

# **Energy Market Consequences of Emerging Renewable and Carbon Dioxide Abatement Policies in the United States**

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## Study Outline

- “Energy Market Consequences of Emerging Renewable and Carbon Dioxide Abatement Policies in the United States”
  - Developed the Rice World Energy Model (RWEM) – a derivative of the Rice World Gas Trade Model (RWGTM) – using *MarketPoint* software.
- A scenario approach was used to examine and compare various outcomes under different sets of assumptions.
  - Degree of CO<sub>2</sub> emissions cuts (no clear policy yet, so we investigate effects by degrees)
  - Safety valves and offset programs
  - The operating and capital costs of various end-use technologies (there is wide disagreement between government and industry here)
  - Elasticity of supply of various fuels
  - Elasticity of demand in different sectors
  - Rate of technological innovation
  - Regional policies versus harmonized federal and international policies.
  - “Carbon leakage”

## Some Key Points

- The price of CO<sub>2</sub> is ultimately determined by the cost of deploying capital that allows the utilization of technologies that lower CO<sub>2</sub> emissions.
  - If \$100/ton is required to deploy Carbon Capture and Sequestration technologies (CCS) and CCS is the least cost option, then the CO<sub>2</sub> price will be \$100/ton.
- Analysis indicates the following factors are very important to determining the outcome:
  - The elasticity of supply of fuels with lower carbon intensity
    - For example, if the supply curve for natural gas is very flat, then the price of CO<sub>2</sub> need only rise to the point at which natural gas substitutes for coal.
    - Shale gas could prove very important in determining the CO<sub>2</sub> price.
  - Elasticity of demand for energy
    - If energy demand is very inelastic, then the price of CO<sub>2</sub>, *ceteris paribus*, will generally be higher to achieve a given reduction.

## Some Key Points (cont.)

- Analysis indicates the following factors are very important to determining the outcome (cont.):
  - Assumptions regarding capital costs
    - In model runs using DOE cost estimates, the cost of deploying IGCC is sufficiently low to ensure that coal maintains market share. Increasing this cost raises the price of CO<sub>2</sub> and reduces coal's long run market share.
  - Assumptions regarding long term load factors
    - If the capacity factors on wind increase, then wind becomes a more favorable option. This tends to lower the price of CO<sub>2</sub>. Thus, any technological innovation that raises the capacity factor of wind is favorable.
  - Assumptions regarding availability of new technologies
    - If new technologies are made available sooner and more cheaply, then the price of CO<sub>2</sub> is directly influenced lower.

## Costs of Generation Technologies

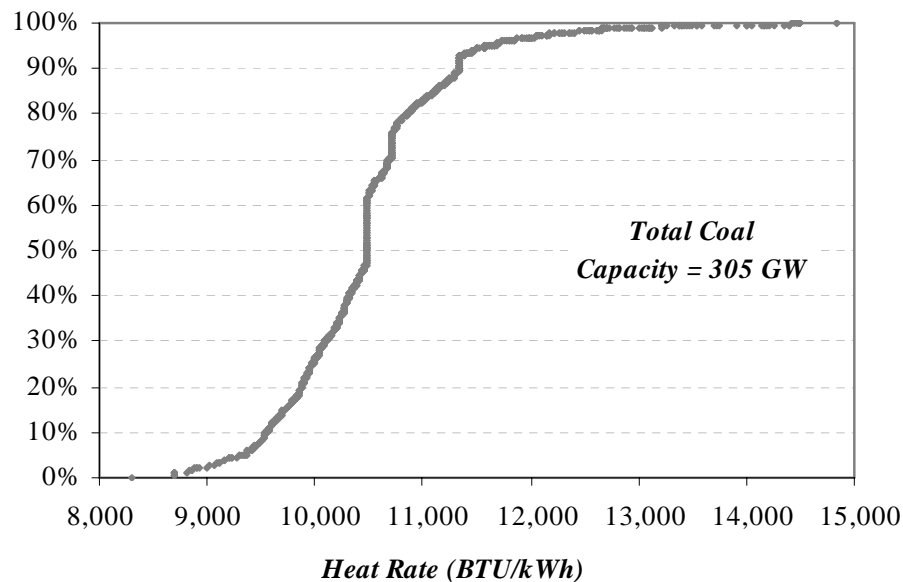
- Substantial disagreement between government and industry... except in the deployment of renewables.

Technology	Total Overnight Cost 2005 \$/kW			Industry Adjustment	Variable O&M	Fixed O&M	Heat Rate
	DOE Source	Industry Sources	DOE Source		DOE Source	DOE Source	
Scrubbed Coal New	\$ 1,939	\$ 3,080	1.588	\$ 0.046	\$ 25.94	9,200	
w/ CCS	\$ 2,993	\$ 4,846	1.619	\$ 0.061	\$ 32.96	11,061	
Integrated Coal-Gasification Combined Cycle	\$ 2,241	\$ 3,714	1.657	\$ 0.029	\$ 36.44	8,765	
w/ CCS	\$ 3,294	\$ 5,480	1.663	\$ 0.044	\$ 43.46	10,781	
Conventional Gas/Oil Comb Cycle (CC)	\$ 907	\$ 1,011	1.115	\$ 0.021	\$ 11.76	7,196	
Advanced Gas Comb Cycle (CC)	\$ 893	\$ 996	1.115	\$ 0.020	\$ 11.03	6,752	
w/ CCS	\$ 1,781	\$ 1,850	1.038	\$ 0.029	\$ 18.75	8,613	
Conventional Combustion Turbine	\$ 631	\$ 747	1.182	\$ 0.036	\$ 11.41	10,810	
Conventional Combustion Turbine (FO6)	\$ 631	\$ 747	1.182	\$ 0.036	\$ 11.41	10,810	
Advanced Combustion Turbine	\$ 597	\$ 712	1.192	\$ 0.032	\$ 9.92	9,289	
Advanced Combustion Turbine (FO6)	\$ 597	\$ 712	1.192	\$ 0.032	\$ 9.92	9,289	
Fuel Cells	\$ 5,051	\$ 6,070	1.202	\$ 0.479	\$ 5.32	7,930	
Advanced Nuclear	\$ 3,127	\$ 5,887	1.883	\$ 0.005	\$ 84.83	10,434	
Distributed Generation Base	\$ 1,291	\$ 1,379	1.068	\$ 0.071	\$ 15.11	9,050	
Distributed Generation Peak	\$ 1,550	\$ 1,628	1.050	\$ 0.071	\$ 15.11	10,069	
Biomass	\$ 3,539	\$ 4,617	1.305	\$ 0.067	\$ 60.73	9,646	
MSW Landfill Gas	\$ 3,339	\$ 4,425	1.325	\$ 0.000	\$ 107.66	13,648	
Geothermal	\$ 1,612	\$ 1,612	1.000	\$ -	\$ 155.15	34,633	
Conventional Hydropower	\$ 2,113	\$ 2,031	0.961	\$ 0.024	\$ 12.84	---	
Wind	\$ 1,812	\$ 1,811	1.000	\$ -	\$ 28.55	---	
Wind Offshore	\$ 3,629	\$ 3,351	0.923	\$ -	\$ 84.32	---	
Solar Thermal	\$ 4,741	\$ 4,619	0.974	\$ -	\$ 53.51	---	
Photovoltaic	\$ 5,690	\$ 5,208	0.915	\$ -	\$ 11.01	---	

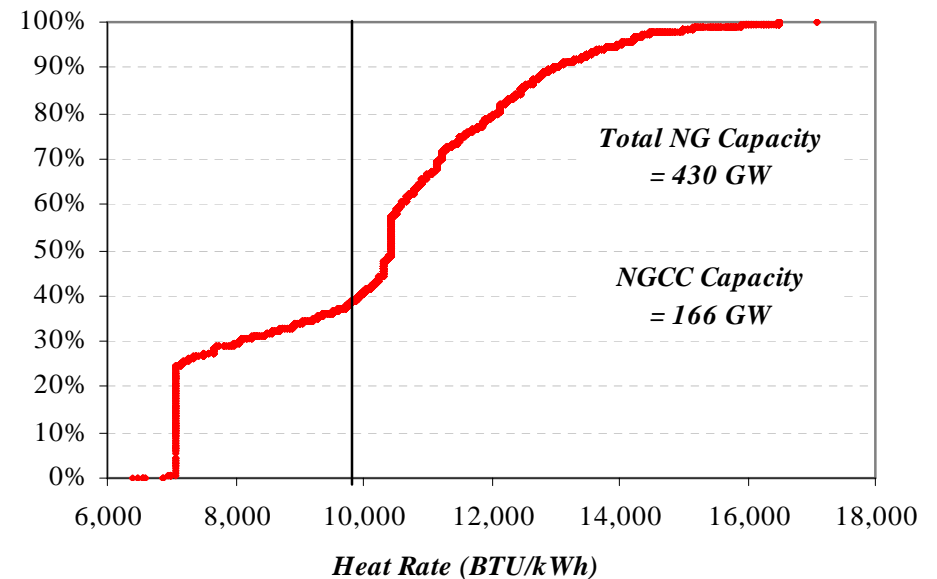
## The Potential for Gas to Displace Coal in Power

- The distribution of capacity by heat rate indicate that implementing a price for CO<sub>2</sub> can alter the competitive dispatch of coal versus gas.
- 17% of coal capacity has HR > 11,500. The HR of NGCC capacity < 7,500.
  - If  $P_{\text{coal}} = \$1.75/\text{mmbtu}$  and  $P_{\text{ng}} = \$7.00/\text{mmbtu}$ , we can displace of 17% of coal capacity with a  $P_{\text{CO}_2} = \$57$ . Note, however, that the price of coal and natural gas both would likely change, meaning  $P_{\text{CO}_2}$  would be higher in practice. This latter point is exacerbated as we seek to displace more coal.

*% Coal Capacity*



*% NG Capacity*



## **Some Study Findings**

## Modeling the Impacts of CO<sub>2</sub> and Other Regulations

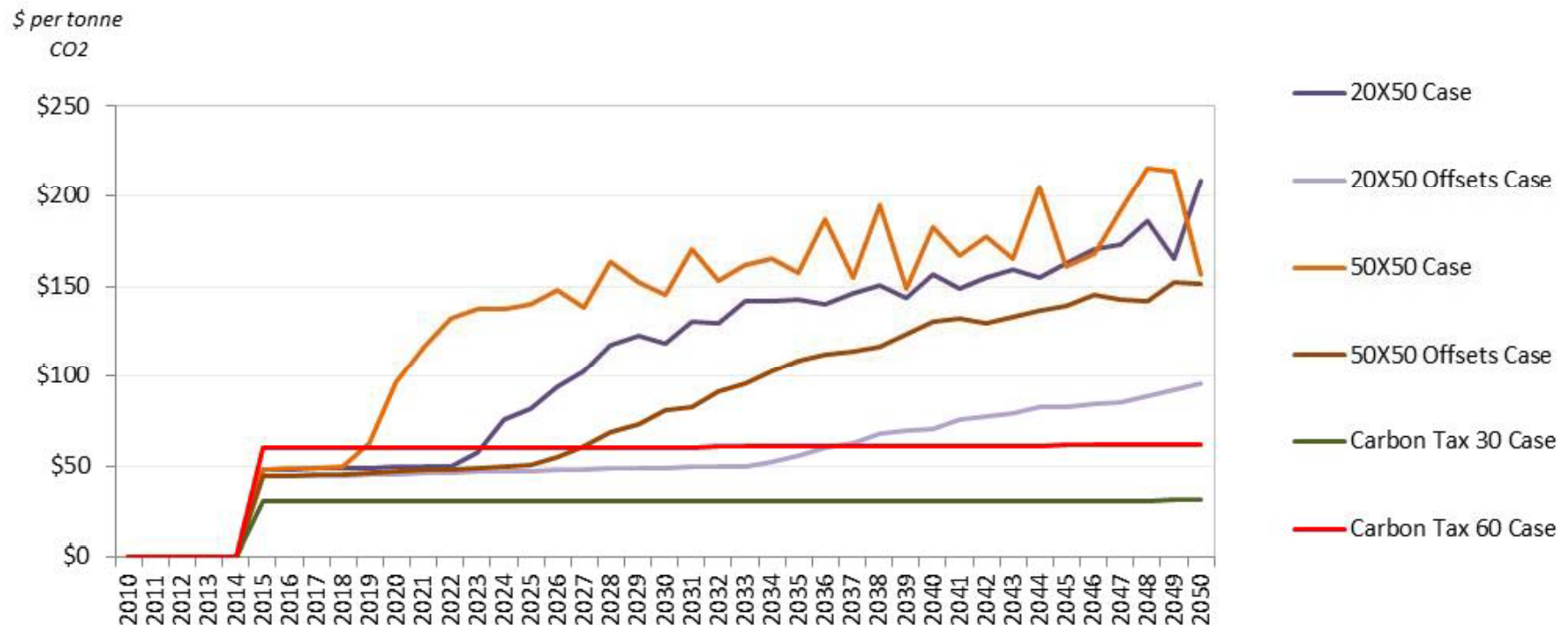
- **Reference** – No carbon caps or technology preferences are mandated. Baseline in which only commercial considerations dictate the outcome.
- **20X50** – CO<sub>2</sub> emissions are forced to fall to 20% below 2005 levels by 2050. The manner of enforcement is through a cap-and-trade scheme in which international trading begins in 2015. No assumptions about renewable portfolio standards or electric vehicles are explicitly made, although investments in renewables and electric vehicles are allowed.
- **20X50 with Offsets** – Same as 20X50 but investment in offsets are allowed. Offsets are classified as energy sector, non-CO<sub>2</sub> gases, and sequestration such as forestry.
- **50X50** – Same as 20X50 except CO<sub>2</sub> emissions fall to 50% of their 2005 levels by 2050.
- **50X50 with Offsets** – Same as 20X50 with Offsets except CO<sub>2</sub> emissions fall to 50% of their 2005 levels by 2050.
- **Carbon Tax 30** – A tax of \$30/ton of CO<sub>2</sub> is levied beginning in 2015.
- **Carbon Tax 60** – A tax of \$60/ton of CO<sub>2</sub> is levied beginning in 2015.
- **EV 30X50**– The electric car is adopted at a rate such that it represents 30 percent of the vehicle fleet by 2050. Note penetration increases over time, reflecting the time it takes for vehicle stock turnover to occur.
- **CNGV 30X50**– Same as EV 30X50 except compressed natural gas vehicles are introduced instead of electric vehicles.
- **RPS** – Renewable portfolio standards (RPS) are introduced such that renewable energy sources must account for 30 percent of electricity generation by 2030 and 40 percent by 2050.
- ...
- **Other Cases** – we also ran cases using DOE costs and cases in which transmission capacity expansions are limited.

## Key Results

- In all cases, the demand for natural gas in North America increases.
  - Largest increases are in the scenarios in which carbon pricing does not encourage the adoption of CCS technologies but do encourage switching from coal to gas in the power sector. Thus, the capital cost of CCS is critical to determining this window.
  - Scenarios in which Electric Vehicles penetrate the transportation sector natural gas demand is favored as the primary electricity source.
  - RPS scenarios tend to curb growth in natural gas demand for two reasons...
    - Higher electricity prices generally reduce overall demand.
    - Wind power takes market share for baseload from both natural gas and coal.
- Demand for oil and coal vary substantially across policies.
  - Oil demand is reduced to varying degrees across cases.
    - CO<sub>2</sub> caps ultimately render oil demand lower as EVs must penetrate to sequester CO<sub>2</sub> from mobile sources by shifting it to point sources.
  - Coal demand is reduced most by policies that raise the price of carbon... to a point. As carbon prices rise, CCS eventually becomes a commercially viable option which restores the use of coal.

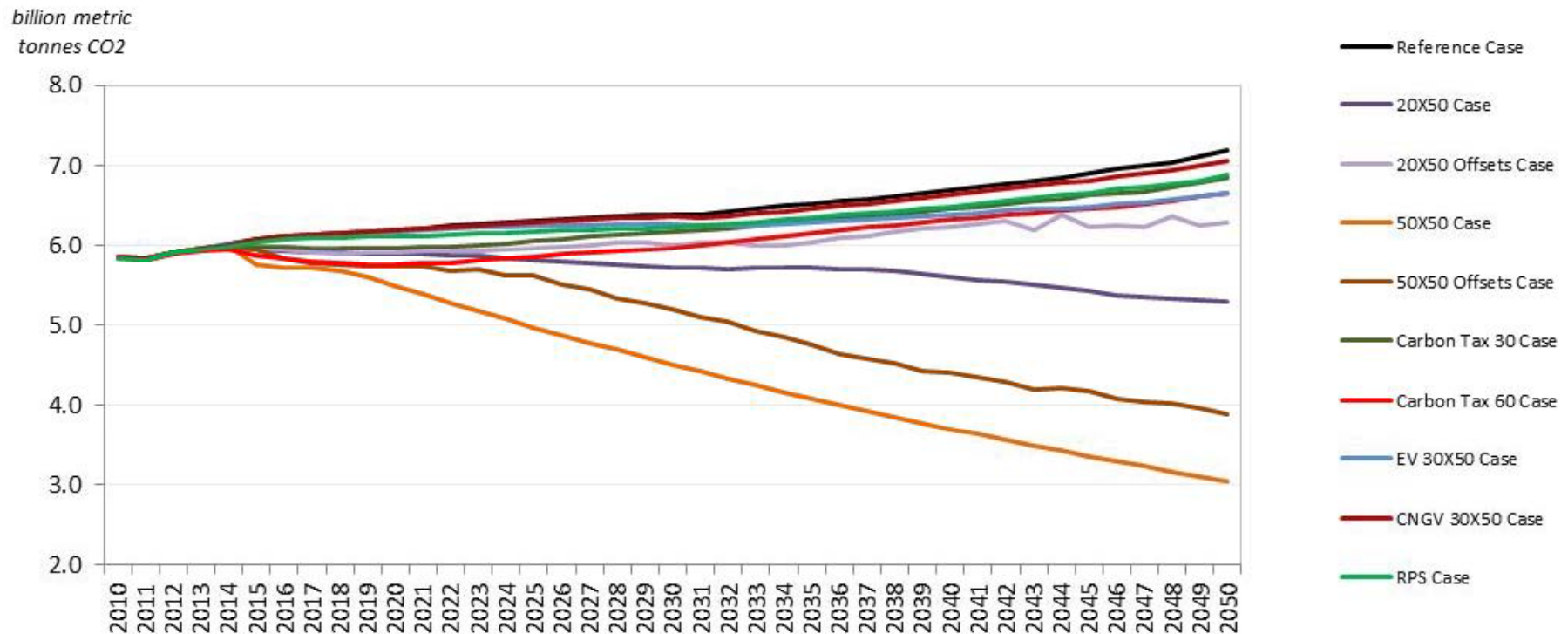
## CO<sub>2</sub> Price is Sensitive to Policy Design

- Increasing restrictions raises price.
- CCS deployment, demand reduction, and offset mechanisms are critical!
- CO<sub>2</sub> caps result in more volatility than a tax, but allowing offsets reduces volatility by allowing the “supply” of CO<sub>2</sub> credits to be more elastic.



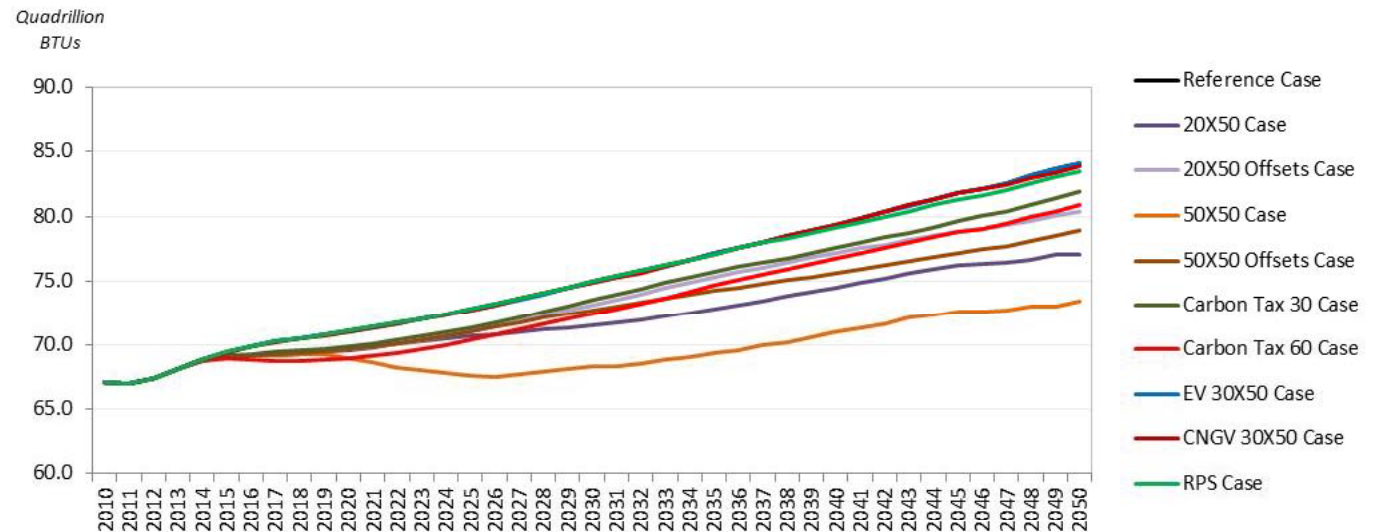
## CO<sub>2</sub> Emissions are Sensitive to Policy Design

- Biggest impact on emissions occur through stringent caps without offsets. Thus, if *net* emissions are targeted, offsets must be *real* to matter.
- RPS has only a modest effect on emissions relative to the Reference case.

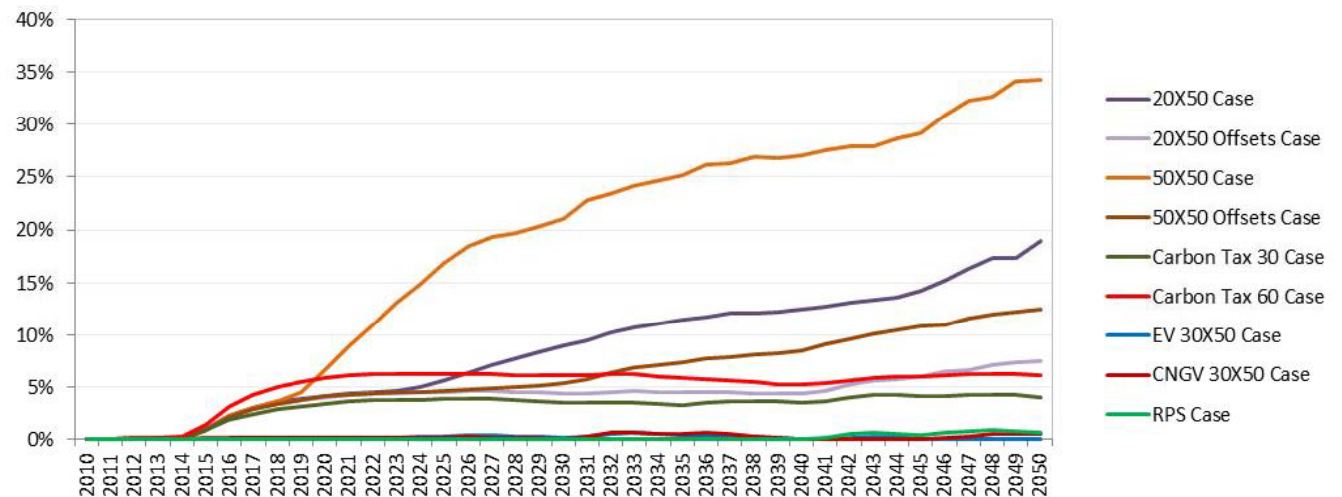


## Trends in Energy Demand Sensitive to Policy Design

- Energy demand reduction could be significant under aggressive policies. Allowing offsets results in less demand erosion.

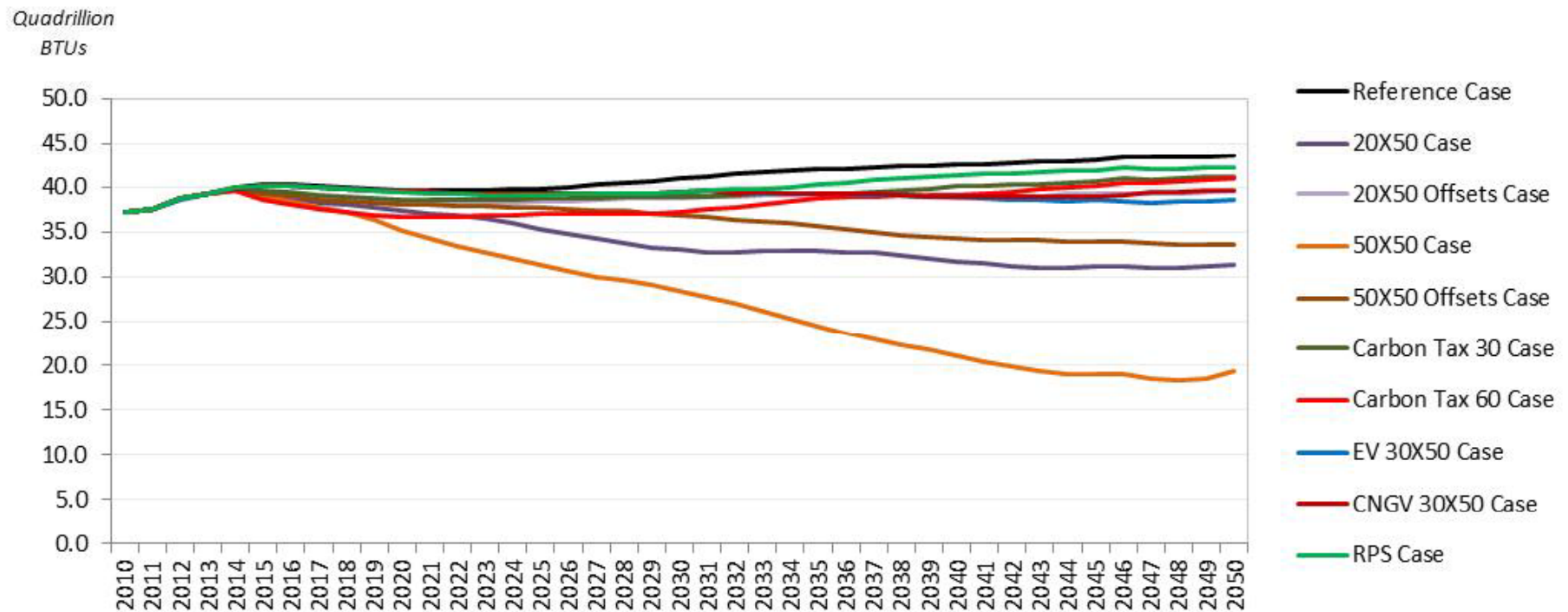


- A large portion of demand reduction occurs due to industrial relocation, or “carbon leakage”



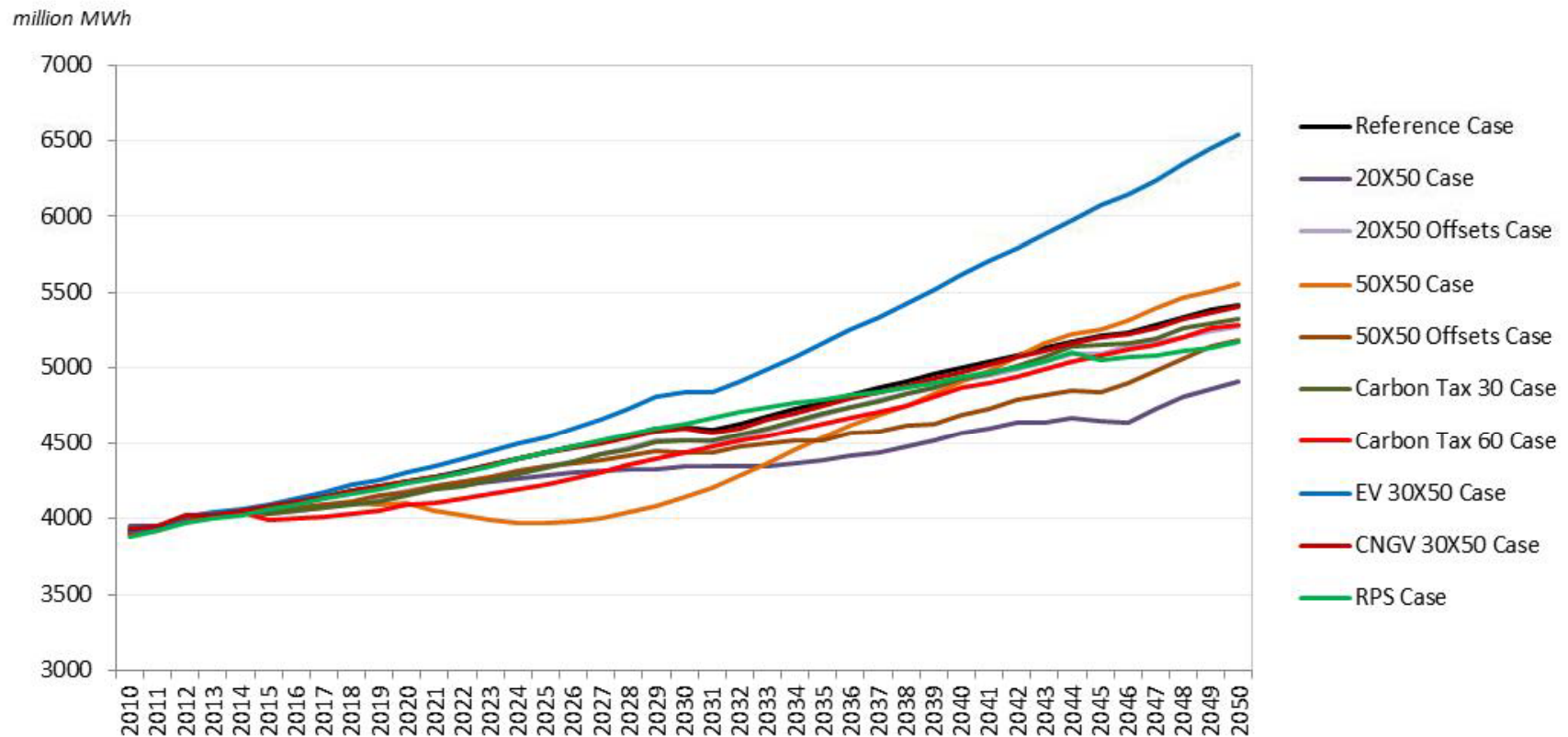
## Trends in Oil Demand Sensitive to Policy Design

- Oil demand reduction could be significant under aggressive policies. Allowing offsets results in substantially less demand erosion.
- RPS has virtually no effect on oil demand.
- EV and CNGV policies have large longer term effects but impacts are limited by the rate of vehicle penetration. Each case, in 2050, results in demand for oil being flat to current use.



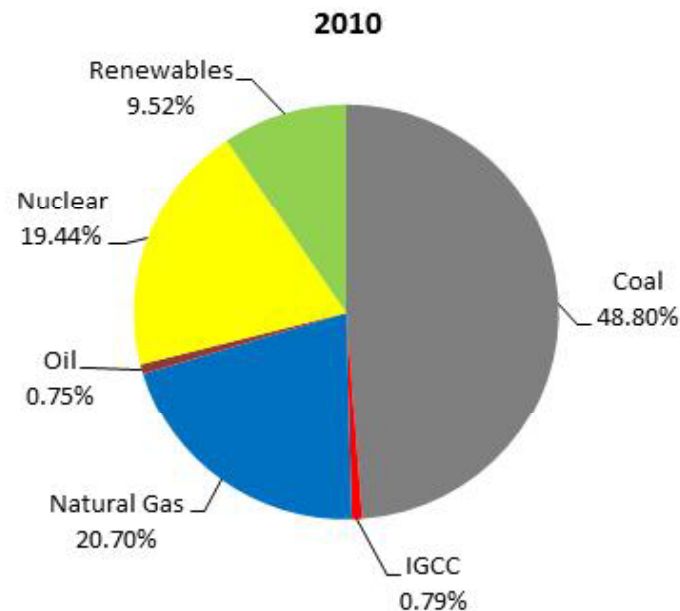
## Trends in the Power Sector: Demand

- EV policies create much greater demand for electricity.
- Raising the price of CO2 results in lower demand relative to the Reference Case
  - Strict CO2 caps have the greatest impact



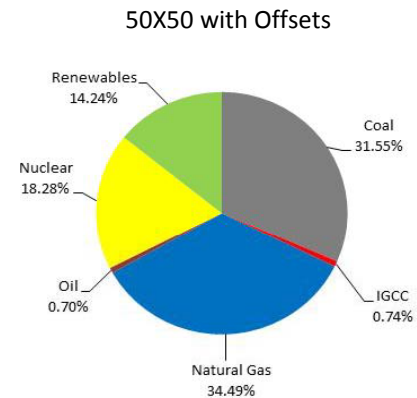
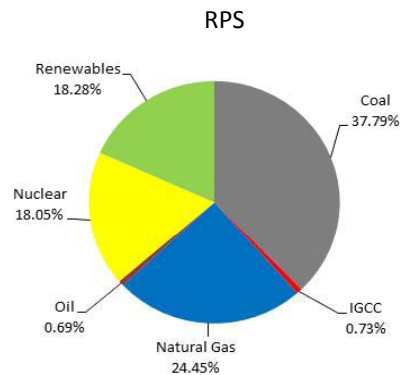
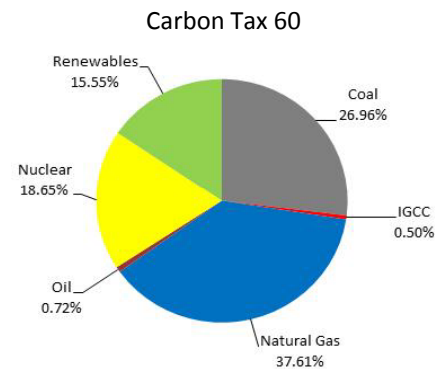
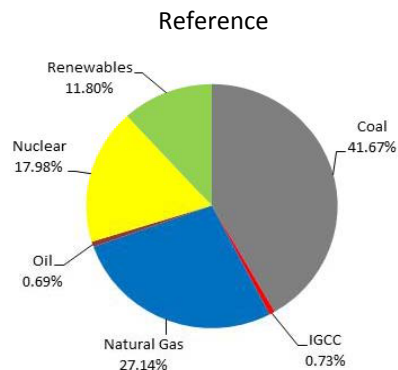
## Trends in the Power Sector: 2010

- The point of departure...
- Coal is the dominant form of power generation, followed by natural gas and nuclear.
- What happens to the fuel mix in the power generation sector as time passes under different policy scenarios?



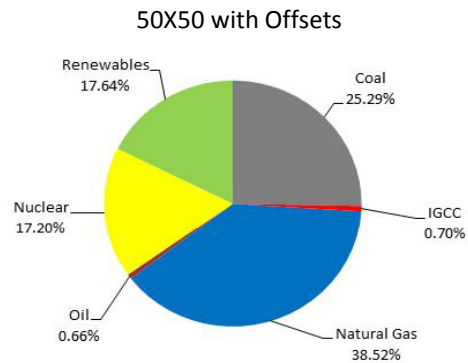
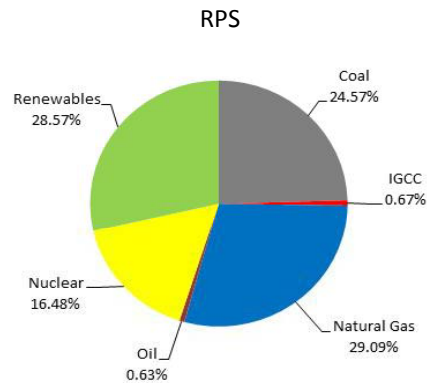
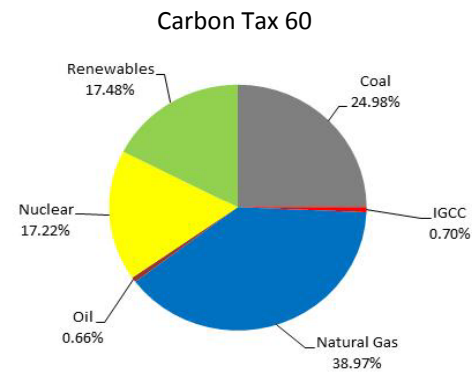
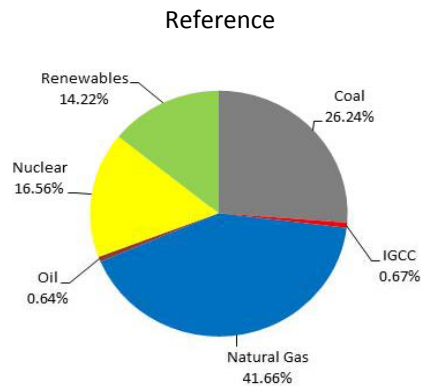
## Trends in the Power Sector: 2020

- Natural gas and renewables grow across cases, but the rate of increase varies



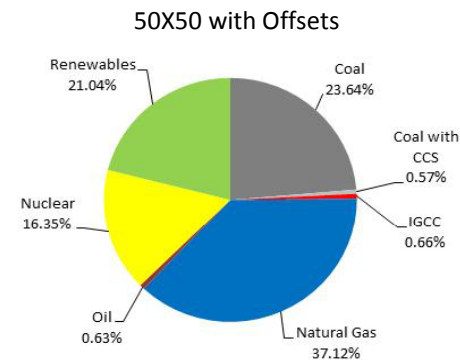
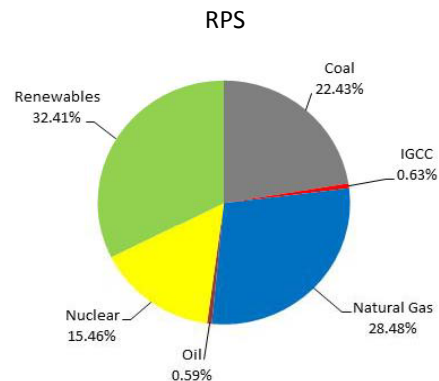
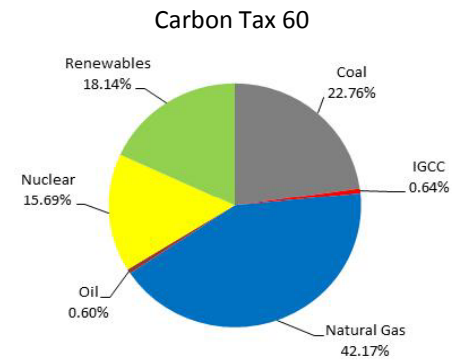
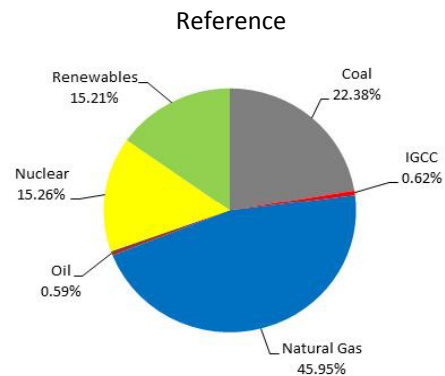
## Trends in the Power Sector: 2030

- Natural gas and renewables continue to grow across cases, but the RPS case sees the strongest market share growth in renewables... about double that in the Reference case.



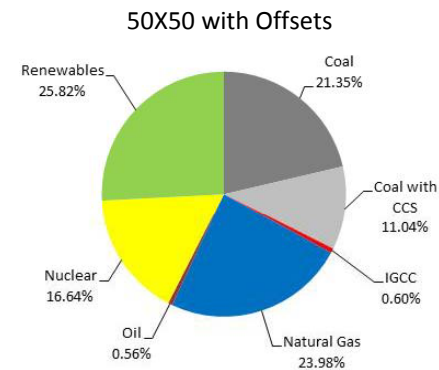
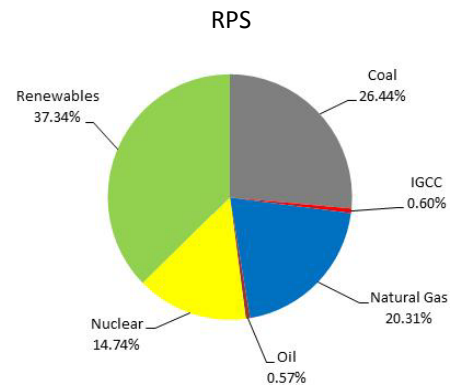
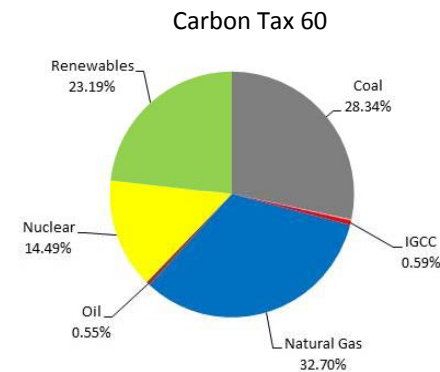
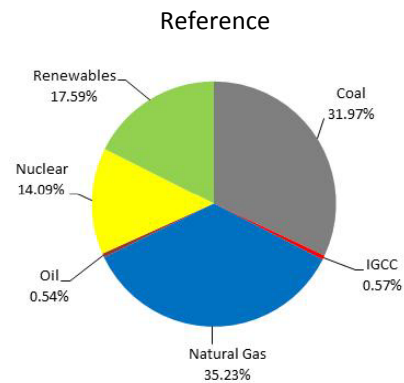
## Trends in the Power Sector: 2040

- In the RPS case, natural gas share begins to shrink, largely due to continued growth in renewables. All other case see continued growth in both renewables and gas.



## Trends in the Power Sector: 2050

- Natural gas shrinks across cases, and renewables continue to grow in every case. (Not pictured: only the EV 30X50 case sees continued growth of gas in power.)



## **Questions**