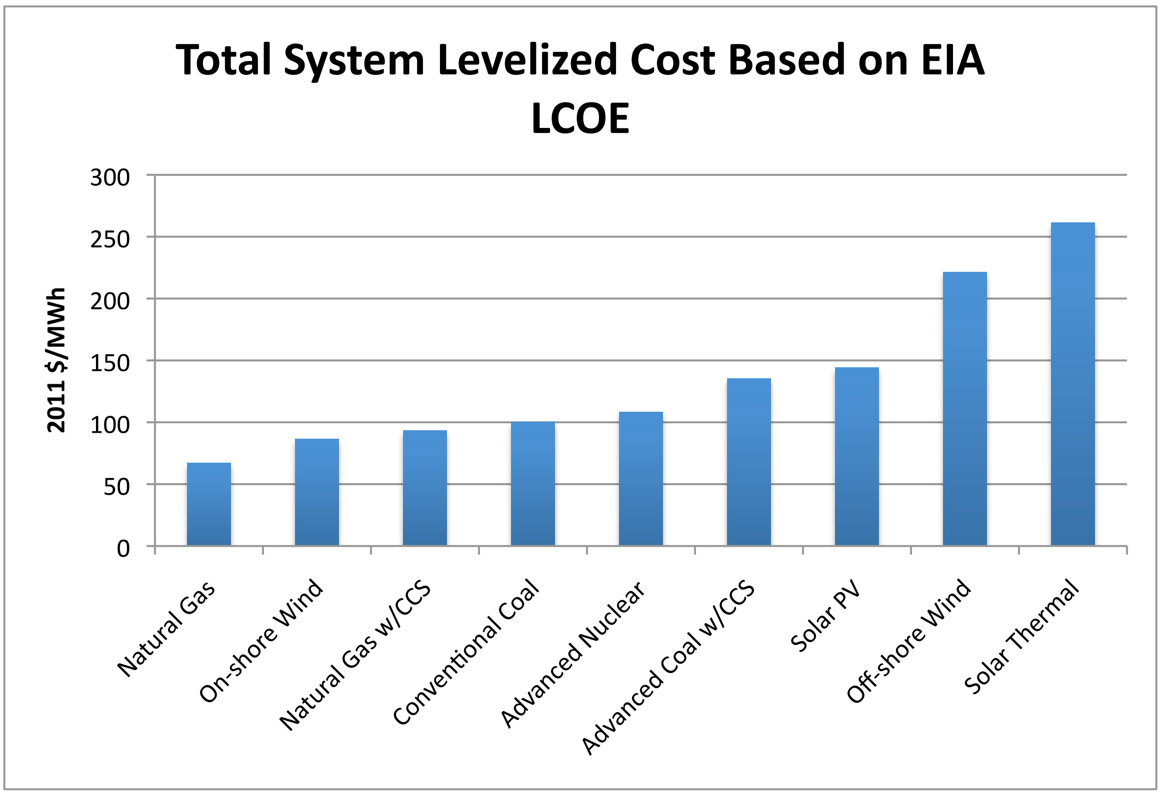
Comparison of CO_2 Abatement Costs in the United States for Various Low and No Carbon Resources

Every year the Energy Information Administration (EIA) publishes its Annual Energy Outlook (AEO). In the AEO, EIA issues its estimates of "Levelized Cost of Electricity" (LCOE). While incomlete in many ways (for example, it doesn't account for the difference in total system cost between dispatchable and non-dispatchable power, see text and box below), LCOE is often used as a convenient way to assess the overall competiveness of different generating technologies (wind, solar, gas, coal, hydro, etc). It is the per-kilowatthour cost (in real dollars) of building and operating an electric generating plant over an assumed financial life. EIA's latest snapshot is below:



EIA's LCOE gives a traditional view of the cost of electricity, which puts traditional natural gas plants in the driver seat and lower carbon technologies to the other end of the spectrum. However, in a carbon constrained world, one where our goal is to reduce CO_2 emissions as effectively as possible, is there another way to compare costs, one that takes into account the cost of the generation, the CO_2 emissions from that generation and compares them to technologies with lower emissions?

Accounting for CO_2 when pricing generating technologies

Using EIA's LCOE data from the 2013 AEO[1], we look at the CO_2 abatement costs of various low- and zero-carbon power generation technologies, such as coal with CCS, gas with CCS, advanced nuclear, solar PV, solar thermal, and on- and off-shore wind. We then compare these using four baseline power sources to illustrate that the cost/ton of abatement is different depending on what type of generation is being displaced. The four baselines are existing and new conventional coal power plants as well as existing and new combined cycle gas power plants, all without carbon capture.

We express the comparison in dollars per MWh and tons per MWh of electrical output, and then translate those basic cost and emission rates into a standardized dollar per ton metric. The bar charts below show the dollars per ton of CO_2 abatement cost of various technologies as compared to each of the assumed baseline cases in turn. For example, we note the CO_2 abatement cost of a gas power plant only if it is replacing an existing coal power plant.

We use the average natural gas price for electric power generation projected for 2018 in the AEO 2013 ($5.25/MMBtu in nominal dollar value).[2] The assumptions on carbon emissions rates from coal and gas generating facilities are derived from analysis made by the NorthBridge Group.[3]

It must be noted that EIA's AEO 2013 makes no attempt to account for the additional grid integration costs associated with variable generating resources such a wind and solar. Such additional integration costs include: balancing capacity, spinning reserve, additional transmission and voltage and frequency support. Many studies suggest that these costs may be as much as double or even triple the marginal costs of variable generation after these sources achieve grid penetration above 20% of total energy production.[4] Therefore, the variable generation options presented below may be considerably more expensive for carbon abatement relative to the baseload and disptachable resources than what is show in the charts below.

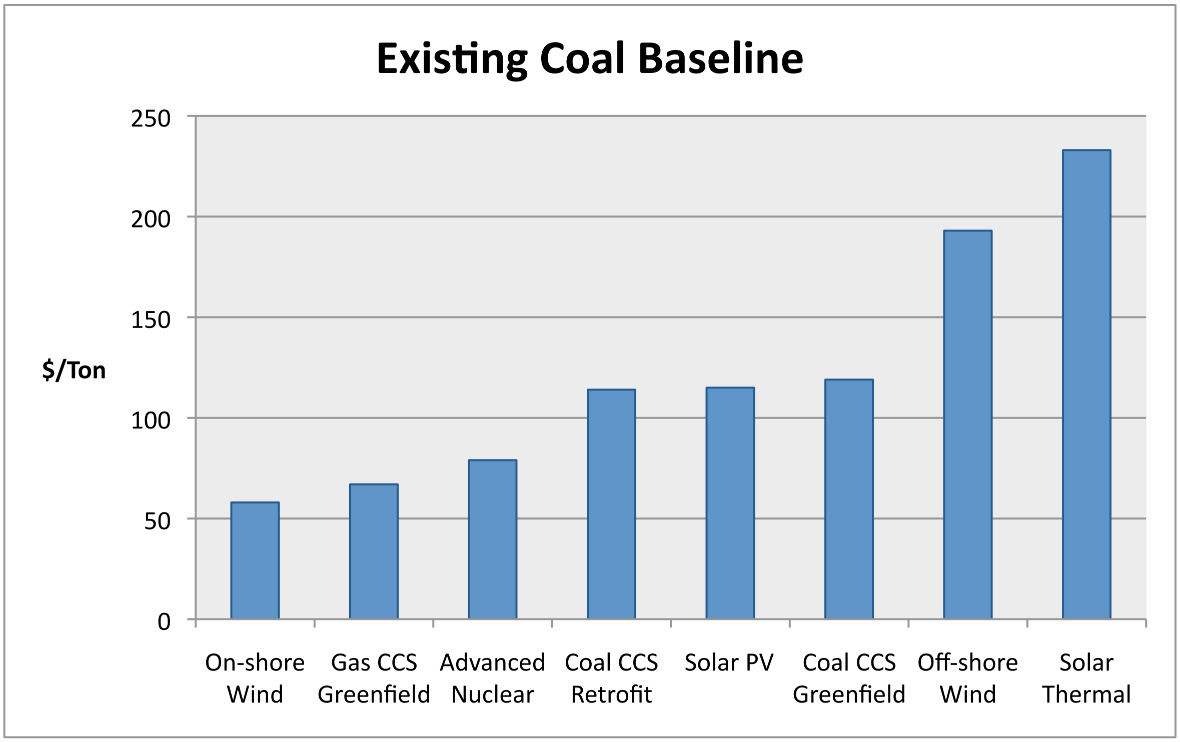


Figure 1. CO_2 abatement cost comparison with existing conventional coal power plant as baseline

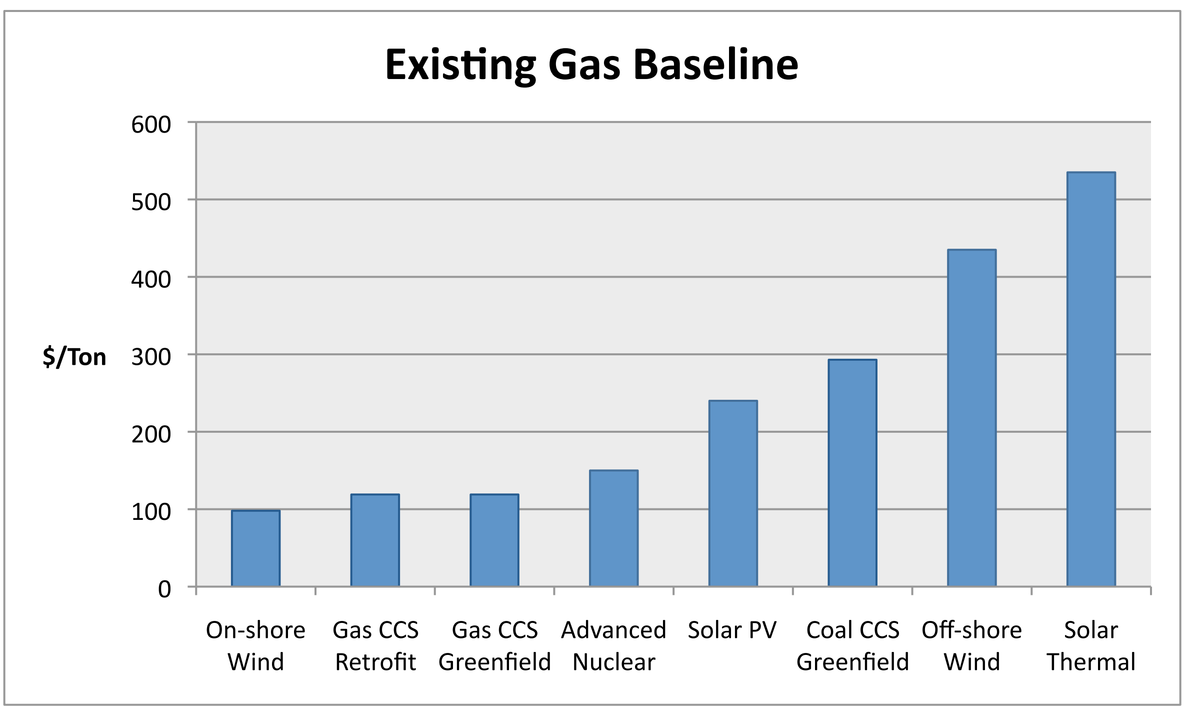


Figure 2. CO_2 abatement cost comparison with existing conventional combined cycle natural gas power plant as baseline

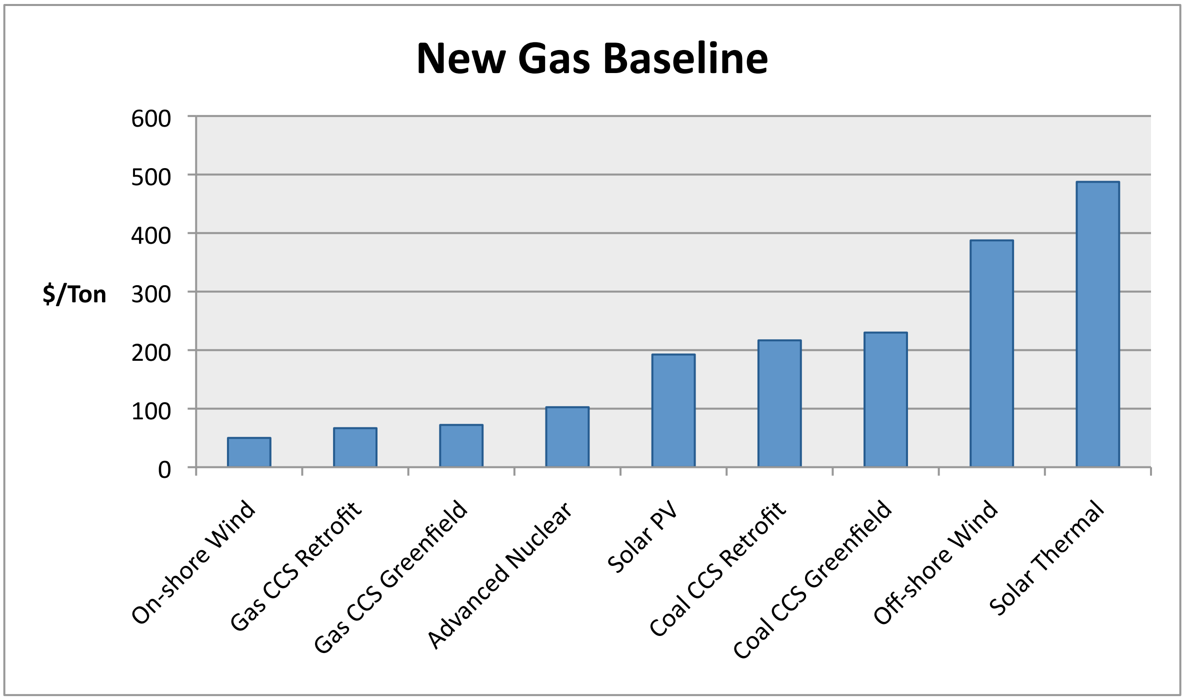


Figure 3. CO_2 abatement cost comparison with new conventional combined cycle natural gas power plant as baseline

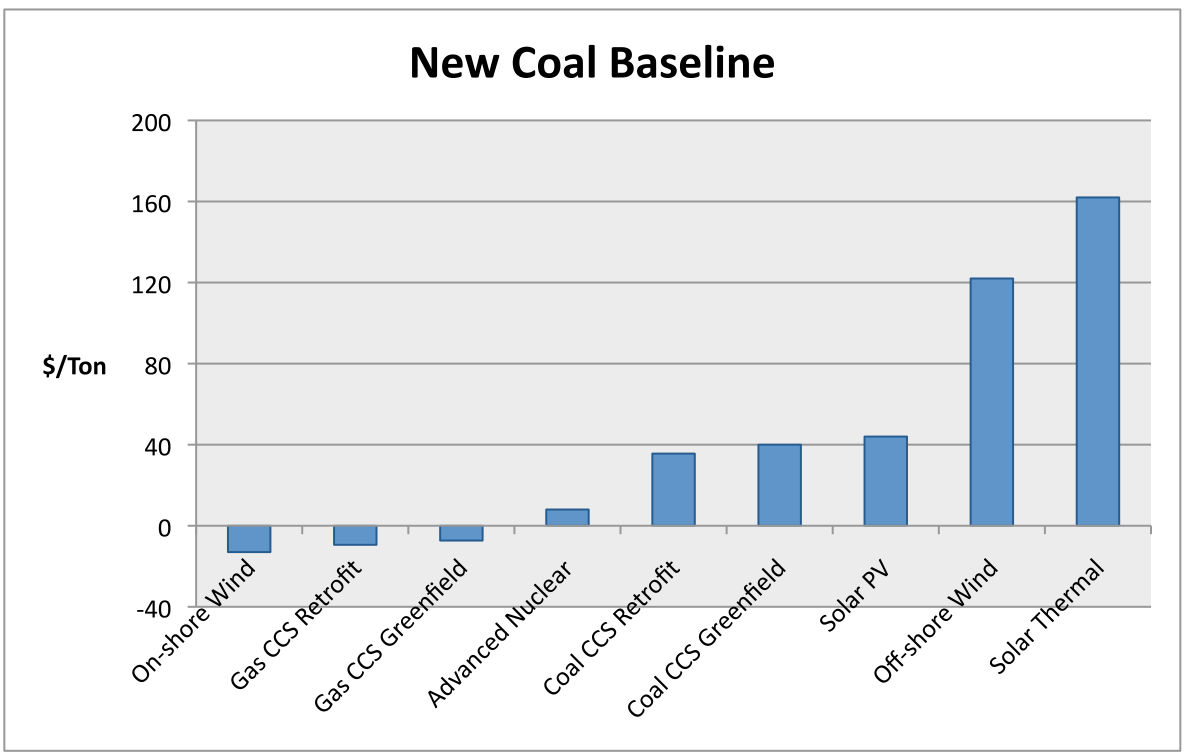


Figure 4. CO_2 abatement cost comparison with new coal power plant (no CCS) as baseline

Baseload vs. Peaking/Intermediate Generating Sources

In terms of CO2 abatement, how should we think about wind and solar replacing coal and gas? Coal and gas (and nuclear) are baseload power options. When wind and solar operate, they initially displace whatever existing resource would otherwise be dispatched on the margin (in most hours of the year and most markets, this would be gas or coal). They can and do affect this displacement without being firmed up, but only to some limited extent - where the displacement is not so deep to cause the existing coal and gas units to shut down. In this situation, the new solar and wind is displacing the energy value of the coal and gas, but not the capacity value or the load following services they provide.

Once wind or solar displace enough coal or gas that the physical coal and gas generating units would retire, the wind and solar units would need to be firmed up so that the coal or gas units could retire and the replacement generation could provide the same reliability and load following services that firm, dispatchable gas and coal can provide.

For each abatement option, displacing coal power plants provides the strongest economic case, on a dollar per ton basis, due to the multiplying effect of deep emission cuts (compared to natural gas power plants where CO_2 emissions are on average 60% less) and lower variable O&M cost (fuel cost included). With existing coal as baseline, on-shore wind appears to be the cheapest option on a dollar per ton basis. But, even if we do not take into account any potential investment needed to upgrade the grid as well as additional combined cycle gas required to back up intermittent wind power, a greenfield gas/CCS power plant with 90% capture appears to provide a competitive option at 65$ per ton of CO_2 abated, and beats solar PV, solar thermal and offshore wind in the competition. Finally, advanced nuclear remains highly competitive from a pure economic perspective. It is important to note that the cost advantage of coal and gas CCS may be further strengthened by revenues from the sale of CO2 captured for enhanced oil recovery, which was not taken into account in this analysis.

The picture is largely the same in comparisons with new/old gas as baseline in that gas CCS remains the most economically competitive base load option while on-shore wind takes the lead overall; they are somewhat closely followed by advanced nuclear. Coal CCS lags behind, mostly due to its much higher capital and fixed O&M cost. Between these two baselines, it on average costs $50 more per ton to displace an existing combined cycle gas power plant than to build alternative technologies.

Many caveats need to be added to this discussion. In addition to the problem of comparing the costs of dispatchable and non-dispatchable power, there is rarely a single LCOE – but a range of costs in different locations; here we have chosen EIA's central estimate. Moreover, technology costs are dynamic. Solar and wind costs have come down considerably in cost in the last two decades due to large scale deployment and "learning by doing" but have recently plateaued in price; by contrast, advanced nuclear and CCS have yet to be deployed at large scale in a manner that might produce similar price reductions.

That said, the comparisons above will hopefully spur further reflection on the cost associated with a variety of options available to reduce power sector carbon.

[1] US EIA. "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013". January 2013.

[2] US EIA. "Annual Energy Outlook 2013" April 2013.

[3] In cases where coal/gas CCS retrofit is involved in the comparison, both fixed and variable O&M costs are avoided, whereas only variable O&M costs are considered non-sunk costs for existing coal/gas plants being displaced by zero carbon sources.

[4] A. Purvins et al, Challenges and options for a large wind power uptake by the European electricity system, *Applied Energy*, Volume 88, Issue 5, May 2011, Pages 1461–1469 cites; Denholm, P., Hand, M., Grid flexibility and storage required to achieve very high penetration of variable renewable electricity. *Energy Policy* (2011); Managing Large-Scale Penetration of Intermittent Renewables, An MIT Energy Initiative Symposium, April 20, 2011, http://web.mit.edu/mitei/research/reports/intermittent-renewables.html; California Council on Science and Technology, California's Energy Future: The View to 2050 (May 2011), http://ccst.us/publications/2011/2011energy.php; Wind Integration Study Report, Idaho Power, February 2012, http://www.idahopower.com/AboutUs/PlanningForFuture/WindStudy/default.cfm