# Deployment of Advanced Coal Power in the U.S. under a Range of Carbon Tax Scenarios

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# Disclaimer

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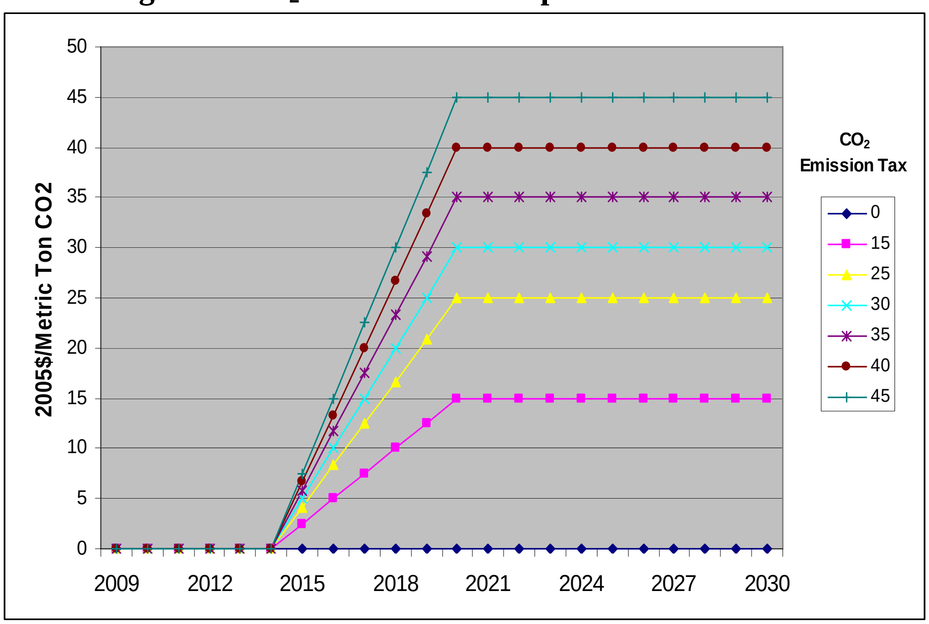
The United States Department of Energy (DOE) seeks to develop technologies for high-efficiency coal power plants with 90% carbon dioxide capture and storage. This analysis forecasts the market penetration potential for advanced coal power by exercising the National Energy Modeling System (NEMS). Both market-based incentives for low carbon emission power and improved technology performance consistent with the DOE Office of Fossil Energy's (FE) research portfolio are considered in the analysis.

The model of NEMS used for this analysis is the AEO 2007 with cost and performance inputs modified by the DOE Applied Energy Research and Development (AERD) group. The AERD group analyzes the progress and penetration of technologies as shown in the AEO2007. Where analysis supports that R&D impacts are embedded in the AEO projections, program effects are removed from the baseline. Additionally, if analysis reveals that the AEO forecast does not show sufficient technology progress, the baseline is adjusted to improve cost and or technology inputs accordingly. Adjustments made to move the AEO2007 to the AERD baseline case are shown in Appendix A.

Figure 1 shows seven carbon tax scenarios ranging from \$0 to \$45/mt$CO_2$ that were used in the analysis. The tax scenarios all begin in 2015 and characterize a policy that is implemented over a discrete and relatively short time period. It is assumed that the tax rate remains level after a transition period. This assumption minimizes complexities associated with the timing of investments and access to perfect or near-perfect information.

**Figure 1. $CO_2$ Emission Tax Implementation Profile**




Each carbon tax scenario was run with a reference case set of assumptions (Appendix A) about the future cost and performance of coal-fired power plants and a second set of assumptions consistent with lower capital cost and improved efficiency consistent with the DOE FE research portfolio[1]. Table 1 sets forth both sets of assumptions for advanced coal power. The improved performance in the FE technology case is based on dry-feed pumps, warm gas sulfur clean up, high-temperature combustion turbines, oxygen/nitrogen membranes, advanced $CO_2$ compression technologies, and syngas conversion via solid oxide fuel cells. The reduced risk premium going from the reference case to the FE technology case is due to field tests of $CO_2$ storage in geologic formations. Beyond the consideration of FE R&D, assumptions about the competitiveness of other generation technologies were unchanged.

**Table 1. Cost and Performance Inputs, FY09**

| | Reference Case | | | With FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| **Advanced Coal Power (no $CO_2$ capture and storage)** | | | | | | |
| Capital cost, $/kW | 1,371 | 1,308 | 1,172 | 1,371 | 1,173 | 989 |
| Efficiency, HHV | 43.0% | 47.4% | 47.4% | 43.0% | 54.3% | 60.0% |
| **Advanced Coal Power with $CO_2$ capture and sequestration** | | | | | | |
| Capital cost, $/kW | 1,946 | 1,820 | 1,618 | 1,745 | 1,331 | 1,252 |
| Efficiency, HHV | 36.7% | 41.4% | 43.1% | 38.0% | 43.2% | 43.9% |
| Risk premium | 3% | 3% | 3% | 0% | 0% | 0% |

NEMS selects power deployments by evaluating the demand for power and the levelized cost of electricity (LCOE) from the different generation options. Table 2 shows how the LCOE from coal technologies compares to other options under scenarios with and without FE R&D and with and without a \$30/mt$CO_2$ carbon tax. Appendix B contains LCOE data for 2010, 2020 and 2030 across the analyzed tax values which range from \$0 to \$45/mt$CO_2$.

Some characteristics of NEMS need to be understood in order to properly assess the LCOE results presented in Table 2. First, NEMS considers feedbacks from markets. For example, if FE R&D makes coal plants cheaper and causes more of them to be built, the cost of coal will likely go up in response which will increase the LCOE (NEMS uses foresight in calculating the LCOE for investment decisions). NEMS also considers learning. In the with-FE case shown in Figure 2 the LCOE of pulverized coal plants goes up slightly due to fewer of these plants being built resulting in a smaller benefit from learning[2]. Finally NEMS applies elasticities of supply to the different power supply options. That is, if the model would choose to build a large number of a certain type of plant in one year, these plants would become more expensive. The numbers shown in Table 2 are the LCOE for the “next” plant that would be built in 2020.

[1] *FY07 Benefit Analysis: FE Input Parameters.* DOE/NETL-402/071607. July 2007.
[2] In the with-FE cases learning is turned off for the generation options with R&D-based future cost and performance inputs. This is due to limits within NEMS and likely causes the impact of R&D to be underestimated.

Table 2 shows an 8% reduction in LCOE for a coal-fired power plant going from the reference to the with-FE research case. The numbers presented are for plants that would begin operating in 2020 having the cost and performance characteristics shown in Table 1, column "with FE Technology, 2020". Technologies represented in Table 2 only include advancements that are expected to have been demonstrated at pre-commercial scale 4-6 years prior to 2020. As such, most of the more advanced FE technologies are not included in this table. The LCOEs for the fully developed technologies expected to be ready for operation in 2030 show a 14% difference between the reference and with-FE cases (see Appendix B).

Table 2 shows that advanced coal with $CO_2$ capture and sequestration is the low-cost option for power under the \$30/mt$CO_2$, with-FE case. Also advanced coal power (no $CO_2$ capture) is the low cost provider in the "no carbon tax," with-FE case.

**Table 2. LCOE Values for Technologies, 2020 (\$/MWh)**

| Power Plant Type | No Carbon Tax | | \$30/mt$CO_2$ | |
|---|---|---|---|---|
| | Reference | with-FE | Reference | with-FE |
| Pulverized coal | 53.6 | 53.8 | 96.3 | 96.6 |
| Advanced coal | 55.4 | 51.0 | 94.3 | 85.9 |
| Adv coal w/ $CO_2$ capture | 84.3 | 60.9 | 87.1 | 64.2 |
| Advanced NGCC | 56.8 | 55.1 | 84.7 | 93.2 |
| Adv NGCC w/ $CO_2$ capture | 77.3 | 74.9 | 81.1 | 87.7 |
| Nuclear | 76.3 | 76.4 | 76.6 | 76.7 |
| Wind | 52.4 | 54.5 | 68.9 | 67.6 |
| Biomass | 61.4 | 61.1 | 67.9 | 66.4 |

FE R&D makes advanced coal power with sequestration the low cost power option

Figure 2 shows the predicted $CO_2$ emissions in the U.S. power sector under a range of carbon tax values, with and without FE research. In the reference technology case, power sector $CO_2$ emissions decrease by roughly 50% when the carbon tax increases from zero to \$45/mt$CO_2$. The with-FE technology case shows a stronger response to the carbon tax beginning at \$25/mt$CO_2$.

**Figure 2. U.S. Power Sector $CO_2$ Emissions in 2030**

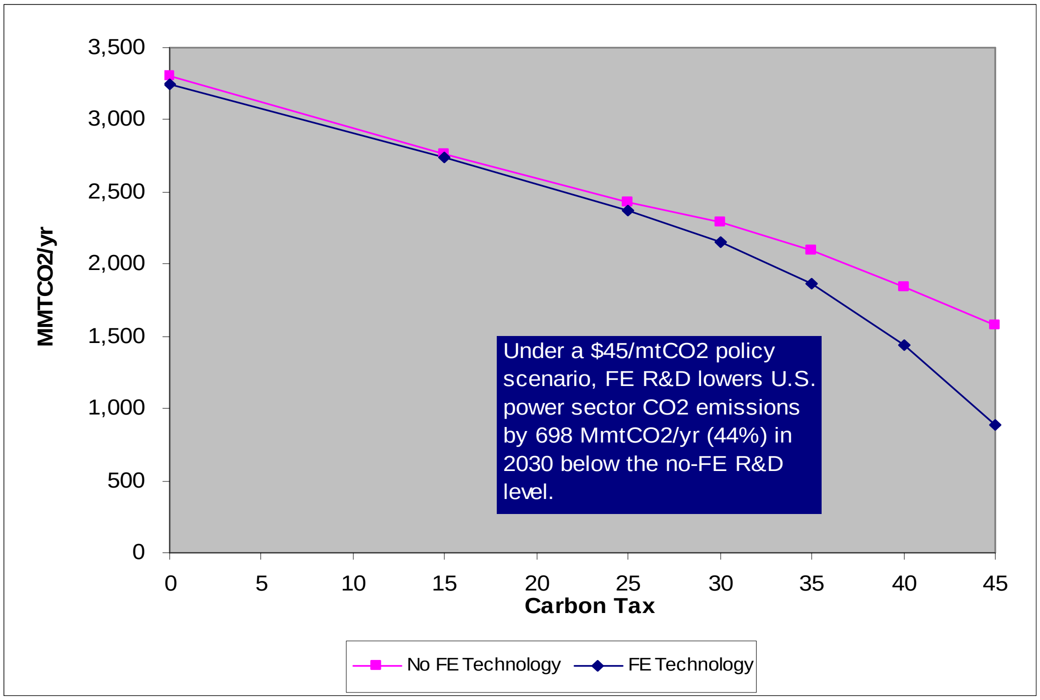
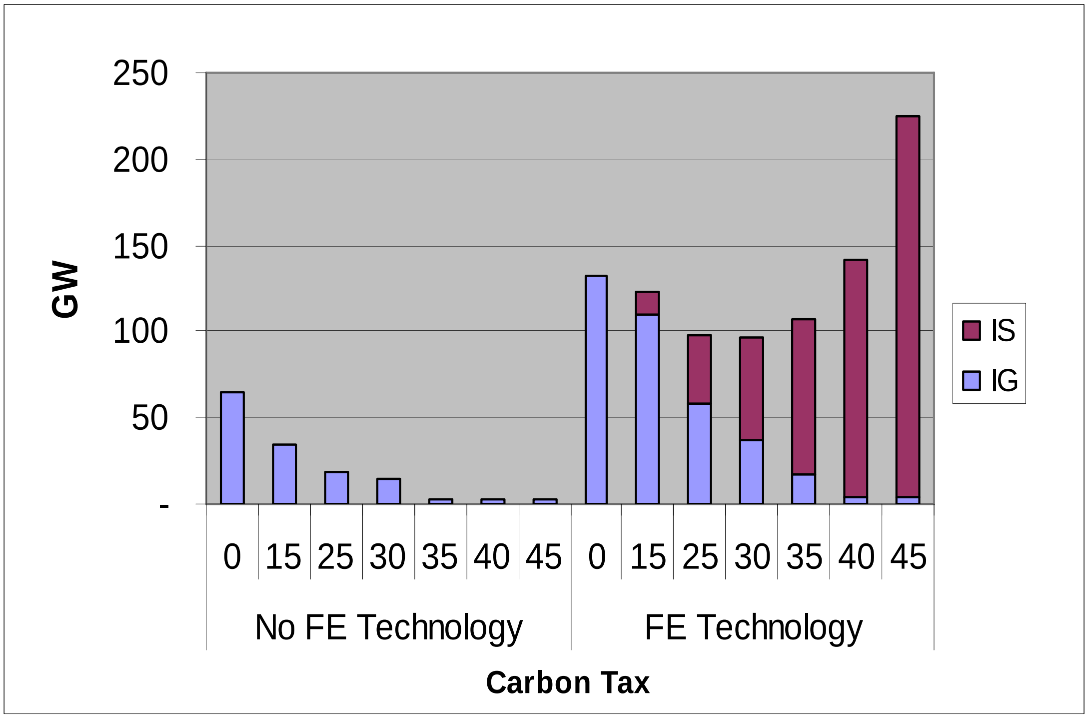



Figure 3 offers a first explanation for the reduced greenhouse gas emissions under the with-FE research case shown in Figure 2. The y-axis in Figure 3 is the cumulative electricity generating capacity in giga-watts (GW) of Integrated Coal Gasification Combined Cycle power plants (IG) and IG power plants with carbon dioxide capture and storage (IS) deployed in the United States through 2030. Figure 3 shows that without FE R&D, the carbon tax pushes advanced coal power out as a deployment option. DOE R&D makes IG more competitive in the no carbon tax scenario. As the carbon tax increases under the FE technology research cases, IG deployments are essentially replaced by IS. Total IG and IS deployments reach a minimum at a carbon tax of \$30/mt$CO_2$; after which total IG and IS builds begin to increase, surpassing the no carbon tax deployment level when the carbon tax reaches \$40/mt$CO_2$.

**Figure 3. U.S. Deployments of IGCC with and without Sequestration, cumulative through 2030**




The emissions impacts shown in Figure 2 are determined by the power technologies displaced by new IG and IS power plants. For example, if a new IS power plant with a $CO_2$ intensity of 0.08 kg $CO_2$/kWh displaces generation from an existing PC power plant emitting 0.9 kg $CO_2$/kWh, $CO_2$ emissions are reduced. An IS power plant will also reduce emissions if it displaces generation from a natural gas combined cycle power plant emitting 0.35 kg$CO_2$/kWh. If the IS plant displaces a wind turbine or a nuclear plant, the effect is to increase $CO_2$ emissions. The net impact of IS in the with R&D cases is the average of all positive and negative displacements.

Figure 4 shows the electricity generating capacity displaced for each technology when the reference case is compared to the with-FE research case for the $0, $15, $30, $35 and $45 /mt$CO_2$ scenarios. Unlike Figure 3, Figure 4 shows net incremental deployments of IG and IS. For example, in the with-FE technology, zero carbon tax scenario, Figure 3 shows IG deployments of 132 GW. In the no-FE case, zero carbon tax scenario, Figure 3 shows 65 GW of IG deployments. So Figure 4 shows a difference of 77 GW, which is the net incremental deployment of IG in this scenario. This result reveals that when FE R&D improvements are integrated into advanced coal generation technologies, IG is a cost effective solution at low and moderate carbon tax levels.

**Figure 4. Net Incremental IGCC Deployments and Associated Displacements Due to FE R&D, cumulative through 2030**

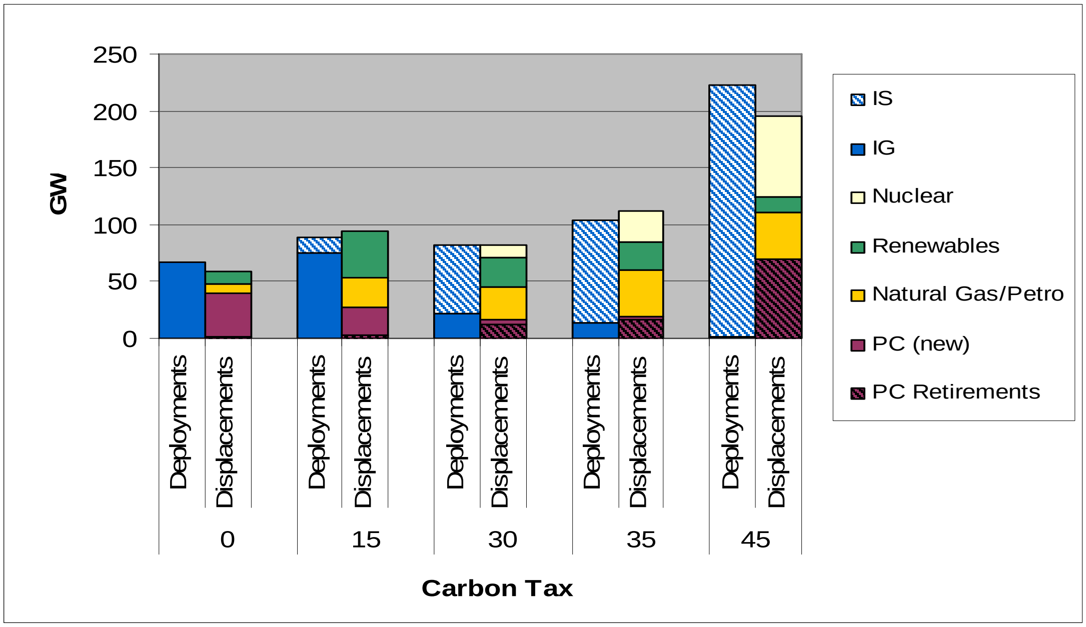



Figure 4 shows interesting changes in the types of technologies that are displaced by IG and IS over the range of carbon tax levels.

- At the $0 tax level, IG technology in the research case mostly displaces new pulverized coal (PC) power plants, along with some natural gas and renewable generating capacity.
- The $15 tax level causes an increase in the amount of renewable generating capacity displaced by IG and IS technology. This is because there are more renewables deployed in the no-FE case when a $15 tax is applied.
- The amount of new, unplanned PC power plants displaced decreases to zero at tax levels of $40 and higher because only planned PC plants are built at high tax levels.
- Under the with-FE case at carbon taxes of $30 and higher, IS begins to compete with nuclear as a backstop baseload power option.
- At a tax level of $30, the combination of market incentives and improved IS technology begins to motivate the retirement of existing PC plants in the with-FE cases.

It is the emissions reduction associated with replacement of existing PC power plants with IS that counterbalances emissions increases associated with displacing nuclear and renewable generating capacity that provides an increased emissions reduction for tax levels above \$30/mt$CO_2$. The reduction, as shown in Figure 2, can be roughly calculated as follows (illustrated as DPG in Table 3):

$$\sum_{type = pc, ig, pt, ng, nk, re, gm} [DPG_{type} * (CI_{type} - CI_{is})]$$

where DPG = displaced generation;
CI = $CO_2$ intensity,
pc = pulverized coal;
is = IGCC w/ capture;
ig = IGCC;
pt = petroleum;
ng = NGCC; nk = nuclear;
re = renewables;
gm = geothermal/municipal solid waste

This calculation captures the majority of emissions impacts that occur when FE technologies are injected into the power sector, however other changes occur that complete the story. Changes in $CO_2$ emissions due to changes in CI and the addition of generation that is not displacing other generation must also be accounted for. These additional components of the net change in emissions are described below.

Emission changes due to CI differences occur when the absolute value of the change in CI between the no-FE and with-FE cases is greater than zero. When this occurs and the generation from the technology increases, the impact of the change in CI is calculated as the generation in the no-FE case times the change in CI: $(G_{no\text{-}FE,x} * (CI_{no\text{-}FE,x} - CI_{with\text{-}FE,x})$, illustrated as $INC_{r1}$ in Table 3. When generation from a technology is constant or declines, the impact of the CI change is calculated as the generation in the with-FE case times the change in CI: $(G_{with\text{-}FE,x} * (CI_{no\text{-}FE,x} - CI_{with\text{-}FE,x})$ , illustrated as $INC_{r2}$ in Table 3.

Emission impacts due to increased generation that is not displacing generation that exists in the no-FE case is calculated as the product of the additional generation and the respective technology's CI, illustrated as ADD in Table 3.

**Table 3. Total Net $CO_2$ Emissions Reduction under a $45/mtCO2 Carbon Tax, 2030**

| | | Change in Generation | Change in $CO_2$ Intensity | Change in $CO_2$ Emissions |
|---|---|---|---|---|
| | | BkWh/yr | $MmtCO_2/BkWh$ | $MmtCO_2/yr$ |
| **DPG** | PC | 788 | 0.89 | 697 |
| | IG(existing) | 2 | 0.71 | 1 |
| | Petro | 6 | 0.86 | 5 |
| | NGCC | 143 | 0.31 | 45 |
| | Nuclear | 541 | -0.07 | -40 |
| | Renewables | 126 | -0.07 | -9 |
| | Geothermal/MSW | 15 | 0.11 | 2 |
| | | | | **701** |
| | | **Generation** | | |
| **$INC_{r1}$** | IG(new) | 21 | 0.25 | 5 |
| | | | | **5** |
| | | | | |
| **$INC_{r2}$** | PC | 456 | 0.01 | 2 |
| | NGCC | 545 | -0.00 | -2 |
| | Geothermal/MSW | 80 | -0.04 | -3 |
| | | | | **-3** |
| | | | | |
| **$ADD_r$** | IG(new) | 8 | 0.54 | -4 |
| | IS[3] | 27 | 0.07 | -2 |
| | | | | **-6** |
| | | | | **698** |

Table 3 shows that in the $45 case IS displaces similar amounts of power from existing PCs and from nuclear and renewable generation. The negative emissions impacts per kWh of nuclear and renewable generation displaced is small, however, compared to the positive impact per kWh associated with shifting from PC to IS. Thus the overall effect is to reduce GHG emissions, cost-effectively.

The results presented in Figure 4 raise two questions (1) why does NEMS retire more existing PC plants in the with-FE case and (2) why does IS displace nuclear rather renewables in the with-FE cases? These are addressed in turn.

(1) NEMS compares the cost of continuing operations at existing PC plants to available base load generation technologies to determine whether it is cost effective to retire existing plants. When the cost of a new base load generation plant is less than the operation costs of existing PC plants, the existing PC plant is retired.

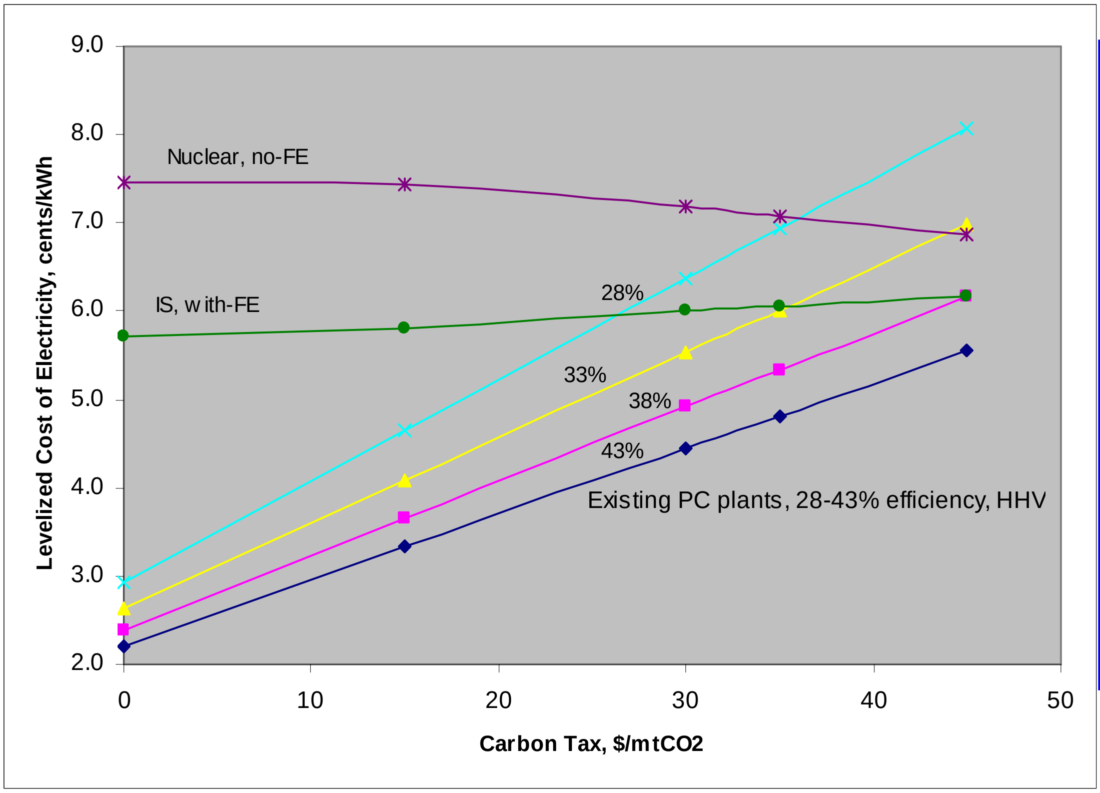
[3] The amount of IS generation classified as additional generation is calculated as the increase in total generation between the no-FE and the with-FE case less additional generation provided by other technologies. In the Table 3 example total generation increases by 35 BkWh, 8 of which is provided by new IG plants, leaving 27 BkWh from IS plants that are not displacing an alternate technology.

Under a $CO_2$ tax scenario the owner of a PC power plant can either continue to operate and pay the tax or retire and build replacement capacity with a new power plant having lower $CO_2$ emissions per kWh. The existing power plant has the cost advantage that all of its capital costs are recovered. Figure 5 shows the levelized cost of electricity for existing PC power plants[4] over a range of carbon tax values. Less efficient plants emit more $CO_2$ per kWh and become increasingly more expensive per kWh as the tax level increases. Also shown in Figure 5 is the LCOE for nuclear in the no-FE case and for IS in the with-FE cases. The lower cost IS beats out nuclear[5] for new builds and it also offers a lower LCOE benchmark for existing PC retirement, consistent with the results shown in Figure 4, thus causing more existing PC plants to exceed the threshold at which it becomes more cost effective to retire and build a new plant.

Figure 2, above, shows an increasing rate of emissions reductions, in the with-FE case, at tax rates of \$35/mt $CO_2$ and above. This result is shown in Figure 5, where the LCOE of additional existing PC power plants is roughly equal to the IS line beginning at this carbon tax level.

[4] The range of efficiencies is calculated with the maximum efficiency of an existing PC power plant equal to that of new advanced coal under t he no-FE case. Efficiencies are decreased in increments of 5 percentage points.
[5] The LCOE for nuclear is even higher in the with-FE cases because IG displaces early deployments, thus hampering LCOE reductions due to learning. This is evident in data presented in Appendix B.

**Figure 5. LCOE for Existing PC Power Plants Compared to Nuclear and IS over a Range of Carbon Taxes, 2030**



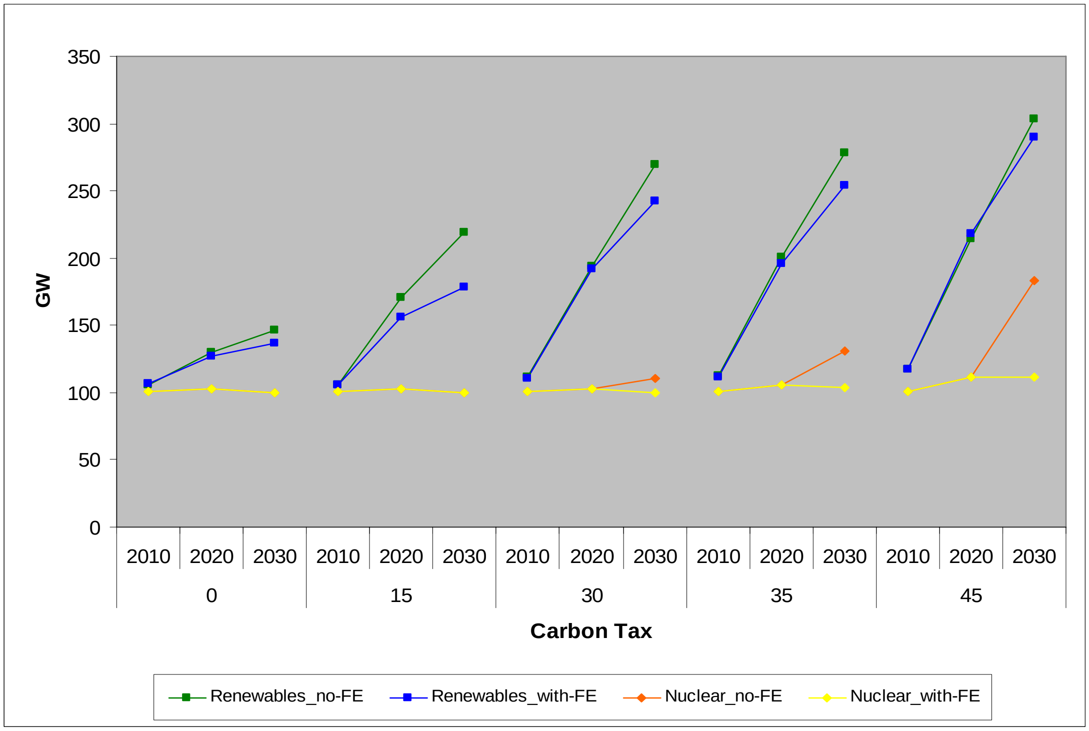

At $CO_2$ tax levels of \$45, PC power plants that are less than 38% efficient are more costly than a new IS plant.

If IS is not available, those PC power plants remain economic. The owners run them and pay the $CO_2$ tax.

(2) Figure 6 offers insight into why there is a large displacement of nuclear power, as opposed to renewable generating capacity, when comparing the \$30 and \$45 scenarios (Figure 4). In the carbon tax scenarios up to \$30/mt$CO_2$, little to no additional nuclear generating capacity is deployed. At \$45/mt$CO_2$ about 80 GW of incremental (relative to 2010) nuclear generating capacity is deployed in the no-FE case, all of it coming post 2020. In contrast, roughly 80 GW of incremental renewables are deployed pre-2020 in the no-FE cases at carbon tax values of \$25 and higher. This 80 GW of renewable generating capacity is deployed prior to the full impact of FE technology; it lowers the cost of renewable technologies through learning and makes them the low-cost option for another 80 GW or more post 2020. Nuclear power generation only enters into the reference cases at the higher tax levels when supply elasticities for renewables increase their cost. As such, nuclear is first to be displaced by IS generating capacity under the with-FE scenario. In these scenarios natural gas generation does not compete due to rising gas prices in the AEO2007 and the AERD NEMS projections[6].

[6] According to the AEO2007 high natural gas prices stimulate production and curb demand. These factors lead to reduced natural gas prices through 2013. Post-2013 production costs, and thus delivered costs rise due to declines in technically recoverable resources.

**Figure 6. Renewables and Nuclear Cumulative Deployment Pattern**




## Conclusion

The development of cost effective IS reduces GHG emissions in the U.S. power sector in NEMS runs with carbon tax values above $25/mtCO2. At lower tax levels the emissions benefit is due to the displacement of new PC with new IG and IS. At the higher tax levels (above $35) IS displaces some nuclear and renewable generation, but it also motivates the retirement of existing PC plants, thus providing a net GHG emissions benefit.

## *Appendix A*

# Cost & Performance Inputs to the AEO2007 and AERD Baseline

## Source: Assumptions to the AEO2007[7] & AERD NEMS Inputs (2005$)

Advanced Coal (IG) Cost and Performance Assumptions

| | Capital Cost | | Fixed O&M ($/kW) | | Variable O&M (mills/kWh) | | Heat Rate (HHV) | |
|---|---|---|---|---|---|---|---|---|
| On-Line Year | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline |
| 2009 | 1377 | 1377 | 36.38 | 36.38 | 2.75 | 2.75 | 8032 | 8032 |
| 2020 | 1308 | 1308 | 36.38 | 36.38 | 2.75 | 2.75 | 7200 | 7200 |
| 2030 | 1172 | 1172 | 36.38 | 36.38 | 2.75 | 2.75 | 7200 | 7200 |

Advanced Coal with CO2 Capture (IS) Cost and Performance Assumptions

| | Capital Cost | | Fixed O&M ($/kW) | | Variable O&M (mills/kWh) | | Heat Rate (HHV) | |
|---|---|---|---|---|---|---|---|---|
| On-Line Year | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline |
| 2009 | 1958 | 1958 | 42.82 | 42.82 | 4.18 | 4.18 | 9397 | 9397 |
| 2020 | 1820 | 1820 | 42.82 | 42.82 | 4.18 | 4.18 | 8236 | 8236 |
| 2030 | 1618 | 1618 | 42.82 | 42.82 | 4.18 | 4.18 | 7920 | 7920 |

Nuclear Cost and Performance Assumptions

| | Capital Cost | | Fixed O&M ($/kW) | | Variable O&M (mills/kWh) | | Heat Rate (HHV) | |
|---|---|---|---|---|---|---|---|---|
| On-Line Year | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline |
| 2014 | 1802◈+ | 1802 | | 63.88+ | | 0.47+ | 10400 | 10400 |
| 2020 | | 1743 | | | | | 10400 | 10400 |
| 2030 | | 1653 | | | | | 10400 | 10400 |

◈Advanced Nuclear available to come on-line in 2014, therefore inputs for 2014 are shown rather than for 2009
+ NEMS applies learning and elasticities to calculate future costs; post-2008 AEO2007 cost data are not exogenous inputs to the model.

[7] *Assumptions to the Annual Energy Outlook 2007*. DOE/EIA-0554(2007). April 2007. http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2007).pdf

On-Shore Wind Cost and Performance Assumptions

| | Capital Cost | | Fixed O&M ($/kW) | |
|---|---|---|---|---|
| On-Line Year | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline |
| 2009 | 1127*+ | 1127+ | 28.51*+ | 26.54 |
| 2020 | | | | 24.95 |
| 2030 | | | | 22.78 |

*NEMS inputs are for 2008 which are the first year of commercial operation.
+ NEMS applies learning and elasticities to calculate future costs; post-2008 AEO2007 cost data are not exogenous inputs to the model.

Off-Shore Wind Cost and Performance Assumptions

| | Capital Cost | | Fixed O&M ($/kW) | |
|---|---|---|---|---|
| On-Line Year | AEO2007 | AERD Baseline | AEO2007 | AERD Baseline |
| 2009 | N/A | 2292+ | N/A | 80.83 |
| 2020 | N/A | | N/A | 71.57 |
| 2030 | N/A | | N/A | 63.15 |

+NEMS then applies learning and elasticities to calculate future costs; post-2008 AEO2007 cost data are not exogenous inputs to the model.

## *Appendix B*

# Detailed Levelized Cost of Electricity Data from NEMS

### Source: NEMS Levelized Cost Summary by NEMS run

Carbon Tax = $0

| | **No FE Technology** | | | **FE Technology** | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 48.5 | 53.6 | 54.5 | 48.4 | 53.8 | 52.1 |
| ADV COAL | 49.5 | 55.4 | 53.6 | 49.2 | 51.0 | 46.1 |
| ADV IG w/ CARBON CAPTURE | 86.8 | 84.3 | 79.0 | 73.7 | 60.9 | 57.2 |
| CNV NGCC | 60.0 | 60.2 | 63.4 | 59.7 | 58.4 | 58.7 |
| ADV NGCC | 57.0 | 56.8 | 59.2 | 56.7 | 55.1 | 53.6 |
| ADV NGCC w/ CARBON CAPTURE | 77.8 | 77.3 | 77.7 | 77.0 | 74.9 | 71.3 |
| CNV COMB TURBINE | 100.4 | 102.5 | 106.8 | 100.2 | 99.8 | 101.0 |
| ADV COMB TURBINE | 89.6 | 88.7 | 91.6 | 89.2 | 85.9 | 83.6 |
| ADV NUCLEAR | N/A | 76.3 | 74.5 | N/A | 76.4 | 74.6 |
| SOLAR THERM | 142.4 | 136.7 | 125.6 | 142.3 | 136.8 | 125.7 |
| WIND | 50.2 | 52.4 | 58.8 | 50.2 | 54.5 | 54.3 |
| SOLAR PV | 308.7 | 238.3 | 197.4 | 308.4 | 238.5 | 197.6 |
| GEOTHERMAL | 62.0 | 65.3 | 64.8 | 62.0 | 65.6 | 64.9 |
| BIOMASS | 61.2 | 61.4 | 58.9 | 61.3 | 61.1 | 58.6 |
| HYDRO | 64.5 | 64.3 | 65.0 | 64.4 | 64.3 | 63.8 |

Carbon Tax = $15

| | No FE Technology | | | FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 58.9 | 76.7 | 77.3 | 58.9 | 76.9 | 77.9 |
| ADV COAL | 59.0 | 74.2 | 72.8 | 58.6 | 68.1 | 61.7 |
| ADV IG w/ CARBON CAPTURE | 87.2 | 85.0 | 80.0 | 74.3 | 62.2 | 58.0 |
| CNV NGCC | 65.9 | 75.1 | 78.8 | 65.6 | 72.8 | 73.0 |
| ADV NGCC | 62.6 | 70.7 | 73.7 | 62.3 | 68.5 | 67.4 |
| ADV NGCC w/ CARBON CAPTURE | 79.6 | 78.8 | 80.2 | 78.8 | 76.1 | 73.1 |
| CNV COMB TURBINE | 109.3 | 125.9 | 131.4 | 109.4 | 122.1 | 123.3 |
| ADV COMB TURBINE | 97.1 | 106.5 | 108.6 | 96.6 | 102.7 | 101.0 |
| ADV NUCLEAR | N/A | 76.4 | 74.4 | N/A | 76.5 | 74.5 |
| SOLAR THERM | 141.9 | 137.1 | 125.4 | 141.9 | 137.1 | 125.5 |
| WIND | 50.1 | 64.1 | 65.5 | 50.1 | 64.0 | 62.7 |
| SOLAR PV | 307.6 | 239.2 | 196.9 | 307.5 | 239.2 | 197.2 |
| GEOTHERMAL | 61.8 | 66.1 | 68.0 | 61.8 | 68.9 | 67.3 |
| BIOMASS | 63.2 | 65.5 | 65.4 | 63.5 | 65.2 | 62.4 |
| HYDRO | 64.3 | 69.1 | 72.1 | 64.3 | 68.6 | 69.2 |

Carbon Tax = $25

| | No FE Technology | | | FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 66.1 | 92.3 | 92.3 | 66.1 | 88.7 | 89.6 |
| ADV COAL | 65.5 | 87.7 | 84.9 | 65.1 | 80.0 | 71.9 |
| ADV IG w/ CARBON CAPTURE | 87.8 | 86.5 | 79.7 | 74.9 | 63.7 | 59.4 |
| CNV NGCC | 71.3 | 84.4 | 89.6 | 70.5 | 83.1 | 84.4 |
| ADV NGCC | 67.7 | 79.4 | 83.8 | 66.9 | 78.0 | 78.6 |
| ADV NGCC w/ CARBON CAPTURE | 81.3 | 79.5 | 82.4 | 80.0 | 77.7 | 76.1 |
| CNV COMB TURBINE | 117.6 | 137.8 | 141.8 | 116.0 | 138.7 | 140.8 |
| ADV COMB TURBINE | 104.3 | 118.2 | 123.8 | 103.2 | 116.1 | 114.7 |
| ADV NUCLEAR | N/A | 76.6 | 74.4 | N/A | 76.6 | 74.4 |
| SOLAR THERM | 141.6 | 137.4 | 125.2 | 141.6 | 137.6 | 125.3 |
| WIND | 50.0 | 64.0 | 68.6 | 50.0 | 66.2 | 67.7 |
| SOLAR PV | 306.9 | 239.9 | 196.7 | 306.9 | 240.3 | 196.8 |
| GEOTHERMAL | 61.7 | 70.0 | 68.6 | 61.7 | 69.0 | 67.2 |
| BIOMASS | 65.0 | 66.7 | 72.8 | 64.9 | 66.3 | 65.5 |
| HYDRO | 64.2 | 72.1 | 76.6 | 64.2 | 71.2 | 72.3 |

Carbon Tax = $30

| | No FE Technology | | | FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 69.6 | 96.3 | 99.8 | 69.7 | 96.6 | 97.5 |
| ADV COAL | 68.8 | 94.3 | 91.2 | 68.3 | 85.9 | 77.1 |
| ADV IG w/ CARBON CAPTURE | 88.1 | 87.1 | 80.1 | 75.1 | 64.2 | 60.0 |
| CNV NGCC | 73.4 | 90.0 | 94.7 | 73.3 | 88.4 | 89.3 |
| ADV NGCC | 69.7 | 84.7 | 88.5 | 69.5 | 83.2 | 83.1 |
| ADV NGCC w/ CARBON CAPTURE | 81.3 | 81.1 | 83.4 | 81.1 | 78.7 | 76.5 |
| CNV COMB TURBINE | 119.4 | 149.3 | 156.1 | 120.4 | 146.5 | 148.0 |
| ADV COMB TURBINE | 106.8 | 126.2 | 129.5 | 106.6 | 122.8 | 120.9 |
| ADV NUCLEAR | N/A | 76.6 | 71.9 | N/A | 76.7 | 74.4 |
| SOLAR THERM | 141.5 | 137.7 | 125.1 | 141.4 | 137.8 | 125.2 |
| WIND | 50.3 | 68.9 | 69.9 | 50.2 | 67.6 | 68.0 |
| SOLAR PV | 306.6 | 240.4 | 196.4 | 306.4 | 240.6 | 196.6 |
| GEOTHERMAL | 61.7 | 70.7 | 68.1 | 61.7 | 70.1 | 66.9 |
| BIOMASS | 65.7 | 67.9 | 72.3 | 65.8 | 66.4 | 66.4 |
| HYDRO | 64.1 | 75.9 | 77.5 | 64.1 | 72.2 | 72.5 |

Carbon Tax = $35

| | No FE Technology | | | FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 73.1 | 104.3 | 107.5 | 73.3 | 104.4 | 105.3 |
| ADV COAL | 72.0 | 101.1 | 97.8 | 71.6 | 91.2 | 82.3 |
| ADV IG w/ CARBON CAPTURE | 88.2 | 88.0 | 80.7 | 75.4 | 64.7 | 60.6 |
| CNV NGCC | 75.5 | 95.4 | 99.5 | 75.6 | 94.0 | 94.3 |
| ADV NGCC | 71.7 | 89.8 | 93.1 | 71.6 | 88.5 | 88.0 |
| ADV NGCC w/ CARBON CAPTURE | 81.3 | 82.3 | 83.8 | 80.9 | 80.5 | 77.3 |
| CNV COMB TURBINE | 124.6 | 156.2 | 163.4 | 123.5 | 151.7 | 144.5 |
| ADV COMB TURBINE | 109.6 | 132.7 | 137.4 | 109.4 | 130.6 | 129.5 |
| ADV NUCLEAR | N/A | 76.7 | 70.7 | N/A | 76.7 | 73.9 |
| SOLAR THERM | 141.4 | 137.9 | 125.0 | 141.3 | 138.0 | 125.2 |
| WIND | 50.2 | 69.9 | 69.9 | 50.2 | 71.4 | 69.9 |
| SOLAR PV | 306.2 | 240.9 | 196.3 | 306.1 | 241.1 | 196.6 |
| GEOTHERMAL | 61.6 | 71.7 | 64.8 | 61.6 | 69.9 | 67.0 |
| BIOMASS | 66.3 | 68.9 | 75.9 | 66.3 | 66.6 | 68.8 |
| HYDRO | 64.0 | 75.6 | 77.3 | 64.0 | 73.9 | 73.3 |

Carbon Tax = $40

| | No FE Technology | | | FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 76.7 | 112.1 | 111.0 | 77.1 | 112.3 | 112.9 |
| ADV COAL | 75.3 | 101.4 | 104.1 | 75.0 | 97.7 | 87.2 |
| ADV IG w/ CARBON CAPTURE | 88.5 | 88.9 | 80.8 | 75.9 | 65.7 | 61.0 |
| CNV NGCC | 79.0 | 101.0 | 103.2 | 79.2 | 99.4 | 98.3 |
| ADV NGCC | 74.8 | 95.2 | 96.7 | 75.0 | 93.5 | 91.5 |
| ADV NGCC w/ CARBON CAPTURE | 83.0 | 84.1 | 83.3 | 83.1 | 81.4 | 76.6 |
| CNV COMB TURBINE | 129.6 | 166.4 | 170.1 | 129.4 | 163.6 | 162.1 |
| ADV COMB TURBINE | 114.2 | 140.4 | 138.4 | 113.8 | 137.4 | 132.2 |
| ADV NUCLEAR | N/A | 77.0 | 69.0 | N/A | 76.9 | 73.0 |
| SOLAR THERM | 141.2 | 138.6 | 124.9 | 141.1 | 138.5 | 125.2 |
| WIND | 50.8 | 71.1 | 70.7 | 50.8 | 71.1 | 69.8 |
| SOLAR PV | 305.8 | 242.4 | 196.1 | 305.7 | 242.3 | 196.5 |
| GEOTHERMAL | 61.6 | 72.0 | 64.7 | 61.6 | 70.4 | 67.1 |
| BIOMASS | 66.9 | 69.6 | 73.8 | 67.0 | 65.7 | 65.2 |
| HYDRO | 63.9 | 80.0 | 79.3 | 63.9 | 76.7 | 75.3 |

Carbon Tax = $45

| | No FE Technology | | | FE Technology | | |
|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| PULV COAL | 80.3 | 119.7 | 118.3 | 81.1 | 120.4 | 121.0 |
| ADV COAL | 78.5 | 107.8 | 109.9 | 78.7 | 103.5 | 92.7 |
| ADV IG w/ CARBON CAPTURE | 88.7 | 89.2 | 80.7 | 76.5 | 66.6 | 61.6 |
| CNV NGCC | 82.2 | 106.5 | 108.0 | 83.2 | 105.5 | 103.4 |
| ADV NGCC | 77.8 | 100.4 | 101.1 | 79.0 | 99.3 | 93.7 |
| ADV NGCC w/ CARBON CAPTURE | 84.1 | 85.5 | 83.9 | 85.3 | 83.2 | 77.4 |
| CNV COMB TURBINE | 132.7 | 174.4 | 177.1 | 137.3 | 172.7 | 170.3 |
| ADV COMB TURBINE | 118.3 | 147.4 | 147.7 | 119.1 | 145.2 | 141.9 |
| ADV NUCLEAR | N/A | 76.0 | 68.7 | N/A | 76.0 | 71.7 |
| SOLAR THERM | 141.1 | 138.4 | 124.9 | 141.1 | 138.3 | 125.0 |
| WIND | 50.8 | 75.8 | 73.2 | 50.7 | 72.5 | 71.6 |
| SOLAR PV | 305.5 | 242.0 | 195.9 | 305.4 | 241.7 | 196.2 |
| GEOTHERMAL | 61.6 | 71.5 | 68.1 | 61.5 | 70.6 | 66.9 |
| BIOMASS | 67.3 | 69.7 | 75.6 | 67.4 | 66.6 | 67.4 |
| HYDRO | 63.9 | 80.8 | 80.5 | 63.9 | 80.4 | 78.8 |