Extending the CCS Retrofit Market by Refurbishing Coal Fired Power Plants

DOE/NETL-2009/1374

Simulations with the National Energy Modeling System

July 31, 2009

Disclaimer

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Acknowledgements

Phil Dipietro, Director of Situational Analysis and Benefits Division, Office of Systems Analysis and Planning, originally suggested and subsequently supported the effort to model refurbishment as an adjunct to CCS retrofitting.

Introduction

This paper summarizes the results of an exploratory study on the use of the National Energy Modeling System (NEMS) to simulate the degree to which the fleet of existing coal fired power plants could refurbish to a higher efficiency (lower heat rate). Various assumptions are tested in relation to climate change policy, advances in refurbishment technology, and stimulus incentives that off-set certain costs related to refurbishment, including new source review requirements.

Refurbishing is defined herein as an optional investment to improve an existing plant's boiler and/or turbine efficiencies. A detailed discussion of specific improvements, along with data relating to actual plant experiences, is presented elsewhere (NETL 2008a). This paper assumes any plant above a target heat rate can be refurbished to that target at a cost proportional to the upgrade. A target heat rate of 9,222 Btu/kWh is assumed throughout, and a generic correlation of available cost data is used:

$$C = 925 \cdot (1 - THR \,/\, OHR) \qquad (1)$$

where:

C = refurbishment capital cost, $/kW (2007 dollars)
OHR = original heat rate, Btu/kWh
THR = target heat rate, Btu/kWh

Since refurbishment may be especially relevant in conjunction with retrofitting for carbon capture and sequestration (CCS), results are presented with and without CCS retrofitting, the latter of interest when carbon constraints are low or when a component of CCS, such as sequestration, is not yet commercially available.

Background

Refurbishment and CCS retrofitting models are not available in versions of NEMS as archived by the Energy Information Administration (EIA). Extensions were developed at NETL to model CCS retrofitting in NEMS, and are described elsewhere (NETL 2008b). These extensions can also be used to model refurbishment as a special form of CCS retrofitting in which the costs of refurbishment are added to the costs of retrofitting, which are then based on the target, rather than original, plant heat rate. Refurbishment without CCS retrofitting can also be modeled, by specifying the CCS capture level for CO_2 to zero.

Figure 1 shows the distribution of heat rates for the fleet of existing coal fired power plants as represented in the NEMS plant level data base. Clearly, a target heat rate of 9,222 Btu/kWh implies essentially all plants are candidates for refurbishment, subject to the tradeoff between refurbishment costs and costs of fuel consumption. For negligible refurbishment costs, nearly all plants should be refurbished if the target heat rate is 9,222 Btu/kWh.

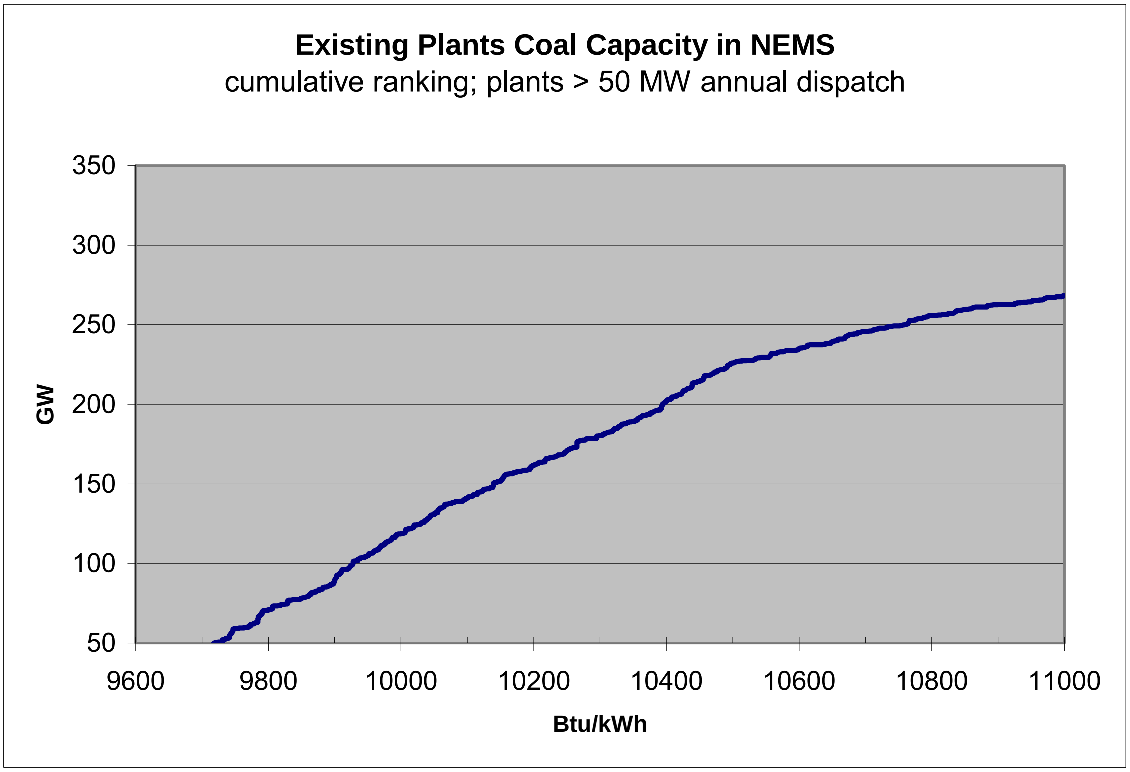

Figure 1. Existing Plants Coal Capacity in NEMS. A target heat rate of 9,222 Btu/kWh is well below the heat rate of most plants in the NEMS data base.

To validate the modeling approach in NEMS, the costs for refurbishment were temporarily set to zero to confirm a nearly complete refurbishment of the fleet. The "Final Release" AEO_2007 version including the Energy Independence and Security Act of 2007 (EISA version) was used. Figure 2 shows how the "Validation Test Case" fell well short of the expectation of complete refurbishment. Two prime factors were ultimately identified. First, the "NSR Factors Case" demonstrates new source review (NSR) requirements. Required installation of missing emission controls can represent additional costs. Second, the "Coding Factor Case" demonstrates a fuel consumption coefficient in NEMS that is formulated in a way that renders NEMS insensitive to heat rate changes in an individual plant. Correcting for these two factors resulted in the expected trend. Whereas NSR costs were set to zero only for these tests, the revised fuel consumption coefficient was retained for all following simulations. The revised fuel consumption coefficient corrects for a disparity between retrofit and capacity planning models, which are formulated at discrete and aggregated plant levels, respectively. Specification of the revised coefficient is described elsewhere (NETL 2008c).

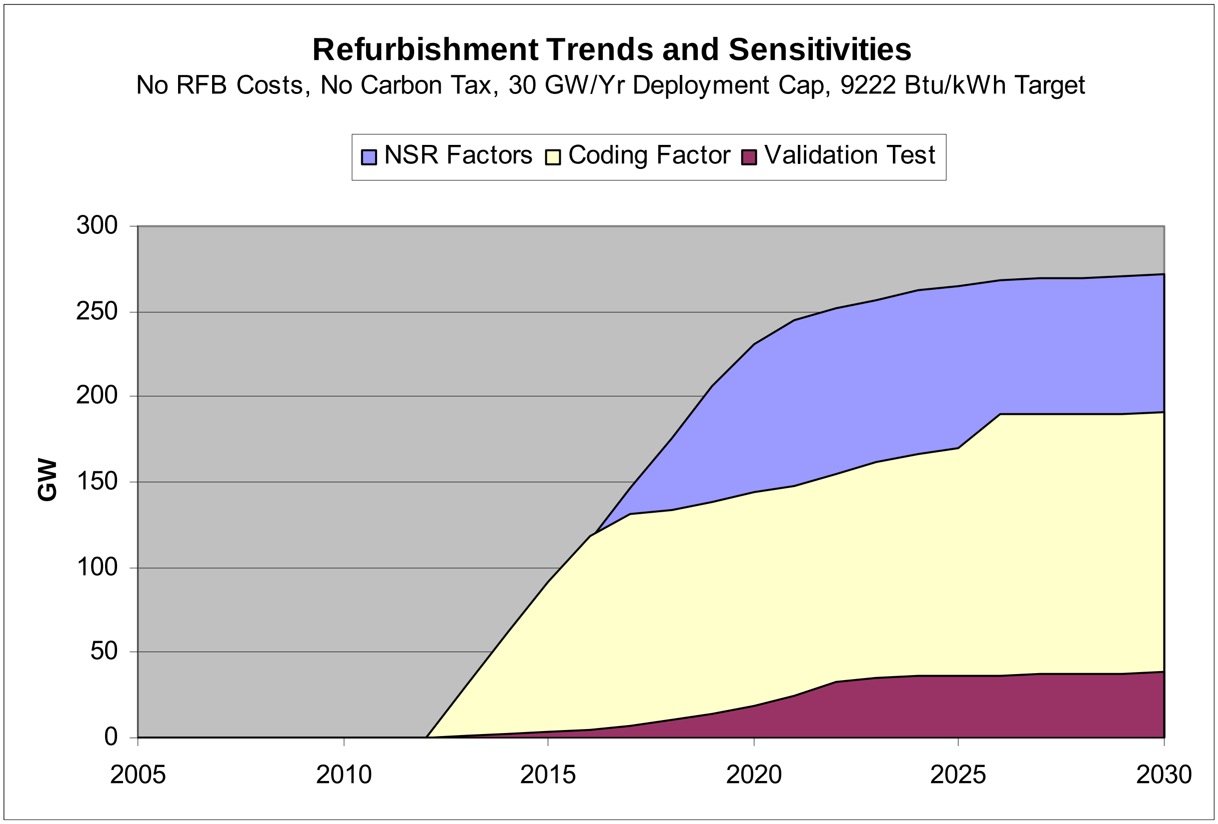

Figure 2. Refurbishment Trends and Sensitivities. The validation test fell well short of expectations of near complete refurbishment of the fleet due to NSR costs and a formulation of a fuel consumption coefficient that is insensitive to heat rate changes for individual plants.

Refurbishment without CCS Retrofitting

Figure 3 shows the scope of the refurbishment market in a scenario without a carbon constraint. The "Baseline Case" includes refurbishment (RFB) costs according to the generic correlation in Equation 1, and NSR costs for installation of missing pollution controls on any plant undergoing refurbishment. The "Negligible RFB and NSR Costs Cases" illustrate limiting cases with respect to those costs, and are indicative of technology advances and/or stimulus incentives which enable early adoption of refurbishment in the absence of a significant carbon constraint that would drive CCS retrofitting. NSR costs are seen as a significant barrier to refurbishment of marginal plants, and the value of a related stimulus incentive is large in the long term. The increase in the rate of refurbishment in the "Baseline Case" between 2020 and 2025 is a reflection of plants eventually adding emission controls, thereby reducing NSR cost barriers (increasing fuel costs over time could also drive such a trend).

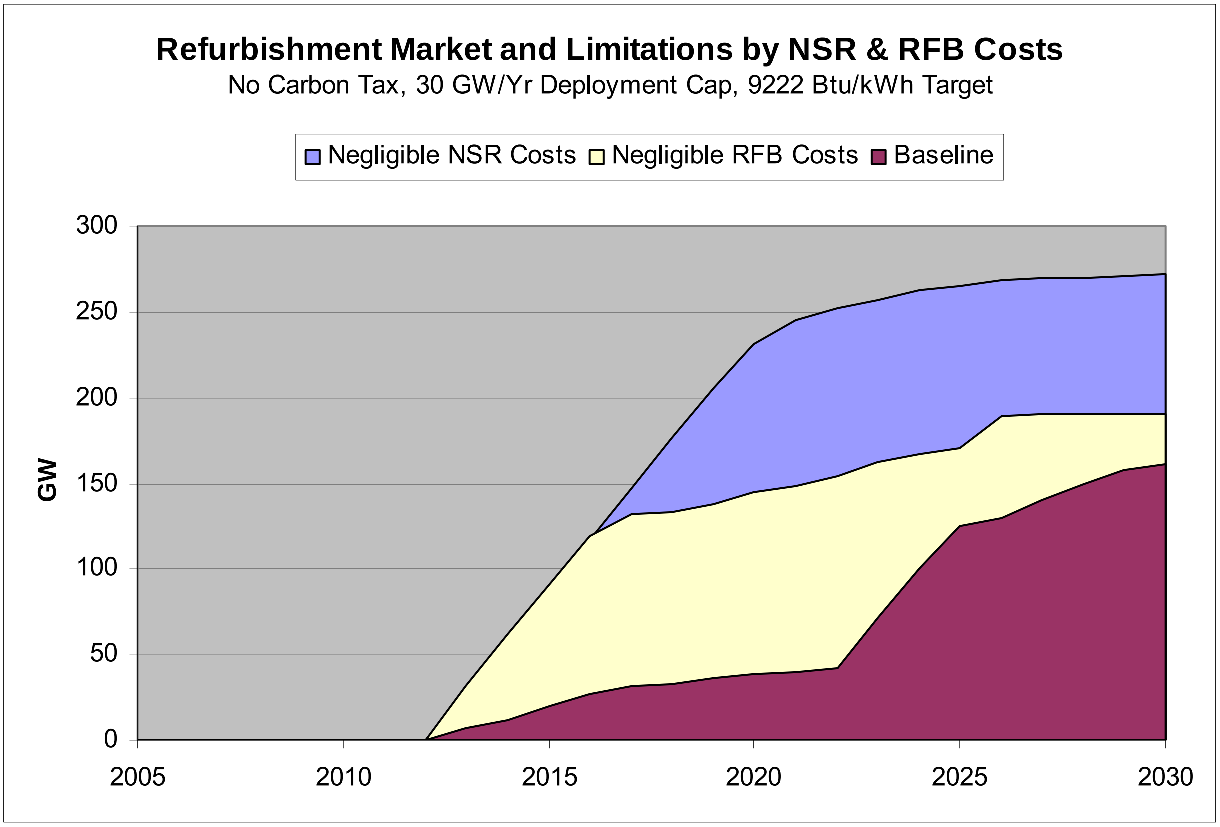

Figure 3. Refurbishment Market and Limitations by NSR and RFB Costs. Existing refurbishment technology would appear to be viable for a substantial portion of the fleet, limited largely by NSR and RFB costs.

Refurbishment with CCS Retrofitting

Figure 4 shows how refurbishment could significantly increase the number of plants retrofitted for CCS in a carbon-constrained scenario. The "Baseline Case" does not include refurbishment as part of the retrofit process. The "Reference RFB Costs Case" includes refurbishment, per the generic correlation of costs in Equation 1. The "Negligible RFB Costs Case" assumes costs for refurbishing are negligible relative to retrofitting and indicates the value of technology advances or stimulus incentives for refurbishment.

Clearly, current technology for refurbishment enables early adoption of retrofitting in the 2015 - 2025 timeframe. Advances in the technology or stimulus incentives related to refurbishing can extend the viability of retrofitting marginal plants in the longer term. All cases refer to a carbon tax of 45 $/mTCO2e, ramping up over the 2015 – 2020 timeframe.

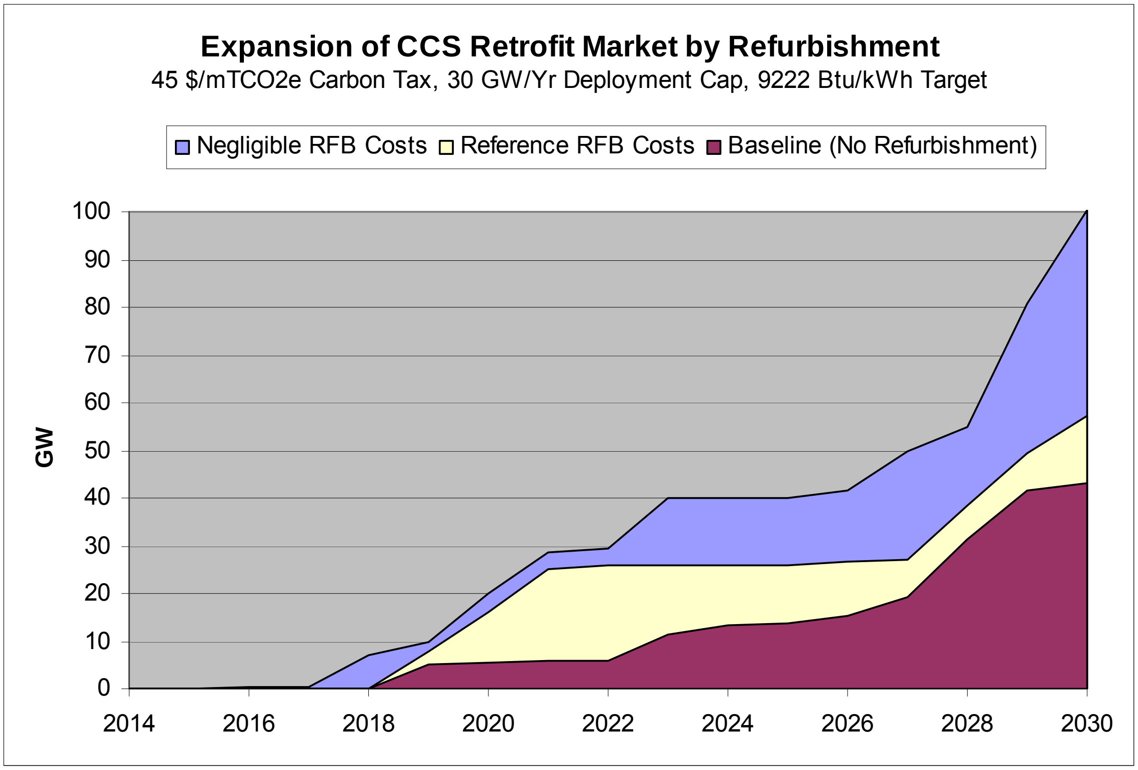

Figure 4. Expansion of CCS Retrofit Market by Refurbishment. Existing refurbishment technology enables early adoption of retrofitting, with further enabling dependent on advances in technology or stimulus incentives.

Application to EPEC Program Benefits Analysis

An exploratory application to benefits analysis of the DOE R&D program for existing coal fired power plants was next completed. Goals of the Existing Plants Emissions and Capture (EPEC) Program are published elsewhere (NETL, 2009). The "Stimulus" AEO_2009 version of NEMS including the American Recovery and Reinvestment Act of 2009 (ARRA version) was used, as opposed to the AEO_2007 "Final Release" version for Figures 3 - 4.

EPEC Program goals on the cost of retrofitting existing plants are stated in terms of reductions in the cost of CCS when integrated into a new power plant at the design stage. The overall goal is a 35 Percent increase in the levelized cost of electricity (LCOE), excluding carbon emission costs, for capture of 90 Percent of CO_2 emissions from a newly designed plant with characteristics as shown in Table 1. The goal is related to cost reduction targets for capital, fixed O&M, variable O&M, capacity derating factor, and costs for CO_2 transportation, injection, and monitoring. Generic cost factors used to model retrofitting in NEMS (NETL 2008b) were used to represent baseline CCS technology in Table 1 for the calculation of LCOE.

Table 1. LCOE increases with respect to baseline CCS costs (NETL 2008, 2009), excluding carbon emission costs, for reference plants designed for 90% net reduction in plant CO_2 emissions (Advanced Technology = EPEC Program Goals).

New PC Plant w/o CCS			
Capital, $/kW	1550		
Capital Recovery Factor	0.144		
Dispatch Factor	0.75		
Efficiency, % HHV	36.8	→ Heat Rate, Btu/kWh	9272
Fixed O&M, $/y/kW	25		
Variable O&M, $/kWh	0.0058		
Fuel Price, $/mmBtu	2.18		
CCS Cost Reduction Targets, % of Baseline CCS Costs		→ LCOE Increase, %	35
Capital	50		
Fixed O&M	20		
Variable O&M	80		
Capacity Derating Factor	65		
Transportation, Injection, & Monitoring	23		
LCOE, $/kWh			
Plant without CCS	0.064	→ CCS Target, $/kWh	0.086
Plant Designed with Baseline CCS Technology	0.104	Design Factor, %	25
Plant Designed with Advanced CCS Technology	0.086	R&D Factor, %	70

To account for limited opportunities to implement an optimal design in a retrofit setting due to site specific constraints, baseline CCS costs in a design setting were assumed to be 25 Percent lower (Design Factor = 25 Percent in Table 1). The Design Factor is assumed to be embedded in the EPEC cost reduction targets, and is used to back out the implied R&D Factor, or portion of EPEC cost reduction targets due to R&D as opposed to optimal design integration. As shown in Table 1, an R&D Factor of 70 Percent is implied when the factor is applied across the board to all EPEC cost reduction targets. Due to slight inconsistencies in the baseline costs for CCS as used in the EPEC Program documentation and in the generic NEMS model, the Design and R&D factors do not sum exactly to 100. The R&D factor is assumed fully applicable to retrofitting, and is used to estimate the impact of EPEC goals on the cost of retrofitting.

LCOE of retrofitted plants, excluding carbon emission costs, for “new” or “old” plants with either baseline or advanced technology (EPEC Program goals) are summarized in Figures 5 and 6, which are calculated directly from the factors presented in Table 1. “New versus old” plants are those whose unrecovered capital investments (before retrofitting) are 100 versus 0 percent, respectively, as limiting cases. As might be expected, retrofitting an “old” plant results in the largest relative increase in LCOE but it still results in the lowest LCOE for any given CCS technology. This is true even if little of the EPEC Program goal is attributed to an R&D factor applicable to retrofitting (of course this presumes the viability of retrofitting an old plant). Due to the assumed Design Factor underlying the EPEC Program goal, LCOE’s for retrofitting “new” plants will always be greater than those for new plants designed for CCS (or for plants designed to be “sequestration ready”). Of course the decision to retrofit or replace a plant with a new plant is more complex than a comparison of LCOE’s, since unrecovered capital investment in an existing plant will remain even if the plant is replaced, giving retrofits an advantage not readily apparent in comparing LCOE's.

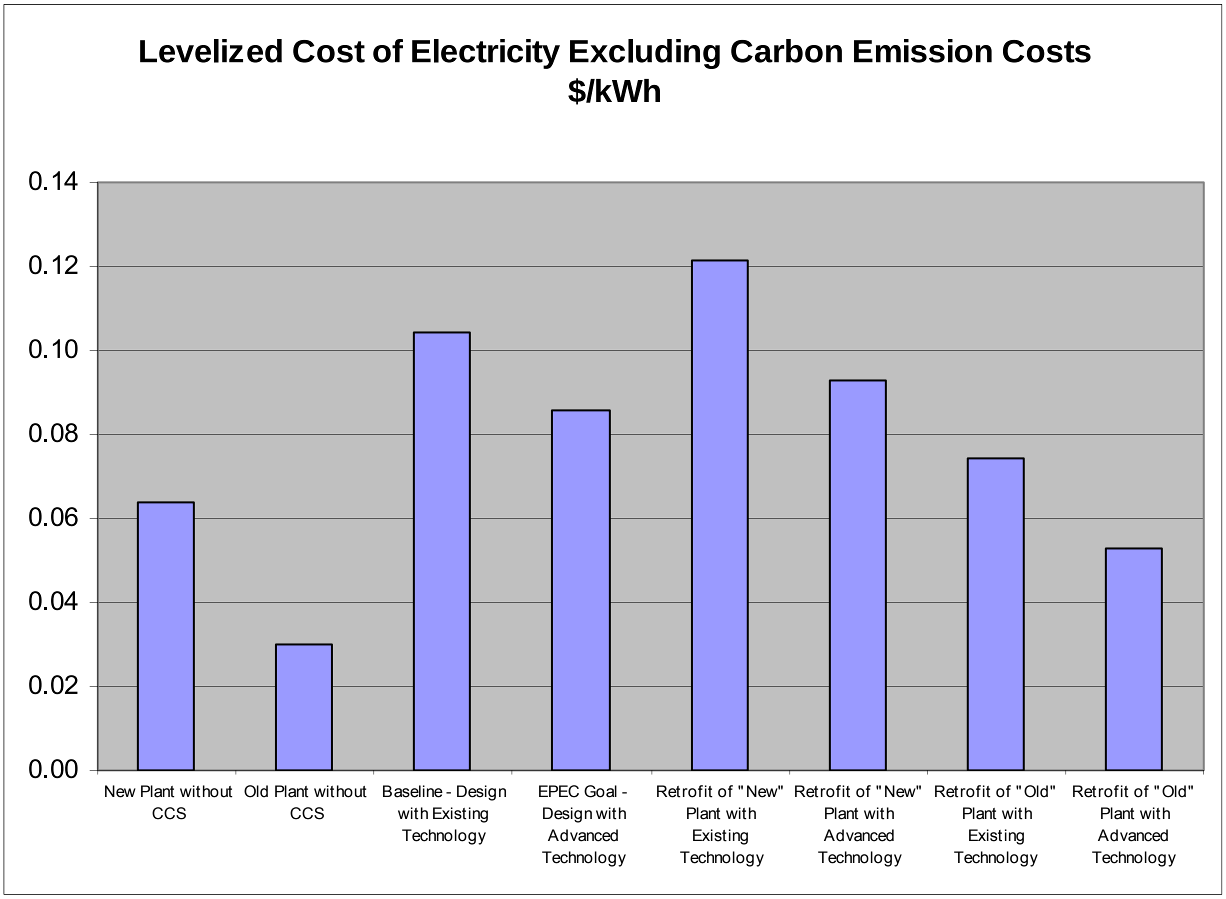

Figure 5. LCOE excluding carbon emission costs for various plants and CCS technologies. Design/ Retrofit = plant designed/retrofitted for CCS; "New/Old" = unrecovered original plant investment before retrofitting = 100/0 percent.

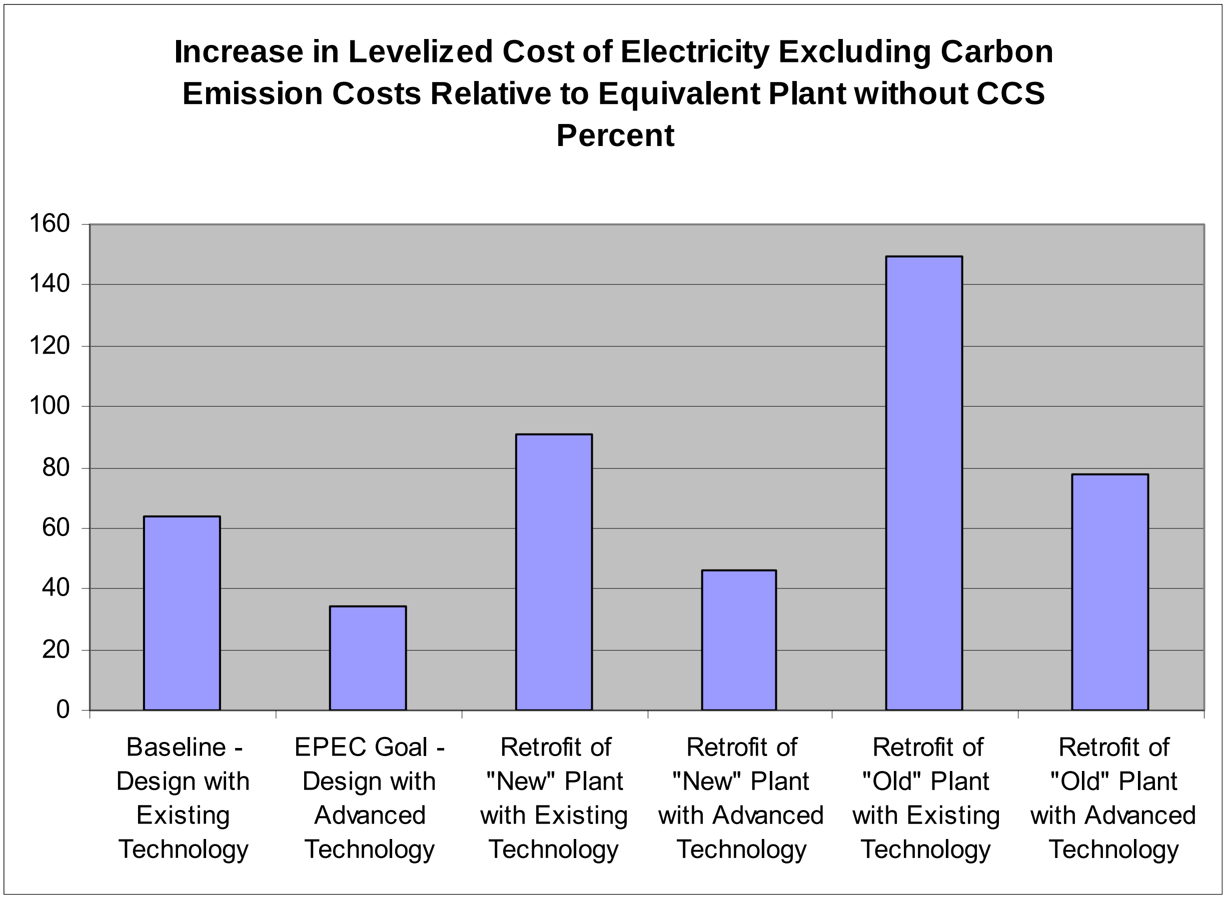

Figure 6. Increase in LCOE relative to equivalent plant without CCS for various CCS technologies. Design/ Retrofit = plant designed/retrofitted for CCS; "New/Old" = unrecovered original plant investment before retrofitting = 100/0 percent.

To model retrofit decisions, especially in the context of regional and time dependent drivers like fuel price, carbon emission allowance price, and demand growth, a more robust decision-making algorithm than LCOE is required. NEMS employs such an algorithm. The impact of EPEC Program goals in NEMS is most evident when carbon taxes are marginally adequate to support extensive CCS retrofitting. Figure 7 illustrates this for a carbon tax that ramps up to a constant 30 \$/mTCO2e by 2020, beginning in 2015. Another perspective from Figure 7 would be that the required carbon emission allowance price for a desired level of retrofitting in the fleet is lowered by the EPEC Program. Also illustrated is the enhancement of retrofitting through refurbishment. Since an R&D program does not formally exist, refurbishment costs were held constant between Baseline and EPEC Program Cases. Corresponding carbon emissions from the utility sector are shown in Figure 8. An important caveat in Figure 7 is that the EPEC Cases are based on R&D program goals and represent an upper bound to outcomes without any adjustments for less than complete program success. As such, these cases are comparable to other studies based on R&D program goals which are typically used to define a baseline for assessing the prospective benefits of R&D programs. With due consideration of risk and developments in alternative technologies, one would expect the range of likely outcomes to be bounded by limits as suggested in Figures 4 and 7. Another important caveat is that selection of any plant for retrofitting is highly dependent on carbon emission allowance prices. Still another caveat to consider when the number of plants selected for retrofitting approaches complete penetration of the fleet, is that no direct screenings of plants have been done in this analysis with respect to site specific factors other than a plant's heat rate, operating cost structure, and configuration with respect to emissions controls.

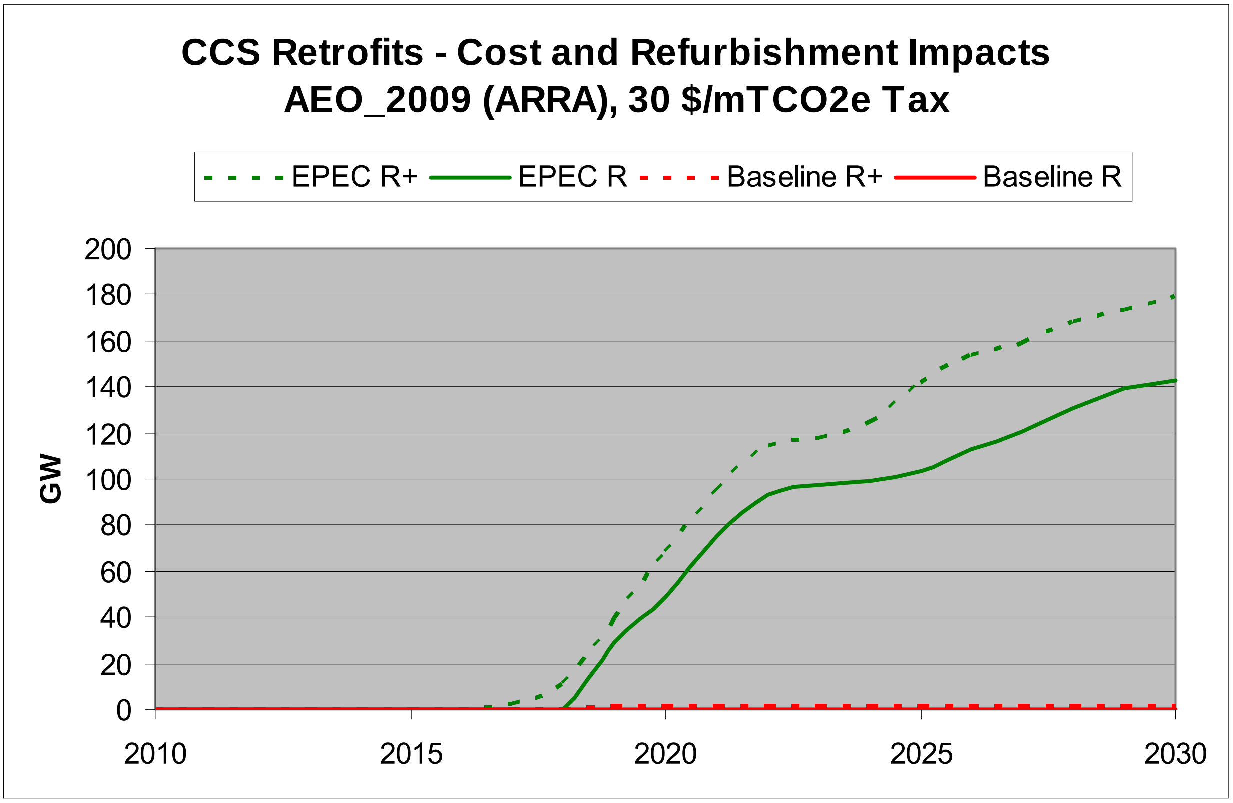

Figure 7. CCS Retrofits. EPEC Program goals for CCS retrofitting are included in the EPEC cases. "R+" designates CCS retrofitting enhanced by refurbishment. Cost and performance parameters for refurbishment are not varied between the Baseline and EPEC Cases.

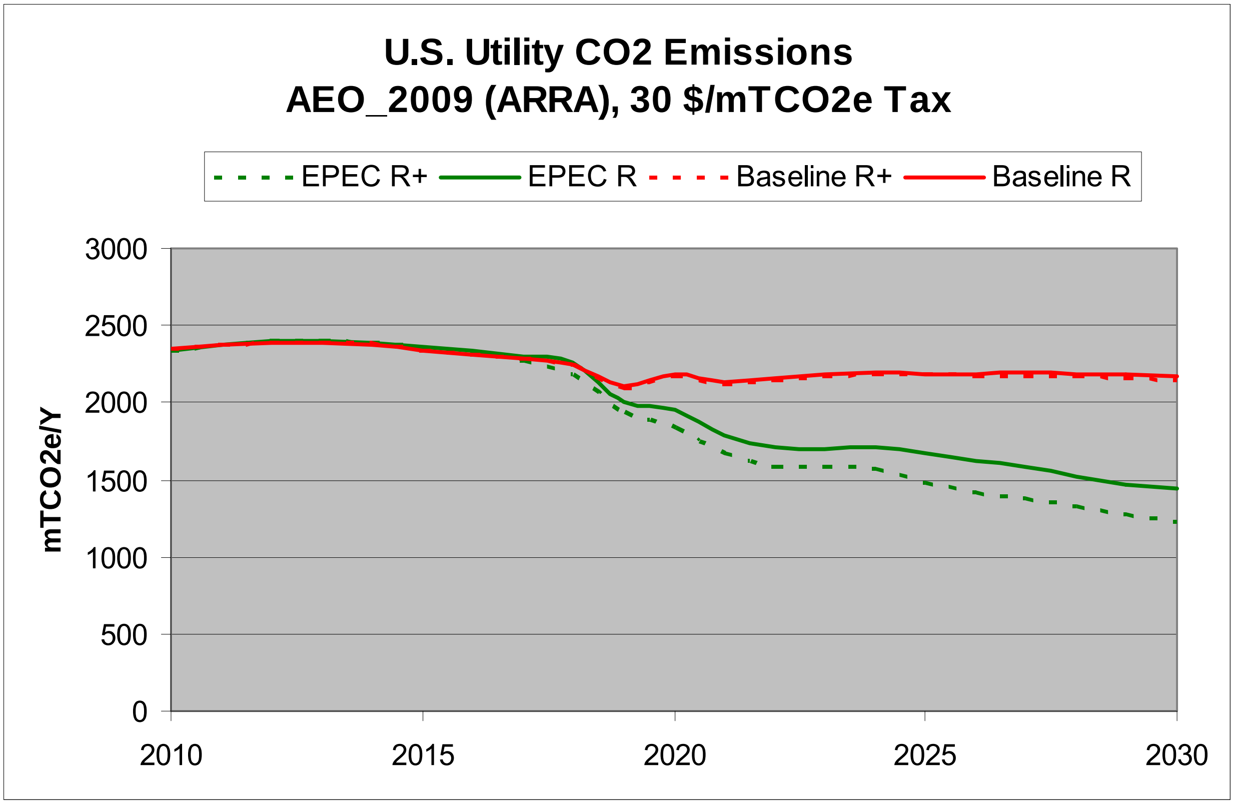

Figure 8. U.S. Utility CO_2 Emissions. EPEC Program goals for CCS retrofitting are included in the EPEC cases. "R+" designates CCS retrofitting enhanced by refurbishment. Cost and performance parameters for refurbishment are not varied between the Baseline and EPEC Cases.

Beyond program benefits analysis, CCS retrofit and refurbishing models are relevant to analysis of legislative proposals for climate change policy, such as the Waxman-Markey bill (H.R.2454 - "American Clean Energy and Security Act of 2009"). A scenario based on legislation will differ in many ways from the scenarios herein, which were derived by simply combining an exogenous carbon tax with a business as usual scenario, like an Annual Energy Outlook. Major differences involve cost of carbon emission allowances, whether specified by legislation or derived from cap and trade, emission allowance bonus incentives, and emission allowance offsets. Adaptation of the retrofit and refurbishment models used herein to EIA's recent analysis of H.R.2454 should be straight-forward, and doing so is an obvious next step.

Conclusions

Previously developed extensions of NEMS for modeling retrofits of coal fired power plants for CCS are adaptable to model refurbishment of plants to higher efficiencies either alone or in conjunction with CCS retrofits. Data for costs of refurbishment suggest a significant potential for refurbishment as an enabler of early adoption of CCS retrofits throughout the fleet. NSR considerations may represent a barrier for plants that would need to install missing controls (e.g. flue gas desulfurization) as part of the refurbishment. Stimulus incentives or advancements in the technology of refurbishment would act to overcome these barriers.

While the implied cost reduction targets for retrofitting existing plants are less than those articulated by the EPEC Program for new plants designed with CCS, they are nevertheless of significance in the analysis of R&D program benefits.

References

NETL 2008a, "Reducing CO_2 Emissions by Improving the Efficiency of the Existing Coal-Fired Power Plant Fleet," DOE/NETL-2008/1329, July 23, 2008. *http://www.netl.doe.gov/energy-analyses/pubs/CFPP%20Efficiency-FINAL.pdf*

NETL 2008b, "Retrofitting Coal Fired Plants for Carbon Dioxide Capture and Sequestration – Exploratory Testing of NEMS for Integrated Assessments," DOE/NETL-2008/1309, January 18, 2008. *http://www.netl.doe.gov/energy-analyses/pubs/v%203%20-%20FINAL%20-%20retrofit_NEMS_exploratory.pdf*

NETL 2008c, "A Net Benefits Methodology for National Energy Modeling Systems Simulations of Retrofitting Coal Fired Power Plants for CO_2 Capture and Sequestration," DOE/NETL-2008/1317, April 5, 2008. *http://www.netl.doe.gov/energy-analyses/pubs/netbenefits040508.pdf*

NETL 2009, "Existing Plants, Emissions and Capture – Setting CO_2 Program Goals," DOE/NETL-2009/1366, April 20, 2009.