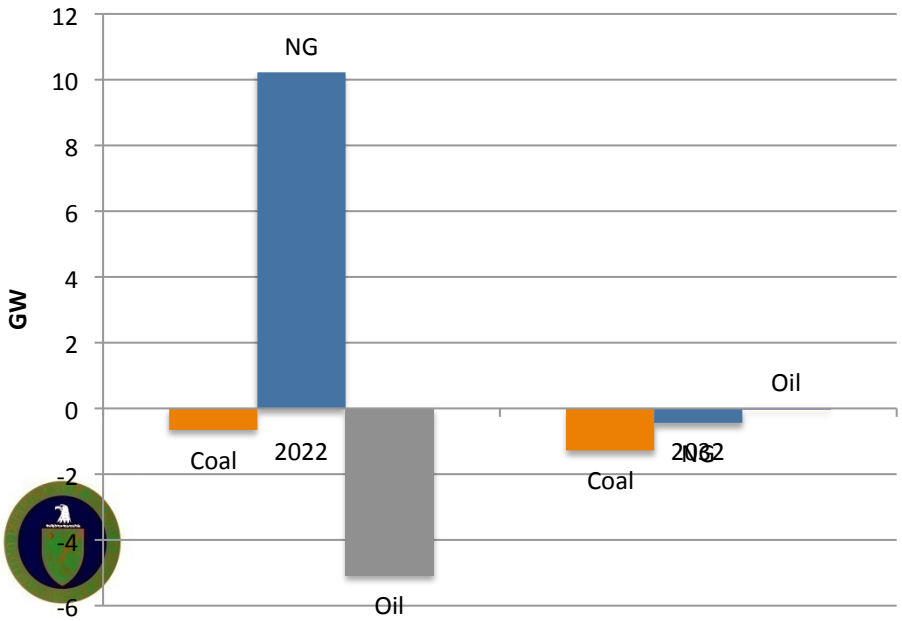
Capacity



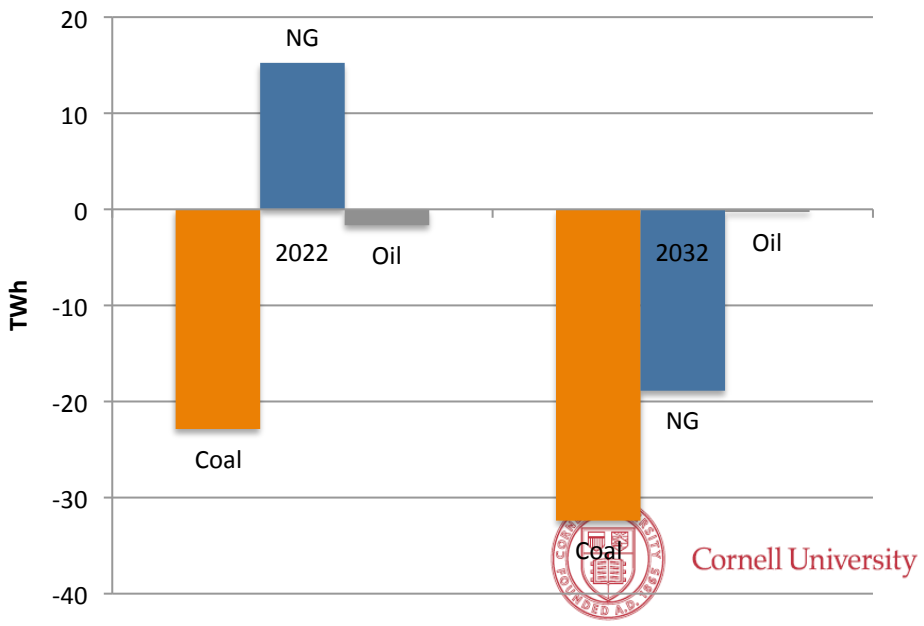
Generation



Capacity Changes



Generaton Changes



Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Marginal Damages

- Hidden Costs of Energy (NRC)
  - Health damages caused by power generation ($63 billion)
    - SO2, NOx, Fine Particulates
  - Average coal plant causes $156 million in damages
    - 10% of coal plants produce 43% of damages
  - Average natural gas plant causes $1.5 million in damages
    - Smaller plants, less damage per kWh
    - 10% of NG plants produce 65% of damages
  - Does not include a network model for transmission and distribution

- Study also reviews
  - Heating ($1.4 billion in damages)
  - Transportation ($56 billion in damages)
  - Damages from mining and related activity
  - Damages related to climate change
  - Infrastructure Risks and Security

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

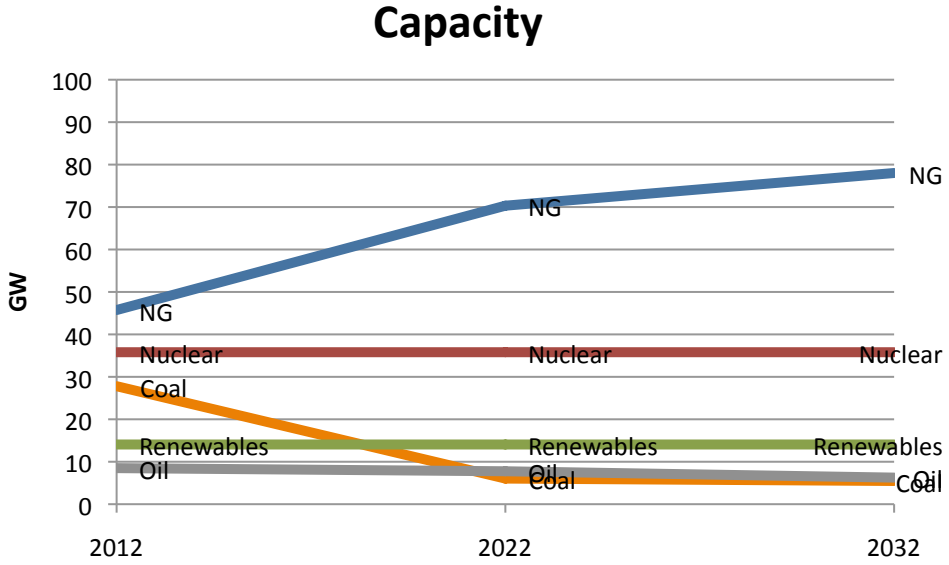
Marginal Damages

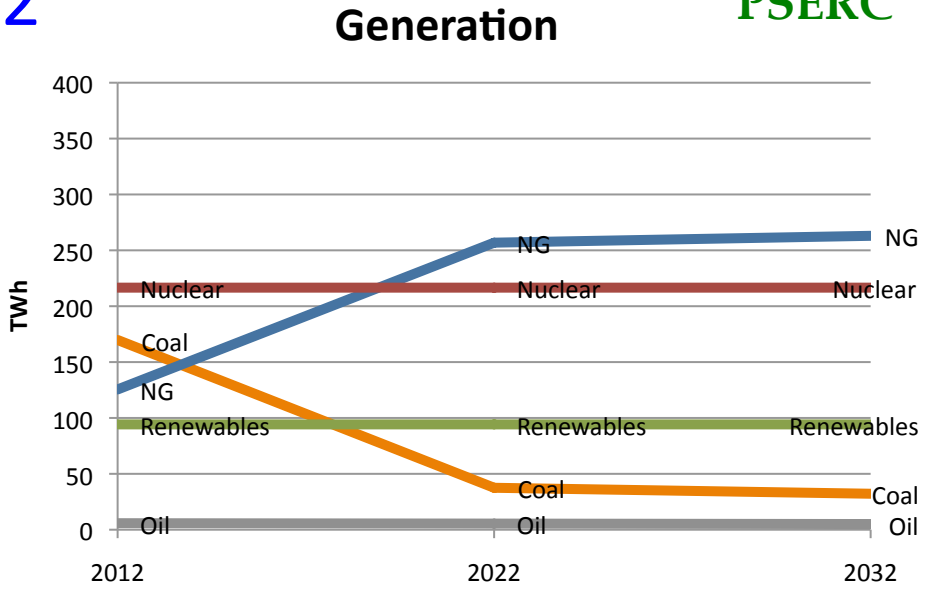
- Use same air transport model as in *Hidden Costs of Energy* for fine particulates
  - Transport coefficients from/to every county in the US and Canada
- Summed over all counties and combined with information about Value of statistical life, mortality and morbidity rates to generate
  - Value of Mortality and Morbidity: $6.9 million / expected life
- Example: AES Cayuga/Millikin Station, a coal-fired power plant near Cornell University, average coal and NG plants, and the most damaging coal plants in the NPCC

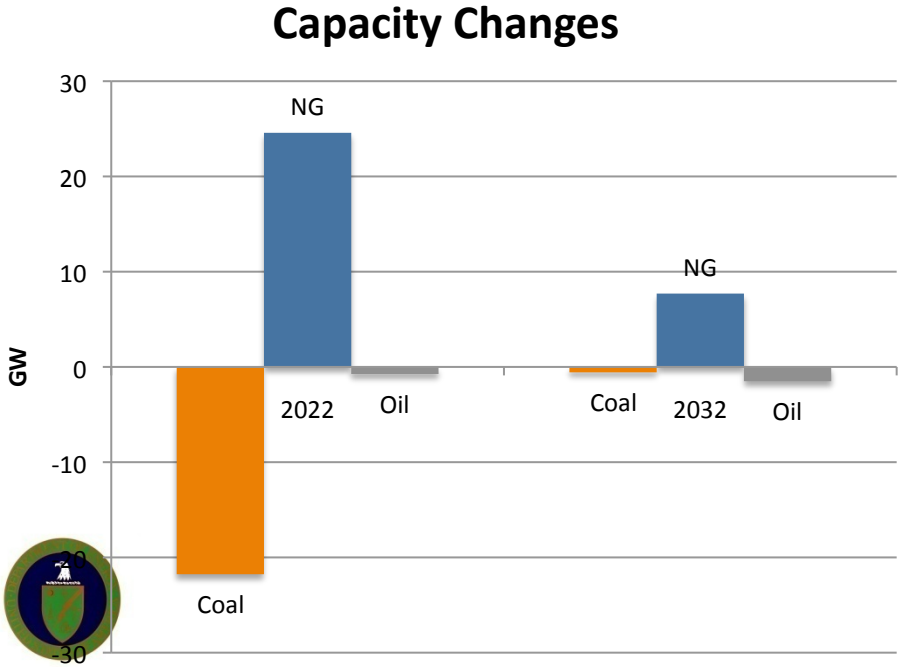
Unit Name	CO2 Rate Tonnes/MWh	SO2 Rate Tonnes/MWh	NOx Rate Tonnes/MWh	MD $/MWh
Milikin Unit 1	0.98	<0.001	<0.001	7.22
Average Coal Plant	1.05	0.0065	0.001	89.87
Max MD Coal Plant	0.9984	0.0134	0.0012	232.20
Average NG Plant	0.65	<0.0001	<0.001	2.36

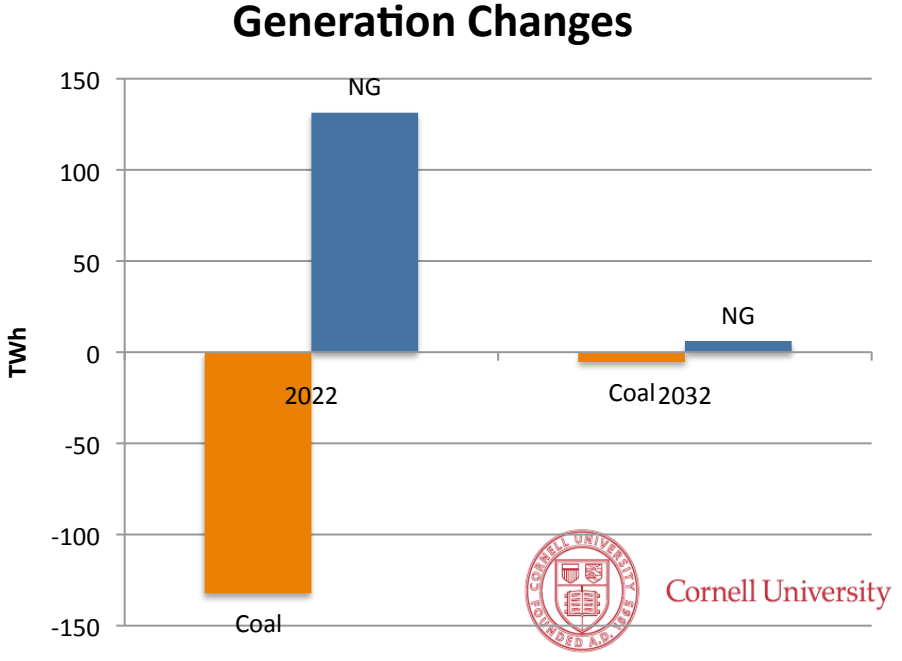
Cornell University

MD for SO_2 and NOx







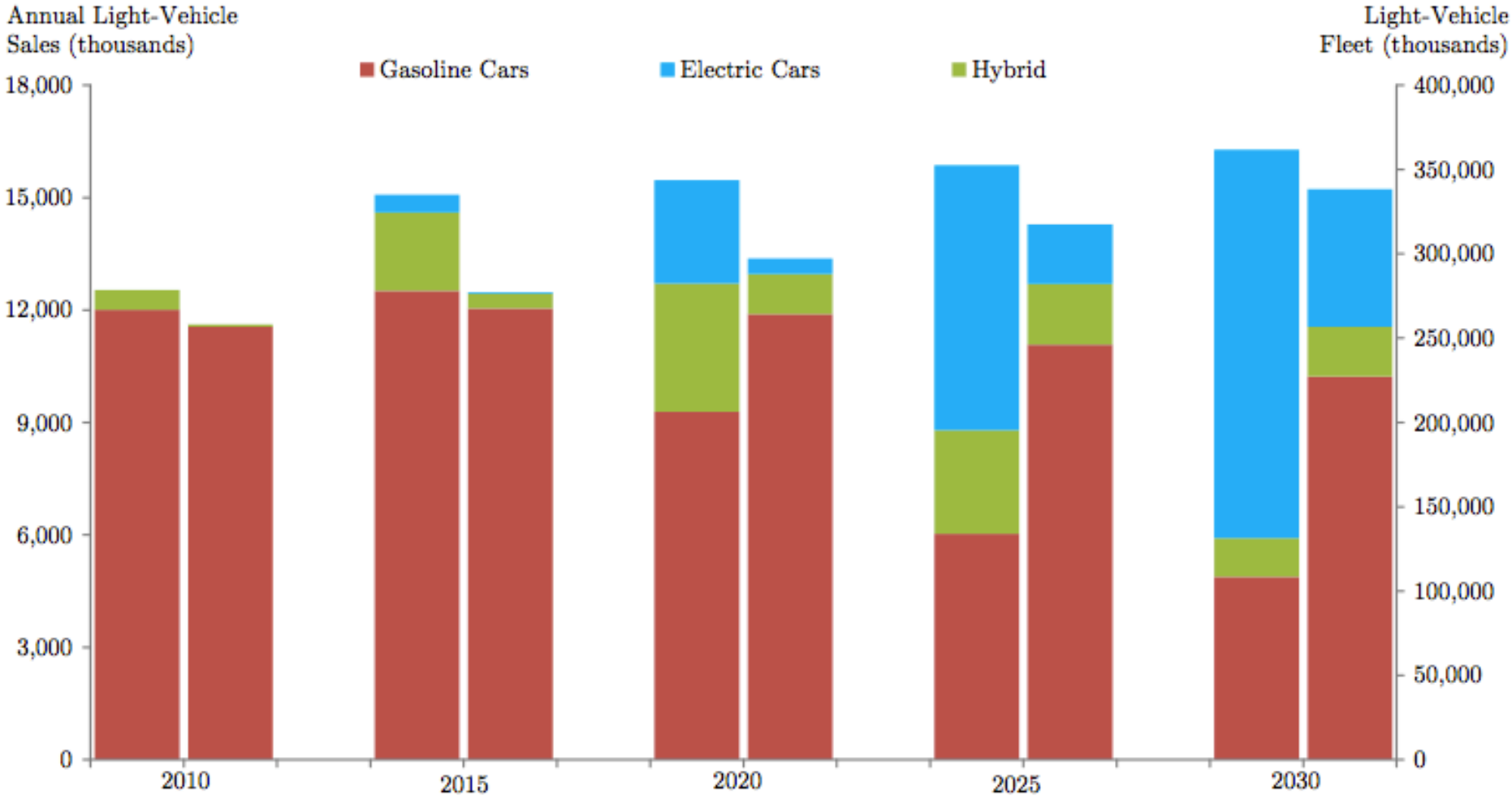


PHEV Load Filling

U.S. Light-Vehicle Sales (left column) and Fleet Composition (right column) Under Baseline Scenarios

From "Electric Vehicles in the United State: A New Model with Forecasts to 2030"

http://cet.berkeley.edu/dl/CET_Technical%20Brief_EconomicModel2030_f.pdf



CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

PHEV Load Filling

- Load added to low demand hours
- Total estimates for country scaled to 25% for population in Northeast
- Add 703 MW of demand in 2022 (Using 2020 estimate)
  - 593,000 PHEV (2kWh); 230,000 EV in Northeast (16 kWh)
- Add 5,412 MW of demand in 2032 (Using 2030 estimate)
  - 725,000 PHEV; 2,000,000 EV in Northeast

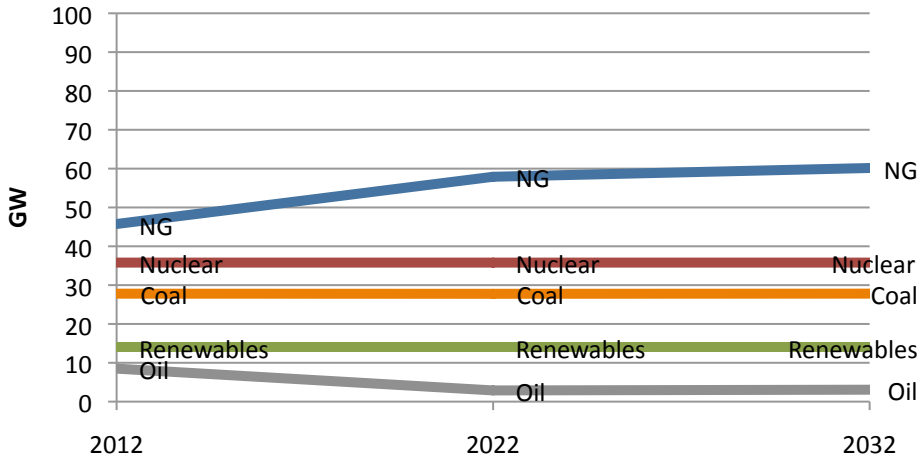
Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

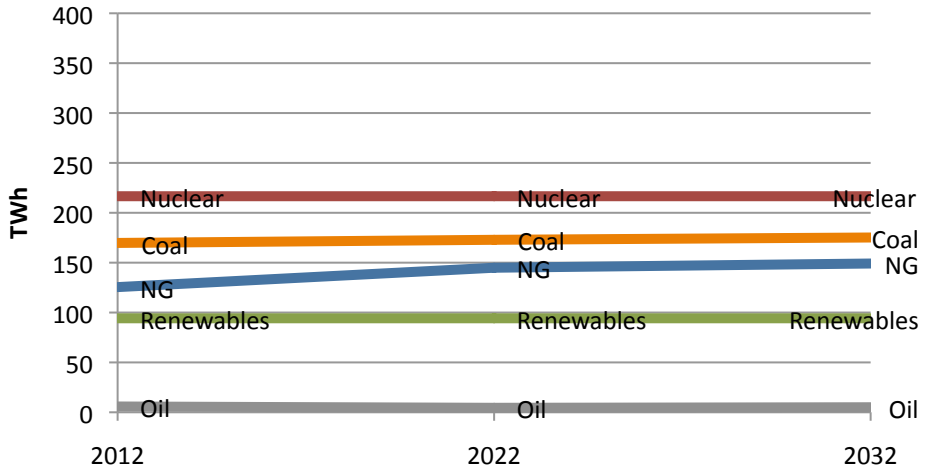
PHEV

PSERC

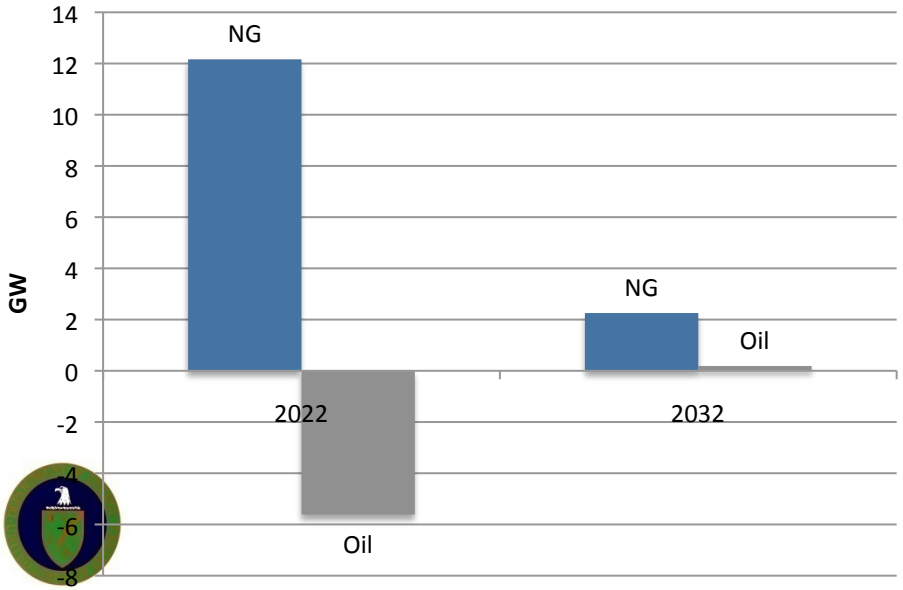
Capacity



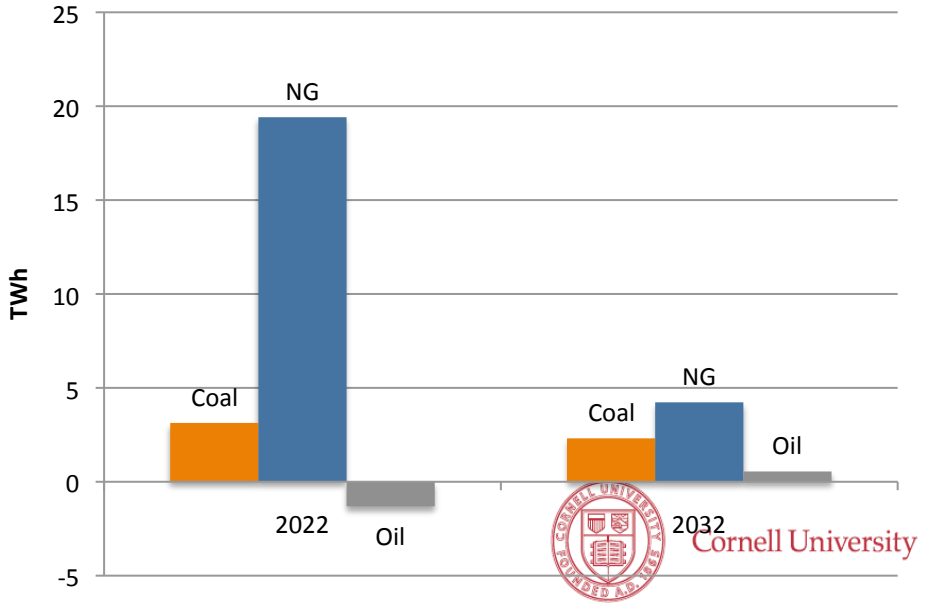
Generation



Capacity Changes



Generation Changes



Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

Wind Incentives

PSERC

Incorporate federal and state level subsidies for wind generation and construction

Generating cost of wind is reduced $52.68 /MWh in the US and $135 - $77.50 /MWh in Canada (if current policies continue)

Capital costs reduced at nodes that contain generating plants in DE, MA, MD and NJ by average of capital incentives present

30% load factor assumed in the modeling

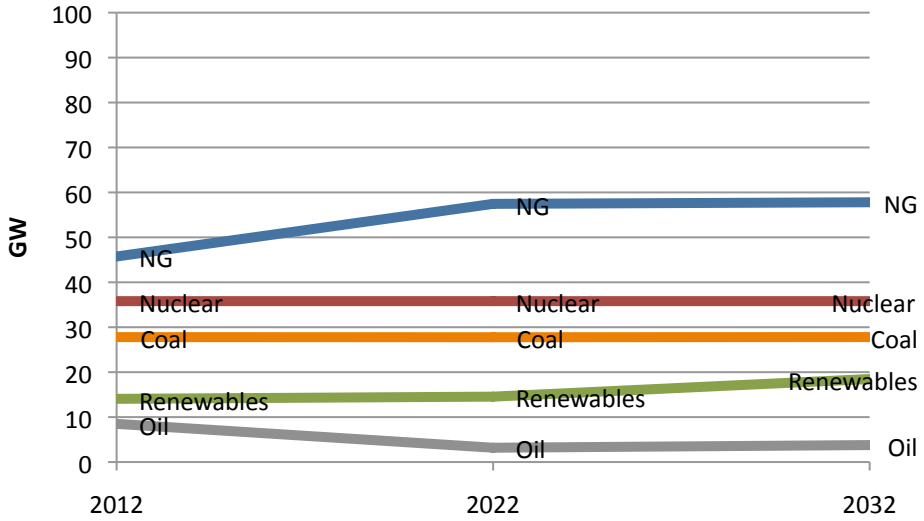
Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

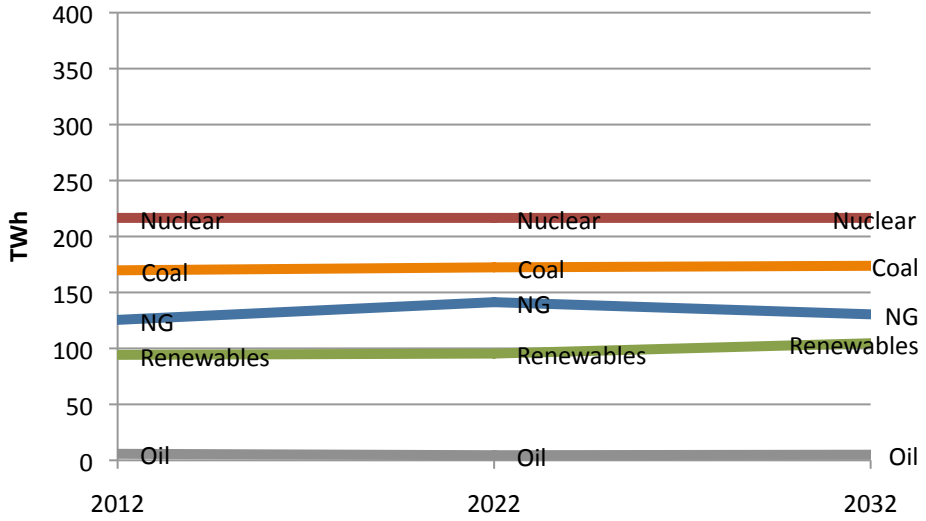
Wind Incentives

PSERC

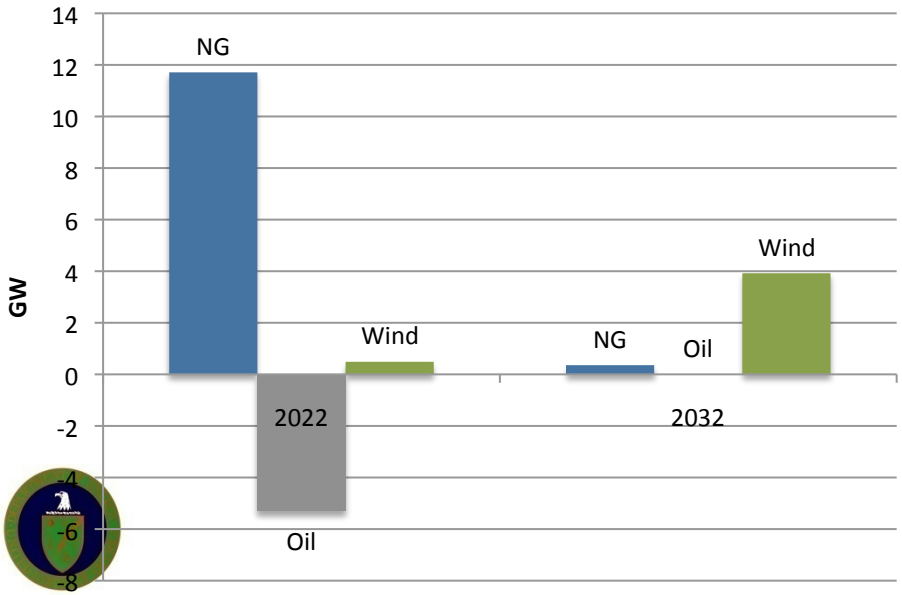
Capacity



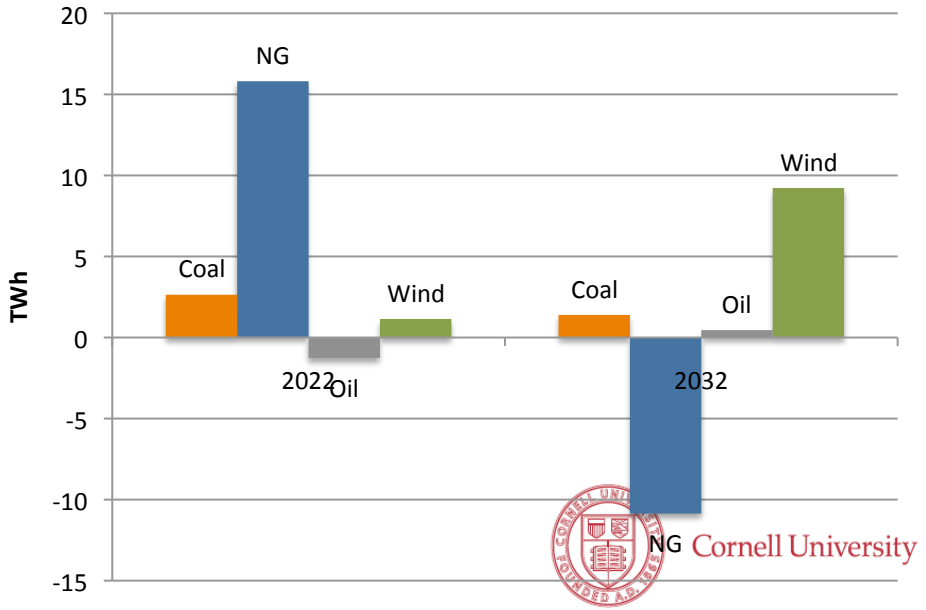
Generation



Capacity Changes



Generation Changes



Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

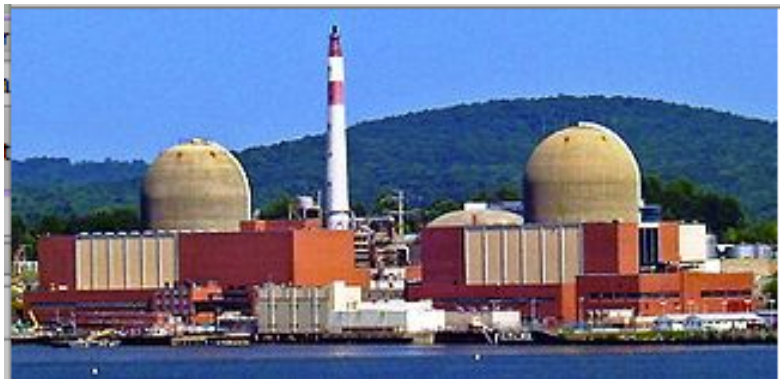
PSERC

No Nuclear Cases

The Fukushima Daiichi nuclear disaster raised questions about the safety of nuclear power. In New York State, Governor Cuomo is pushing for the closure of the Indian Point Energy Center, less than 40 miles from NYC. Indian Point could be replaced by fossil fuel units (mostly NG) but the model predicts an additional 8.75 fatalities a year from the increased emissions. We consider two cases where we decommission ALL nuclear plants in 2022:

Decommission with no new environmental rules

Decommission with Kerry-Lieberman CO2 Cap and Trade (Much like what Germany is actually doing)



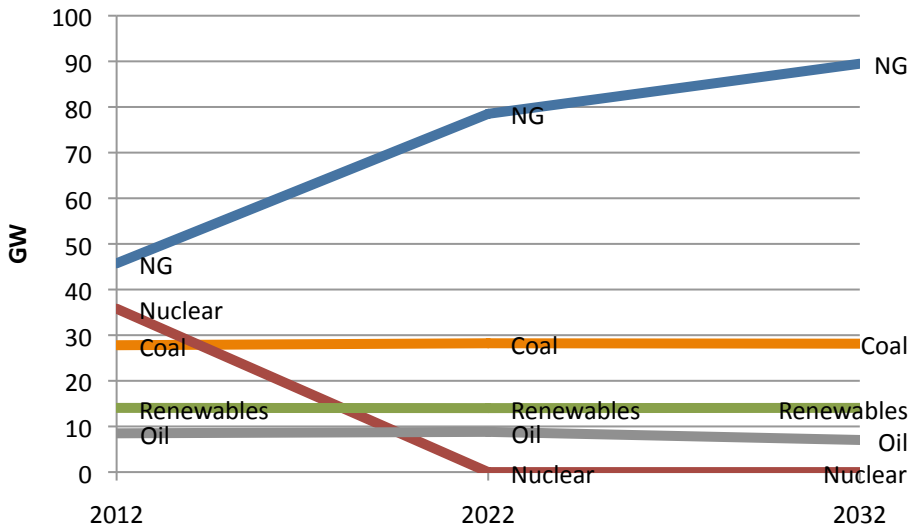
Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

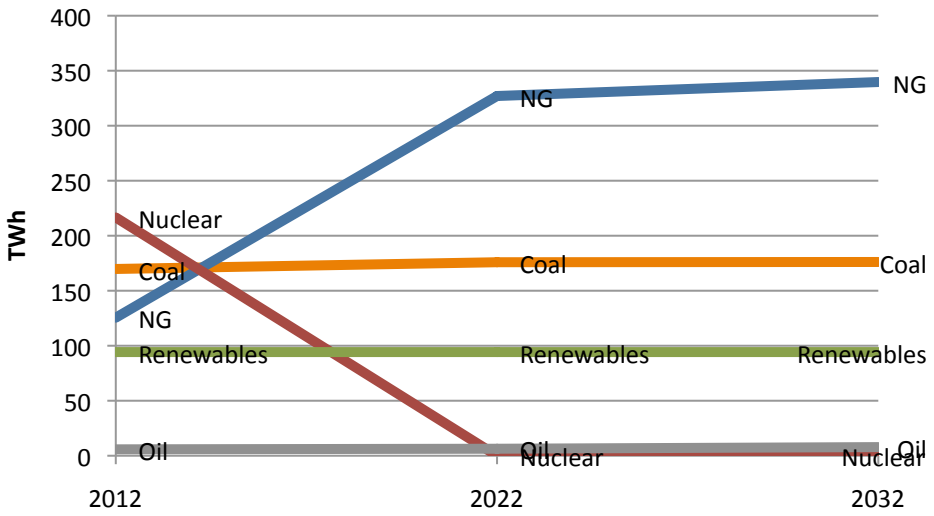
No Nuc, No New Regulations

PSERC

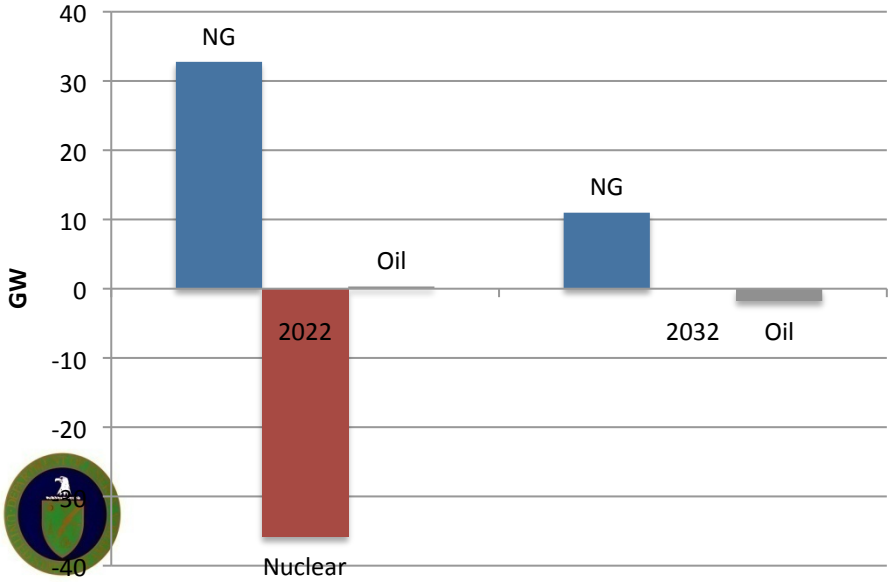
Capacity



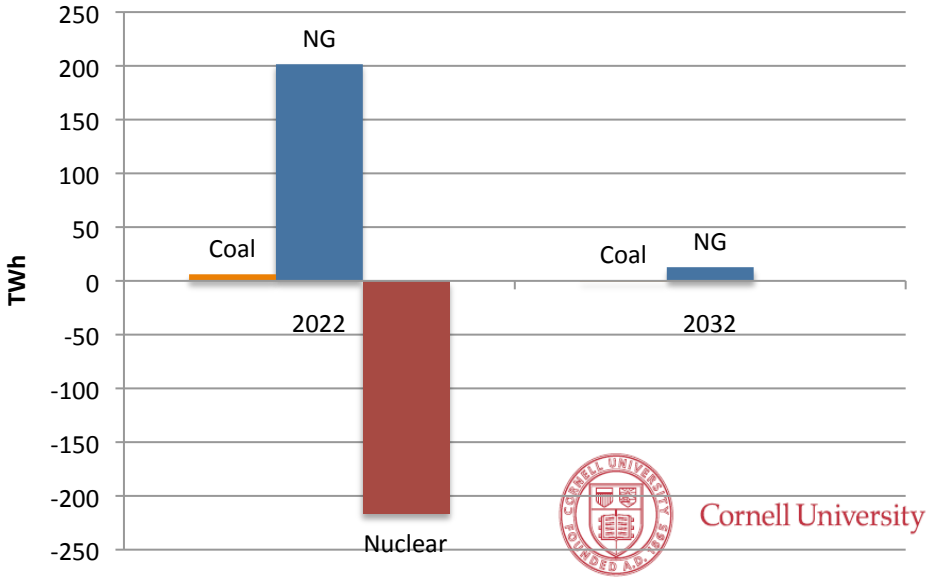
Generation



Capacity Changes



Generation Changes



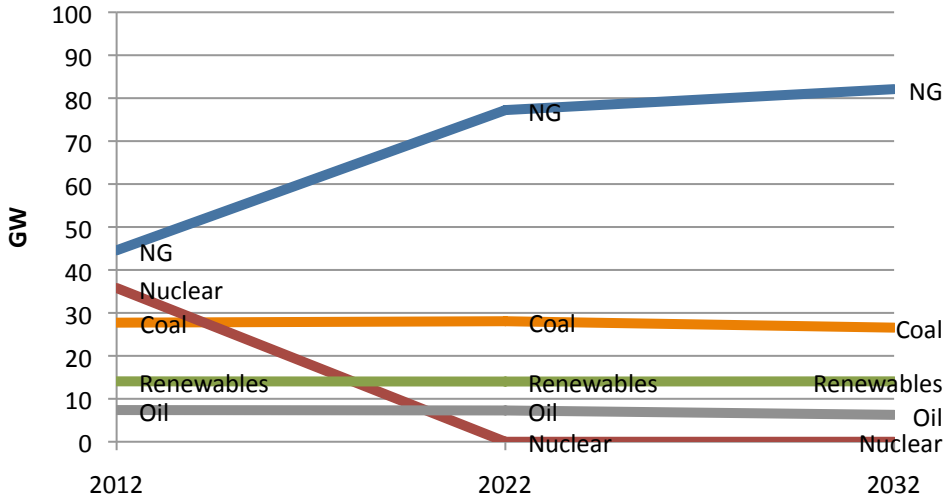
Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

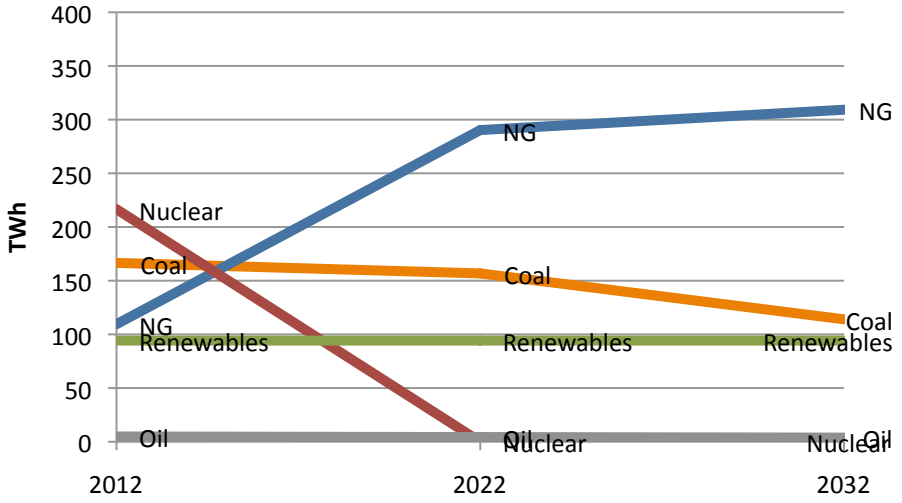
No Nuc, K-L CO2

PSERC

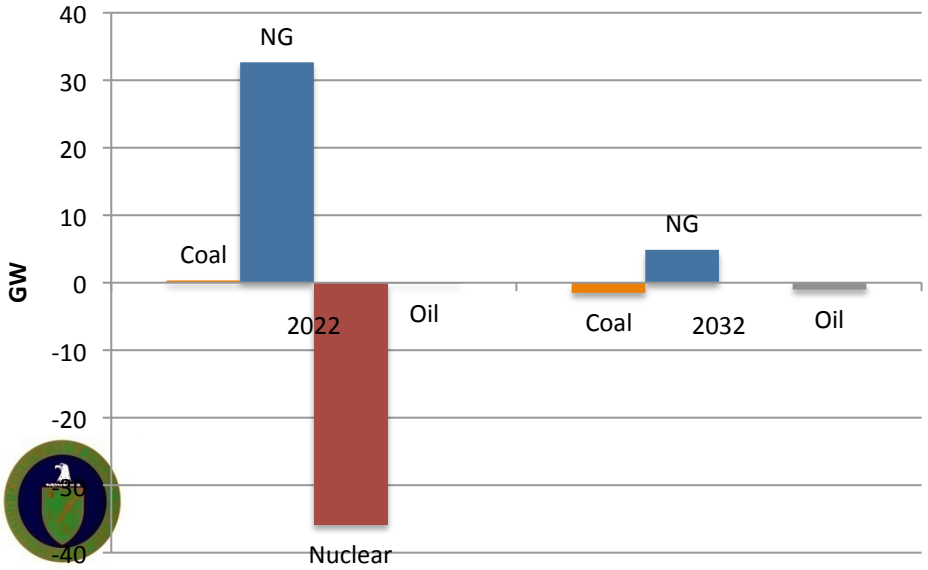
Capacity



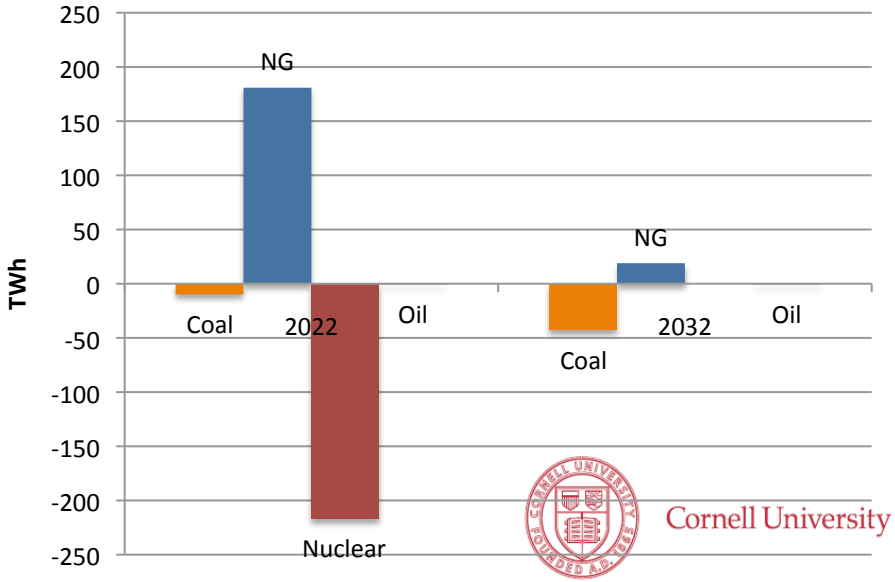
Generation



Capacity Changes

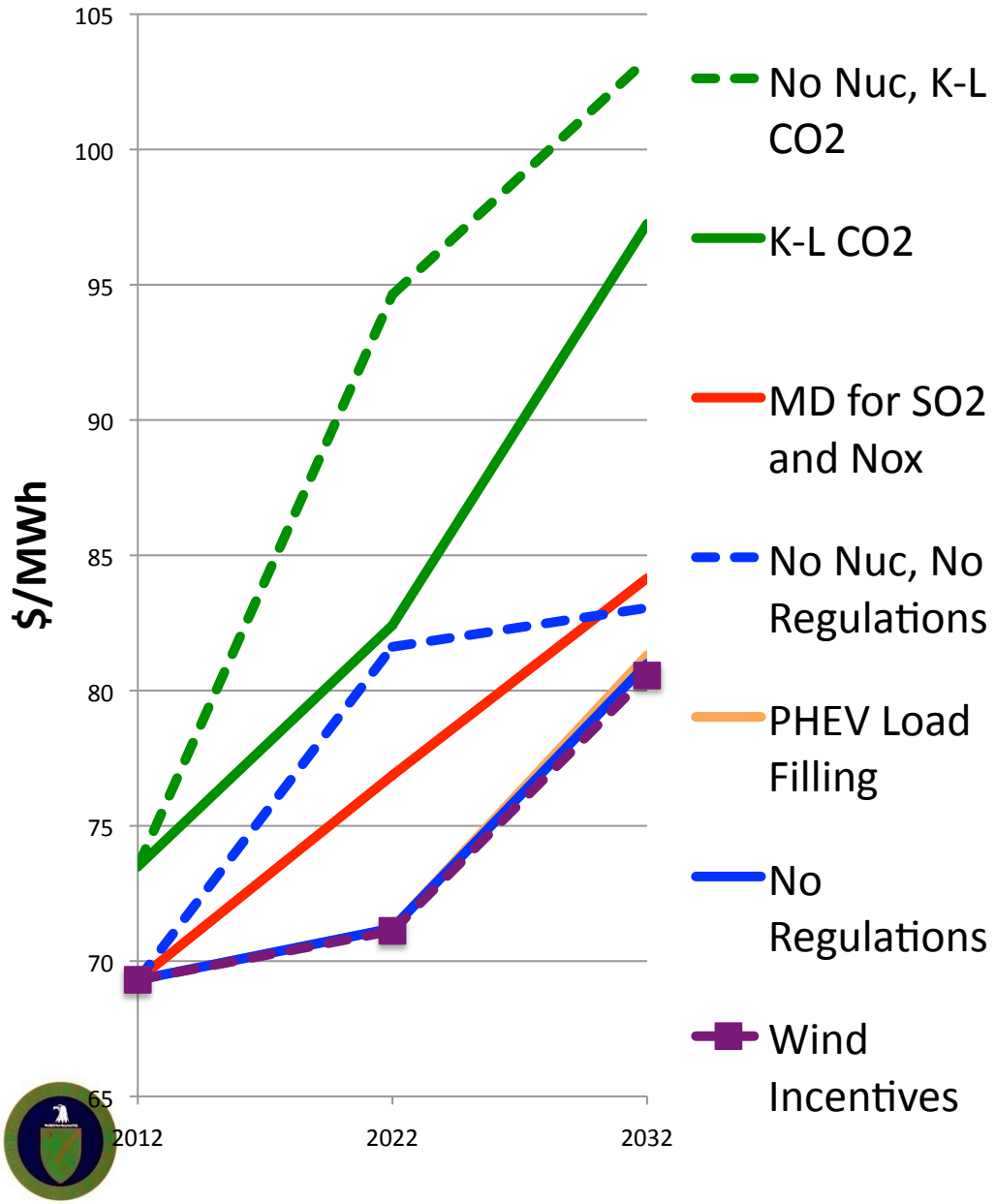


Generation Changes



Cornell University

Average Wholesale Prices

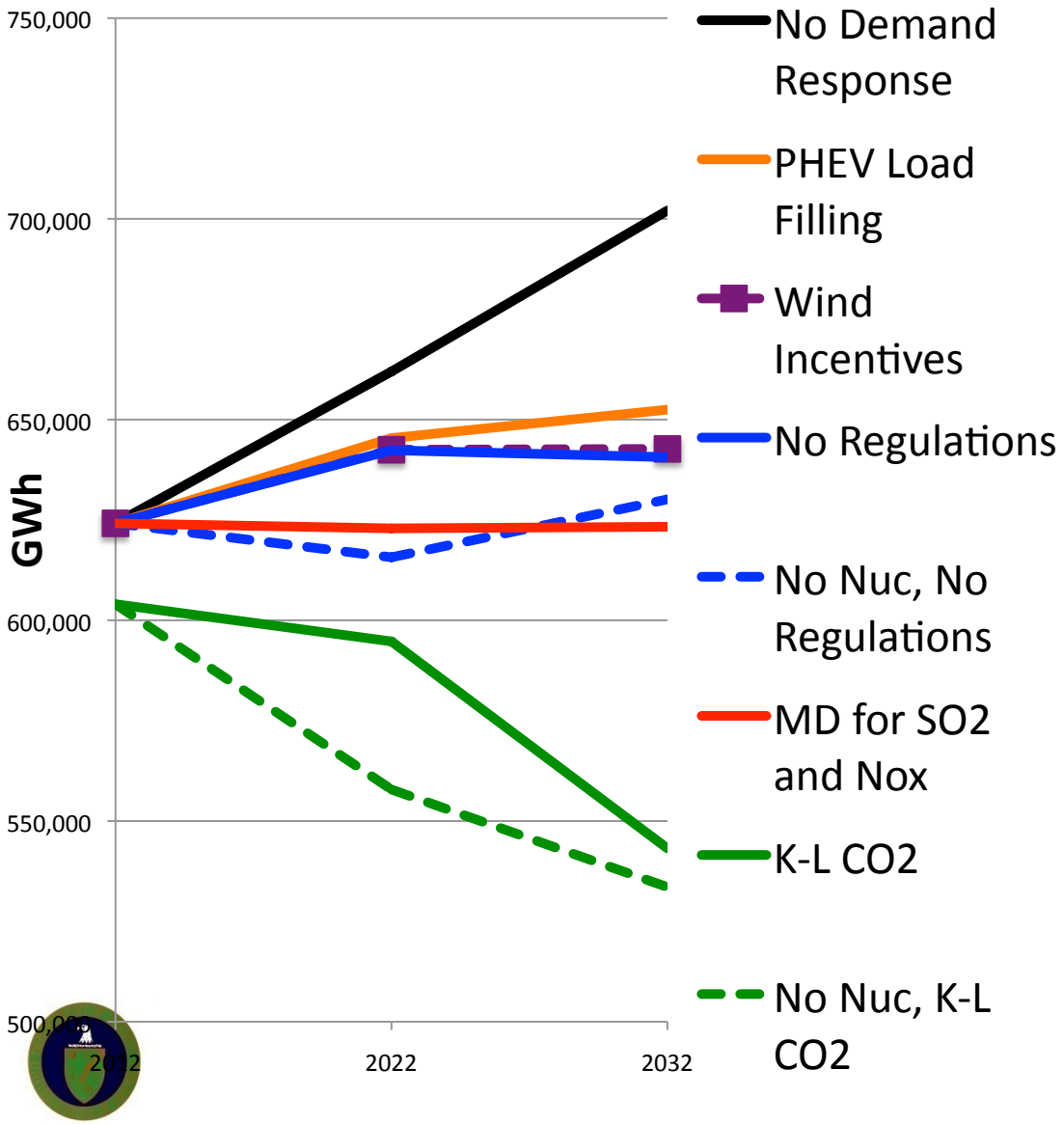


Origin is not at $0/MWh

No New Environmental Regulations is almost collinear with wind incentives, but wind is slightly lower.

Although the PHEV case increases generation and capacity, the effect on average LMP is modest, because generation is only increased during the low demand hours.

Total Demand



Origin is not zero to highlight differences.

Wind and No New Env Reg are almost collinear. Wind has slightly more generation because wind incentives slightly lower the wholesale price, resulting in less demand response.

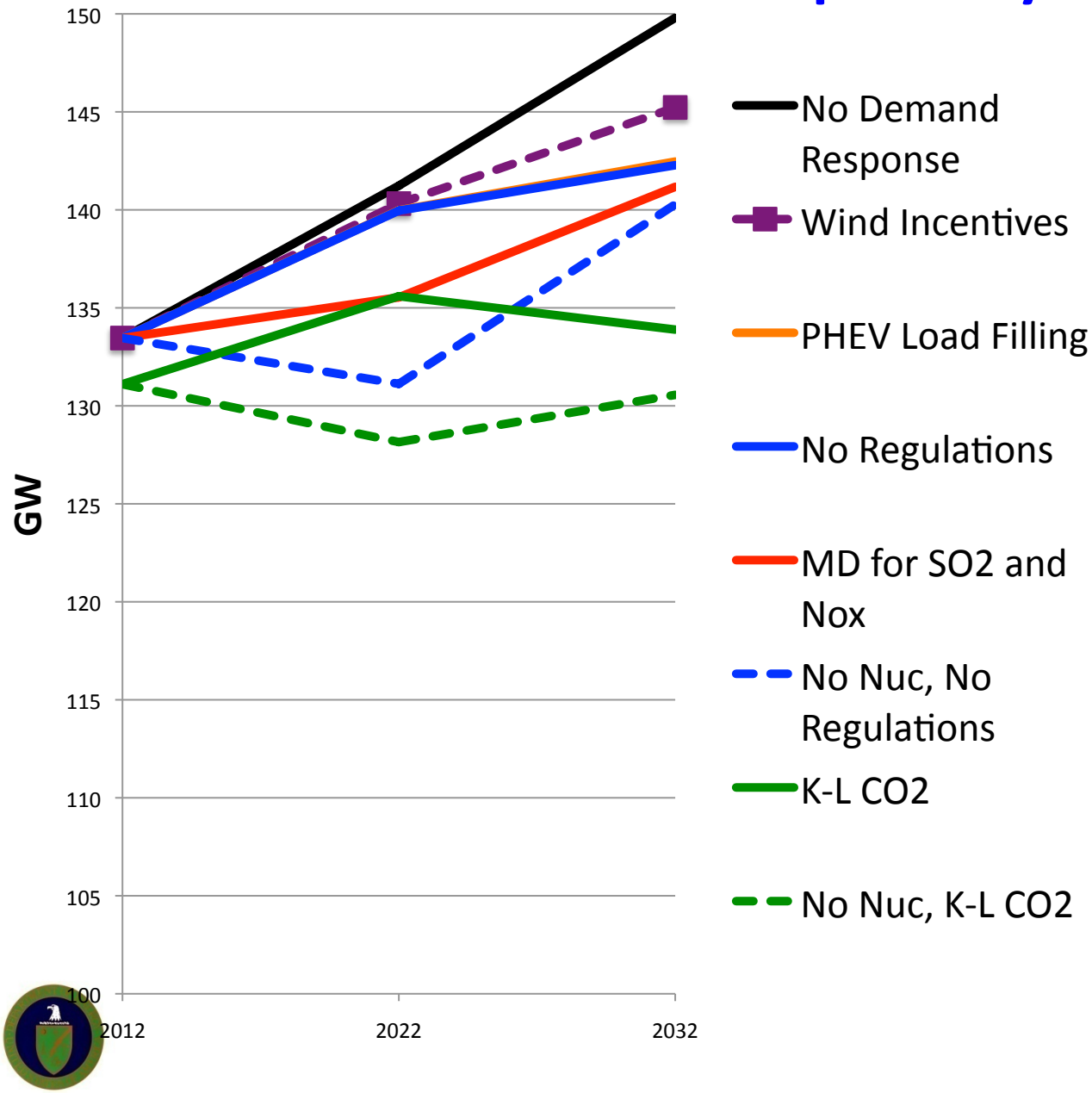
The No Demand Response case shows the total effect of demand response in the rest of the cases.

Maximum demand response is about 21% in the Kerry-Lieberman cases.

For most charts, order of entries in legend is same as final size in 2032.

CERTS
Consortium for Electric Reliability Technology Solutions

Total Capacity



PSERC

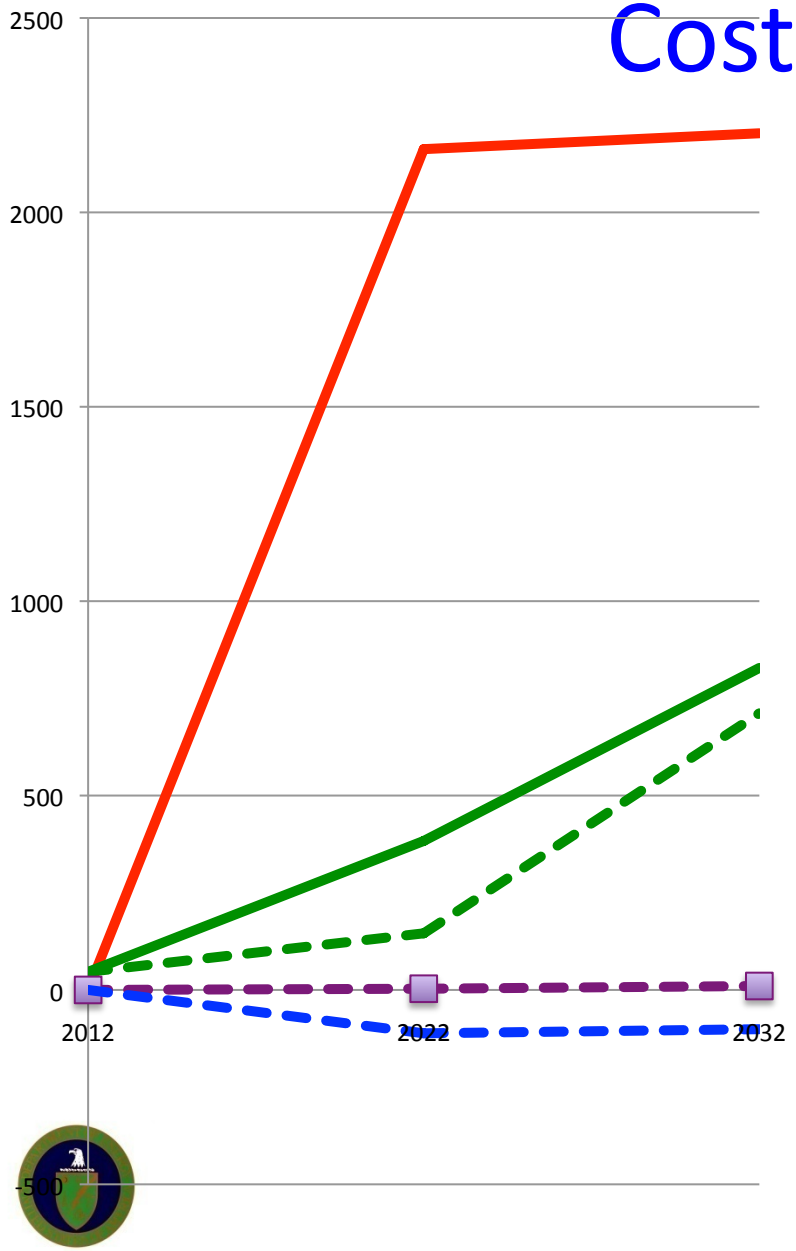
The No Demand Response lines illustrates the importance of demand response in reducing the need for new capacity.

The large capacity dips in the No Nuclear cases reflect nuclear plants being decommissioned.

PHEV and No New Env Reg are almost collinear. PHEV slightly higher

Cornell University

Lives Saved (Based on Hidden Costs of Energy)*



- MD for SO2 and Nox
- K-L CO2
- No Nuc, K-L CO2
- Wind Incentives
- No Nuc, No Regulations

Removing nuclear plants without imposing new environmental regulations is expected to cause about 100 deaths per year

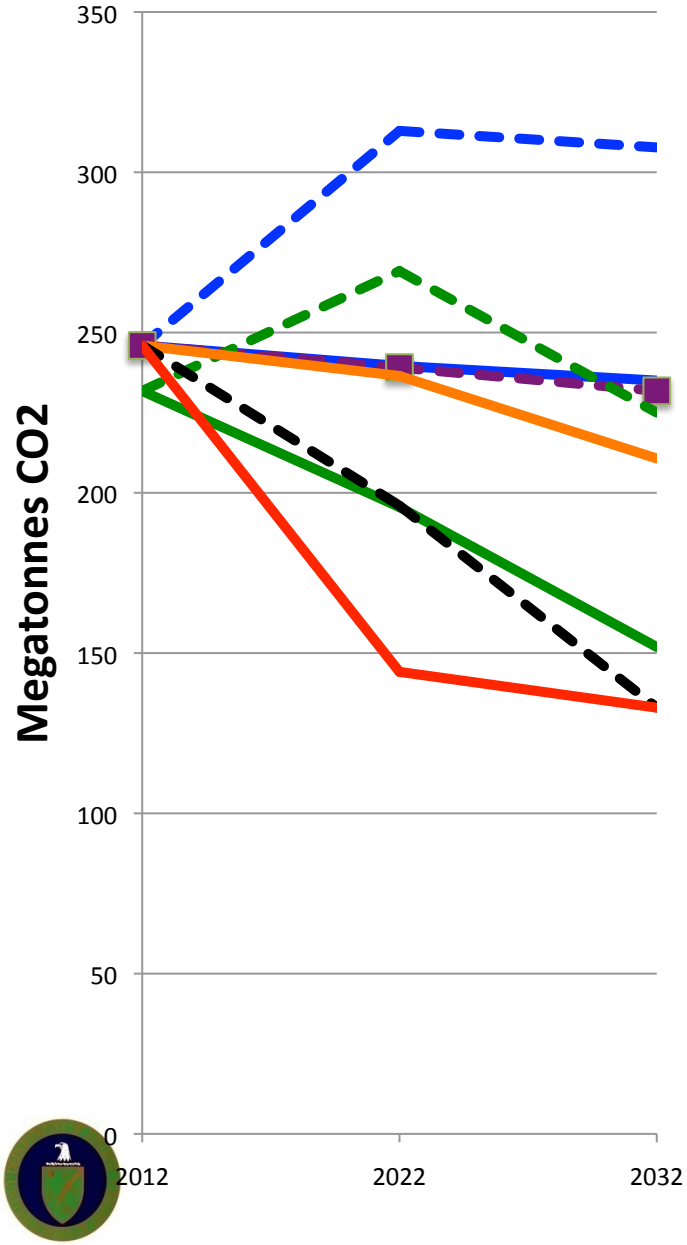
Every other option saves lives.

Wind incentives save 4-10 lives per year

*Health effects of fine particulates remain controversial

Cornell University

CO2 Emissions



- No Nuc, No Regulations
- No Regulations
- Wind Incentives
- No Nuc, K-L CO2
- PHEV Load Filling
- K-L CO2
- K-L Target
- MD for SO2 and Nox

Only imposing marginal damages for SO2 and NOx and K-L CO2 can meet or exceed Kerry-Lieberman targets.

K-L CO2 prices are at the floor in 2012, very close to the ceiling in 2022, and at the ceiling in 2032.
(Compared to base case, allowing investment and demand response delays the movement to the price ceiling, but does not prevent it.)
This is overly optimistic for the US as a whole, because the Northeast starts out with more low-carbon generation

Removing nuclear plants puts the price at the ceiling in 2022 under K-L

PHEV: Estimates included for CO2 reduction from reduced gasoline use

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Conclusions

- Industry advisors find results sensible
  - But argue for including all high voltage lines in the network model
  - Also find "open source" very desirable for planning purposes
  - Want to look at a broad range of possible policies (at least a 20 year time horizon since generators last up to 50 years)
- Natural Gas Combined Cycle
  - Unless wind is subsidized, only generation type built
  - Other runs (not shown) included Advanced Combustion Turbine Natural Gas for peaking units, but none were built
  - Fuel switching to reduce CO2
- MD for SO_2 and NO_X
  - Most effective at reducing CO2
  - Most effective at reducing health effects
  - Lower prices than Kerry-Lieberman CO2

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

PSERC

Future Directions

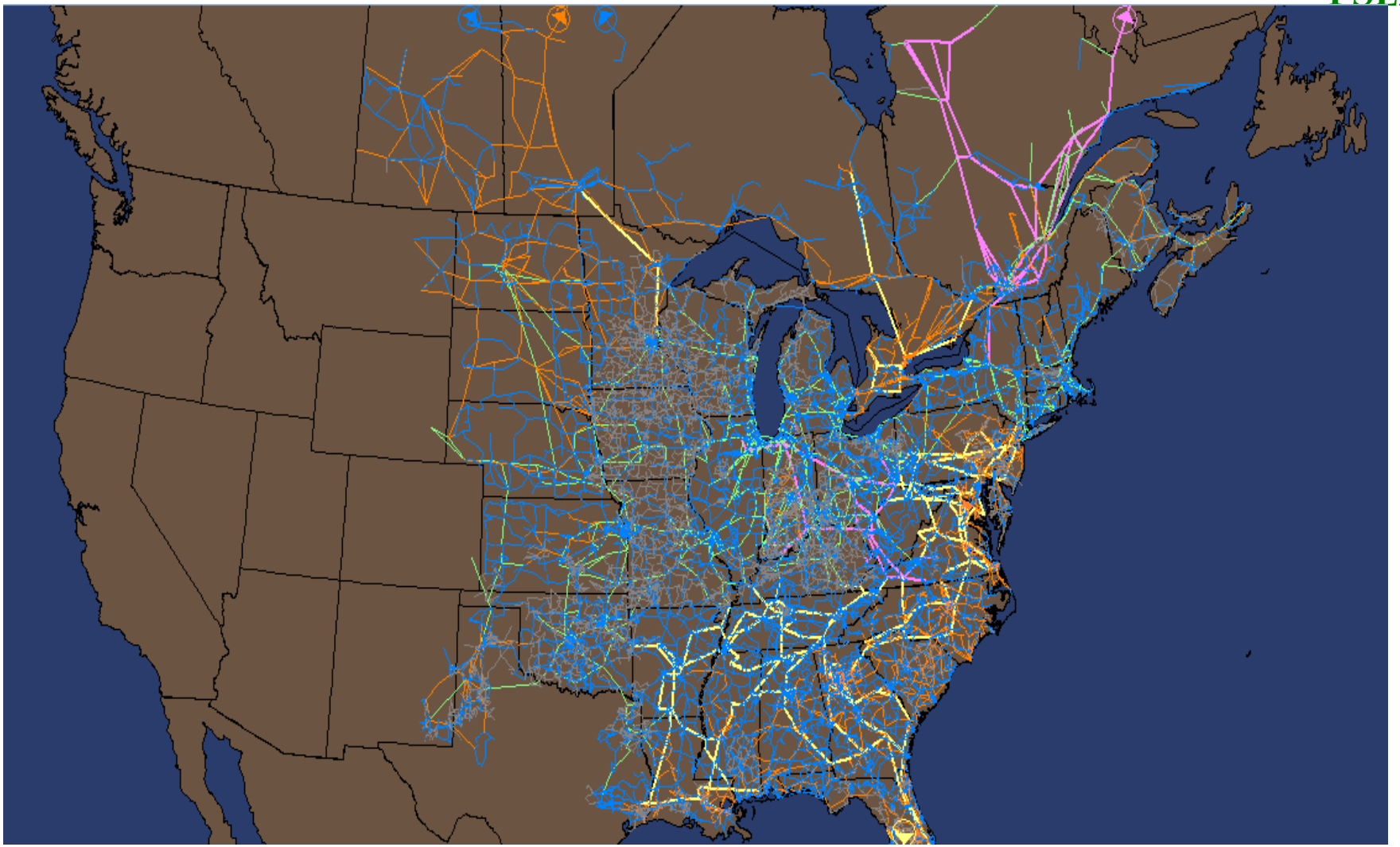
- Expand network complexity
  - Include all high voltage lines 5,200 nodes for Eastern Interconnect)
  - Lines are important for determining investment
- Expand network scope
  - Include entire Eastern Interconnect
  - Merge with ERCOT and WECC to complete nation
- Add contingencies
- Add but not optimize new lines (Tres Amigas)
- Suggestions?

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

The Original EI System Looks like..

PSERC



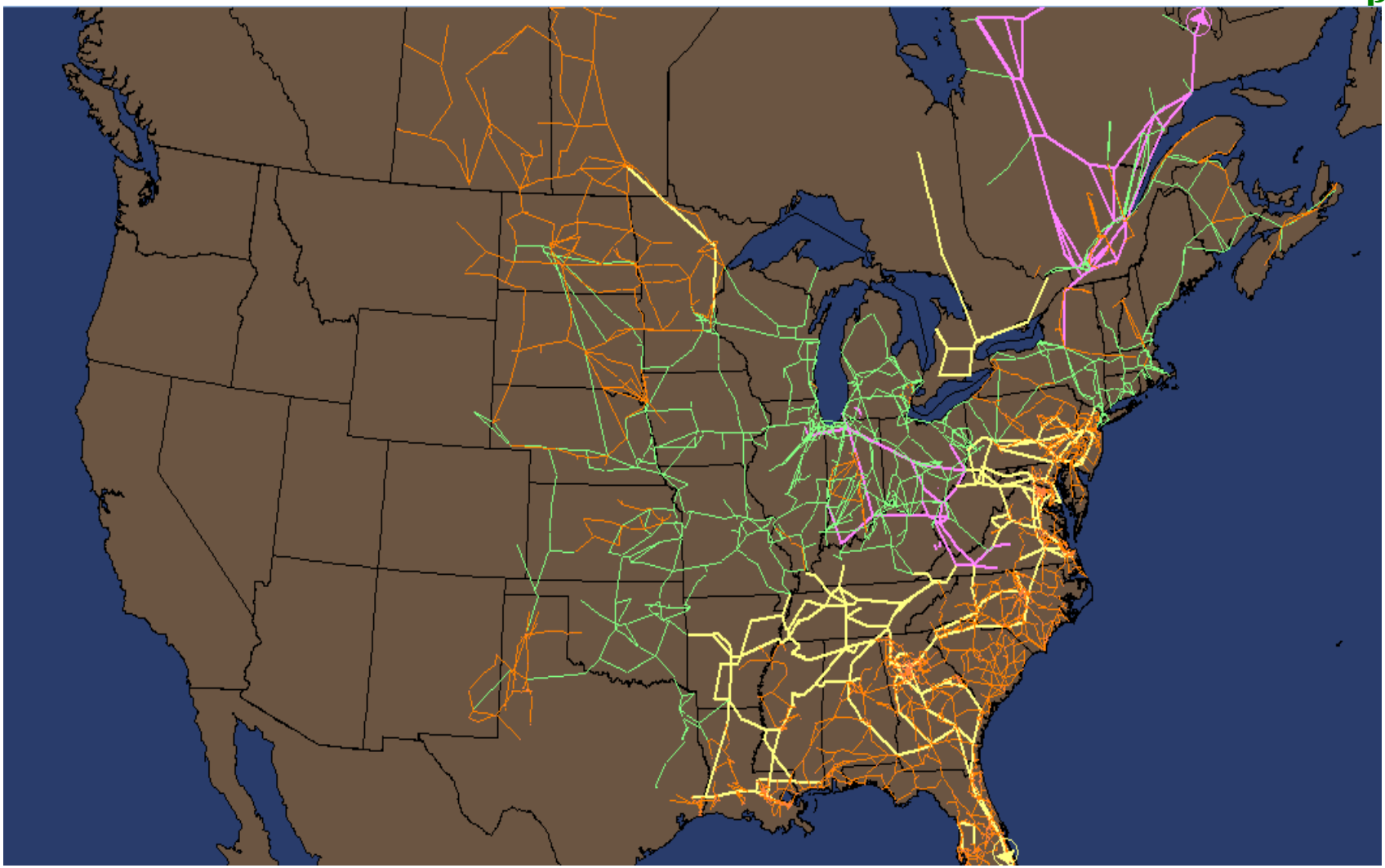
- Original system includes: 62013 buses, 8190 generators, 79766 branches, and 24 HVDC lines

Cornell University

CERTS
Consortium for Electric Reliability Technology Solutions

The Reduced EI Looks like (equivalent lines not shown)

PSERC



- Reduced system includes: 5222 buses, 8190 generators, 14225 branches, and 24 HVDC lines

Cornell University