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Environmental Policies on the Grid:

Findings from an Integrated Economic, Engineering, and Environmental Model

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SuperOPF Planning Tool

Uses three network reductions (for the East, the West, and Texas) to cover the entire nation. These reductions retain all high voltage lines of 230 KV and above.

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Overview of Features

- Detailed electrical model of grid
- Optimizes operation, investment, and retirement every ten years: Minimizes sum of operating, investment, and demand response costs over the next ten years
- Can also include value of premature mortality and other emission damages

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Some Features

- Electrical model of grid and its operation ("DC" linear approximation of the AC system)
  - 5000+ node equivalent model for East
  - 2300+ node equivalent model for West
  - 1000+ node equivalent model for Texas
- 12 representative hours
- Demand responds to price

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Environmental Features

- Emissions of CO_2, NOX and SO_2
- Atmospheric modeling of fine particulates and resulting mortality

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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
- Exposure-response functions from NRC
- Valuation per premature death is US government standard value

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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

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Typical Run

- Adjust input parameters reflect a policy, investment, or behavior
- Sequential optimization of three periods
  - 2012 current fleet
  - 2022 allowing retirement and new investment
  - 2032 allowing retirement and new investment

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Problem Size

- For 5222-bus Eastern Interconnect model, with 2882 aggregated generators, the simulation is a linear programming problem with 750,000 variables, 2,000,000 constraints
- Sequence of 3 periods solves in about 45-60 hours on 12-core, Mac Pro workstation

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Generator and Load Data Overview

- Detailed information about existing generation 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

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

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New Power Plant Costs

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Fuel Type	Capital Recovery Required ($/MW/Year)	Annual Total Fixed Costs ($/MW)	Total Variable Cost $/MWh	Total Possible Capacity Additions in East
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 Mcf; varies)	110 GW
Wind*	$392,322**	$30,710	$0	249 GW (2022) 285 GW (2032)
Nuclear w/ subsidies & loan guarantees	$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 (Southwest, Midwest) based on varying capacity factors.

! Cost/MW in Florida and Southwest 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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Investment and Retirement

- Base year is 2012. Investment allowed in 2022 and 2032. New plants must recoup capital in 10 years.
- Underused plants are retired.
- Note that old plants must only cover variable costs and taxes while new plants must additionally cover investment costs.

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Building Blocks of Cases: Natural Gas Prices

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 2011

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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Building Blocks of Cases: CO_2 Cap and Trade Program

- Based on Kerry-Lieberman legislation, which included a ceiling and a floor on the price of the emission permits.
- Assume price is at the ceiling, which increases by 5% annually
- $36.94/metric tonne in 2022
- $60.18/metric tonne in 2032

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Building Blocks of Cases: Proposed USEPA CO_2 Regulation

- 1000 pound per MWh limit for new baseload and shoulder fossil fueled plants
- Coal-fired plants can comply only if adopt carbon capture & sequestration within ten years
- We assume no new coal-fired units will be built as a result

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Building Blocks of Cases: Production Tax Credit for Wind and Solar

- Federal Production Tax Credit of $22/MWh

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Cases

1) "Base HG": Base Case, High Gas Price
2) "Base LG": Base Case, Low Gas Price
3) "C&T HG": Cap and Trade, Wind & Solar Production Tax Credit, High Gas Price
4) "C&T LG": Cap and Trade, Wind & Solar Production Tax Credit, Low Gas Price
5) "EPA HG": No new coal units, Production Tax Credit, High Gas Price
6) "EPA LG": No new coal units, Production Tax Credit, Low Gas Price

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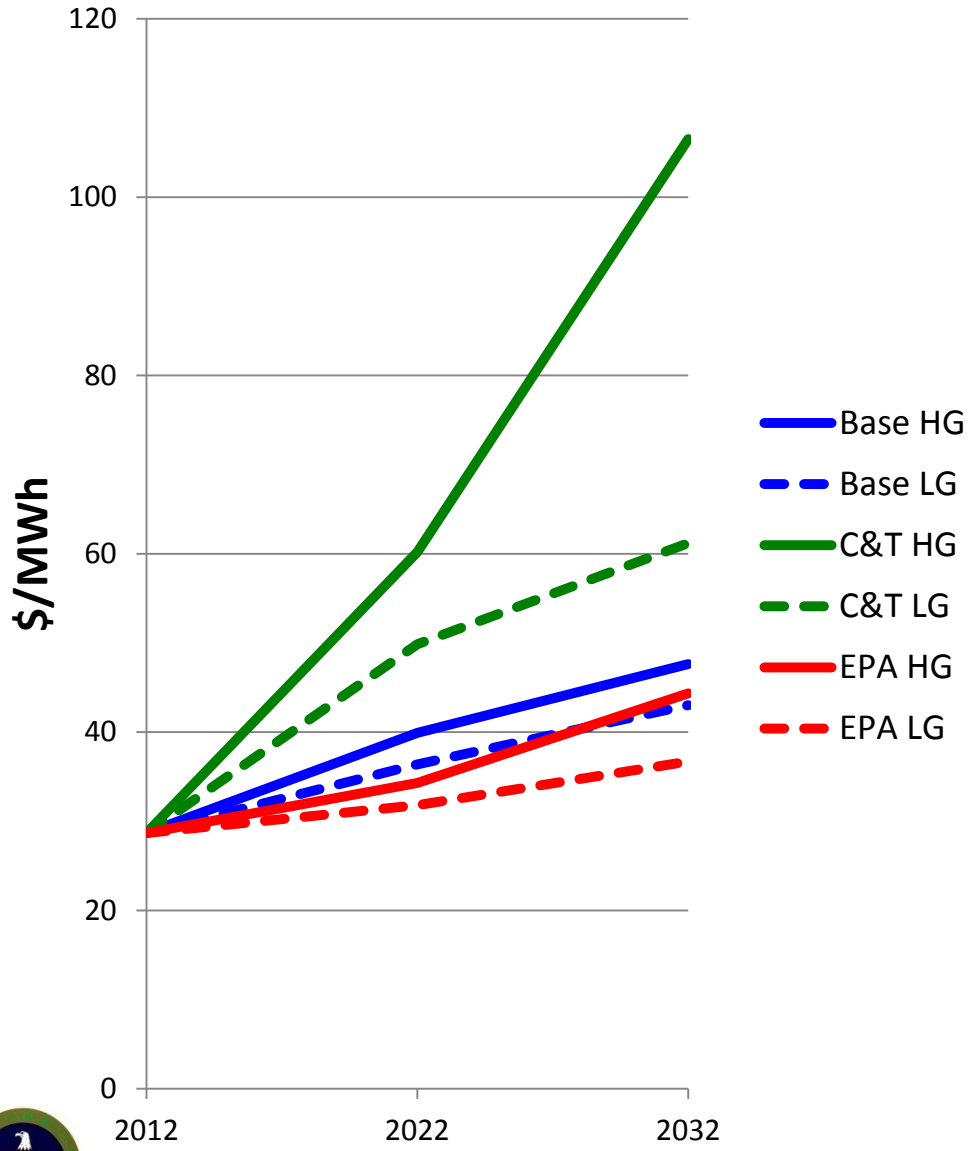
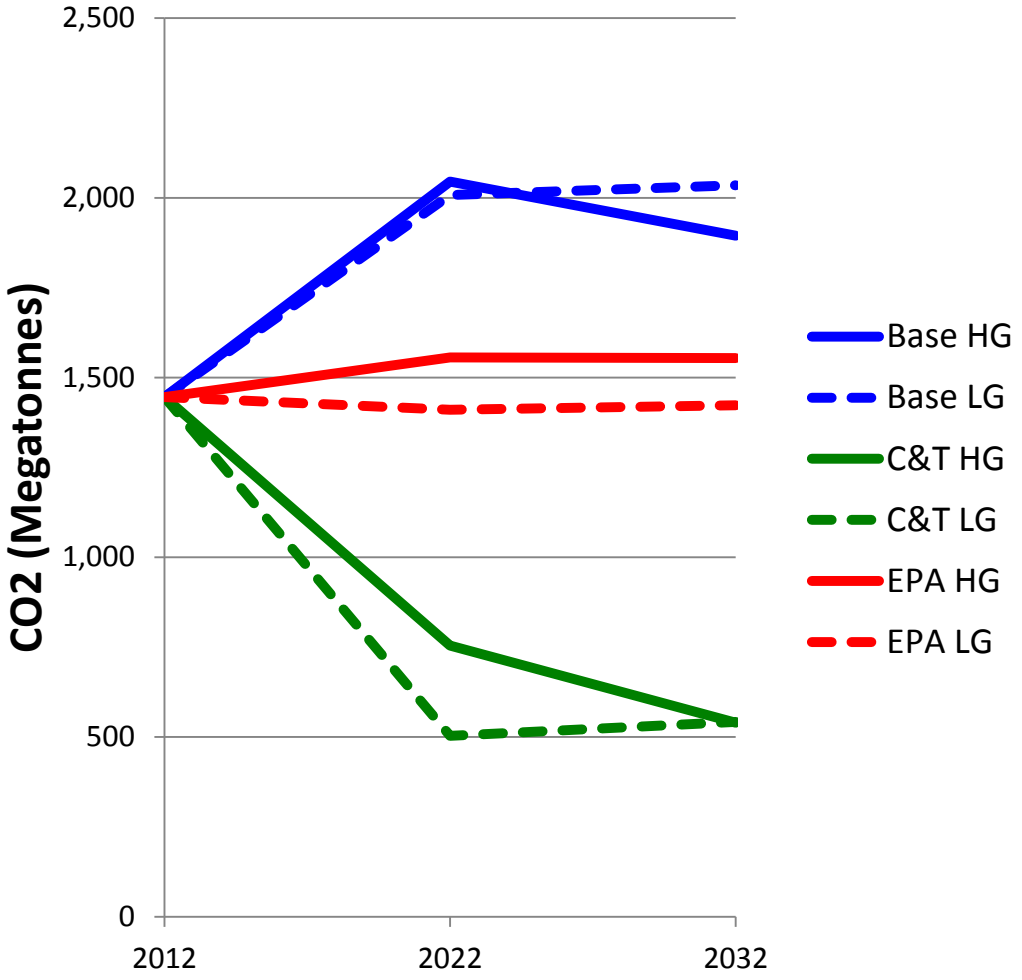
Results: Average Wholesale Prices



Cap and Trade would increase average electricity prices substantially.

EPA cases lower prices compared to base cases because of production tax credit for wind & solar

Results: CO2 Emissions

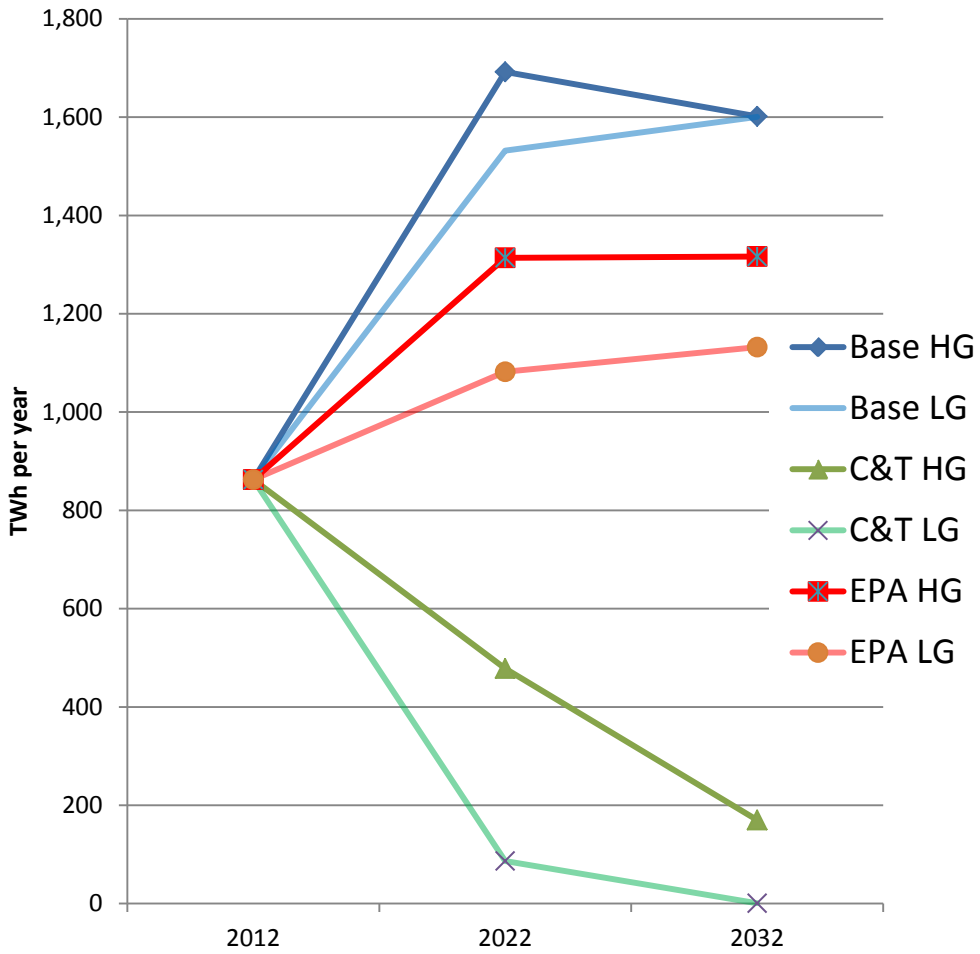


EPA lowers CO2 not by eliminating coal but because of PTC

In the Base Cases, more older NG are eliminated in the HG case, which lowers CO2 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 CO2 emissions

Generation from Coal

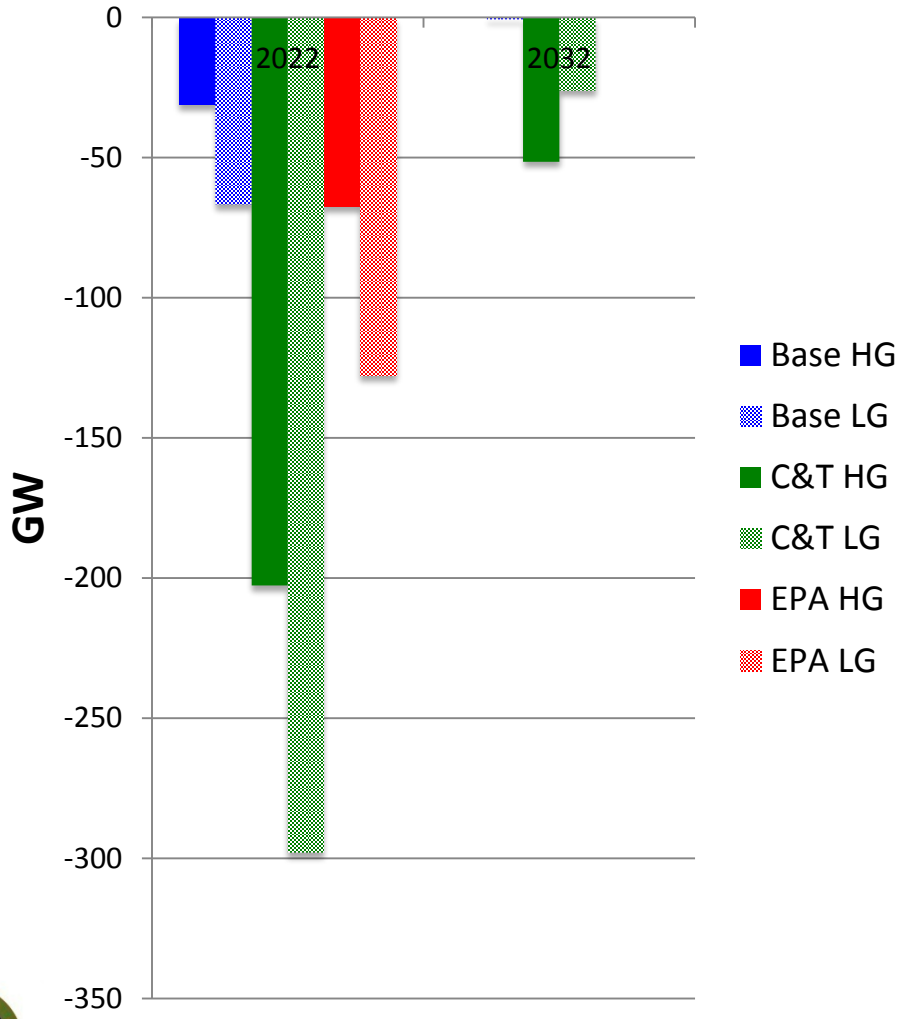


Increases Substantially Under Base Cases Because of Higher Gas Price and Increased Load (blue)

Increases Somewhat with Production Tax Credit and Ban on New Coal-Fired Generators (red)

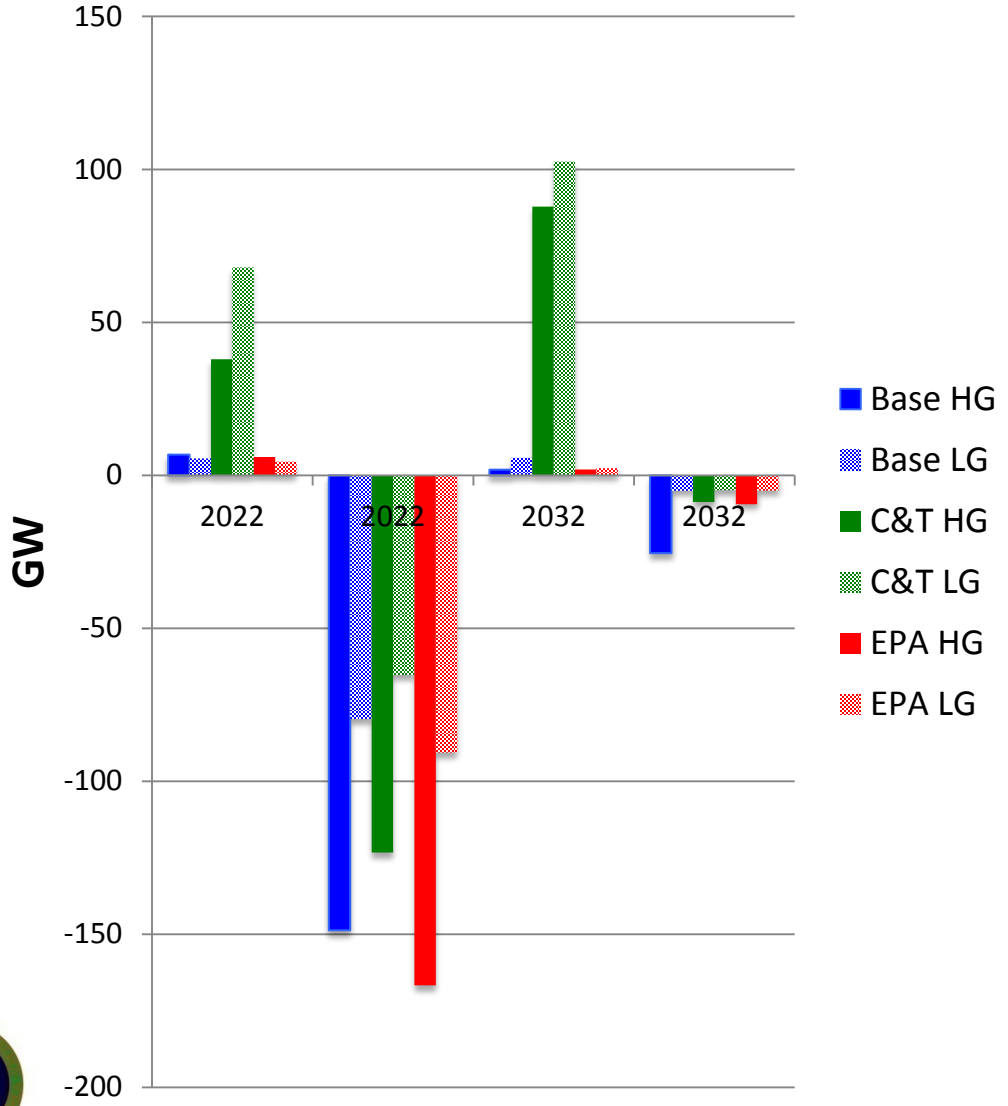
Declines Dramatically with Cap & Trade + Production Tax Credit (green)

Coal Retirements



CO2 emissions charges force greater retirement of coal units; PTC allows more units to be retired in favor of renewables

NG Additions and Retirements



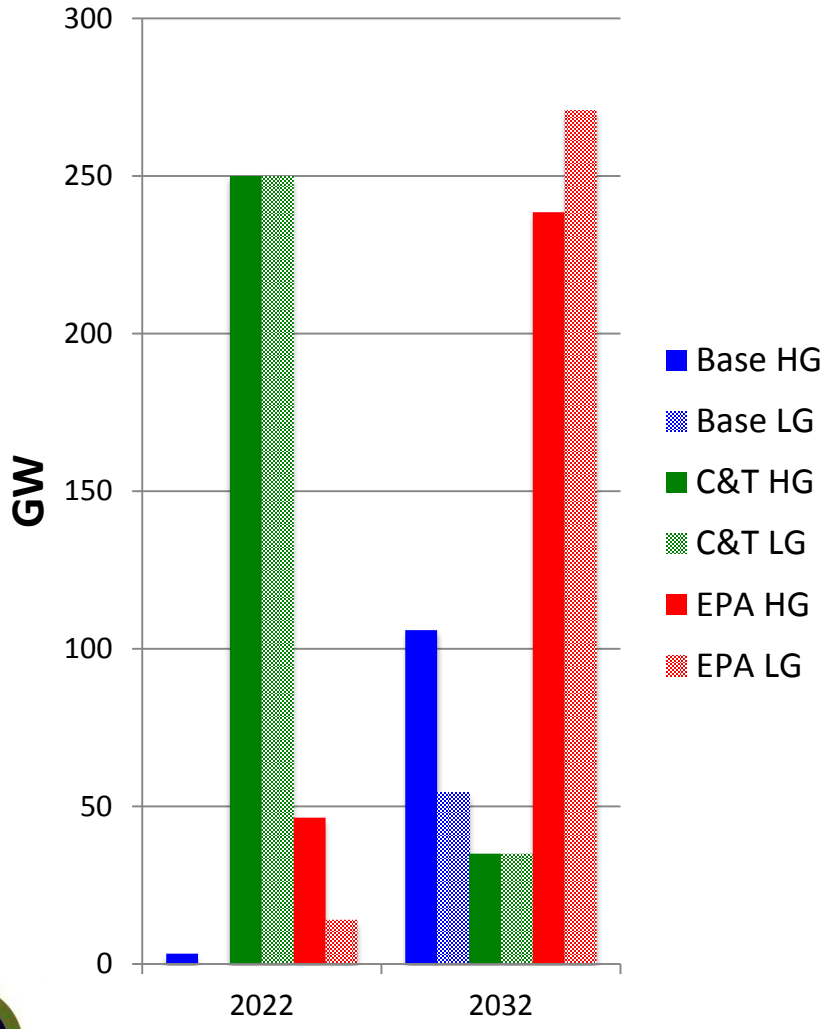
NGCC is built in New England in all cases

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

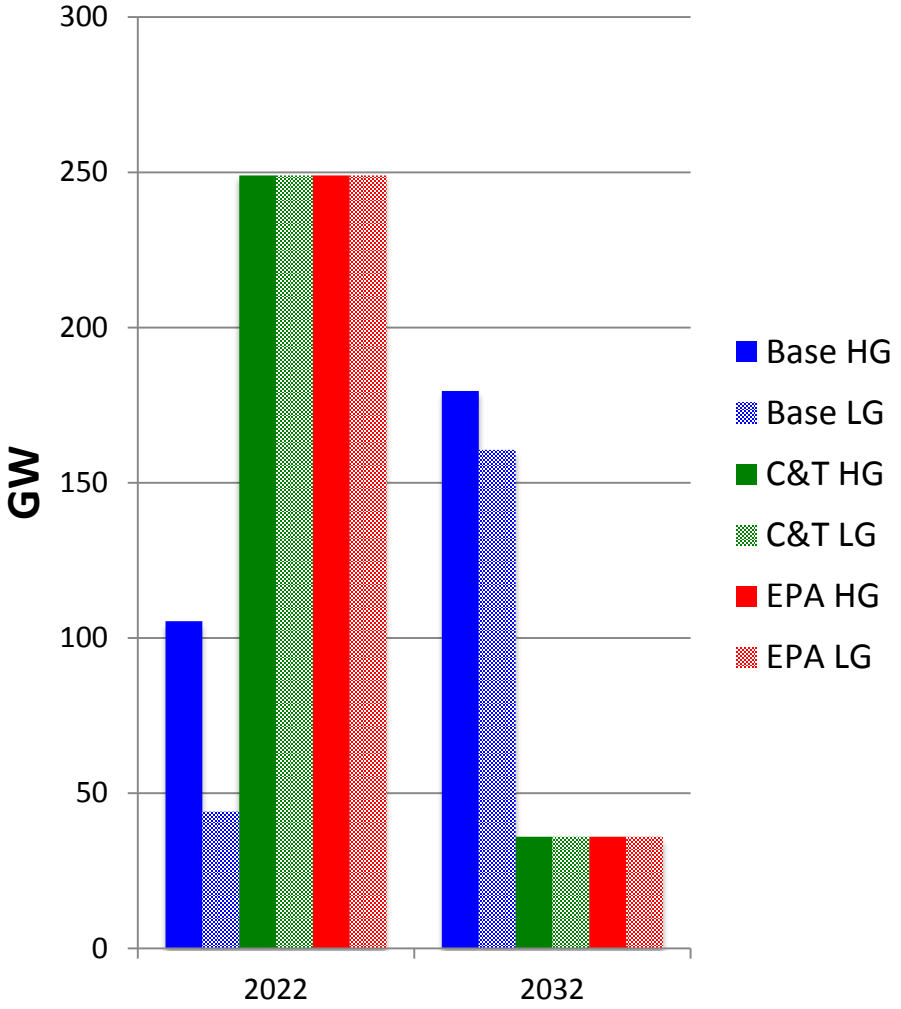
Solar Additions



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

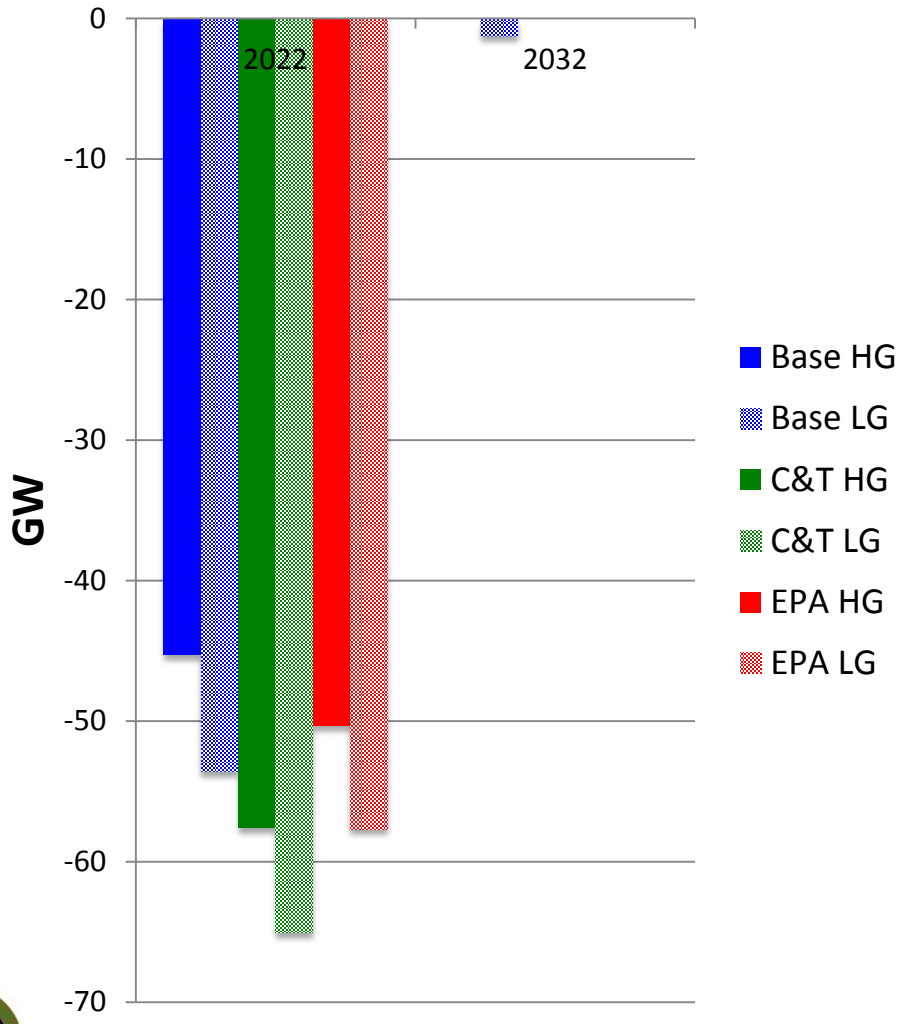
Wind Additions



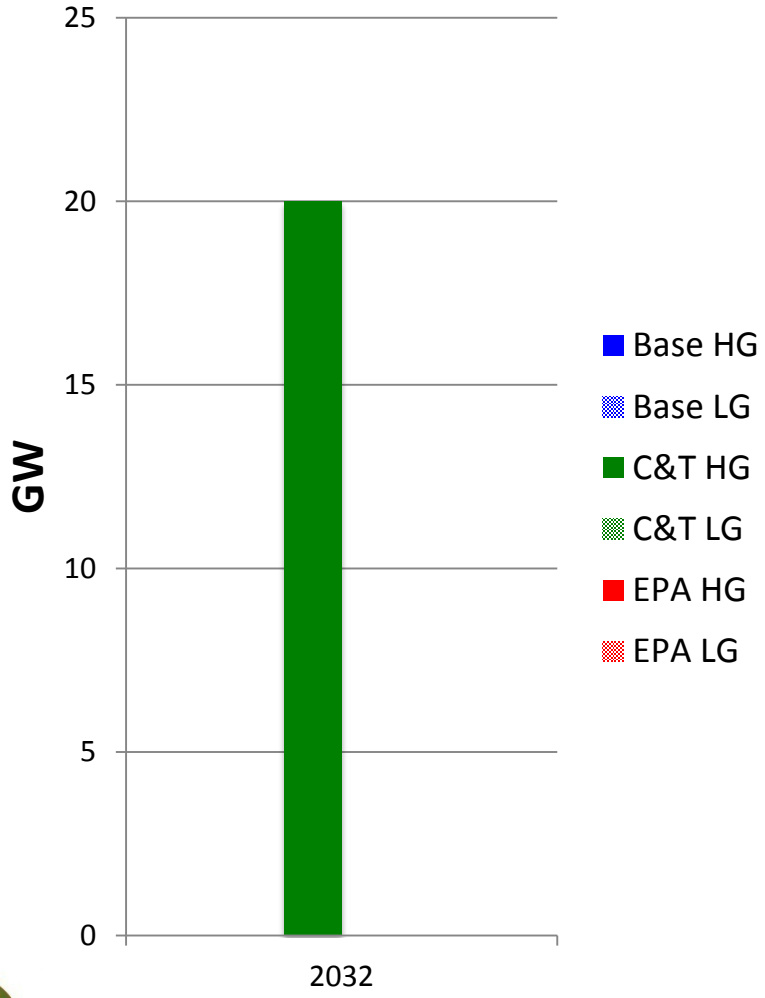
The largest share of wind is built in the Southwest Power Pool (mostly Kansas and Oklahoma)

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

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

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Conclusions

- CO_2
  - CO_2 may increase without additional regulations
  - Production tax credit (PTC) for wind & solar reduces CO_2 substantially
  - Cap & Trade + PTC cause large decreases in CO2
- 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 Cap & Trade High Gas Price case

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