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Mapping Energy Futures: The SuperOPF Planning Tool

Bill Schulze, Dick Schuler, Ray Zimmerman, Dan Shawhan, John Taber, Jubo Yan, Andy Kindle

Cornell University

Existing Planning Tools

- Are either very detailed but do not optimize investment over the planning region or
- Are highly aggregated using bubbles and pipes (or only a few nodes) to represent the network
- Don’t include environmental modeling

SuperOPF Planning Tool

Uses three network reductions (for the EI, ERCOT and WECC) from Dan Tylavsky to cover the entire nation. These reductions retain all high voltage lines of 230 KV and above.

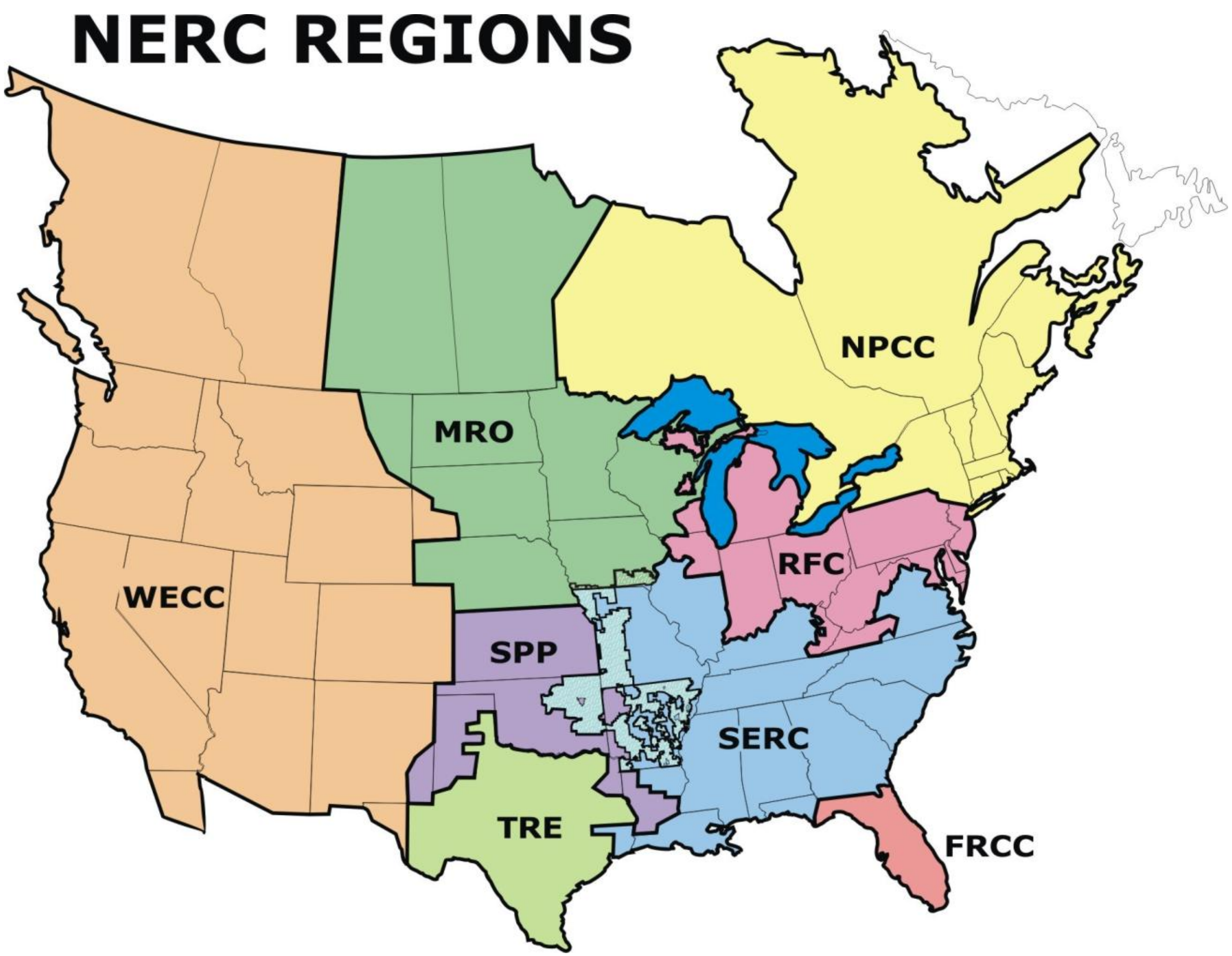
Features

- Investment in new generation
- Retirement of old generation
- Emissions of CO_2, NO_X and SO_2
- Atmospheric modeling of fine particulates and resulting mortality

Features

- Network modeled with DC power flow
  - 5000+ bus equivalent of Eastern Interconnect
  - 2300+ bus equivalent for WECC
  - 1000+ bus equivalent for ERCOT
- 12 representative hours
- Reserves considered via capacity factor
- Long run price response
- Maximizes expected net benefits

Eastern Interconnect



NPCC: New England, Western Canada

RFC: PJM

SERC: South East

FRCC: Florida (minus the panhandle)

SPP: Southern Power Pool (Kansas and Oklahoma)

MRO: Midwest

Long Run Price Response (Conservation)

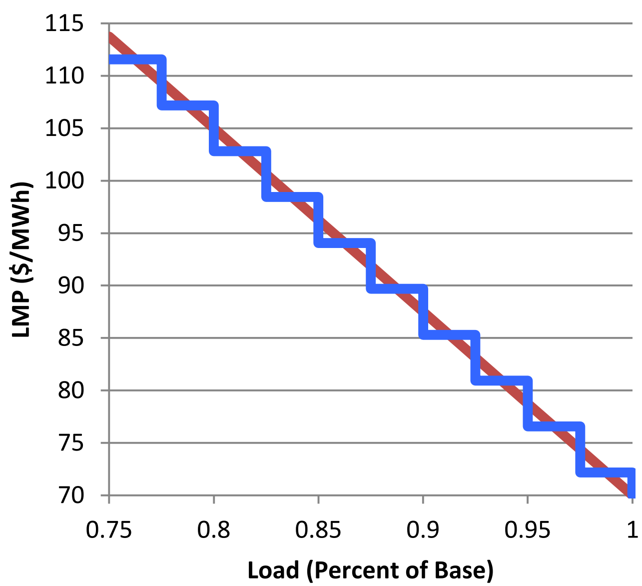
Actual Demand Response (Red)
Modeled Demand Response (Blue)

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)

We use an elasticity of 0.8 to combine the short and long run.

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

Typical Run

- Select a given policy scenario
- Sequential optimization of three periods
  - 2012 current fleet
  - 2022 allowing retirement and new investment
  - 2032 allowing retirement and new investment

Problem Size

- For 5222-bus Eastern Interconnect model, with 2882 aggregated generators, largest island (4856 buses) results in …
- Equivalent DC OPF
  - 58,000 buses, 200,000 generators, 160,000 lines
- LP with
  - 750,000 variables, 2,000,000 constraints
- Sequence of 3 periods solves in about 45-60 hours on 12-core, Mac Pro workstation

Generator and Load Data Overview

- Information about existing units combined from 12 sources
- Investment costs from EIA
- Fuel cost projections from EIA
- Pollution transfer coefficients from EPA-funded model
- Fine PM mortality effects and valuation from NRC
- Twelve hour types represent the year. Vary in terms of unit availability (from NERC) and load (from ISOs and NERC).
- Load grows at 0.59% per year (before long run demand response) per NYISO projections for initial runs

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

For each US generation unit, we match up the data from the following data sets:

- EIA EGU list (master list, state, max MW, fuel type, unit type)
- EIA plants list (latitude and longitude, which NERC region unit is in)
- Energy Visuals (MMWG) Transmission Atlas EGU list (location on network)
- EPA Continuous Emission Monitoring hourly data (heat rate)
- EPA Clean Air Markets EGU list (emission rates)
- Energy Visuals FirstRate EGU list (heat rate if not available from EPA)
- EIA flue list (stack(s) associated with each unit, and stack parameters necessary to calculate effective stack height of each)
- Air pollution transfer coefficients for each unit from EPA contractor, same as used in National Research Council's *Hidden Costs of Energy* study

The match-ups that require experimentation and sophisticated coding

- EPA unit list with other datasets
- EIA units with Energy Visuals units (those not already matched)
- Combined cycle parts with each other
- Units with interconnections (because of errors in data on which NERC region each unit is in)
- Units not in Energy Visuals data with network nodes
- EIA flues with EIA units
- Air pollution transfer coefficients with other datasets

Most sophisticated data processing aside from the matchups

- Heat rate of each unit from EPA CEMS hourly data—only the hours during which units are at or above 70% of max capacity
- Emission functions of each unit from EPA CEMS hourly data (in progress), taking into account effects of ramping and start-up
- Ramp rate of each unit from EPA CEMS hourly data (future)
- Aggregation of similar units to reduce number of control variables

Missing data we are filling in with predicted values

- Heat rates, VOM, and emission rates using averages by subtype or regression analysis
  - At units for which we have full info, calculate average by subtype or average relationship between universally known variables (e.g. age, size, pollution controls) and the ones above
  - Use those relationships to estimate the unknown variables at units where they are missing
- Use non-linear regression analysis in polar coordinates, and atmospheric science principles, to estimate missing pollution transfer coefficients

Problems with MMWG data for which we are correcting

- Phantom units (in MMWG data)
- Incorrect heat rates (in supplementary data)

Converting pollution into estimated mortality cost

- Seventy million county-to-county transfer coefficients from EPA-funded model
- Population per county, and percentage over 30, from US and Canadian censuses
- Dose-response functions from NRC
- Valuation per premature death from US government standard value

Verification of air quality aspect of modeling

- Annual 2010 US premature mortality estimated from our data on the generators is 13,000, which is entirely consistent with a prior study's national estimate using the same exposure-response function.
- Health damages and mortality not included in example runs shown today

New Power Plant Costs

Fuel Type	Capital Recovery Required ($/MW/Year)	Annual Total Fixed Costs ($/MW)	Total Variable Cost $/MWh (in 2012)	Total Possible Capacity Additions in EI
Coal (Dual Unit Advanced PC)	$497,201	$35,255	$29.05	34 GW
Natural Gas (Advanced NGCC)	$181,824	$20,661	$39.05 (if $5.50 per Bcf; varies)	110 GW
Wind*	$392,322**	$30,710	$0	249 GW (2022) 285 GW (2032)
Nuclear	$470,226	$95,571	$2.04	20 GW
Solar*	$520,000 (2022)! $390,000 (2032)!	$17,548	$0	250 GW (2022) 285 GW (2032)

*Excluding production tax credit for wind and solar (included in some runs)
**Cost shown is per MW of average output, not capacity, and assumes wind capacity factor of 33%. Some regions have higher cost (Florida), some regions have lower cost (SPP, Midwest) based on varying capacity factors.
! Cost/MW in Florida and SPP with 20% capacity factor. Other regions have a higher costs depending on capacity factors.

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

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Representative hours

- 12 hours represent the year
- 4 each for summer, winter, and fall/spring
- For example, summer peak hour type represents the 5% of summer hours with the highest hourly EI-wide load
- Load varies independently in each region of the EI, based on actual 2010 data for each region and representative hour bin

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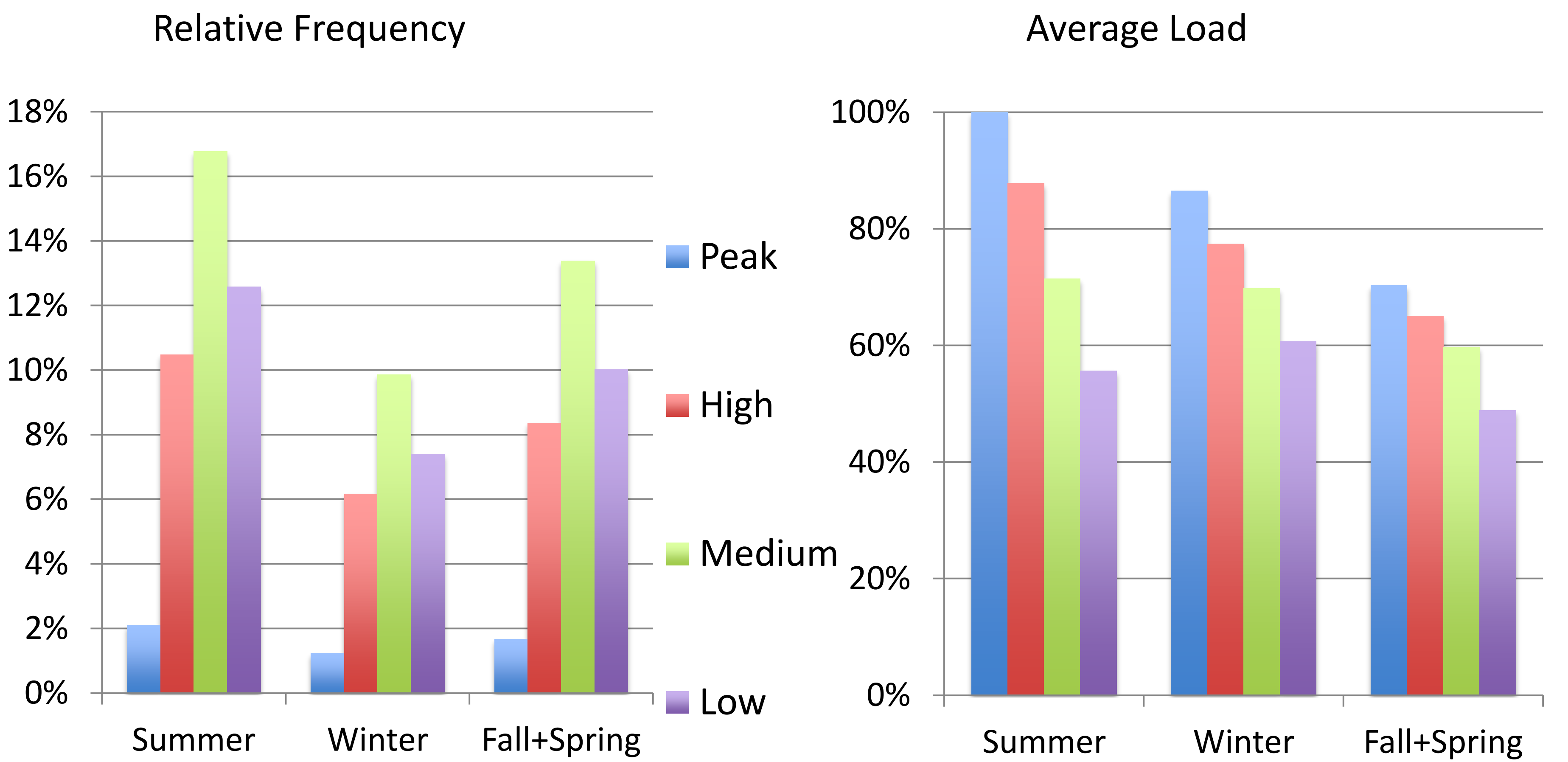
Representative Hours in EI Model



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Investment and Retirement

- 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.
- Millikin Station

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Cases for Analysis: Fuel Costs

High Natural Gas prices assume low prices in the short term due to shale gas, which increases in 2022 due to depletion and converges to the world price by 2032. DOE recently lowered reserve estimates for the Marcellus shale by 64%.

Low Natural Gas prices are estimates from the EIA

Coal and Oil costs are assumed to remain unchanged

PHOTO: MLADEN ANTONOV/AFP/GETTY IMAGES

$/MBTU	2012	2022	2032
Natural Gas (High)	$2.50	$7	$14
Natural Gas (EIA)	$2.50	$4.77	$5.86

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Cases for Analysis: CO_2 Cap and Trade

Cap and Trade is lowest cost way to reduce CO2. But these markets are unstable with large price swings for permits. Answer is Floor and Ceiling for prices (Price collar)

Assume price is at the ceiling and increases by 5% annually

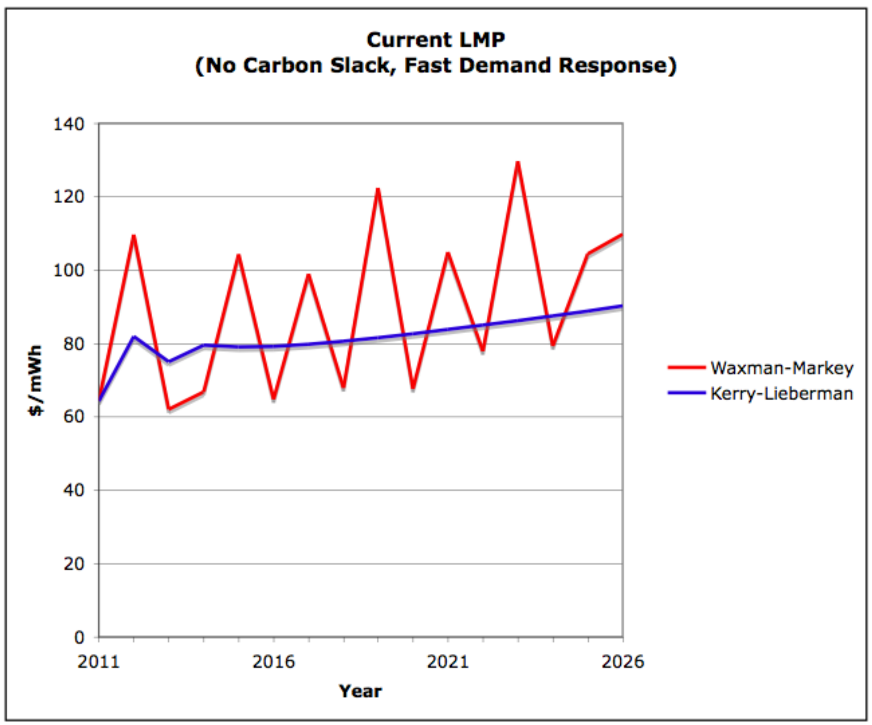


Figure compares predicted CO2 permit prices with and without a price collar

Cases for Analysis: Proposed USEPA CO2 Regulation

- 1000 pound per MWh limit for new fossil fuel plants
- Achievable today by only combined cycle natural gas units
- Coal units could operate for 10 years without CCS and then for 20 more years with CCS as long as the lifetime average emissions meet the proposed standard
  - No one will take this bet

Cases for Analysis:
Production Tax Credit for Wind and Solar

- Federal Production Tax Credit is $22/MWh
- Uncertain future
- Ignore State-level programs

Summary of Case Descriptions

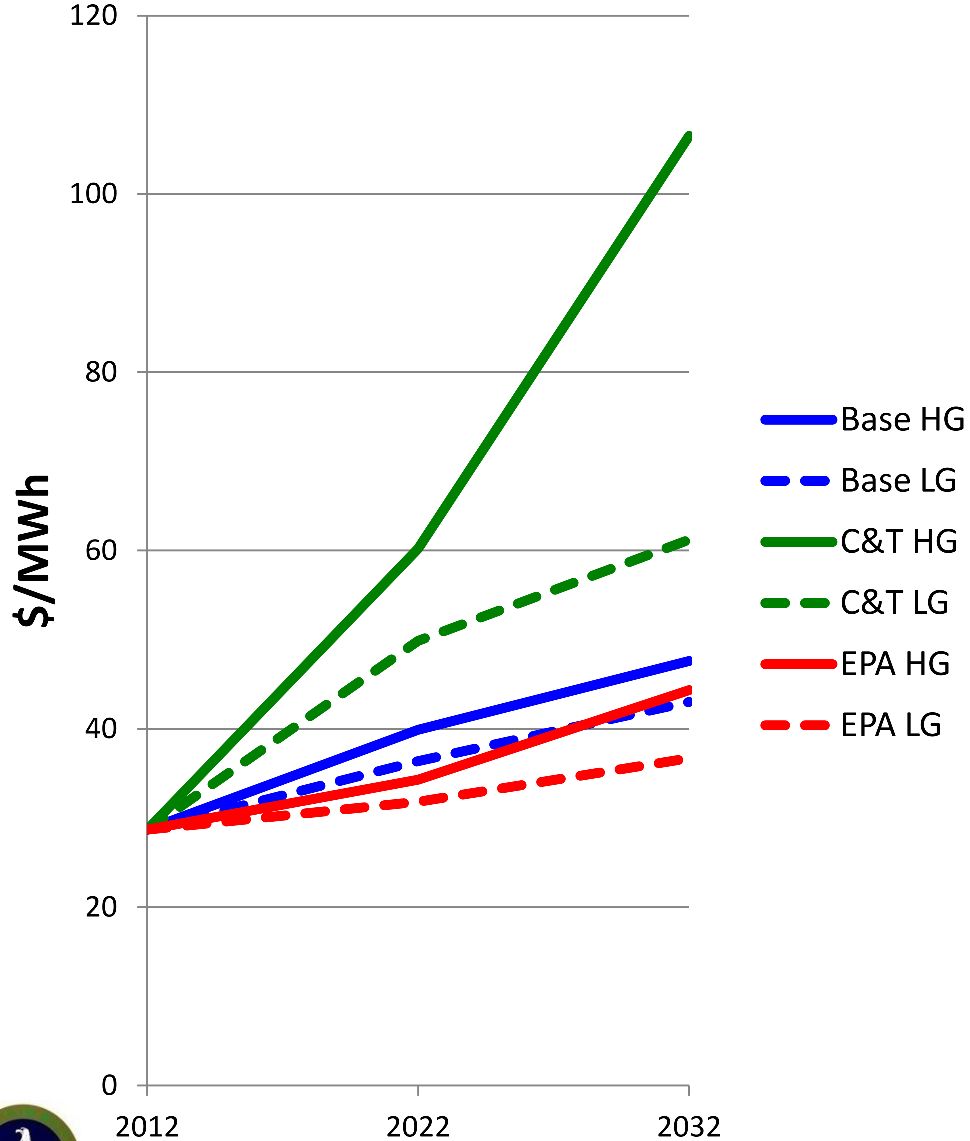
- HG: High Gas Prices; LG: Low Gas Prices
- C&T: Cap and Trade for CO2 at price cap in 2022 ($36.94/metric tonne) and 2032 ($60.18/metric tonne) or alternatively
- EPA: EPA regulations for CO2 on new generators effectively prohibits new coal units
- PTC: Production Tax Credit ($22/MWh) for wind and solar

Combined Cases

- 1) Base Case, HG
- 2) Base Case, LG
- 3) C&T, PTC, HG
- 4) C&T, PTC, LG
- 5) EPA, PTC, HG
- 6) EPA, PTC, LG

John Taber would present these results but has just moved to Washington to Start work at FERC.

Results: Average Wholesale Prices



Cap and Trade (C&T) would increase LMP dramatically.

EPA regulations lower prices in part because of PTC for renewables compared to the Base cases

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Results: CO2 Emissions

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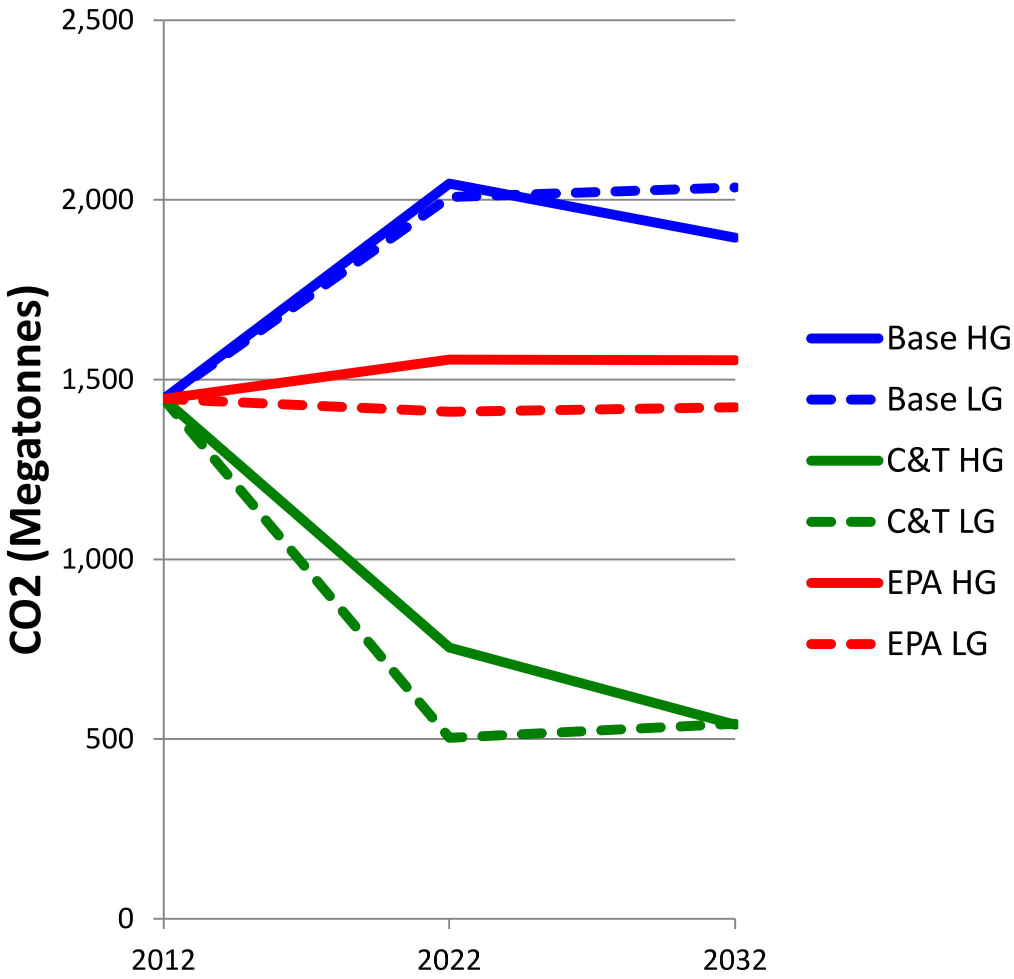

EPA lowers CO_2 not by eliminating coal but because of PTC

In the Base Case, more older NG are eliminated in the HG case, which lowers CO_2 emissions in 2032, though less fuel switching occurs

In the C & T case, higher gas prices result in less Coal->NG fuel switching, which increases CO_2 emissions

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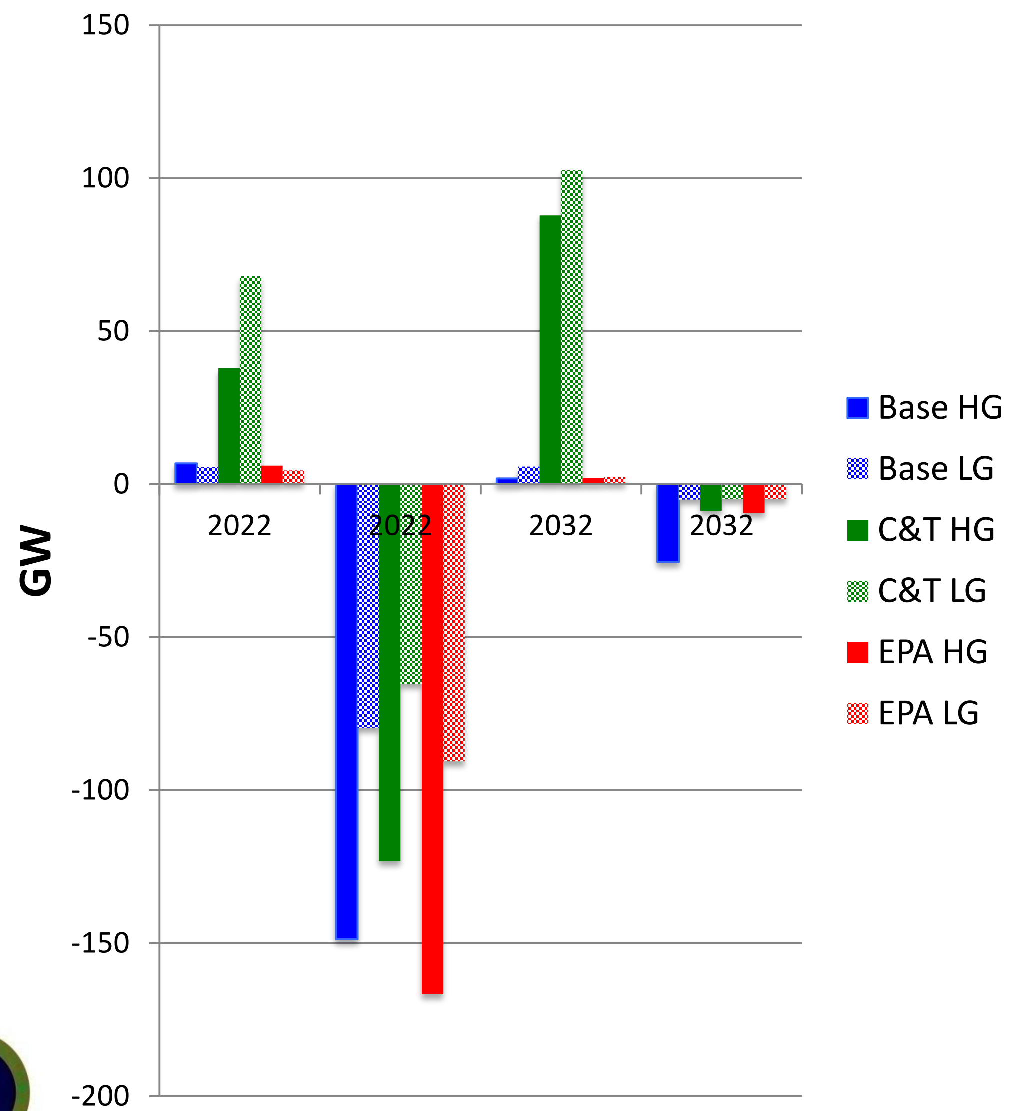
NG Additions and Retirements



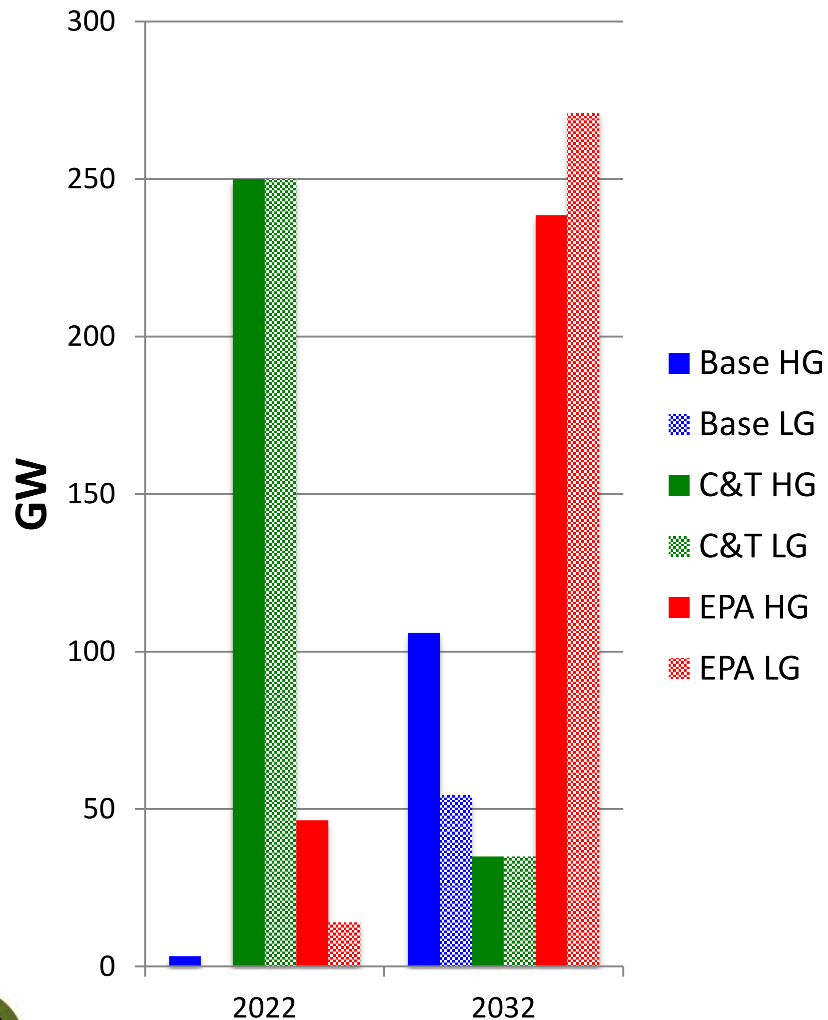
NGCC is built in New England in all cases

In the Base Case, some NGCC is built in Florida under both gas prices and PJM under low gas prices.

In Cap & Trade, NGCC is built in all regions

Retirements are much larger than additions as older, inefficient units are retired

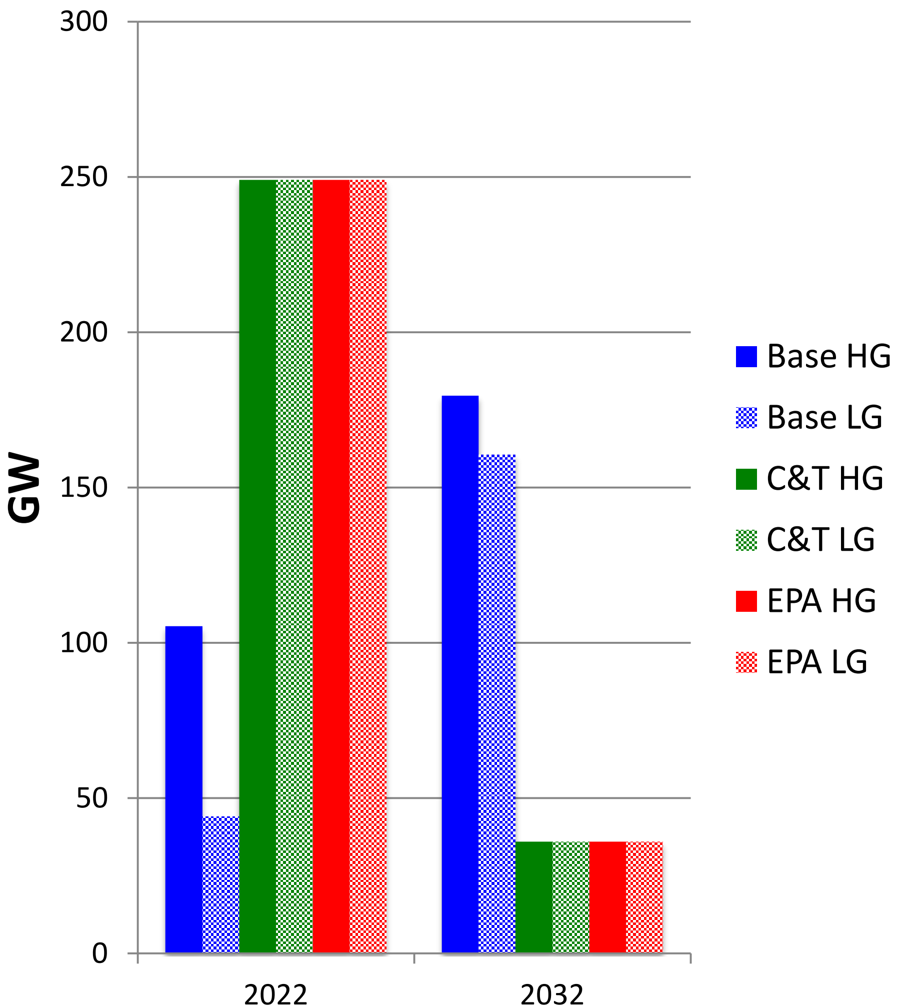
Solar Additions



Solar is built in Florida in all cases.

In Kerry-Lieberman and EPA cases, which include the PTC, solar is also built in the southeast US

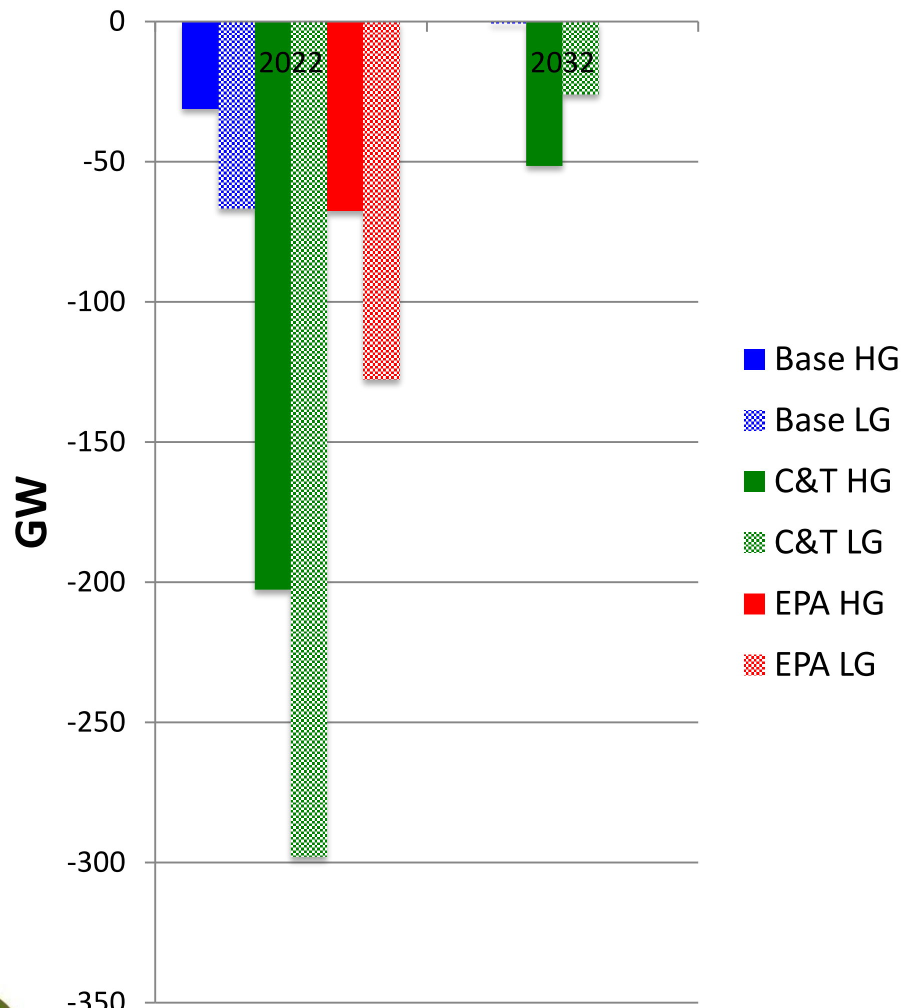
Wind Additions



The largest share of wind is built in the SPP (mostly Kansas and Oklahoma)

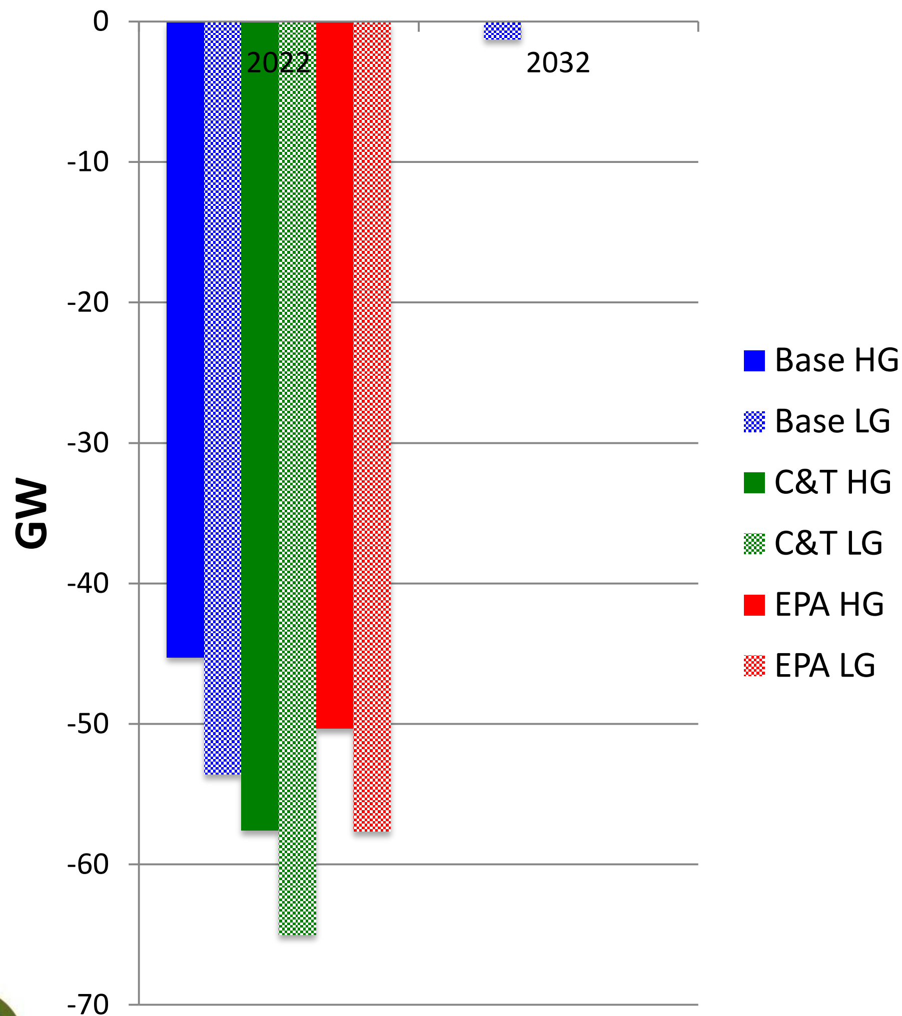
Some wind is built in the other regions (except for Florida)

Coal Retirements

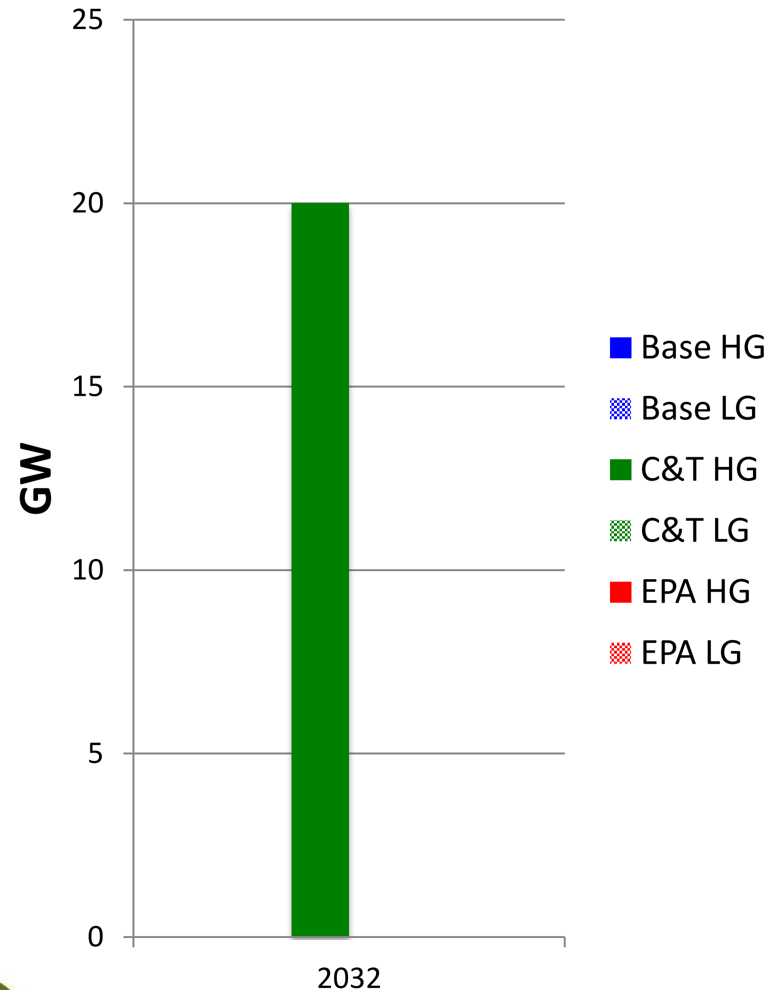


CO_2 emissions charges force greater retirement of coal units; PTC allows more units to be retired in favor of renewables

Oil Retirements



Nuclear Additions



Only in the Kerry-Lieberman High Gas case is Nuclear built.

Limits for Solar and Wind reached, Nuclear cheaper than NGCC at $14 gas

Conclusions

- CO_2
  - CO_2 may continue to increase without additional regulations
  - PTC for renewables reduces CO_2
  - C&T + PTC cause large decreases in CO_2
- Generation
  - Even without PTC or environmental regulations, a range of generation technology (NGCC, wind and solar) are built.
  - Wind and Solar driven to build limits if a PTC exists
  - Nuclear is only built in C&T HG case
  - Coal is never built

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Future Work: Example Proposals for New or Upgraded Transmission

- Proposal in New York State for a new line under the Hudson river to connect Hydro Quebec to NYC—backup for wind
- BPA Proposal to upgrade I-5 corridor to provide power to Portland Oregon—shortages expected to develop in a few years
- Texas needs new lines for anticipated wind expansion

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Optimizing Lines is Complicated by Simultaneous Economic Interaction of Load, Generation, and Transmission

- Think of a new freeway
  - Business will locate where consumers can now travel more easily to work or shop
  - Consumers will locate homes to be near jobs, shopping, and recreation
  - Resulting congestion will create need for more new roads
- Similarly, new load drives need for new generation that drives new line capacity that allows for more economic growth but also new technology (wind, solar, storage) may drive need for more or less transmission

Transmission Planning Model Needs to Incorporate...

- Long run load in response to population and economic growth and local electricity prices
- Generation investment driven by line capacity, load and changing technology, regulations, capital costs, and fuel prices
- Optimal transmission needs driven by the above

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The SuperOPF Planning Tool:

- Already has
  - piecewise linear benefits (step function long run demand response of load to price)
  - DC load flows
  - Allows optimal investment in new generation by type
  - Uses a detailed network reduction that retains all high voltage lines (e.g., 5200 node reduction of Eastern Interconnection)
- *Add optimization of capacity of selected additional new and existing lines*
- *Could be solved as a quadratically constrained mixed integer optimization problem for which good solvers exist*

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