# [PS]How a Carbon Tax Could Benefit US NG Producers, But How Much and for How Long?*

**James M. Rine[1]**

Search and Discovery Article #42392 (2019)**
Posted July 22, 2019

*Adapted from poster presentation given at AAPG 2019 Annual Convention & Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/42392Rine2019

[1]Wayne State University, Detroit, MI, United States (James.Rine@Wayne.edu)

## Abstract

The analyses presented show how a Federal carbon fee could benefit US natural gas (NG) producers while meeting the COP21 goal of avoiding an increase in global temperatures of +2 ºC (3.6 ºF) above pre-industrial levels. Also addressed are how growth of renewable energy and lower costs of commercial energy storage might impact US demand for NG. The basis of the analysis is a modeled response to a 25-year national carbon fee & dividend (CFD) program beginning in 2025 at $10/metric ton (t) of $CO_2$ emissions and increasing annually by $10/t. The CFD program, if enacted nationwide, would within a decade begin the elimination of coal usage for electrical power generation while incentivizing carbon capture and storage (CCS) for NG. In theory, US NG producers with a CFD stimulated CCS program could not only attain an 80% drop in US carbon emissions by 2050 (for combined coal and NG usage), they could produce more NG than following a business as usual approach. Because a carbon fee would stimulate more use of renewable energy, the speed at which renewables might replace NG is examined. Present day levelized costs of energy for new commercial-scale solar and wind powered facilities are already competitive with NG facilities. But growth of US renewable energy projected by the Energy Information Administration (EIA) for 2025 to 2050 (~70%) is a fraction of the growth necessary to replace fossil fuel usage by 2050. Assuming the EIA projected growth through 2024 is correct (~80%), the growth in renewable energy from 2025 to 2050 must exceed 700% to completely replace energy produced from NG and coal. This is more than double the maximum growth of renewable energy that occurred between 2004 to 2010 (~300%). Consequently, there will be a need for NG to help fuel the transition to primarily renewable energy by 2050. Also considered, is the competitiveness of commercial- or municipal-scale battery storage versus NG powered peaking plants. Because of the large variability in both the levelized costs of energy from gas peaking plants and storage costs for batteries, predicting when battery storage becomes an optimum source for intermittent energy is problematic. Present-day estimates for low cost battery storage indicate they could replace high cost NG peaking plants immediately after instituting a CFD plan. Whereas a low-cost NG peaking plant may be competitive even 25 years after the initiation of an annually increasing carbon fee.

## References Cited

BNEF, 2019, Clean Energy Investment Exceeded $300 Billion Once Again in 2018, January 16,2019 (Bloomberg NEF), https://about.bnef.com/blog/clean-energy-investment-exceeded-300-billion-2018/

BP, 2018, BP Statistical Review of World Energy Downloads, accessed February 28, 2019, https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html

CDP, 2017, Putting a price on carbon, Integration climate risks into business planning, accessed March 15, 2019, https://b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/002/738/original/Putting-a-price-on-carbon-CDP-Report-2017.pdf?1507739326

CPLC, 2017, Report on the High-Level Commission on Carbon Prices, Carbon Pricing Leadership Council, accessed August 10, 2018, https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices/

C-ROADS, 2018, Climate Change Policy Simulator, Climate Interactive, accessed March 14, 2019, https://www.climateinteractive.org/tools/c-roads/

EIA, 2011, Emissions of Greenhouse Gases in 2009, US Energy Information Administration, accessed March 30, 2019, https://www.eia.gov/environment/emissions/ghg_report/pdf/0573%282009%29.pdf

EIA, 2017, Annual Energy Outlook 2017 with projections to 2050, US Energy Information Administration, accessed March 14, 2018, https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

EIA, 2018, Annual Energy Outlook 2018 with projections to 2050, US Energy Information Administration, accessed March 14, 2018, https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf

EICDA, 2019, Energy Innovation and Carbon Dividend Act, H.R. 763, accessed March 14, 2019, https://energyinnovationact.org/

EPA, 2017, Clean Power Plan, Fact Sheet: Overview of the Clean Power Plan, US Environmental Protection Administration, accessed March 14, 2019, https://archive.epa.gov/epa/cleanpowerplan/fact-sheet-overview-clean-power-plan.html

Jenkins, D. and Thernstrom, S., 2017, Deep decarbonization of the electric power sector insights from recent literature, EIRP, March 2017, accessed March 29, 2019, https://www.innovationreform.org/analysis/

Lazard, 2018a, Lazard's levelized cost of storage analysis - Version 4.0, accessed March 14, 2019, https://www.lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf

Lazard, 2018b, Lazard's levelized cost of energy analysis - Version12.0, accessed March 14, 2019, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

Mad, 1955, What, me worry?, Mad Magazine, no. 24, 7/1955, https://en.wikiquote.org/wiki/Mad_(magazine)

NCA, 2018, Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States, accessed March 14, 2019, https://nca2018.globalchange.gov/

REMI/Synapse, 2014, The Economic, Climate, Fiscal, Power, and Demographic Impact of a National Fee-and-Dividend Carbon Tax, Regional Economic Models, Inc. and Synapse Energy Economic, Inc., accessed March 14, 2019, https://citizensclimatelobby.org/remi-report/

Rine, J.M., 2014. An Examination of Carbon Budgets, Carbon Taxes, Industry Attitudes to Global Warming, and AAPG: Environmental Geosciences, v. 21, no. 4 (December 2014), p. 127-140.

Rine, J.M. (in review) How Action on Climate Change Could Benefit US Natural Gas Producers, But Not without Federal Mandates, AAPG Bulletin.

Ross, M. T., 2018, The future of the electricity industry: Implications of trends and taxes, Energy Economics, v. 73, p. 393–409, accessed March 14, 2019, https://doi.org/10.1016/j.eneco.2018.03.022

Rubin, E.S., J.E. Davison, H.J. Herzog., 2015, The cost of CO2 capture and Storage, International Journal of Greenhouse Gas Control, v. 40, p. 378–400, accessed August 24, 2018, https://www.cmu.edu/epp/iecm/rubin/PDF%20files/2015/Rubin_et_al_ThecostofCCS_IJGGC_2015.pdf

Shaner, M.R., S.J. Davis, N.S. Lewis, and K. Caldier, 2018, Geophysical constraints on the reliability of solar and wind power in the United States, Energy and Environmental Science, Issue 4, 2018, https://escholarship.org/uc/item/96315051

Shell, 2018, Shell Scenarios, Sky Meeting the Goals of the Paris Agreement, accessed August 8, 2018, http://www.ourenergypolicy.org/wp-content/uploads/2018/03/shell-scenarios-sky-1.pdf

Sterman, J., T. Fiddaman, T. Franck, A. Jones, S. McCauley, P. Rice, E. Sawinb, and L. Siege, 2012, Climate interactive: the C-ROADS climate policy model, System Dynamics Review System Dynamics Review, v. 28, no. 3 (July-September 2012), p. 295–305, published online 25 July 2012 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/sdr.1474

USGCP (2014) Billion Dollar Weather/Climate Disasters. Map is no longer available (where I could find it) on the Trump Administration’s censured-.gov websites.

USGCRP, 2018, U.S. Global Change Research Program, Climate Science Special Report: Fourth National Climate Assessment (NCA4), Volume II, Impacts, risks, and adaptation in the United States, accessed March 13, 2019, https://www.globalchange.gov/nca4

WSJ, 2017, The consensus climate solution (Paid Advertisement), Wall Street Journal, June 20, 2017, accessed August 2, 2018, https://www.clcouncil.org/wp-content/uploads/2017/06/Climate_Leadership_Council_WSJ_Ad.pdf

Wayne State University College of Liberal Arts & Sciences
Department of Geology

# How a Carbon Tax Could Benefit US NG Producers, But How Much and for How Long?

James M. Rine, Ph.D.




## ABSTRACT

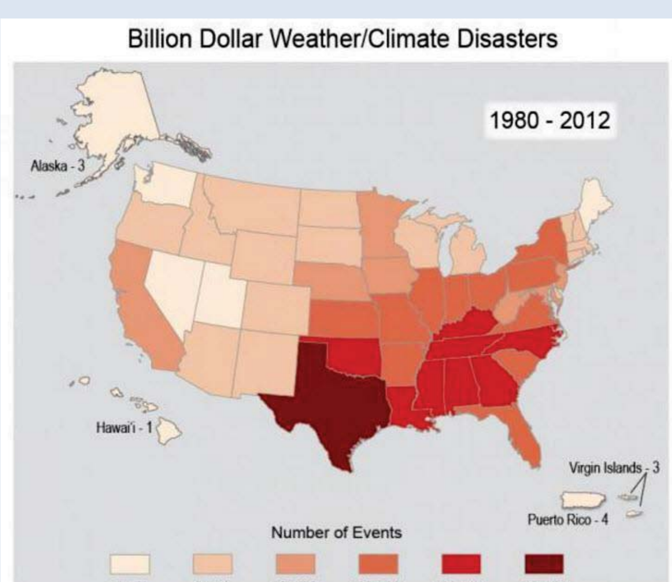
The analyses presented show how a Federal carbon fee could benefit US natural gas (NG) producers while meeting the COP21 goal of avoiding an increase in global temperatures of +2ºC (3.6ºF) above pre-industrial levels. Also addressed are how growth rates of renewable energy and cost of commercial energy storage might impact US demand for NG. The basis of the analysis is a modeled response to a 25-year national carbon fee & dividend (CFD) program beginning in 2025 at $10/metric ton (t) of $CO_2$ emissions and increasing annually by $10/t. The CFD program, if enacted nationwide, would within a decade begin the elimination of coal usage for electrical power generation while incentivizing carbon capture and storage (CCS) for NG. In theory, US NG producers with a CFD stimulated CCS program could not only attain an 80% drop in US carbon emissions by 2050 (for combined coal and NG usage), they could produce more NG than following a business as usual approach (BAU). Because a carbon fee would stimulate more use of renewable energy, the speed at which renewables might replace NG is examined. Present day levelized costs of energy from new commercial-scale solar and wind powered facilities are already competitive with NG facilities. But growth of US renewable energy projected by the Energy Information Administration (EIA) for 2025 to 2050 (~20%) is a fraction of the growth necessary to replace fossil fuel usage by 2050. Other studies of past growth in renewable energy calculated that between 2004 and 2010 there was a growth of approximately 300%. Assuming the EIA projected growth through 2024 is correct (~??%), growth in renewable energy would have to exceed 700% from 2025 to 2050 to completely replace energy produced from NG and coal. This unprecedented growth requirement indicates there will be continued need for energy from NG during this period. The competitiveness of commercial- or municipal-scale battery storage versus NG powered peaking plants is also considered. Because of the large variability in the levelized costs of energy from gas peaking plants and storage costs for batteries, predicting when battery storage becomes the go-to for intermittent energy needs is problematic. Present-day estimates for low cost battery storage could replace high cost NG peaking plants immediately after instituting a CFD plan. Whereas a low-cost NG peaking plant may still be competitive even 25 years after the initiation of an annually increasing carbon fee.


Contact author (james.rine@wayne.edu ) for poster references and/or copy of Rine, J.M. (in review) *How Action on Climate Change Could Benefit US Natural Gas Producers, But Not without Federal Mandates*, AAPG Bulletin.

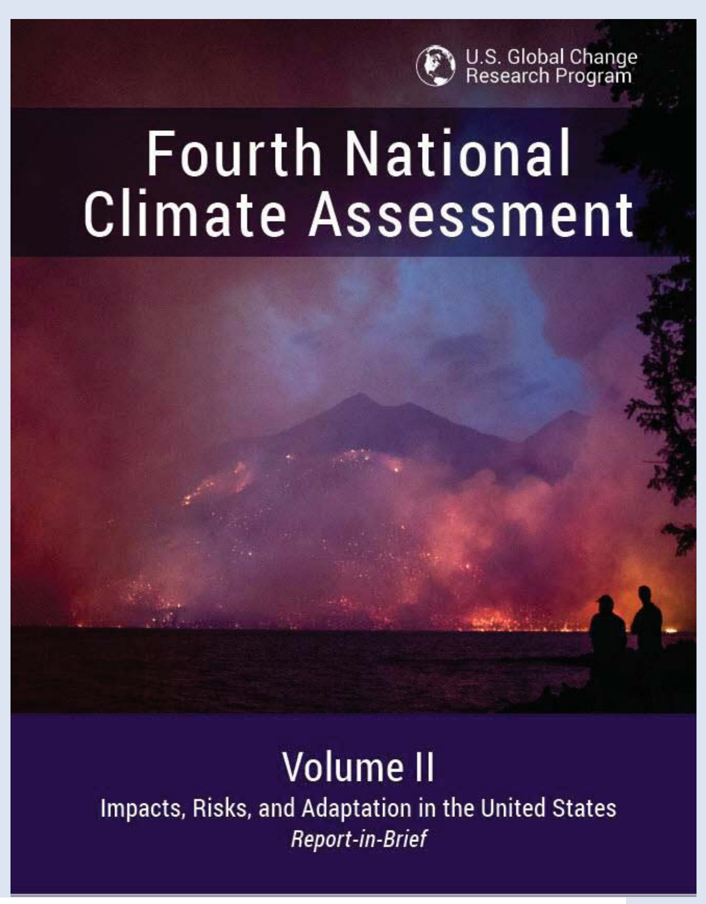
## Climate change is happening

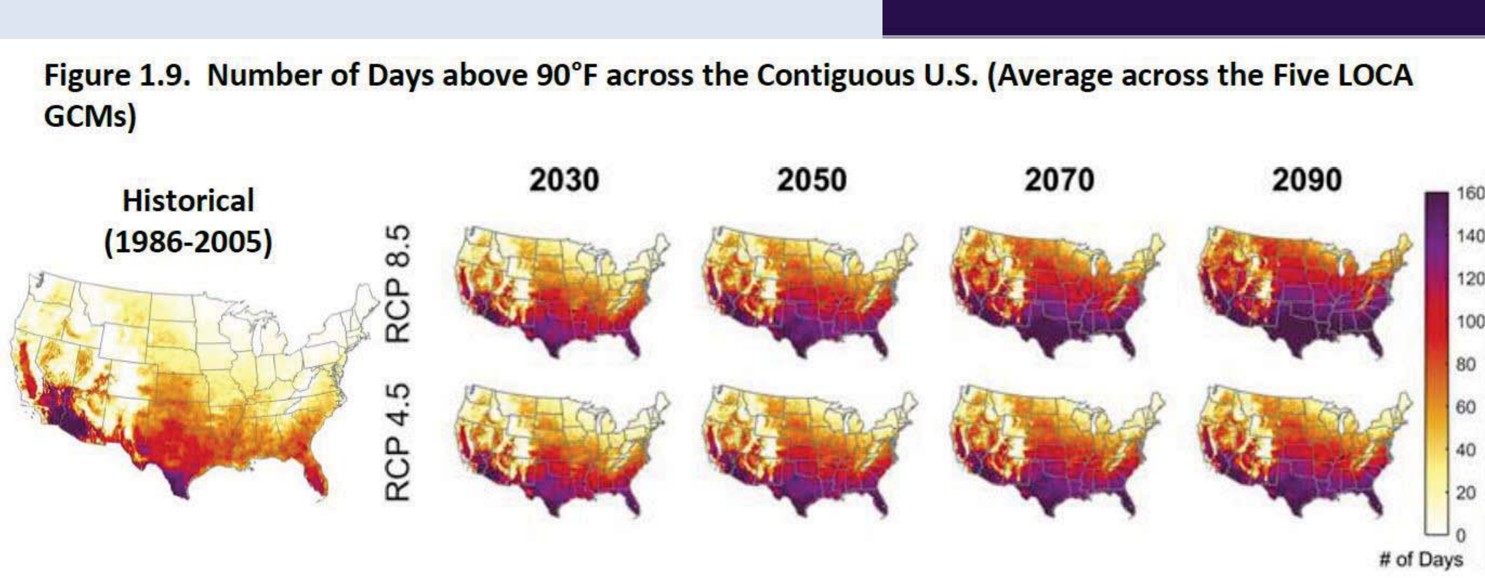
## 1

## What do we do to avoid the worst?



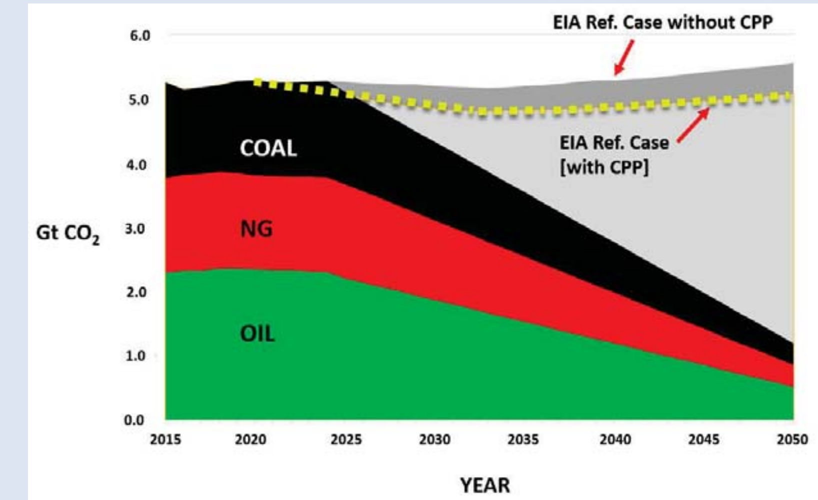

Map (above) summarizes number of times each state was affected by weather and climate events costing more than a billion dollars in damages between 1980 to 2012. The SE USA has been affected by more billion-dollar disasters than any other region. The primary disaster type of coastal states is hurricanes, while interior and northern states in the region experience sizeable numbers of tornadoes and winter storms. Source: USGCP (2014) Billion Dollar Weather/Climate Disasters. Map is no longer available (where I could find it) on the Trump Administration-censured .gov websites



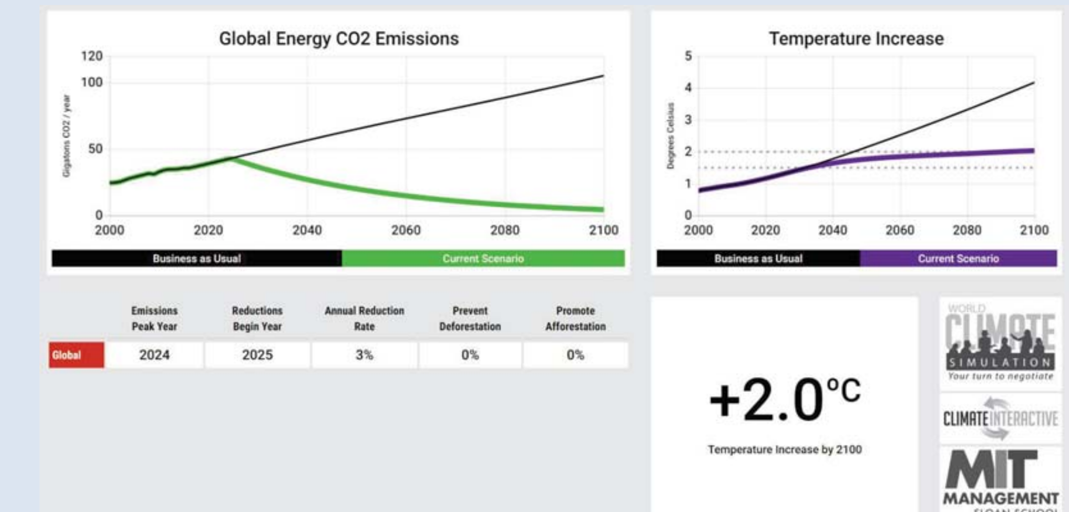




## 2

## One option for avoiding +2ºC



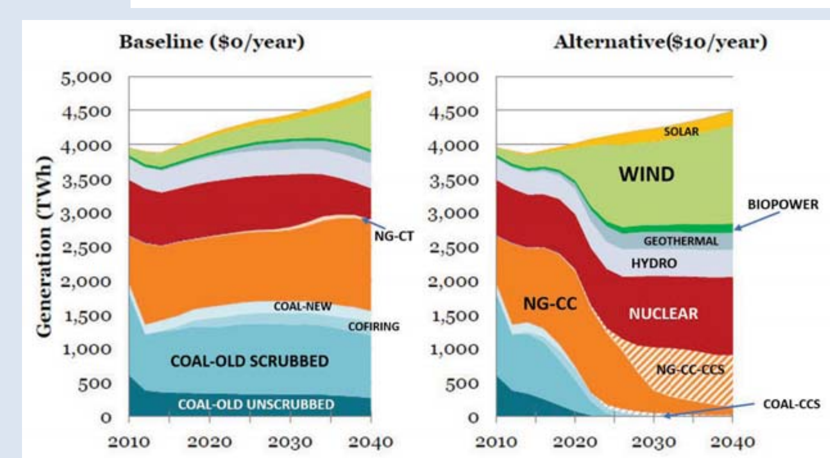

Graphic, which shows relative US emissions from coal, natural gas (NG), and oil, is based on EIA (2017) $CO_2$ emissions (without Clean Power Plan [CPP]) from 2015 to 2024 and with a uniform average annual reduction of 3.0% from 2025 to 2050. In 2050 the total emissions are 20% of 2005 total emission levels for coal, NG, and oil. Also plotted are EIA Reference Case emissions with and without CPP as projected by EIA (2017). The 2005 emission level is from EIA (2011). Figure is from Rine (in review).




Open access C-ROADS World Climate program plot of hypothetical case with global wide pursuit of an annual average emission reduction of 3% beginning in 2025 with emissions peaking in 2024. To simplify the model, other mitigation efforts, such as promoting afforestation or preventing deforestation were not applied. If mitigation efforts promoting afforestation and preventing deforestation are applied 100%, the resulting modeled temperature increase is lowered to +1.8ºC (3.2ºF). The scenario was run on the C-ROADS World Climate program (C-ROADS, 2018). Figure is from Rine (in review).

## 3

## An option of avoiding +2ºC and producing NG > BAU




REMI/Synapse (2014) modeled US electrical power generation for the period between 2010 to 2040 without a carbon tax [Baseline ($0/year)] and with a carbon tax [Alternative ($10/year)]. The alternative modeled a carbon tax starting at $10/ton $CO_2$ in 2015 and increasing $10/ton annually until 2035. The Rine (in review) study utilizes the Alternative ($10/year) energy model to establish timing of termination of coal use, within 10 to 15 years, and the beginning of significant increase in the utilization of CCS for NG, also starting within 10 to 15 years. The REMI/Synapse (2014) model replaces NG-CC (NG-Combined Cycle) with NG CCS. NG-CT = combustion turbine. Figures are modified from REMI/Synapse (2014).

Table 1. Summary of projected US emissions under various scenarios from 2025 to 2050. From Rine (in review).

| CATEGORY | Equivalent Emissions 2025 to 2050 (Gt $CO_2$) | Total Consumption with CCS 2025 to 2050 (Mtoe) | NG Consumption with CCS 2025 to 2050 (Tcf) [2] | Average Annual Rate of Reductions in Emissions 2025 to 2050 (%) | Reduction in Emissions from 2005 Levels by 2050 (%) |
|---|---|---|---|---|---|
| EIA (2017) Total all Fossil Fuel: Reference case (with CPP[1]) | 127.6 | 47408.3 | NA | 0.0 | 9.2 |
| EIA (2017) Total all Fossil Fuel: Reference case without CPP | 137.7 | 49913.3 | NA | -0.2 | 0.6 |
| Total all Fossil Fuel: modeled 3% annual reduction 2025 to 2050 from EIA (2017) reference case without CCP | 82.0 | 29427.8 | NA | 3.0 | 80.0 |
| Oil: EIA (2017) Total by Fuel: Reference case (with CPP) | 56.7 | 19371.6 | NA | 0.0 | 13.3 |
| Oil: EIA (2017) reference case without CPP | 57.0 | 19463.5 | NA | 0.0 | 12.9 |
| NG: EIA (2017) reference case (with CPP) | 43.6 | 20766.4 | 814.0 | -1.0 | -58.1 |
| NG: EIA (2017) reference case without CPP | 42.7 | 20311.8 | 796.2 | -0.9 | -54.0 |
| Coal: EIA (2017) reference case (with CPP) | 27.7 | 7270.4 | NA | 1.1 | 57.1 |
| Coal: EIA (2017) reference case without CPP | 38.0 | 10138.0 | NA | 0.1 | 33.3 |
| Oil: Modeled 3% annual reduction 2025 to 2050 | 35.4 | 12088.0 | NA | 3.0 | 80.3 |
| NG: Modeled 3% annual reduction 2025 to 2050 | 23.4 | 11165.7 | 437.7 | 2.9 | 70.9 |
| Coal: Modeled 3% annual reduction 2025 to 2050 | 23.2 | 6174.1 | NA | 3.0 | 84.5 |
| Coal: Modeled reduction to 10% by 2025 and 0% by 2035 | 8.5 | 2291.8 | NA | 3.8 | 100.0 |
| NG Replacement of Coal modeled between 2025 to 2050 | 14.6 | 6932.6 | 271.8 | NA | NA |
| NG $CO_2$ CCS modeled between 2025 to 2050 (Does not count towards emission total) | 6.4 | 3031.1 | 118.8 | NA | NA |
| Total NG: NG with 3%/y Decline + modeled NG Replacement of Coal + NG CCS (between 2025 to 2050) | 38.0[3] | 21129.4 | 828.3 | NA | 42.2 |

[1] CPP = Clean Power Plan (EPA, 2017)
[2] 1 Mtoe equals 0.0392 Tcf (or 39.2 Bcf; BP, 2017)
[3] Total NG usage adding CCS equates with 44.4 Gt $CO_2$

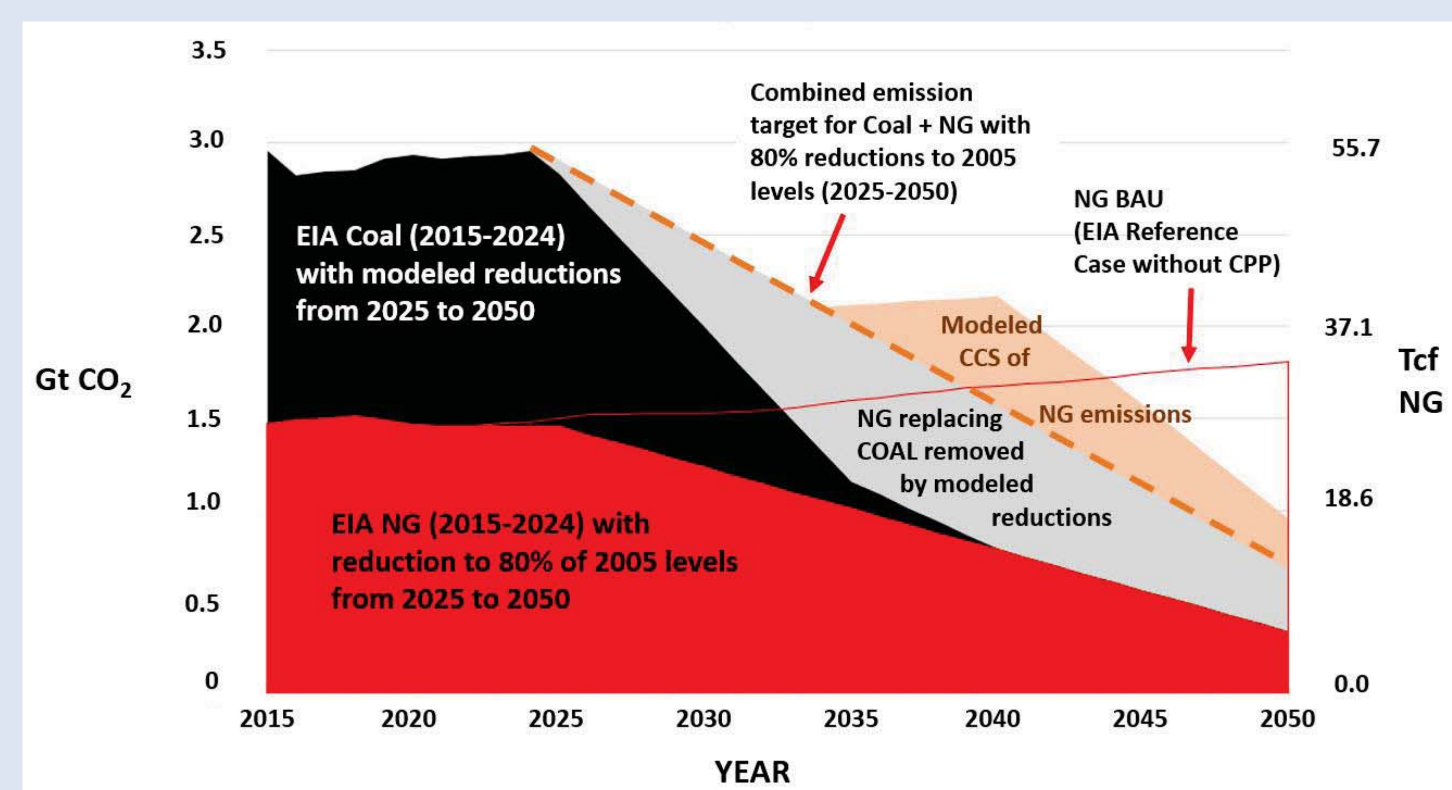



Figure graphically illustrates the relative $CO_2$ emissions and consumption of NG and coal within the US from 2015 until 2050 under the scenario proposed in Rine (in review). Emissions levels between 2015 to 2024 are based on EIA (2017) projections without CPP. Emission reductions starting in 2025 reach 20% of 2005 levels by 2050. This scenario incorporates early termination of coal usage and utilization of carbon capture and storage (CCS) based on the REMI/Synapse (2014) model but extrapolated to 2050. The combined emissions between 2025 to 2050 of NG (red), coal (black), and NG replacing eliminated coal emissions (gray) match the emission reduction levels necessary to reach the 2050 target for NG and coal. The NG emissions sequestered by CCS (pale orange) are not tallied with the total allowable emissions. The combined total of NG consumed with this scenario exceeds the amount of NG projected by EIA to be consumed with business as usual (BAU; EIA Reference case without CPP; EIA, 2017; Table 1). Figure is from Rine (in review).

## 4

## Is a high carbon tax needed for CCS?

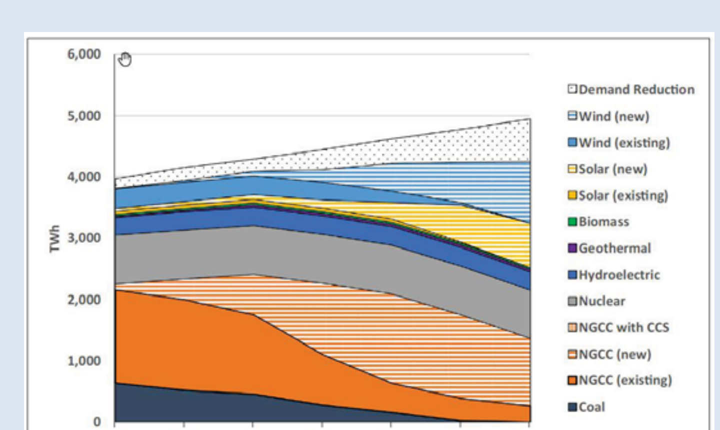



Figure from Ross (2018; Fig. 9) shows generation across the US for the various categories of energy sources under of a scenario $25/ton carbon tax with an annual increase of 5% for the period 2020 to 2050. Note that CCS is not present. "The policy scenarios are analyzed using an updated version of the Dynamic Integrated Economy/Energy/Emissions Model (DIEM), developed by Dr. Ross at Duke University's Nicholas Institute for Environmental Policy Solutions" (Ross, 2018).

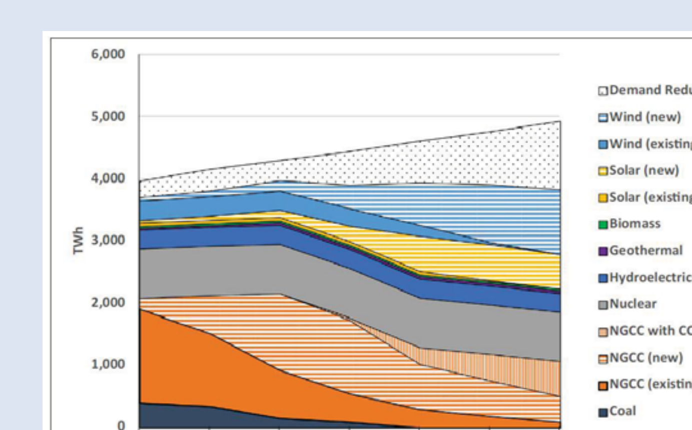
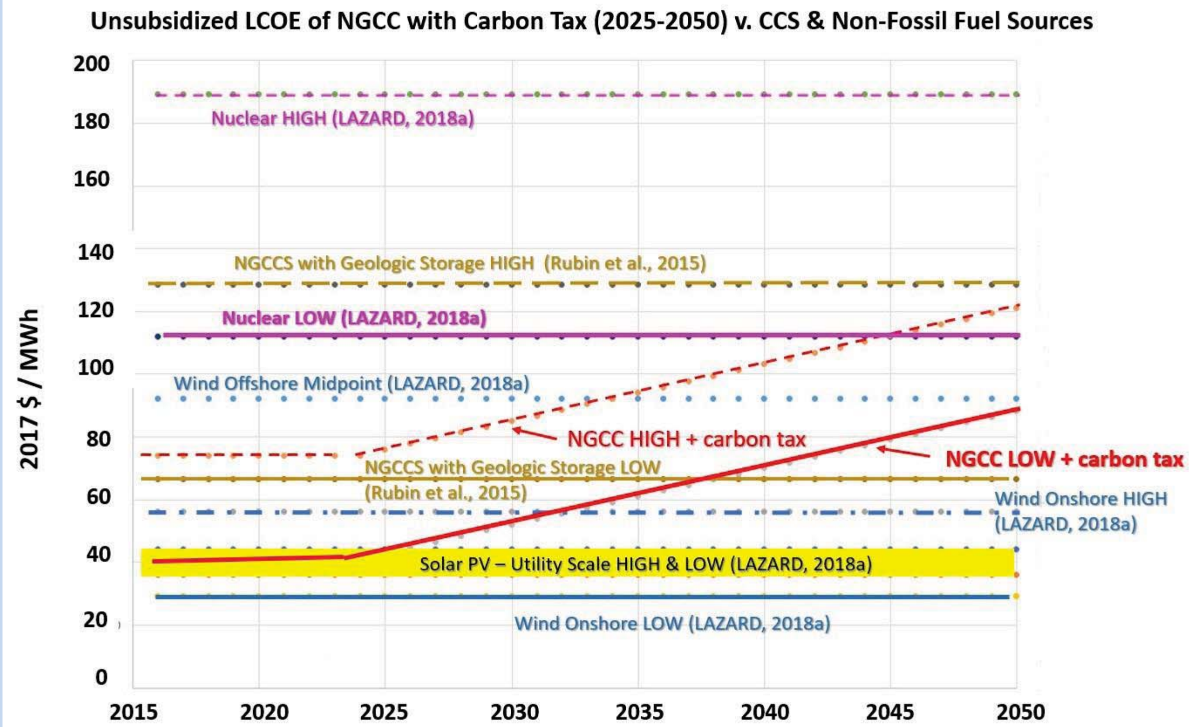



Figure from Ross (2018; Fig. 10) shows generation across the US for the various categories of energy sources under a scenario of $50/ton carbon tax with a 5% annual increase for the period 2020 to 2050. Note that NGCC with CCS begins 10 to 15 years after the start of the scenario, which is similar to the timing modeled by REMI/Synapse (2014).

# 5

# How long can fossil fuels compete with renewables under a carbon tax?



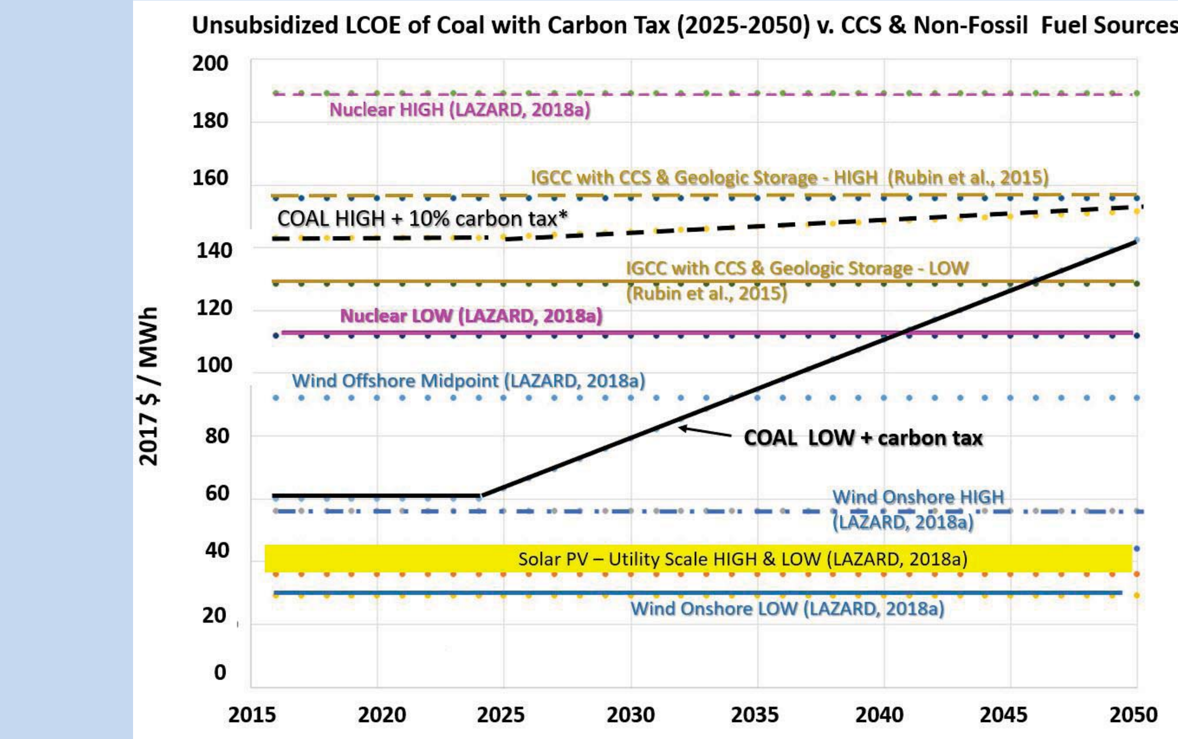
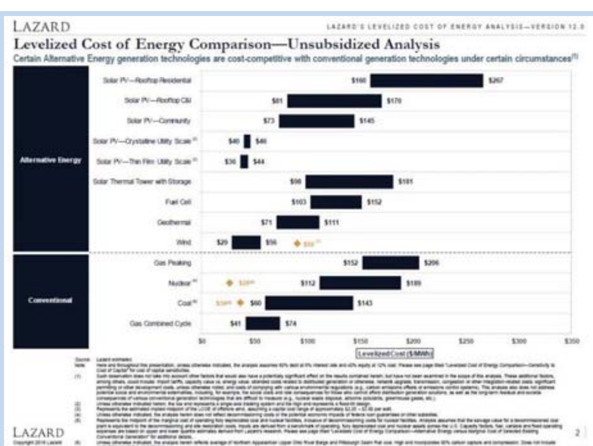




Chart shows unsubsidized levelized cost of energy (LCOE) from new NG combined cycle power plants (NGCC) with the addition of a carbon fee (+$10/MT CO2 per year beginning in 2025) compared with LCOEs of non-fossil fuel sources and LCOE of NGCC with CCS. Chart shows solar PV (both crystalline and thin film) utility-scale are already competitive with low cost NGCC without a carbon tax. Low cost onshore wind is also cheaper. Low cost NGCC with a carbon tax becomes more expensive than high cost onshore wind in 5 to 10 years and almost matches current estimates of offshore wind sources within 25 years. Low cost NGCC becomes more expensive than low cost NGCC with CCS after 10 to 15 years of a carbon tax (~$100 to $150/MT $CO_2$). After 25 years of a carbon tax, high cost NGCC facilities approach the cost of high cost NGCC with CCS and geologic storage. LCOE source values are from LAZARD (2018a). The LCOEs of NGCC plants with CCS and geologic storage are from Rubin et al. (2015) with values converted to 2017 $.

Chart shows unsubsidized LCOE from new integrated coal gasification combined cycle (IGCC) power plants with the addition of a carbon fee (+$10/MT CO2 per year beginning in 2025) compared with LCOEs of non-fossil fuel sources and LCOE of IGCC with CCS. Chart shows solar PV (both crystalline and thin film) utility-scale and all onshore wind are less expensive than LCOE from a new IGCC plant even without the addition of a carbon fee. Low cost IGCC with a carbon tax becomes more expensive than the Rubin et al. (2015) for low cost IGCC with CCS only after 20 years of a carbon tax (~$200/MT $CO_2$). The LAZARD (2018a) high cost LCOE for IGCC includes costs of capture and compression but not transportation and storage. It should be noted that the midpoint of the marginal cost of operating fully depreciated coal plant is $36, inclusive of decommissioning. LCOE values are from LAZARD (2018a). The LCOEs of IGCC plants with CCS and geologic storage are from Rubin et al. (2015) with values converted to 2017 $.



From LAZARD (2018a)

From Rubin et al. (2015)

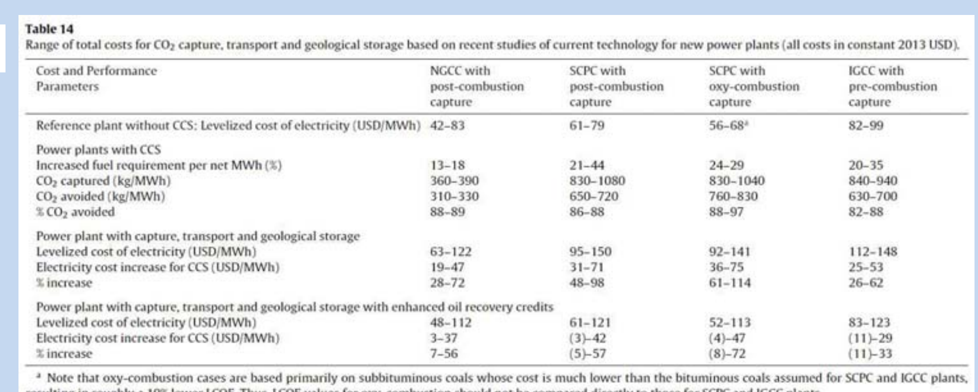


**Table 14**
Range of total costs for $CO_2$ capture, transport and geological storage based on recent studies of current technology for new power plants (all costs in constant 2013 USD).

| Cost and Performance Parameters | NGCC with post-combustion capture | SCPC with post-combustion capture | SCPC with oxy-combustion capture | IGCC with pre-combustion capture |
|---|---|---|---|---|
| Reference plant without CCS: Levelized cost of electricity (USD/MWh) | 42–83 | 61–79 | 56–68[a] | 82–99 |
| Power plants with CCS | | | | |
| Increased fuel requirement per net MWh (%) | 13–18 | 21–44 | 24–29 | 20–35 |
| $CO_2$ captured (kg/MWh) | 360–390 | 830–1080 | 830–1040 | 840–940 |
| $CO_2$ avoided (kg/MWh) | 310–330 | 650–720 | 760–830 | 630–700 |
| % $CO_2$ avoided | 88–89 | 86–88 | 88–97 | 82–88 |
| Power plant with capture, transport and geological storage | | | | |
| Levelized cost of electricity (USD/MWh) | 63–122 | 95–150 | 92–141 | 112–148 |
| Electricity cost increase for CCS (USD/MWh) | 19–47 | 31–71 | 36–75 | 25–53 |
| % increase | 28–72 | 48–98 | 61–114 | 26–62 |
| Power plant with capture, transport and geological storage with enhanced oil recovery credits | | | | |
| Levelized cost of electricity (USD/MWh) | 48–112 | 61–121 | 52–113 | 83–123 |
| Electricity cost increase for CCS (USD/MWh) | 3–37 | (3)–42 | (4)–47 | (11)–29 |
| % increase | 7–56 | (5)–57 | (8)–72 | (11)–33 |

[a] Note that oxy-combustion cases are based primarily on subbituminous coals whose cost is much lower than the bituminous coals assumed for SCPC and IGCC plants, resulting in roughly a 10% lower LCOE. Thus, LCOE values for oxy-combustion should not be compared directly to those for SCPC and IGCC plants.

# 6

# Gas Peaking v. Utility-Scale Solar with Storage

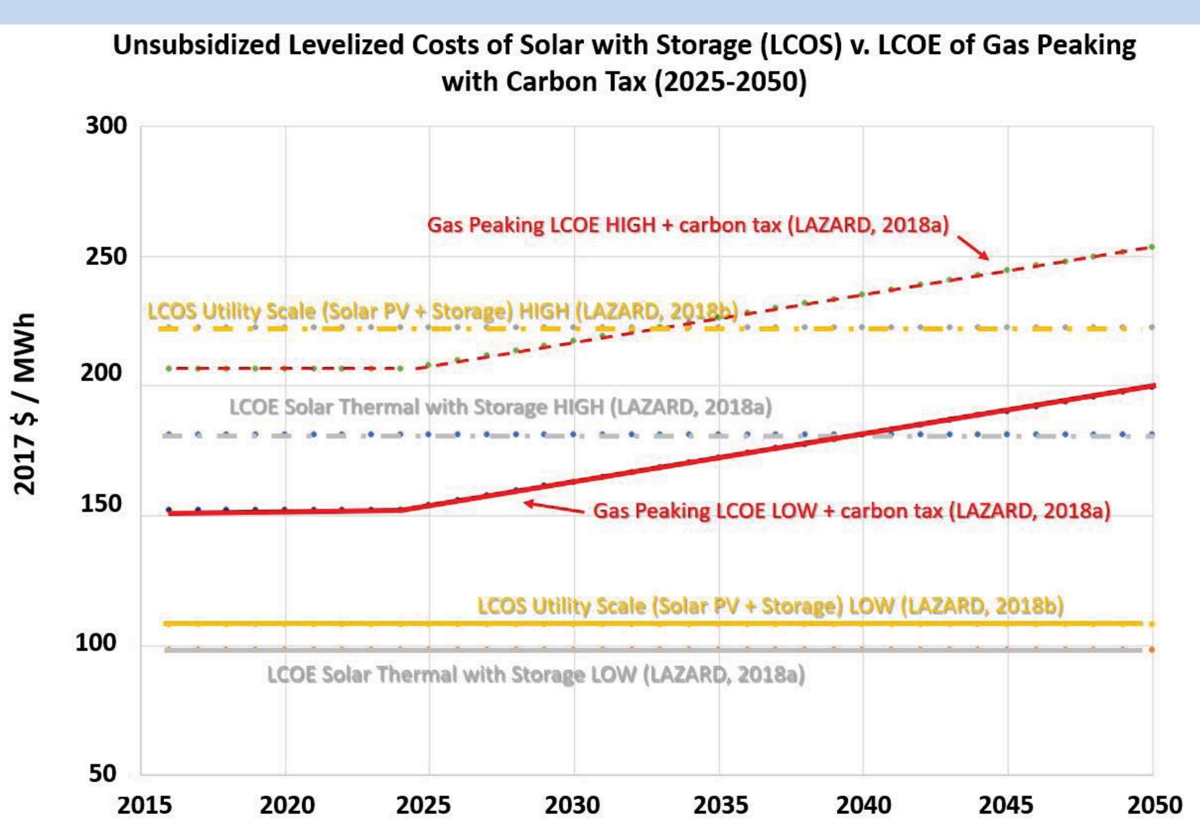
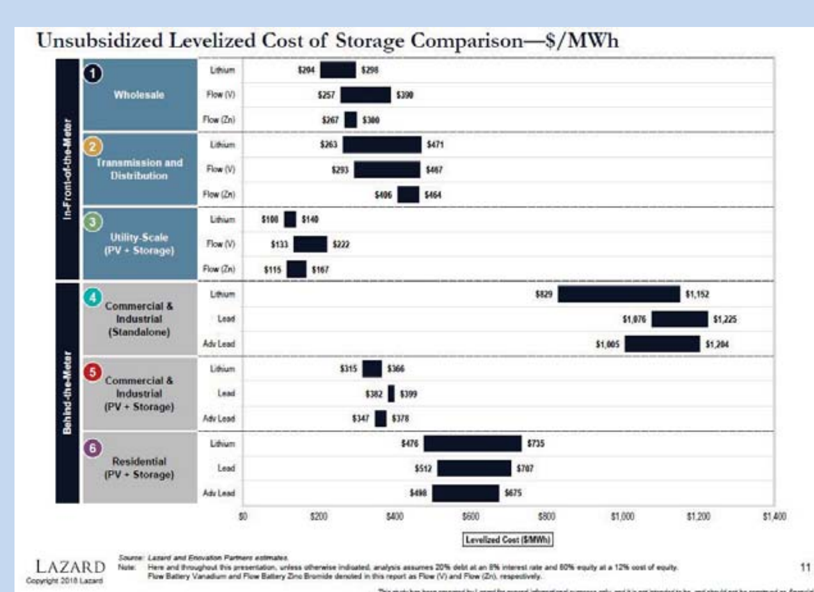
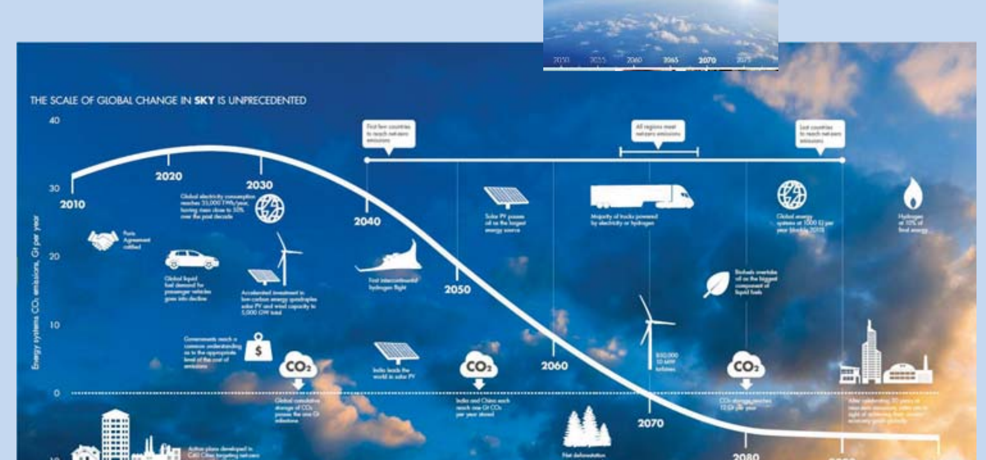



Chart shows high and low unsubsidized levelized costs of storage (LCOS) of new utility scale solar (PV with storage) compared with the LCOE of NG gas peaking plants with the addition of a carbon fee (+$10/MT CO2 per year beginning in 2025). Also charted are the LCOE of solar thermal with storage. NG gas peaking plants are more expensive than low cost solar sources without a carbon tax. LCOE values are from LAZARD (2018a). LCOS values are from LAZARD (2018b).



From LAZARD (2018b)



V.


Wayne State University College of Liberal Arts & Sciences
Department of Geology

# 7

# Problems with Renewables

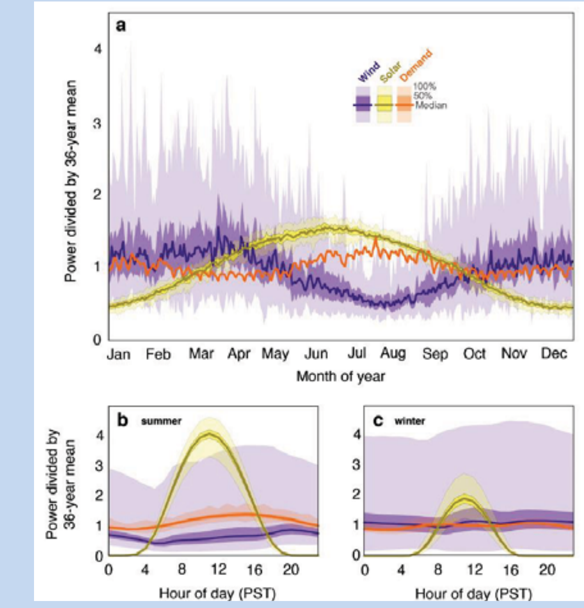
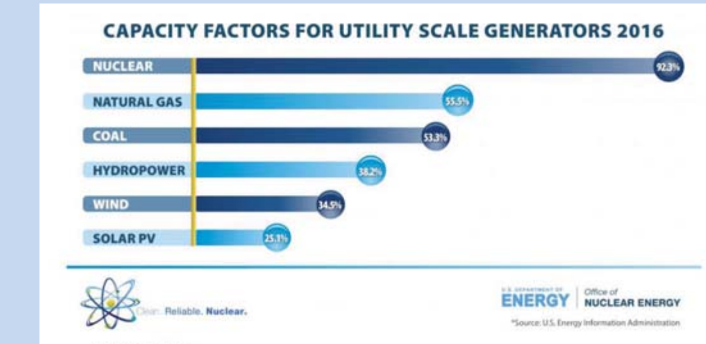


Figure from Shaner et al. (2018) depicts the "temporal variability of solar and wind resources and electricity demand. Climatological variability of the area-weighted median power from wind (purple) and sun (yellow) resources over the contiguous U.S. during the 36-year period 1980–2015: (a) Daily and seasonal; (b) hourly summer for June, July, August; (c) hourly winter for December, January, and February. The lines represent the median, the dark shading represents the inner 50% of observations (25th to 75th percentile) and the light shading represents the outer 50% of observations (0th to 100th percentile). Orange curves in each panel represent U.S. electricity demand for a single year from July 2015–July 2016." According to Shaner et al. (2018) to achieve ~80% wind and solar energy would require a US-wide transmission grid or 12 hours of energy storage.




The net **capacity factor** (CF) is the ratio of an actual electrical energy output over a given period of time to the maximum possible electrical energy output over that period (https://en.wikipedia.org/wiki/Capacity_factor ). Because of their low CF, using only wind and solar would require 2.0-2.2 X generation capacity to meet 99.97% of electricity demand (Shaner et al., 2018).

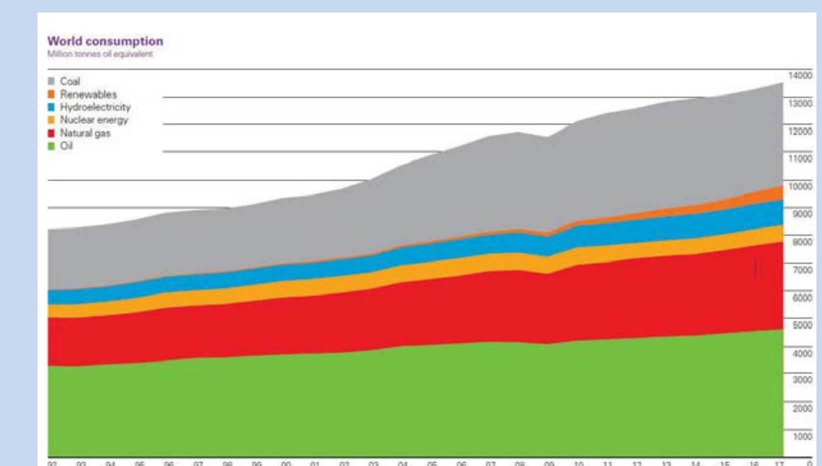
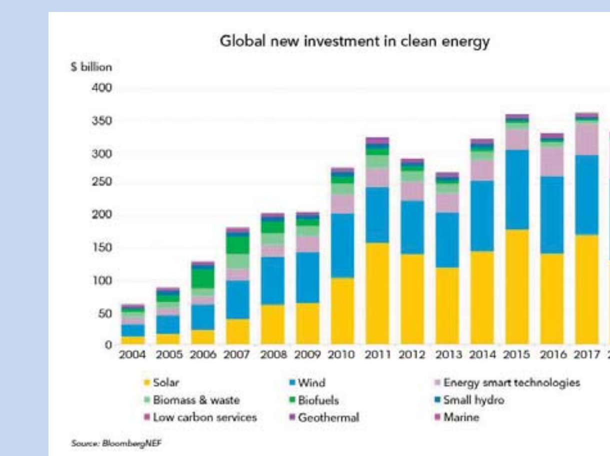


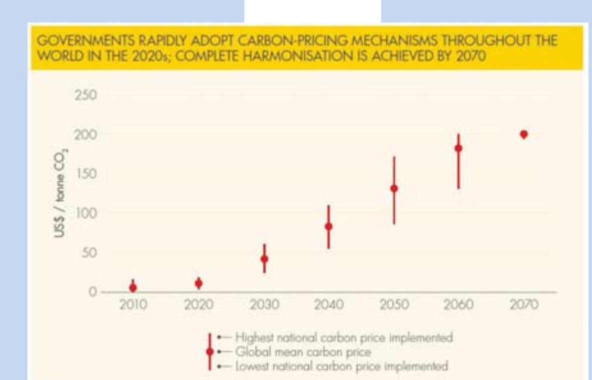
Chart from BP Statistical Review of World Energy, 67th Edition (June 2018) shows "World primary energy consumption grew by 2.2% in 2017, up from 1.2% in 2016 and the highest since 2013. All fuels except coal and hydroelectricity grew at above-average rates. Natural gas provided the largest increment to energy consumption at 83 million tonnes of oil equivalent (mtoe), followed by renewable power (69 mtoe) and oil (65 mtoe)." In 2016, renewable energy comprised 7.9% of total energy consumed by the USA (EIA, 2017).




Growth of US renewable energy projected by the EIA (AEO 2017) for 2025 to 2050 (~70%) is a fraction of the growth necessary to replace fossil fuel usage by 2050. Assuming the EIA projected growth through 2024 is correct (~80%), the growth in renewable energy from 2025 to 2050 must exceed 700% to completely replace energy produced from NG and coal. This is more than double the maximum growth of renewable energy that occurred between 2004 to 2010 (~300%). Chart is from Bloomberg NEF (2019).

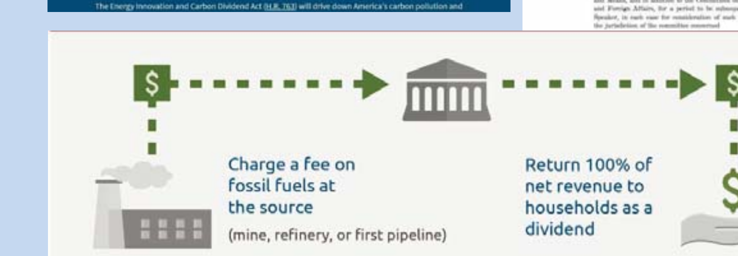
# 8

# Will there be a carbon tax?




As of 2017, 136 North American companies are internally pricing carbon with 22 of those being energy companies (CDP, 2017). The range in carbon prices, for those 10 companies reporting, is $9 to $64.30 per metric ton (MT or t) of $CO_2$ (CDP, 2017). A 2017 report by the Carbon Pricing Leadership Coalition (CPLC), whose authors included economists Joseph Stiglitz and Lord Nicholas Stern, concluded "…the explicit carbon-price level consistent with achieving the Paris temperature target is at least US40–80/t$CO_2$ by 2020 and USD50–100/t$CO_2$ by 2030" (CPLC, 2017). More recently, over 40 economists, including former Secretaries of State and Chairs of the Federal Reserve signed a statement supporting a carbon tax (WSJ, 2019). The plan endorsed is similar to the one described in this poster, in Rine (in review), and introduced in the 116th Congress as the *Energy Innovation and Carbon Dividend Act* (H.R. 763).






# 9

**Discussion Points / Conclusions:**

1. US NG production levels could theoretically exceed BAU and still be part of an energy scenario that avoids exceeding +2°C (+3.6°F). But this cannot happen without timely elimination of coal-fired power plants and institution of significant use of CCS.

2. A rigorous carbon tax is the most expedient way to eliminate coal-fired power plants, institute significant use of CCS, and increase attractiveness of renewable energy.

3. To take advantage of rebated carbon taxes, costs of CCS with geologic storage must be kept low.

4. The growth in renewable energy from 2025 to 2050 must exceed 700% to completely replace energy produced from NG and coal. This is more than double the maximum growth of renewable energy that occurred between 2004 to 2010 (~300%).

5. The LCOE for lower cost utility-scale solar PV and solar thermal, both with storage, are currently competitive with LCOE of new gas peaking plants. After 10-15 years of a rigorous carbon tax, even high cost utility-scale solar with storage will be cheaper than the LCOE of new gas peaking plants.

6. "Zero or near-zero $CO_2$ emissions—is best achieved by harnessing a diverse portfolio of low-carbon resources (Jenkins and Thernstrom, 2017). "Low carbon" includes NG with CCS.

7. There can be discussion about how to go forward to deal with climate change or we can say "what me worry" and explain that decision to our grandchildren.

**REFERENCES CITED**


BNEF, 2019, Clean Energy Investment Exceeded $300 Billion Once Again in 2018, January 16,2019 (Bloomberg NEF), **https://about.bnef.com/blog/clean-energy-investment-exceeded-300-billion-2018/**

BP, 2018, BP Statistical Review of World Energy Downloads, accessed February 28, 2019, https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html .

CDP, 2017, Putting a price on carbon, Integration climate risks into business planning, accessed March 15, 2019, https://b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/002/738/original/Putting-a-price-on-carbon-CDP-Report-2017.pdf?1507739326 .

CPLC, 2017, Report on the High-Level Commission on Carbon Prices, Carbon Pricing Leadership Council, accessed August 10, 2018, https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices/ .

C-ROADS, 2018, Climate Change Policy Simulator, Climate Interactive, accessed March 14, 2019, https://www.climateinteractive.org/tools/c-roads/ .

EIA, 2011, Emissions of Greenhouse Gases in 2009, US Energy Information Administration, accessed March 30, 2019, https://www.eia.gov/environment/emissions/ghg_report/pdf/0573%282009%29.pdf .

EIA, 2017, Annual Energy Outlook 2017 with projections to 2050, US Energy Information Administration, accessed March 14, 2018, https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf .

EIA, 2018, Annual Energy Outlook 2018 with projections to 2050, US Energy Information Administration, accessed March 14, 2018, https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf .

EICDA, 2019, Energy Innovation and Carbon Dividend Act, H.R. 763, accessed March 14, 2019, https://energyinnovationact.org/ .

EPA, 2017, Clean Power Plan, Fact Sheet: Overview of the Clean Power Plan, US Environmental Protection Administration, accessed March 14, 2019, https://archive.epa.gov/epa/cleanpowerplan/fact-sheet-overview-clean-power-plan.html .

Jenkins, D. and Thernstrom, S., 2017, Deep decarbonization of the electric power sector insights from recent literature, EIRP, March 2017, accessed March 29, 2019, https://www.innovationreform.org/analysis/.

Lazard, 2018a, Lazard's levelized cost of storage analysis - Version 4.0, accessed March 14, 2019, https://www.lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf .

Lazard, 2018b, Lazard's levelized cost of energy analysis - Version12.0, accessed March 14, 2019, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf .

Mad, 1955, What, me worry?, Mad Magazine, no. 24, 7/1955, https://en.wikiquote.org/wiki/Mad_(magazine)

NCA, 2018, Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States, accessed March 14, 2019, https://nca2018.globalchange.gov/ .

REMI/Synapse, 2014, The Economic, Climate, Fiscal, Power, and Demographic Impact of a National Fee-and-Dividend Carbon Tax, Regional Economic Models, Inc. and Synapse Energy Economic, Inc., accessed March 14, 2019, https://citizensclimatelobby.org/remi-report/ .

Rine, J.M., 2014. An Examination of Carbon Budgets, Carbon Taxes, Industry Attitudes to Global Warming, and AAPG: Environmental Geosciences, v. 21, no. 4 (December 2014), p. 127-140.

Rine, J.M. (in review) How Action on Climate Change Could Benefit US Natural Gas Producers, But Not without Federal Mandates, AAPG Bulletin.

Ross, M. T., 2018, The future of the electricity industry: Implications of trends and taxes, Energy Economics, v. 73, p. 393–409, accessed March 14, 2019, https://doi.org/10.1016/j.eneco.2018.03.022 .

Rubin, E.S., J.E. Davison, H.J. Herzog., 2015, The cost of $CO_2$ capture and Storage, International Journal of Greenhouse Gas Control, v. 40, p. 378–400, accessed August 24, 2018, https://www.cmu.edu/epp/iecm/rubin/PDF%20files/2015/Rubin_et_al_ThecostofCCS_IJGGC_2015.pdf .

Shaner, M.R., S.J. Davis, N.S. Lewis, and K. Caldier, 2018, Geophysical constraints on the reliability of solar and wind power in the United States, Energy and Environmental Science, Issue 4, 2018, https://escholarship.org/uc/item/96315051 .

Shell, 2018, Shell Scenarios, Sky Meeting the Goals of the Paris Agreement, accessed August 8, 2018, http://www.ourenergypolicy.org/wp-content/uploads/2018/03/shell-scenarios-sky-1.pdf .

Sterman, J., T. Fiddaman, T. Franck, A. Jones, S. McCauley, P. Rice, E. Sawinb, and L. Siege, 2012, Climate interactive: the C-ROADS climate policy model, System Dynamics Review System Dynamics Review, v. 28, no. 3 (July-September 2012), p. 295–305, published online 25 July 2012 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/sdr.1474.

USGCP (2014) Billion Dollar Weather/Climate Disasters. Map is no longer available (where I could find it) on the Trump Administration's censured-.gov websites.

USGCRP, 2018, U.S. Global Change Research Program, Climate Science Special Report: Fourth National Climate Assessment (NCA4), Volume II, Impacts, risks, and adaptation in the United States, accessed March 13, 2019, https://www.globalchange.gov/nca4 .

WSJ, 2017, The consensus climate solution (Paid Advertisement), Wall Street Journal, June 20, 2017, accessed August 2, 2018, https://www.clcouncil.org/wp-content/uploads/2017/06/Climate_Leadership_Council_WSJ_Ad.pdf .