Recent Projections for Carbon Dioxide Emission Reduction in the U.S. Power Sector

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Abstract
The replacement of the Clean Power Plan (CPP) with the Affordable Clean Energy act brings into question the extent to which future carbon dioxide (CO_2) emissions may decrease in the U.S. power sector to meet the emission reduction targets set out in the Paris Agreement, despite the impending withdrawal. To answer this question, we use data from the U.S. Energy Information Administration's Annual Energy Outlook (AEO) reports to evaluate the impact of projected natural gas price on these emissions. We find that while lower natural gas prices historically result in lower CO_2 emissions, projections from AEO 2017 and AEO 2019 differ dramatically in both the projected gas price and the associated impact on CO_2 reduction. This change in marginal emission-reduction rate with natural gas price emanates from decreasing capital costs for solar and wind generation sources. As such, the power sector's contribution to the Paris Agreement targets for 2020 and 2025 may be achieved on schedule and the CPP 2030 target may be meet as early as 2020, even with a stagnant or rising natural gas price. The question now becomes what policies are required to meet new reduction targets.

Introduction

Previous analysis[1,2] of the Energy Information Administration's (EIA) 2030 projections for natural gas price and carbon dioxide (CO_2) emissions for the electric power sector reported in the 2017 Annual Energy Outlook (AEO)[3] indicated that the sector's total emissions would not meet the Clean Power Plan (CPP) 2030 or 2025 mass targets, in the absence of the CPP regulation.[4] To meet the 2025 target, *ceteris paribus*, the 2030 projected natural gas price would need to be less than \$3.40/MMBtu.[*] It was further speculated that either a greater reduction in natural gas price (which would increase natural gas combined cycle (NGCC) capacity) or further incentives for renewable energy to increase wind capacity were required to meet the 2030 mass target.

In the 2019 AEO, the EIA updated their projections for natural gas prices and CO_2 emissions from the electric power sector.[†5] For the seven cases modeled, none of which incorporate the CPP or the Trump administration's Affordable Clean Energy Act (ACE),[6] two cases can be compared directly to the AEO 2017 projections: the reference and high oil and gas resource and technology (which results in low natural gas prices) cases without the CPP. Such a paired comparison relative to the CPP emission targets for the years in question, Table 1, indicates that the projected emissions for AEO 2019 are reduced beyond the targets for each year, whereas the AEO 2017 projections only meet the 2020 emission target.

Results and discussion

Natural gas price and emission reduction

The comparison also shows that the aforementioned relationship between lower natural gas prices and greater emission reduction is broken, Figure 1. Historically, decreases in natural gas prices have led to decreases in emissions, related primarily to increases in generation from natural gas sources and decreases from coal-fired sources, Figure 2. Hence, the higher natural gas price projections in AEO 2017 were associated with higher projected emission levels, relative to recent historical levels. Correspondingly, when the projected natural gas prices are lower, due to high oil and gas resource and technology (high natural gas supply), the projected emissions are significantly reduced. Yet when the AEO 2019 reference case projections for

[*] Natural gas prices in dollars per million British thermal units (\$/MMBtu) are converted to 2010 dollars with the Consumer Price Index (CPI).[15] Natural Gas prices for the EIA are based upon national averages.

[†] Core cases are updated annually; however, side cases are updated biennially, starting in 2014.

natural gas price are greater than the historical 2018 price, the projected emission reductions are substantially greater. In further contradiction, when similar natural gas prices were projected for the AEO 2017 high natural gas supply case and the AEO 2019 reference case, the projected emission levels for 2019 are less than those for 2017. Application of lower natural gas prices from higher supply to AEO 2019 reference case then results in marginal emission-reduction rates that are in sharp contrast to those for the AEO 2017 cases. (See Figures 3 and 4 for historical and projected steam coal and natural gas prices from 2005 to 2030.)

Marginal emission-reduction rate

The data underlying these projections offer some model insights as to why the relationship has changed. In comparing the 2030 projections for the reference and high natural gas supply cases from AEO 2017 and AEO 2019 (Table 2, Figures 5-11), the variation in net generation between the corresponding cases is less than 1%; however, coal-fired generation in AEO 2019 is approximately 28% less than that for the corresponding cases in AEO 2017. This lost generation is replaced primarily with additional natural gas generation related to projected natural gas prices that are at least 16% less in AEO 2019, while coal prices decrease by no more than 12%. Such a change in generation fuel-type does follow the expected trend of natural gas generation replacing coal-fired generation with decreasing gas price and indicates an accelerated decrease in coal-fired capacity that may be due to more than lower natural gas prices. Yet in AEO 2019, there is only a 1% further decrease in emissions when the natural gas price in the reference case is further reduced by 17% for the high natural gas price case, as compared to a 8% decrease in emissions from a 27% decrease natural gas price in AEO 2017.

This marginal emission-reduction rate change in the natural gas price and emissions relationship may relate to the decreased reliance on nuclear generation—a 13% and 35% decrease for the two AEO 2019 cases in question. In the reference case comparison, this generation decrease is almost offset by a 20% increase in renewable generation that comes from a tripling of solar generation related to both increased capacity and capacity factors. The further reduction in emissions for the AEO 2019 high natural gas supply, notwithstanding a greater relative decrease in nuclear generation, is due to the greater absolute reduction in coal-fired generation and 33% increase in natural gas generation. Even so, while onshore wind and solar generation is only 1% lower in the AEO 2019 high natural gas supply case, solar generation is almost 140% greater. This overall decrease in reliance upon wind generation in favor of solar generation suggests a decrease in solar capital costs that may also be a component of the trajectory change.

The relationship change is particularly evident for the low oil and gas resource and technology (low natural gas supply) case for which gains in natural gas price reduction from fracking and horizontal drilling are diminished beyond 2009 levels, yet the CO_2 emissions are projected to be less than that for any other case—a further 4% emission decrease given a 41% natural gas price increase, relative to the AEO 2019 reference case. While coal-fired generation is increased by 15% to offset a 37% reduction in natural gas-fired generation, Figures 12 and 13, this reduction is accomplished by increasing carbon-free generation to levels that are otherwise only slightly greater those achieved in 2017, Figure 14. Nuclear generation is increased by 8%, wind and solar generation by 49% for an overall reduction of only 2% in total net generation. Such a large increase in renewable electricity is driven primarily by a 90% increase in solar generation to a level where solar generation is only 10% less than wind generation.

Power generator cost

Examining the power-generator cost trends from previous AEOs is useful to understand the source of the deeper emission reductions now projected and the source of the trajectory change. For natural gas generation, which is substantially due to NGCC capacity, Figure 2, the levelized cost of electricity (LCOE) for the reference-case conventional and advanced units decrease significantly from AEO 2015[7] to AEO 2019, Table 3. This capacity-weighted average cost, based upon region-specific cost adders, decreases by almost 50% for each technology from AEO 2015 to AEO 2019. For the conventional unit, almost 80% of this decrease results from a reduction in variable operation and maintenance (VOM) cost related to changes in fuel price[3,5,7,8,12] and from modeling a more efficient gas turbine from the 2016 AEO onwards.[8] The remaining decrease is due primarily to the levelized capital costs that decline gradually from the 2015 AEO level and then drop by 39% between the 2018 and 2019 AEOs,[19, 13] related to reductions in the cost of investment capital and region-specific cost adders rather than to decreasing overnight capital costs, Table 8.[†] Similarly, 71% of the decrease in LCOE for the

[†] The impact of the regional cost adders is apparent in the capacity-unweighted and weighted levelized capital cost from the 2018 and 2019 AEOs. In 2010 dollars, the 2018 AEO unweighted capital cost is $0.35 less than the

advanced NGCC unit is due to a reduction in VOM related to fuel price.[3,5,7,8,12] However, a reduction in the overnight capital cost for this technology (Table 8) in the 2019 AEO[13,24] causes a 55% decrease in levelized capital cost from the 2018 AEO[19,23] that accounts for almost all of the remaining decrease. This reduction is attributed in part to economies of scale from using the GE 7HA.02 combustion turbine for future NGCC plants and standalone combustion turbines.[9] Therefore, the difference in the 2017 and the 2019 AEO assumptions for VOM and levelized capital cost that results in a $16/MWh decrease in the conventional NGCC LCOE (from a $10/MWh decrease in VOM and a $6/MWh decrease in levelized capital cost, Table 3a) and a $14/MWh decrease in the LCOE for the advanced NGCC unit (from a $7/MWh decrease in VOM and a $7/MWh decrease in levelized capital cost, Table 3b) likely accounts for the observed increase in projected natural gas generation in the 2019 AEO, when the high-supply case in the 2017 AEO and the reference case in the 2019 AEO have similar projected natural gas prices.

The costs for wind and solar generation also decreased sharply. From AEO 2015 to 2019 without tax credits, the capacity-weighted average LCOE for wind generation decreased by 46% and that for solar decreased by almost 64%, Table 4. Taking tax credits into account for the AEO 2019 scenario, these decreases result in a solar LCOE that is less than $1/MWh greater than that for wind, which exemplifies the importance of these credits. Most of these reductions relate to levelized capital costs that decreased by 33% and 41% for wind and solar generation, respectively, from the 2017 to 2019 AEO projections, Table 5. These reductions vary year-over-year, Table 6, related to finance cost and as modeled capacity expansion will occur in regions (each with region-specific cost adders) most favorable to the specific fuel types and available new technology—an attribute that is also observed in the AEO capacity-factor variation, Table 7. The capital-cost reduction can be partially unpacked by looking at the total overnight capital-cost upon which these capacity-weighted average costs are based, Table 8. Here, the overnight cost continues to decrease for all solar technologies, as does that for wind. Fixed-solar overnight costs are reduced by 50% from AEO 2015 to 2019, assuming the use of fixed-solar technology dominates the AEO 2015 total overnight-cost, and wind overnight costs decrease by 24%.[*]

weighted cost, while that for the 2019 AEO is $1 more than the weighted cost. Using the unweighted costs changes the 2018 to 2019 AEO drop in levelized capital cost from 39% to 27%.

[*] Prior to AEO 2018, the AEO did not distinguish utility-scale photovoltaic generation into these two categories of collectors.

Model comparison

One may benchmark of the assumption that solar costs will decrease sufficiently to displace new NGCC and wind generation in the low supply case by 2030 with modeling done by other agencies: the Environmental Protection Agency (EPA) and the National Renewable Energy Laboratory (NREL). The EPA uses the Integrated Planning Model (IPM) to determine future U.S. power-sector dispatch, least-cost capacity expansion, and emission-control strategies for environmental policies formulation and evaluation. As part of this, the EPA publishes the assumed total overnight-costs and other LCOE components for the generation technologies for various service introduction years, for which they use the EIA fuel-price projections.[10]

NREL's 2019 Annual Technology Baseline (ATB) documents detailed projected cost and performance assumptions about renewable and conventional electricity-generating technologies, using EIA fuel-price projections, for least-cost capacity expansion modeling.[11] For wind, a national wind-resource profile for potential wind generation is grouped into ten techno-resource groups (TRGs) to define the appropriate wind turbine technology and associated costs for each region. The TRGs are then used to identify the group for which the plant characteristics best align with recently installed and projected near-term installation as a baseline for constant, mid and low technology cost scenarios, and to provide the upper and lower bounds for these scenarios. Similarly, the solar-generation projected cost and performance characteristics are based upon a potential solar-resource profile. Rather than use TRGs to define the best aligned and bounding plant characteristics, the solar profile uses collectors sited in specific cities. Projected NGCC costs are determined as an average of the EIA reported conventional and advanced unit costs, where the representative unit has a high capacity factor and natural gas price determines the high and low bounds.

In a comparison of the projected overnight capital-costs for solar generation, Figure 15, the IPM values fall within the bounds of the ATB values, with each showing a decline in capital cost as the available service-year horizon increases. However, the point value for AEO 2019 is almost $600/kw greater than the ATB value for 2020. Projections for wind capital costs also show agreement between IPM and ATB values for declining costs and the AEO 2019 value is near the ATB 2021 upper bound, Figure 16. For NGCC capital costs, the AEO value falls between the IPM and ATB projections, Figure 17, for which the projected costs are almost constant.

Therefore, the agreement between the ATB and IPM values for these technologies indicates that the declining capital costs are expected for wind and solar, As such, the ATB projection for a solar LCOE* being similar to that for wind and NGCC, Figure 18, reinforces the AEO 2019 projection that solar generation may replace some of the wind generation from AEO 2017 and that high natural gas prices may lead to greater use of solar capacity.

Levelized avoided cost of electricity

However, if one compares only the generation technology LCOEs to make capacity investment decisions, not all economic-competitiveness factors are being considered. Consideration can be given to other factors such as the value of capacity-related grid services, the ability of the generator to meet load given the existing fleet generation-profile, and the generation technology that may be replaced. One method used to account for these additional factors is to determine the levelized avoided cost of electricity (LACE). LACE can be considered as the marginal cost of energy and capacity, as it is the cost of electricity if the considered technology is not available and another technology must be used instead for the new capacity. Here, if LACE is greater than LCOE for the same technology, then it is favorable to invest in that technology relative to the alternative technologies, absent other investment factors.

While the EIA does not use LACE for decisions in the AEO capacity expansion modeling, LACE is determined and the value-cost ratio (LACE divided by LCOE) is calculated for various available service-years, Table 9. From this analysis, both solar and wind generation are seen as favorable investments for AEO 2016 to 2018.[12] However, only solar generation is a favorable technology to the alternatives in AEO 2019, due largely to expiration of the production tax credit that is applicable to onshore wind generation. In subsequent available service-years when the investment tax credit also expires, neither technology has a value-cost ratio greater than 1 in the AEO 2019 reference case,[13] Figure 19. However, the value-cost ratio for each technology is projected to be greater than 1 by 2030, due to decreases in capital costs and improved capacity factors.[13] Therefore, additional solar and wind capacity may be favorable when higher priced natural gas makes expansion of NGCC capacity less favorable.

* LCOE for solar and wind generation includes the reduction and expiration of investment and production tax credits.

Conclusion

In AEO 2019, the EIA projects that the CO_2 emission-reduction targets set out in the CPP can still be achieved without the plan or subsequent ACE regulations but through current environmental regulations and policies, and market mechanisms. As such, the substantial contribution in emission reduction with which the electric power sector was tasked to meet the Paris Agreement targets may be achieved and even exceeded.[14] While low natural gas price is still a prominent factor in achieving these reductions, decreasing capital cost for generating sources is also important.

The decreasing NGCC plant capital cost coupled with lower natural gas price projections are enabling factors in AEO 2019 for reductions beyond the 2030 emission target. However, these factors also hide the continued capital cost reductions for solar and wind generation. If the historical natural gas price decrease achieved through hydraulic fracking and horizontal drilling were to disappear (due to increasing LNG export, regulations curtailing such extraction, or a carbon tax[*]) and return to 2010 levels, the lower projected capital costs for these renewables (particularly solar) are low enough to reverse the trend of emissions increasing with increasing natural gas price. The dramatic change between AEO 2017 and 2019 in the capital costs for these generating sources, even with similar service years, also indicates how difficult it may be to set policy for 5-20 years in the future, given the uncertainty in fuel prices and rapidly changing technology fronts in energy generation and storage. Therefore, both promotion of technological improvement and economies of scale from installed capacity in these renewable technologies to ensure lower levelized costs may serve as one backstop to avert increased emissions with higher natural gas prices and to promote higher penetration of carbon-free generation by 2030.

[*] If one assumes that the 7,649 Btu/kWh NGCC heat rate for the current fleet[28] were to decrease to that for a conventional NGCC plant (6,350 Btu/kWh)[24] by 2030, then a $25/ton carbon tax is sufficient to increase the equivalent price of natural gas from $3.7/MMBtu for the 2030 projected reference case[5] to the $5.2/MMBtu projected price for low natural gas supply,[5] *ceteris paribus*.

Tables

Table 1. Clean Power Plan CO_2 emission targets and AEO 2017and 2019 projected CO_2 emissions for 2020, 2025, and 2030.[3-5] AEO reference and high oil and gas resource and technology (high natural gas supply) cases are shown with AEO 2019 low oil and gas resource and technology (low NG supply) case, without CPP. Values in boldface indicate that the case meets the target.

	Annual CO_2 Emissions (million short tons)		
Case/Year	2020	2025	2030
CPP Target	2,073	1,901	1,814
2019 Reference	**1,822**	**1,771**	**1,765**
2017 Reference without CPP	**2,024**	2,039	2,078
2019 High Natural Gas Supply	**1,784**	**1,779**	**1,741**
2017 High Natural Gas Supply without CPP	**1,936**	1,914	1,922
2019 Low Natural Gas Supply	**1,861**	**1,765**	**1,703**

Table 2. AEO 2017 and 2019 national power sector characteristics for 2030.[3,5] AEO reference and high oil and gas resource and technology (high NG supply) cases are shown are shown with AEO 2019 low oil and gas resource and technology (low NG supply) case, without CPP. Dollar year converted to 2010 with CPI.[15]

Parameter	Units	AEO 2017		AEO 2019		
		Reference	High NG Supply	Reference	High NG Supply	Low NG Supply
Excess CO_2	Million short tons	264	108	(49)	(73)	(111)
Coal capacity*	Gigawatts	217.1	184.9	161.8	139.4	182.6
NGCC capacity*	Gigawatts	239.1	267.6	343.8	402.9	299.1
Wind capacity*	Gigawatts	140.3	133.5	119.7	116.5	142.6
Solar PV capacity*	Gigawatts	37.9	32.9	92.3	66.4	169.9
Nuclear capacity*	Gigawatts	95.1	96.5	81.7	59.9	88.6
Coal net generation†	Terawatt-hours	1,389.4	1,099.9	986.9	787.7	1,131.6
NG net generation†	Terawatt-hours	1,060.5	1,431.9	1,487.3	1,985.1	934.3
Wind net generation†	Terawatt-hours	419.7	448.6	368.7	356.6	457
Solar PV net generation†	Terawatt-hours	72.4	63.4	219.5	151.1	417.7
Nuclear net generation†	Terawatt-hours	768.0	757.1	663.9	488.4	716.8
Total net generation‡	Terawatt-hours	4,332	4,366	4,287	4,329	4,222
Natural gas price	2010$/MMBtu	4.61	3.63	3.67	3.03	5.18
Steam coal price	2010$/MMBtu	2.20	2.08	1.93	1.85	2.00
Electricity price§	Nominal cents/kWh	14.5	13.8	13.9	13.4	14.7

*net summertime capacity; †power only; ‡net generation to grid; §summation of generation, transmission and distribution costs

Table 3. Change in LCOE for (a) conventional and (b) advanced NGCC plants from AEO 2015 to AEO 2019, based upon capacity-weighted averages.[13,16-19] Dollar year converted to 2010 with CPI.[15] VOM includes fuel cost.

Table 3a

		$/MWh			Year-over-year change (fraction)		
AEO	**Service yr**	**LCOE**	**VOM**	**CC**	**VOM**	**CC**	**Capacity factor**
2015	2020	70.39	54.10	13.48	-	-	0.87
2016	2022	51.89	37.90	11.78	-0.299	-0.126	0.87
2017	2022	53.24	38.16	12.72	-0.007	-0.080	0.87
2018	2022	43.02	29.21	11.58	-0.234	-0.09	0.87
2019	2023	37.26	28.12	7.05	-0.038	-0.391	0.87

Notes: VOM: variable operation and maintenance cost, including fuel; CC: levelized capital cost.

Table 3b

		$/MWh			Year-over-year change (fraction)		
AEO	**Service yr**	**LCOE**	**VOM**	**CC**	**VOM**	**CC**	**Capacity factor**
2015	2020	67.96	50.17	14.88	-	-	0.87
2016	2022	52.62	35.05	14.17	-0.301	-0.048	0.87
2017	2022	48.88	34.07	12.72	-0.028	-0.102	0.87
2018	2022	42.84	26.99	13.81	-0.208	-0.085	0.87
2019	2023	34.99	26.72	6.18	-0.010	-0.552	0.87

Notes: VOM: variable operation and maintenance cost, including fuel; CC: levelized capital cost.

Table 4. Wind and solar LCOE from AEO 2015 to AEO 2019, based upon capacity-weighted averages.[13,16-19] Dollar year converted to 2010 with CPI.[15]

		Wind ($/MWh)		Solar ($/MWh)	
AEO	**Service yr**	**No credit**	**Credit**	**No credit**	**Credit**
2015	2020	68.89	68.89	117.29	106.99
2016	2022	53.83	46.83	68.26	53.46
2017	2022	50.70	40.25	66.96	52.79
2018	2022	42.75	32.87	52.64	41.51
2019	2023	37.26	31.86	42.48	32.73

Table 5. Change in wind and solar LCOE components from AEO 2015 to AEO 2019, based upon capacity-weighted averages.[13,16-19] Value of tax credits is omitted. Dollar year converted to 2010 with CPI.[15]

		Wind ($/MWh)		Solar ($/MWh)	
AEO	**Service yr**	**OM**	**CC**	**OM**	**CC**
2015	2020	11.98	54.01	10.67	102.78
2016	2022	11.50	39.84	8.74	56.30
2017	2022	11.9	36.16	9.18	54.33
2018	2022	11.31	29.39	6.68	42.93
2019	2023	10.97	24.20	7.66	32.29
Fractional change (2017-2019)		-0.08	-0.33	-0.17	-0.41

Notes: OM: operation and maintenance cost; CC: levelized capital cost.

Table 6. Year-over-year change in wind and solar LCOE components from AEO 2015 to AEO 2019, based upon capacity-weighted averages.[13,16-19] Value of tax credits is omitted.

		Wind (fraction)		Solar (fraction)	
AEO	**Service yr**	**OM**	**CC**	**OM**	**CC**
2015	2020	-	-	-	-
2016	2022	-0.040	-0.262	-0.181	-0.452
2017	2022	0.035	-0.092	-0.05	-0.035
2018	2022	-0.05	-0.187	-0.272	-0.21
2019	2023	-0.030	-0.177	0.147	-0.248
Fractional change (2015-2019)		-0.085	-0.552	-0.282	-0.686

Notes: OM: operation and maintenance cost; CC: levelized capital cost.

Table 7. AEO 2015 to AEO 2019 capacity factors for new generation capacity entering service.[13,16-19]

	Capacity factor (fraction)	
AEO	**Wind**	**Solar**
2015	0.36	0.25
2016	0.40	0.25
2017	0.41	0.25
2018	0.43	0.33
2019	0.44	0.29

Table 8. Conventional and advanced NGCC, wind and solar total overnight capital costs ($/kW) from 2015 to 2019 AEO Assumptions.[20-24] Dollar year converted to 2010 with CPI.[15] Value of tax credits is omitted.

AEO	Conv. NGCC	Adv. NGCC	Wind	Solar	Solar Fixed	Solar Tilt
2015	854	952	1,853	3,069		
2016	880	994	1,512	2,282		
2017	880	994	1,532	2,069		
2018	875	987	1,476		1,649	1,875
2019	870	691	1,414		1,552	1,714

Table 9. Change in value-cost ratio from AEO 2015 to AEO 2019,[13,16-19] based upon capacity-weighted averages. Value-cost ratio is the levelized avoided cost of electricity (LACE) divided by the LCOE. When ratio is greater than one, the generating source is favorable to alternatives. Dollar year converted to 2010 with CPI.[15]

		LACE ($/MWh)			Value-cost ratio		
AEO	**Service yr**	**NGCC**	**Wind**	**Solar**	**NGCC**	**Wind**	**Solar**
2015	2020	66.83	60.47	75.26	0.95	0.878	0.703
2016	2022	49.40	49.40	62.01	1.094	1.056	1.156
2017	2022	53.06	49.06	60.69	0.997	1.219	1.15
2018	2023	41.42	38.21	64.49	0.963	1.163	1.554
2019	2023	33.34	29.34	35.08	0.895	0.921	1.072

Figures

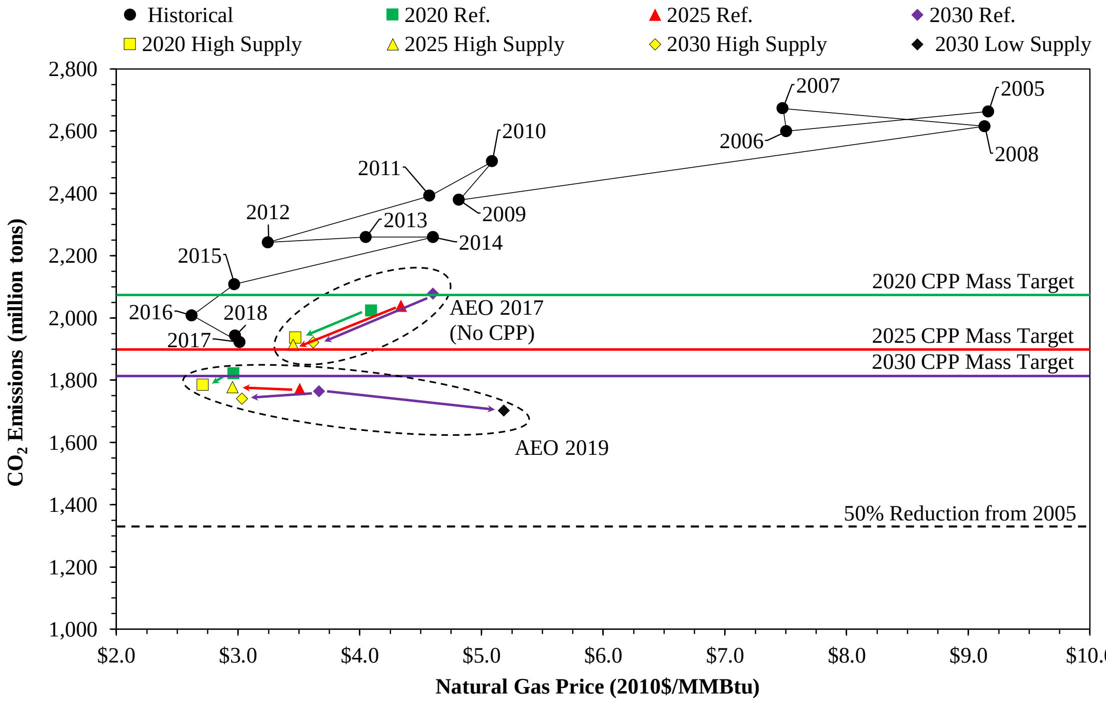


Figure 1. Historical* and projected 2020, 2025, and 2030 CO_2 emissions from the U.S. power sector in relation to natural gas price.[25] Projected emissions and gas prices are national averages based on scenarios in the 2017 and 2019 Annual Energy Outlook (AEO) for the reference (ref.) and the high oil and gas resource and technology cases (high supply), and for the low oil and gas resource and technology case for 2019 (low supply).[3,5] Only the scenarios without the CPP are shown. Historical and projected natural gas prices from AEO 2017 and 2019 are converted to 2010 dollars with the Consumer Price Index.[15]

* The correlation between price and reduction is not chronologically perfect, however. Coal prices, capacity planning, regulations and policy mechanisms (such as state-specific renewable portfolio standards and federal tax credits for solar and wind energy), unforeseen events, technology changes, and hedging related lags [29-31] may account for some of the imperfect responses between the natural gas price and the reduction, as occurs from 2006 to 2008 and from 2012 and 2014, when the natural gas prices increase but the emission intensities remain constant.

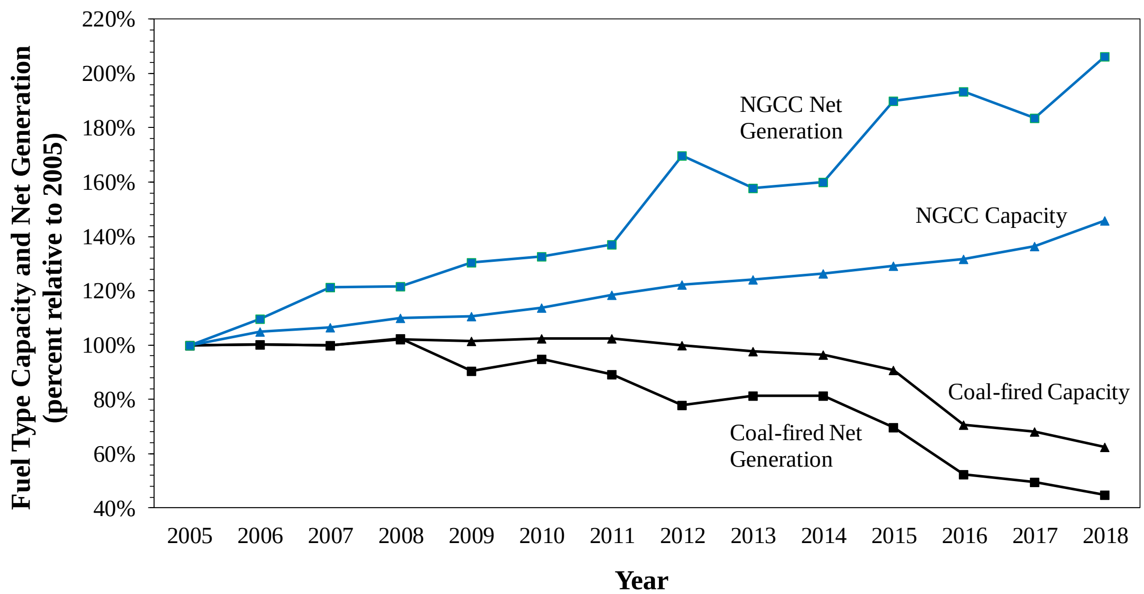


Figure 2. Historical coal-fired and NGCC net generation and capacity levels relative to 2005.[26,27]

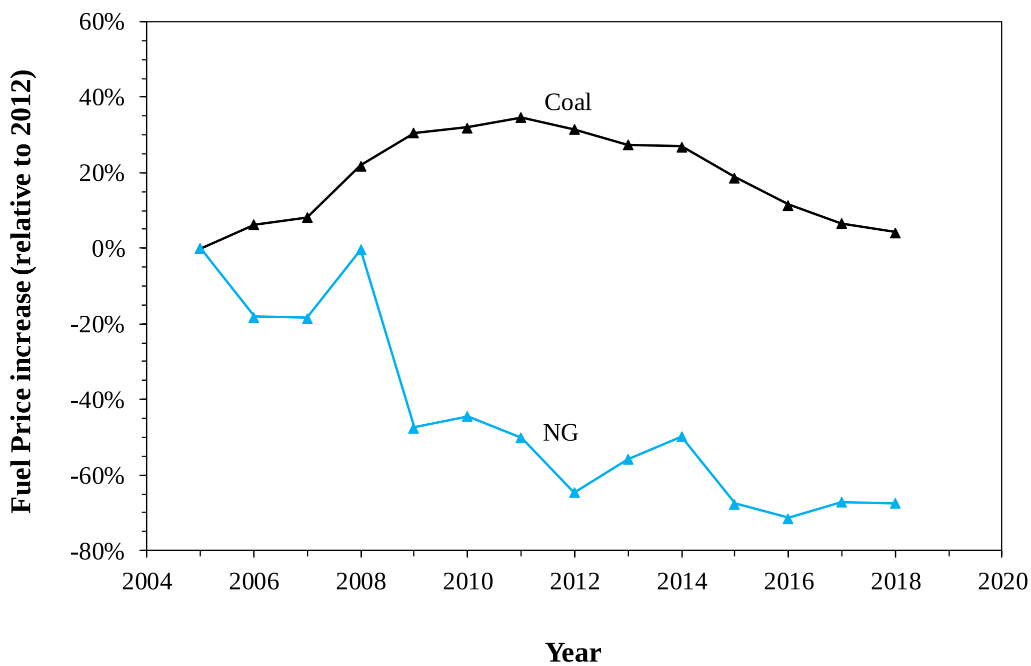


Figure 3. Historical steam coal and natural gas prices relative to 2005 levels.[25]

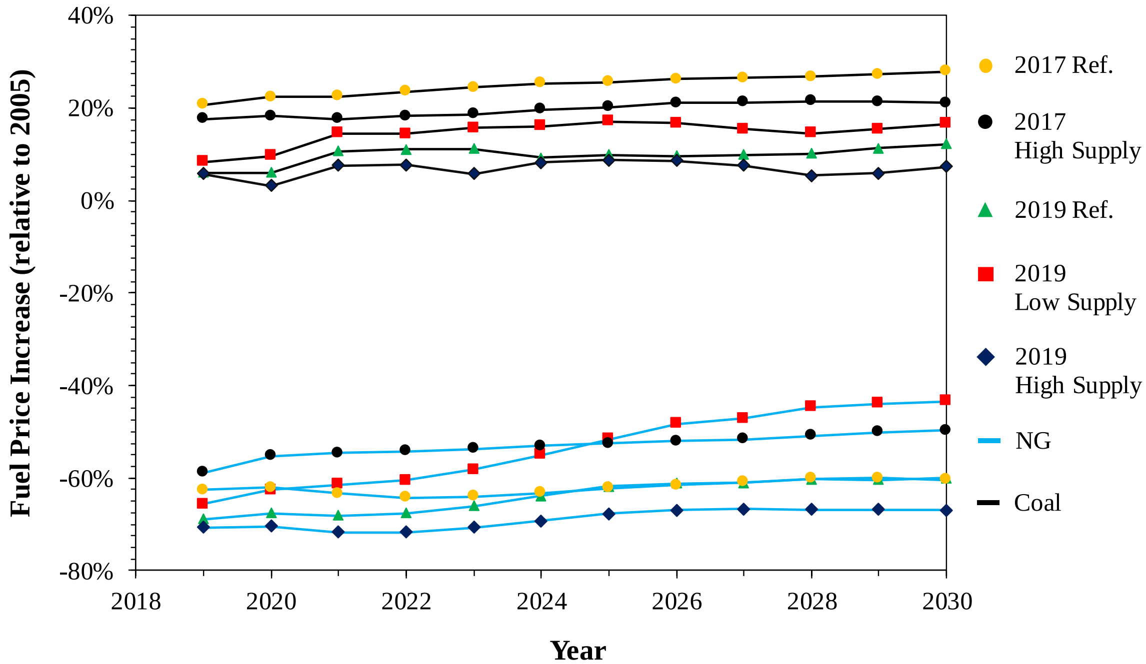


Figure 4. Projected steam coal and natural gas prices from AEO 2017 and 2019 relative to 2005 levels.[3,5]

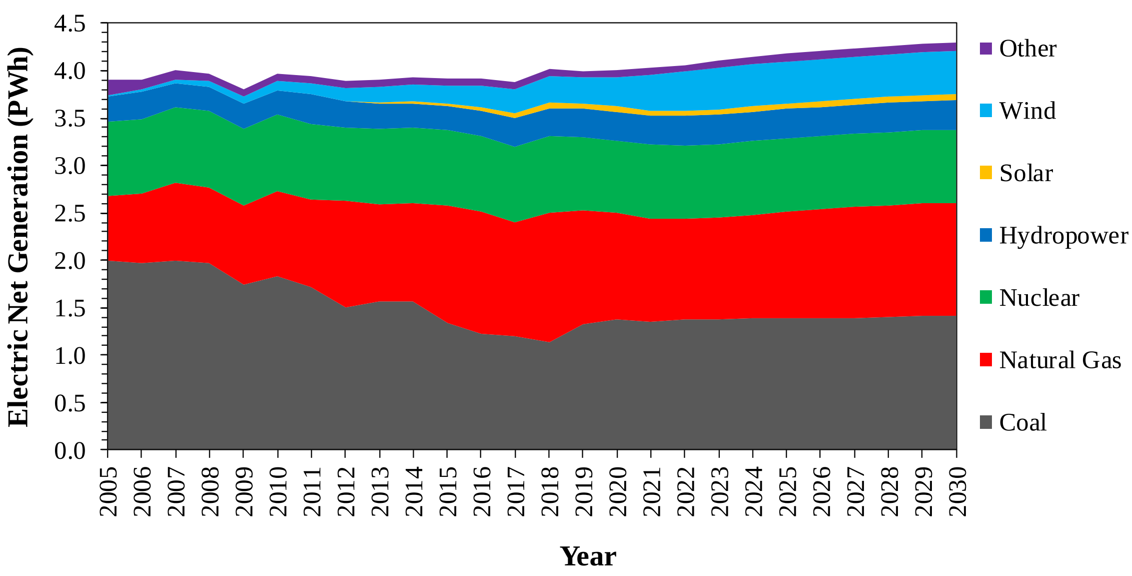


Figure 5. Historical[25] and projected net generation for the U.S. power sector by source. Projected generation is for the reference case in AEO 2017.[3]

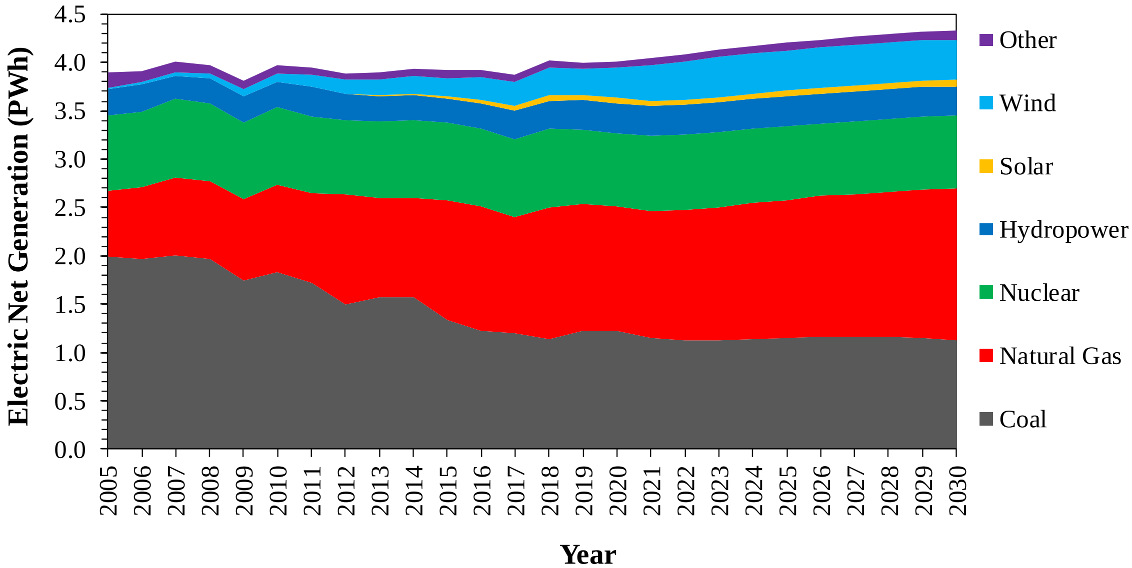


Figure 6. Historical[25] and projected net generation for the U.S. power sector by source. Projected generation is for the high oil and gas resource and technology cases (high natural gas supply) case in AEO 2017.[3]

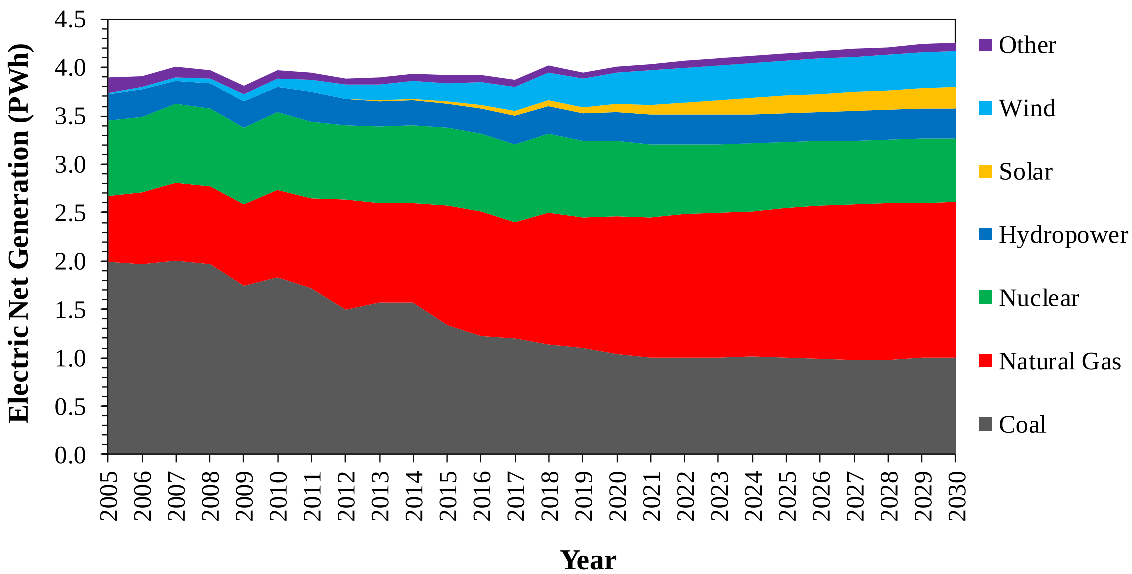


Figure 7. Historical[25] and projected net generation for the U.S. power sector by source. Projected generation is for the reference case in AEO 2019.[5]

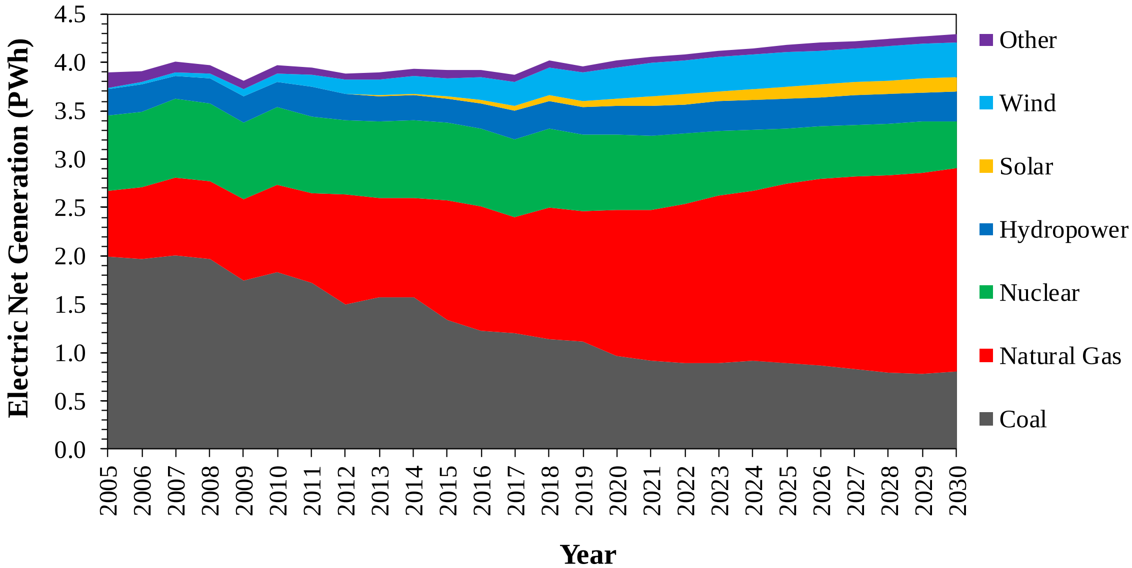


Figure 8. Historical[25] and projected net generation for the U.S. power sector by source. Projected generation is for the high oil and gas resource and technology cases (high natural gas supply) case in AEO 2019.[5]

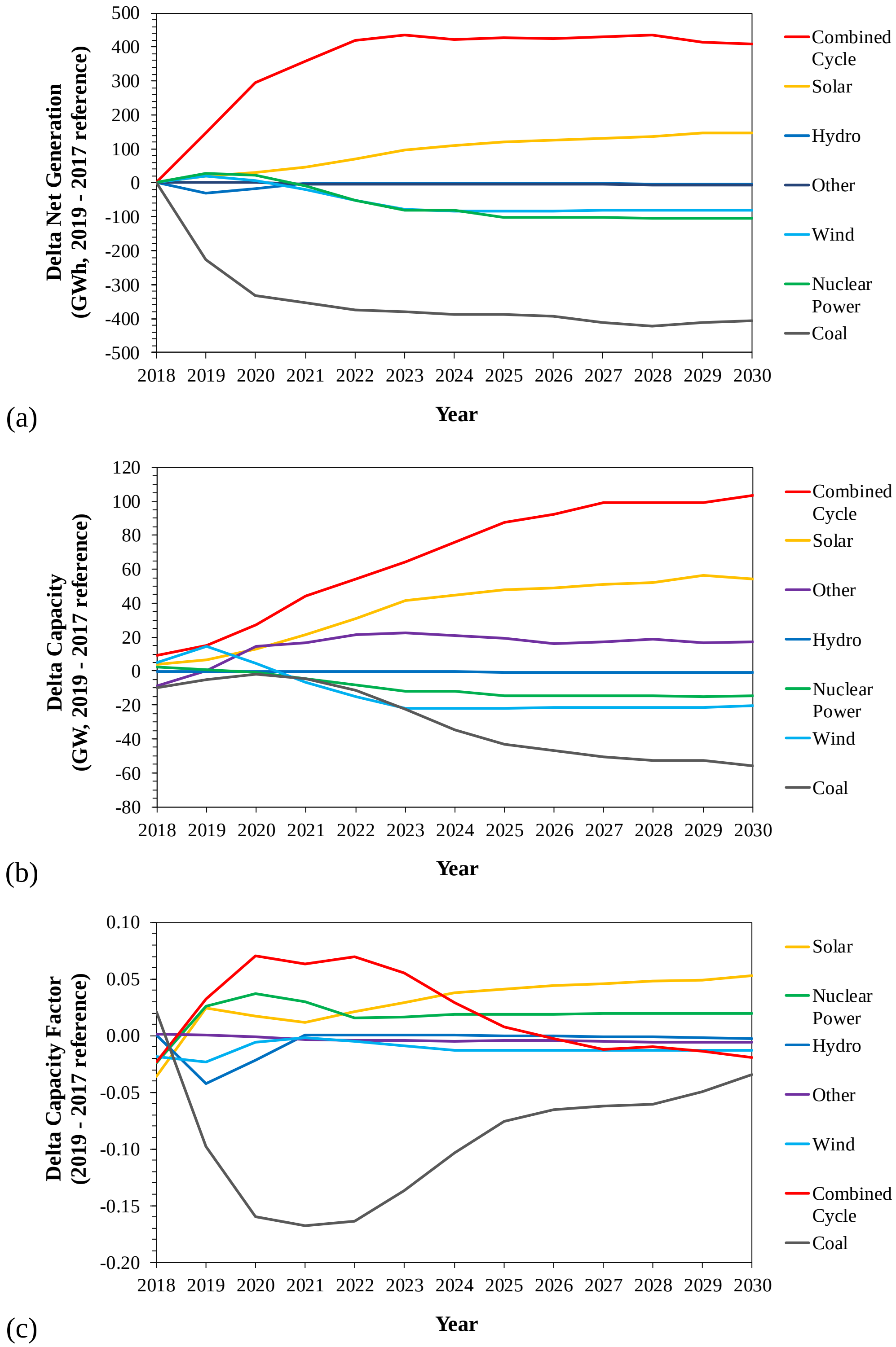


Figure 9. Difference in projected (a) net generation, (b) capacity, and (c) capacity factor for the U.S. power sector by source, as projected for the reference case in AEO 2017 and 2019.[3,5] Capacity factor is based upon net summertime capacity.

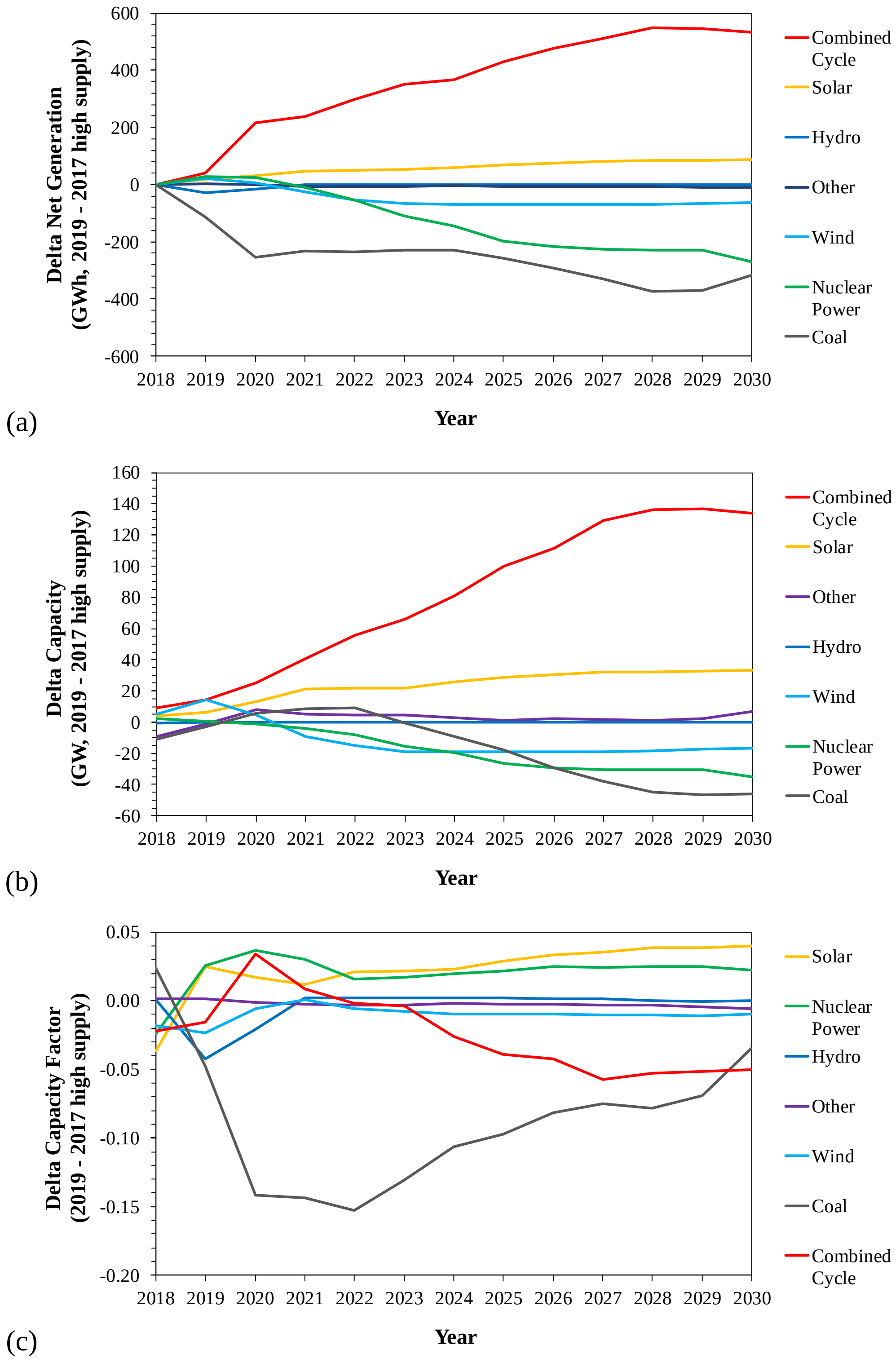
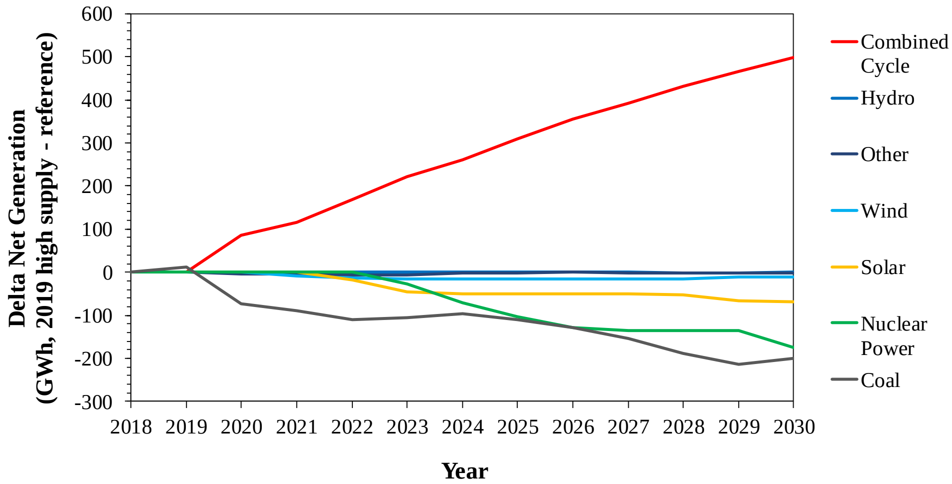
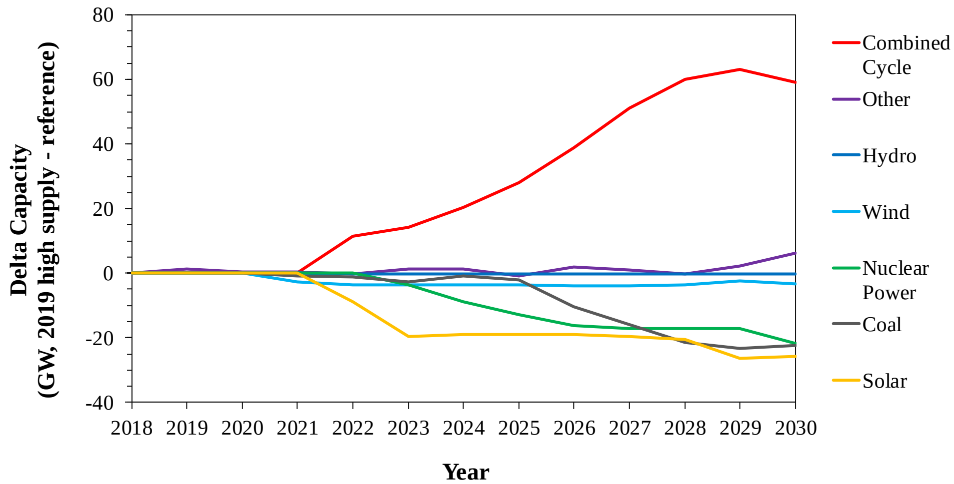


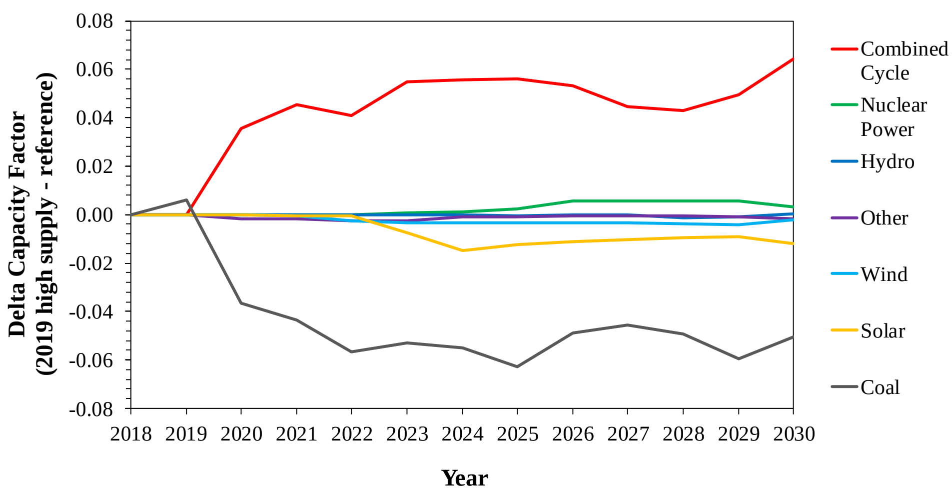
Figure 10. Difference in projected (a) net generation, (b) capacity, and (c) capacity factor for the U.S. power sector by source, as projected for the high oil and gas resource and technology cases (high natural gas supply) case in AEO 2017 and 2019.[3,5] Capacity factor is based upon net summertime capacity.



(a)



(b)



(c)

Figure 11. Difference in projected (a) net generation, (b) capacity, and (c) capacity factor for the U.S. power sector by source, as projected for the high oil and gas resource and technology cases (high natural gas supply) and reference case in AEO 2019.[5] Capacity factor is based upon net summertime capacity.

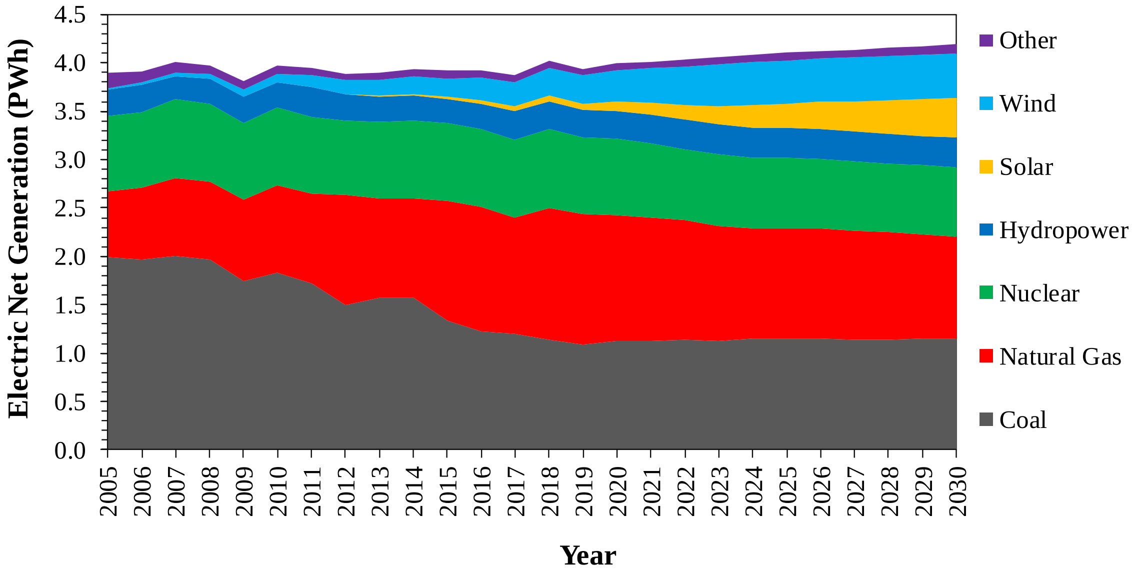
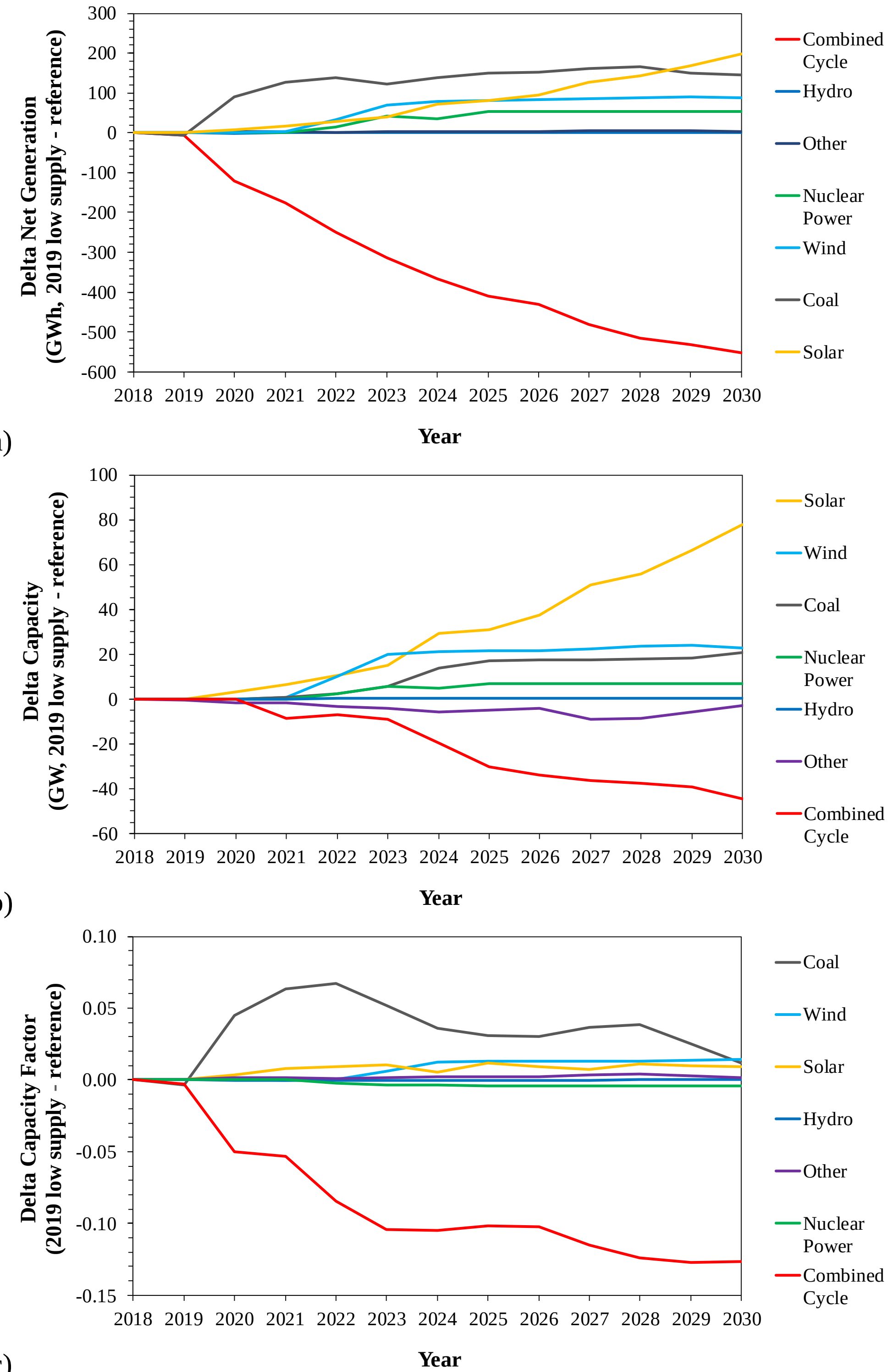


Figure 12. Historical and projected net generation for the U.S. power sector by source. Projected generation is for the low oil and gas resource and technology cases (low natural gas supply) case in AEO 2019.[5]



(a) (b) (c)

Figure 13. Difference in projected (a) net generation, (b) capacity, and (c) capacity factor for the U.S. power sector, as projected for the low oil and gas resource and technology cases (low natural gas supply) and reference cases in AEO 2019.[5] Capacity factor is based upon net summertime capacity.

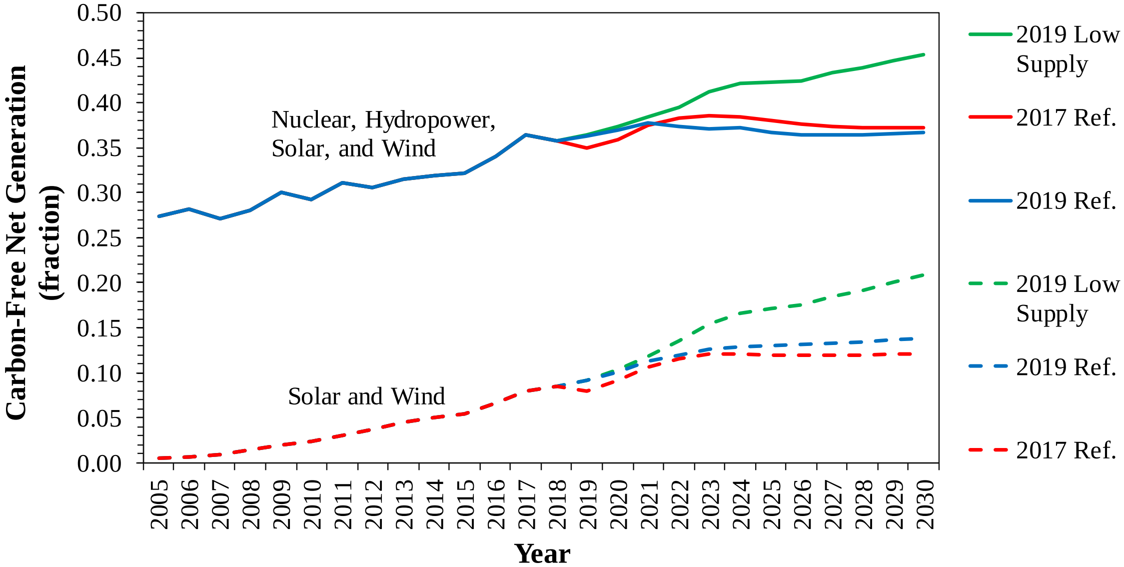


Figure 14. Historical[25] and projected carbon-free net generation for the U.S. power sector. Projected generation is for the reference cases in AEO 2017 and 2019.[3,5] Generation for low oil and gas resource and technology cases (low natural gas supply) case is from AEO 2019.[5] Carbon-free generation is comprised solely of nuclear, hydropower, solar and wind generation. Biomass and similar fuels are excluded.

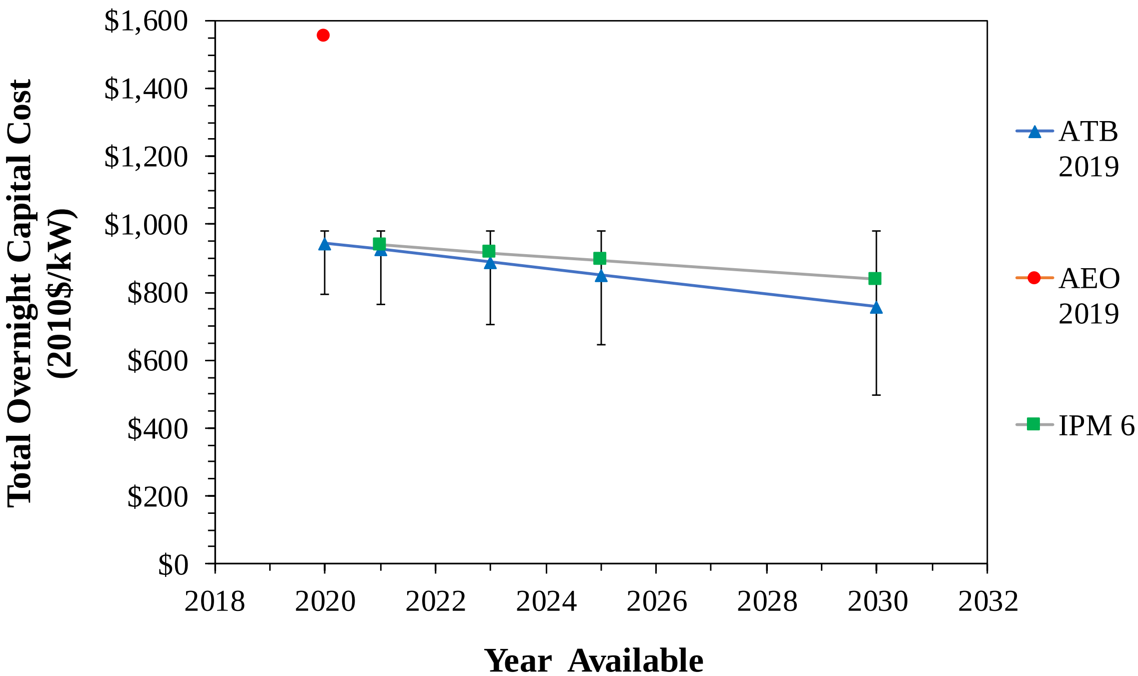


Figure 15. Comparison of total overnight capital cost for solar sources from 2019 ATB,[11] AEO 2019,[5] and IPM 6.[10] Value for ATB is representative of a site in Kansas City, MO. Upper bound of error bar on ATB values is that for a site in Daggett, CA and lower bound is that for a site in Seattle, WA, as defined in the ATB. Values are not capacity weighted.

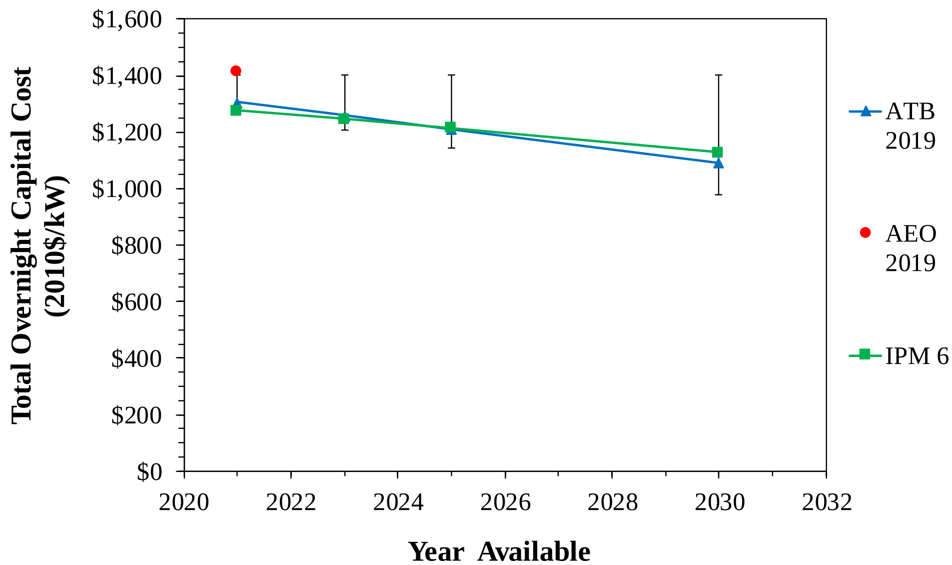


Figure 16. Comparison of total overnight capital cost for wind sources from 2019 ATB,[11] AEO 2019,[5] and IPM 6.[10] Value for ATB is representative of techno-resource group 4. Upper bound of error bar on ATB values is representative of techno-resource group 10 and lower bound is representative of techno-resource group 1, as defined in the ATB. Values are not capacity weighted.

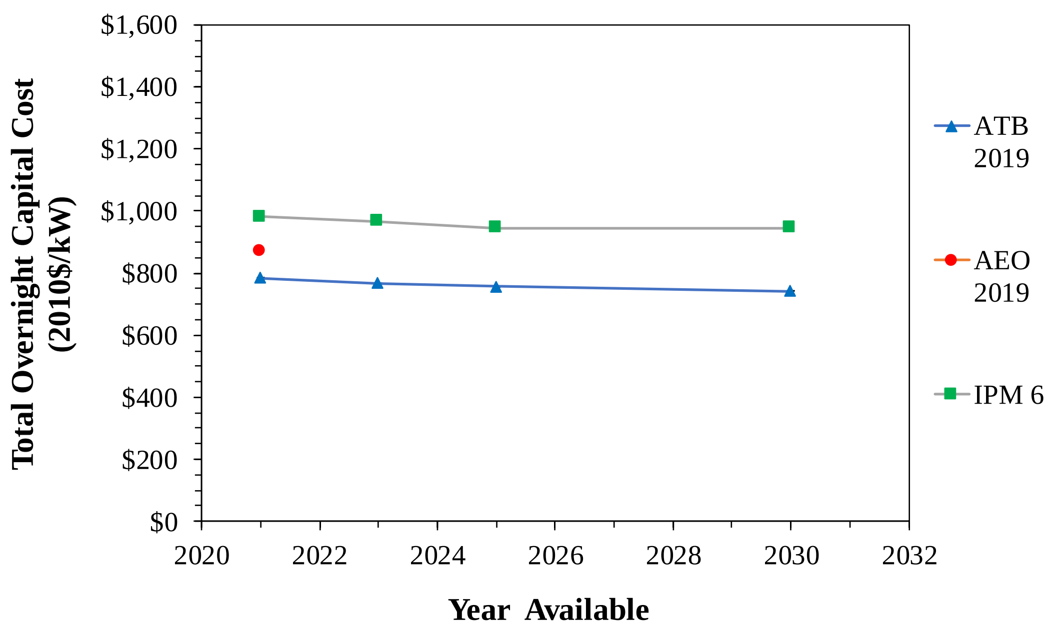


Figure 17. Comparison of total overnight capital cost for NGCC sources from 2019 ATB,11 AEO 2019,[5] and IPM 6.[10] Upper and lower bounds for ATB values are determined by natural gas price and are omitted. Values are not capacity weighted.

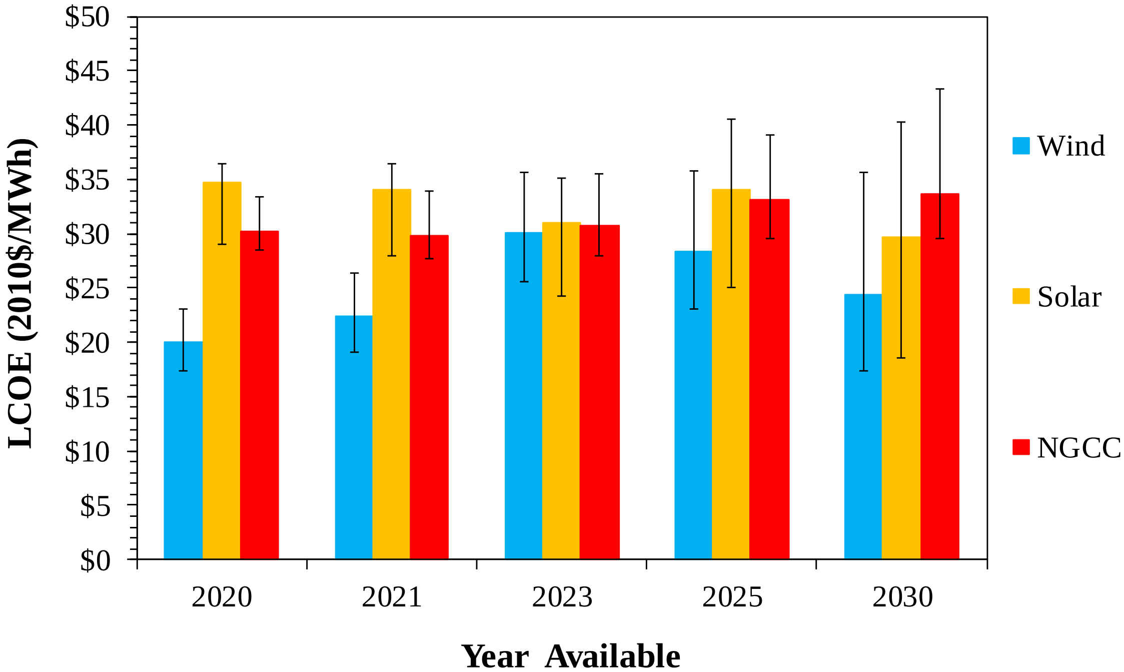


Figure 18. LCOE for NGCC, solar, and wind sources from the 2019 ATB.[11] Error bars are based on LCOE range for default comparisons defined in ATB. NGCC error bars include low, mid and high projections for fuel cost for a high capacity factor unit .

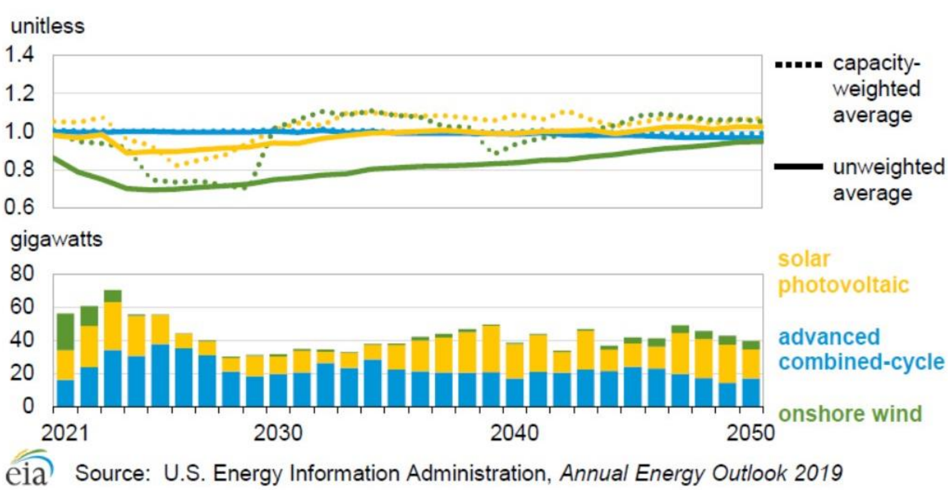


Figure 19. EIA projected levelized avoidance cost of electricity (LACE) for onshore wind, advanced NGCC, and solar photovoltaic generation from AEO 2019.[13]

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