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The Power to Reduce CO_2 Emissions: the Full Portfolio

2008 Economic Sensitivity Studies

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Energy Technology Assessment Center

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EXECUTIVE SUMMARY

EPRI's 2007 analysis [1], "The Power to Reduce CO_2 Emissions: the Full Portfolio," (see summary, Appendix A) showed that by deploying a full portfolio of advanced, cost-effective technologies the electricity sector can substantially reduce the cost of reducing CO_2 emissions. The analysis factored key assumptions about the costs and timing of various technologies, including advanced nuclear and advanced coal generation with CO_2 storage and capture. Because these technologies generate huge amounts of electricity while emitting little or no CO_2, their presence in a generation portfolio strongly influences economic impacts and the degree to which other technologies enter the generation mix over time. Continuing EPRI's analysis, a critical question follows: in the event of higher costs or delays in technology availability, how are the costs of CO_2 policy and deployments of different technologies affected?

By "keeping options open," the electricity sector can be more effective in responding to changing market conditions. The key to keeping options viable and accelerating the deployment of the full portfolio is continued and sustained research, development, and large-scale technology demonstration of key generation and demand side technologies. If the electricity sector can deploy these technologies more rapidly, then it can limit the costs of CO_2 emissions constraints and increases in electricity production costs.

The uncontrolled growth of emissions in developing countries has the potential to offset and negate the developed world's move toward zero emissions, significantly delaying the solution of the fundamental problem of global warming. In 2009, EPRI will prepare detailed studies assessing the implications of technology scenarios for global CO_2 emissions reductions, and hence the benefits of technology advancement from a global perspective.

Building on the 2007 analysis, EPRI analyzed a series of scenarios evaluating how the economy would respond to variable costs and timing of key technologies under a CO_2 emissions constraint. Table 1 summarizes the variables evaluated and the economic impact (discounted sum of U.S. GDP losses between 2000 and 2050) for each technology scenario. The key variables were:

- Higher nuclear electricity production costs (based on higher capital costs),
- Substantially higher CO_2 transport and storage costs
- Delay until 2030 of the commercial availability of large-scale CO_2 capture and storage (CCS)

Table 1
U.S. GDP impact (billions, year 2000 $) of a generic CO_2 emissions constraint under different nuclear, CCS assumptions

	CO_2 Capture/Storage Available in 2020		**CO_2 Capture/Storage Available in 2030**	
Nuclear Electricity Production Costs (approximate all-in capital cost)	**CO_2 Transport/Storage Costs = \$10/ton CO_2**	**CO_2 Transport/Storage Costs = \$30/ton CO_2**	**CO_2 Transport/Storage Costs = \$10/ton CO_2**	**CO_2 Transport/Storage Costs = \$30/ton CO_2**
$64/MWh (~$3600/kW)	$624 B	$607 B	$606 B	$606 B
$80/MWh (~$5100/kW)	$726 B	$757 B	$767 B	$753 B
$94/MWh (~$6200/kW)	$813 B	$925 B	$904 B	$942 B
$122/MWh (~$8700/kW)	$871 B	$1,061 B	$987 B	$1,135 B

Note: nuclear electricity production and CO_2 transport/storage cost assumptions shown here are in 2006 $.

These scenarios provide new insights that that underscore the urgency of RD&D necessary to deploy the full portfolio of advanced technologies:

- By 2050, if the U.S. is to meet probable emissions constraints of 50% below 1990 levels **and** simultaneously meet projected growth in electricity demand, it will very likely require concurrent major deployment of advanced nuclear, advanced coal plants with CO_2 capture and storage, non-hydro renewables, and technologies such as the smart grid that enable large-scale load management and demand response.
- No scenarios emerge in which **both** nuclear and advanced coal+CCS are available but not deployed. The combination of these two technologies represents 45%-64% of generation by 2050, depending upon the specific scenario.
- By 2050, 17%-28% of electricity generation will come from non-hydro renewables, with the higher end of this range occurring when nuclear and coal+CCS both do not achieve optimistic levels of cost and availability.
- Increased energy efficiency will play an important role in managing load growth and demand. Efficiency improvements result from both price-induced and policy-induced technology investments.
- Even with more pessimistic technology assumptions, the cost to the economy of a CO_2 emissions reduction policy is substantially reduced by the availability of the full portfolio. RD&D leading to increased technology options, earlier technology availability, and lower technology deployment costs will reduce the GDP losses associated with a CO_2 constraint.

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1

DECARBONIZED ELECTRICITY VIA THE FULL PORTFOLIO

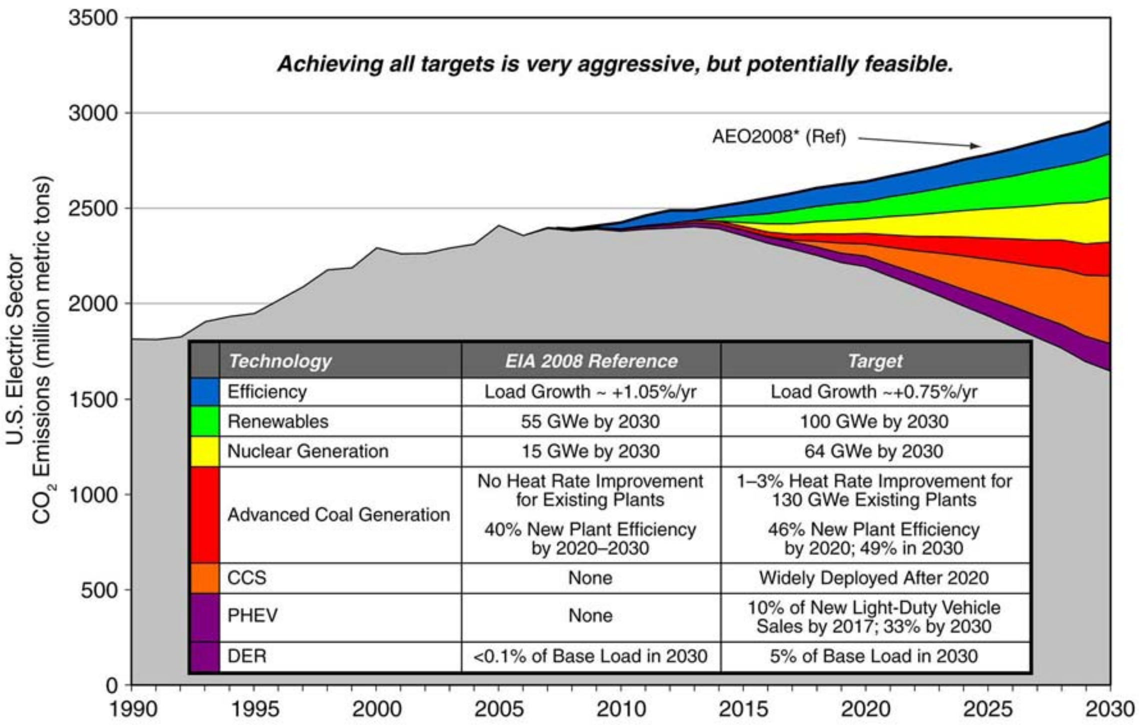
The actions required to mitigate climate change effects associated with greenhouse gas emissions involve removing or reducing the amount of carbon in the global economy. “Decarbonizing” the economy will not be easy or cheap; success will hinge to a large degree on the availability of low-carbon technologies for the electricity sector.

The imperative to deploy advanced, climate-friendly technologies to mitigate greenhouse gas emissions cannot be over-emphasized. Recent evidence indicates that emissions are growing faster than previously forecast, particularly in developing countries, and there is evidence that climate sensitivity may be higher than expected. In its 4th Assessment Report [3], the Intergovernmental Panel on Climate Change (IPCC) concluded that average surface temperatures are definitely increasing and that human activity is very likely the principal cause. The chairman of the IPCC has stated: “Today, the time for doubt has passed. The IPCC has unequivocally affirmed the warming of our climate system, and linked it directly to human activity [4].”

Greenhouse gases have different residence times in the atmosphere. Carbon dioxide, for example, has an atmospheric lifetime of between 50 and 200 years. The consequences of today’s emissions may affect climate far into the future. Preventing or delaying damages associated with warming requires slowing the rate of growth in emissions, stopping the rate of growth, and then reducing emissions. If emissions targets currently under consideration are to be achieved, this transition must begin now.

The task is daunting, but not impossible, requiring both political and technological initiatives. The global scientific community has concluded that advanced technology development and deployment represents the optimal response, technically and economically.

Any effort to decarbonize the economy must encompass CO_2 emissions reductions from electricity production (Figure 1-1), which is responsible for about one-third of global CO_2 emissions. Once achieved, decarbonized electricity becomes integral to reducing emissions in other economic sectors. For example, vehicles powered by decarbonized electricity reduce the emissions from the transportation sector and hence from the economy as a whole.



	Technology	*EIA 2008 Reference*	*Target*
🟦	Efficiency	Load Growth ~ +1.05%/yr	Load Growth ~+0.75%/yr
🟩	Renewables	55 GWe by 2030	100 GWe by 2030
🟨	Nuclear Generation	15 GWe by 2030	64 GWe by 2030
🟥	Advanced Coal Generation	No Heat Rate Improvement for Existing Plants 40% New Plant Efficiency by 2020–2030	1–3% Heat Rate Improvement for 130 GWe Existing Plants 46% New Plant Efficiency by 2020; 49% in 2030
🟧	CCS	None	Widely Deployed After 2020
🟪	PHEV	None	10% of New Light-Duty Vehicle Sales by 2017; 33% by 2030
🟪	DER	<0.1% of Base Load in 2030	5% of Base Load in 2030

Figure 1-1
Potential for decarbonizing the U.S. electric sector - the full portfolio
Comparison of EIA 2008 [5] projections for electricity sector annual emissions growth to a decreasing emissions profile resulting from assumptions of advanced technology development and deployment.

Decarbonization will rely heavily on research, demonstration and deployment of advanced technologies. EPRI's RD&D strategy focuses on developing technologies that can achieve potential CO_2 emissions targets associated with electricity production and use while minimizing the economic impact of meeting these targets. Driving this RD&D effort is a series of analyses defining key RD&D priorities and quantifying their benefits.

The 2007 analysis [1], "The Power to Reduce CO_2 Emissions: the Full Portfolio," (see summary, Appendix A) showed that deploying a full portfolio of advanced, cost-effective technologies will minimize the cost of emissions reductions in contrast to a conservative scenario with limited technology options.

This 2008 analysis explores the robustness of the advanced technology portfolio strategy by examining scenarios under less optimal conditions. EPRI stress-tested the full portfolio by varying key assumptions regarding costs and technology availability. The analysis revealed that even with higher nuclear electricity production costs, delays in the availability of carbon capture and storage technology, and higher CO_2 transport and storage costs, the full portfolio approach substantially reduces the economic impact associated with a given CO_2 emission constraint (Figure 1-2). As a result, the analysis points to a significant economic incentive to mitigate the impact of emissions reduction targets by aggressively pursuing major expansions in nuclear, advanced coal + CCS, non-hydro renewables, and smart grids.

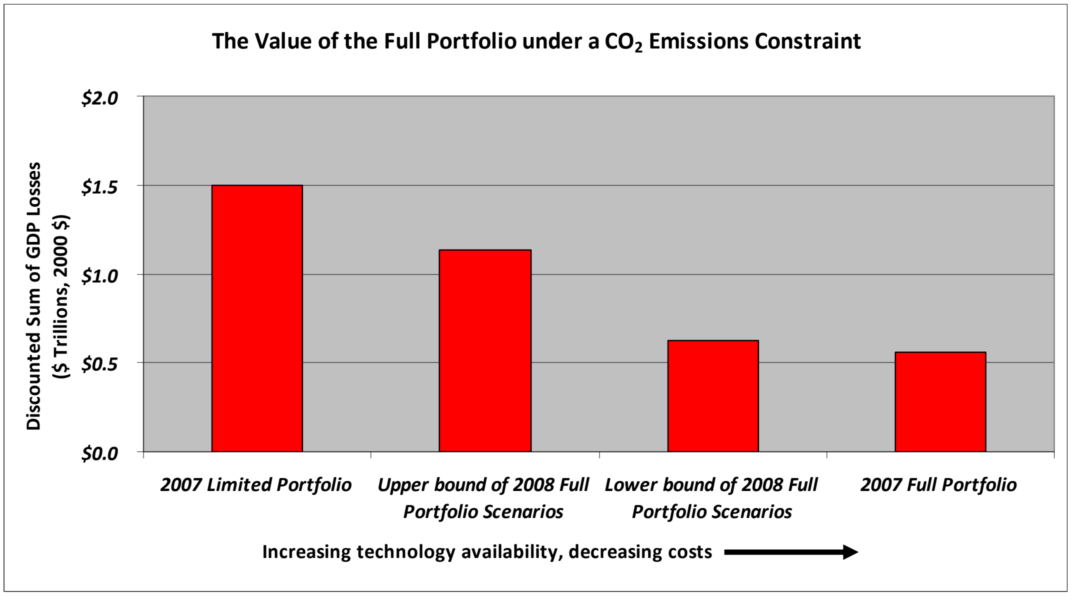


Figure 1-2
Cost of CO_2 emissions constraints (2000-2050)
EPRI's 2007 analysis1 compared economic impact of a representative economy-wide CO_2 emissions constraint between a full portfolio of advanced technologies based on aggressive RD&D, and a limited portfolio of technologies. EPRI's 2008 analysis shows that investment in RD&D will improve the cost benefit of the full portfolio through earlier technology availability and lower costs.

Securing an advanced technology portfolio requires a significant RD&D commitment. Ultimately, the level of RD&D investment will affect the timing of technology availability, levels of performance, and costs. Therefore, the RD&D strategy has a direct impact on the cost of achieving emissions reductions. A key component of this RD&D strategy is to conduct major technology demonstrations of advanced technologies so that they can tested at larger scale and proven ready for commercial deployment.

The Link to Global Decarbonization

The uncontrolled growth of emissions in developing countries has the potential to offset and negate the developed world's move toward zero emissions, significantly delaying the solution of the fundamental problem of global warming. Developing countries need energy for economic growth and increasing standards of living. The ultimate goal is to develop advanced technologies that can ensure worldwide access to energy that is both affordable and climate friendly. In 2009, EPRI will prepare detailed studies assessing the implications of technology scenarios for global CO_2 emissions reductions, and hence the benefits of technology advancement from a global perspective.

2

INSIGHTS FROM THE SENSITIVITY ANALYSIS

Analysis Overview

The 2007 EPRI research [1] (see summary, Appendix A) concluded that a full portfolio of electricity technologies, including prominent deployment of advanced nuclear and coal plants with CO_2 capture/storage, is essential to reducing the costs of meeting a CO_2 emissions constraint. These results clearly showed that significant deployment of several generation and demand-side technologies are required for an optimal technology mix to minimize GDP losses.

However, uncertainties exist regarding capital cost escalation, the timing of commercial availability of large-scale CO_2 storage, and the future availability of cost-effective energy-efficient CO_2 capture for pulverized coal and integrated gasification combined cycle plants. Both nuclear and advanced coal with CCS technologies are capital-intensive technologies, raising critical questions how higher costs or delays in technology availability could influence the cost of meeting emissions reductions targets. Consequently, several key sensitivities were chosen for further analysis (see Table 2-1):

- Higher nuclear electricity production costs (based on higher capital costs),
- Delayed commercial availability of large-scale CO_2 capture and storage (CCS) until 2030, and
- Substantially higher CO_2 transport and storage costs.

Table 2-1
Full portfolio scenarios analyzed in 2008 EPRI analysis

	CO_2 Capture/Storage Available in 2020		CO_2 Capture/Storage Available in 2030	
Nuclear Electricity Production Costs	**CO_2 Transport/Storage Costs = \$10/ton CO_2**	**CO_2 Transport/Storage Costs = \$30/ton CO_2**	**CO_2 Transport/Storage Costs = \$10/ton CO_2**	**CO_2 Transport/Storage Costs = \$30/ton CO_2**
\$64/MWh (~\$3600/kW)	Scenarios addressing 16 different combinations of nuclear electricity production costs, timing of CCS availability, and CO_2 transport and storage costs.			
\$80/MWh (~\$5100/kW)				
\$94/MWh (~\$6200/kW)				
\$122/MWh (~\$8700/kW)				

Note: electricity production and CO_2 transport/storage cost assumptions shown here are in 2006 \$. Other assumptions shown in Appendix C.

Assumptions for other technologies are consistent with EPRI Technology Assessment Guide (TAG) data as of October 2007 (see Appendix C). The analysis is based on a representative **economy-wide** CO_2 constraint requiring emissions to be flat from 2010-2020, followed by a 3%/year reduction beyond 2020.

The scenario analyses were based on a range of values selected to address the key uncertainties regarding nuclear and advanced coal technologies. Note that the assumed range of nuclear electricity production costs effectively covers 95% of the range of historical values for the existing nuclear fleet7 (this range includes nearly all of the historically highest-cost plants).

The decision to investigate the effects of a 10-year delay in the availability of CO_2 capture and storage (i.e. 2030 rather than 2020) was based on consultation with EPRI domain experts. While CO_2 transport and storage costs are commonly projected to be around \$10/ton CO_2, cases associated with \$30/ton were analyzed to assess the impact of limited storage site availability resulting from relatively stringent site characterization, measurement, and monitoring criteria.

These scenarios (see detailed results, Appendix B) provide new insights that that underscore the urgency of RD&D that can accelerate the deployment of advanced technologies:

- By 2050, in order to meet both probable emissions constraints on the US economy on the order of 50% below 1990 levels **and** growing electricity demand, the electricity sector will likely be required to concurrently deploy advanced nuclear, advanced coal plants with CO_2 capture and storage, non-hydro renewables, and technologies such as the smart grid which enable widespread load management and demand response.
- No scenarios emerge in which **both** nuclear and advanced coal+CCS are available but not deployed. Together, these two technologies represent 45%-64% of generation by 2050, depending upon the specific scenario.
- It is likely that 17%-28% of electricity generation will come from non-hydro renewables, with the higher end of this range occurring if nuclear and coal+CCS do not both achieve optimistic levels of cost and availability.
- Significant improvements in end-use efficiency are likely due to effects induced both by market (price) and non-market (regulatory) factors.
- Substituting electricity at the point of end-use in other sectors of the economy will play a major role in meeting emission reduction goals.
- Even with more pessimistic technology assumptions, the cost to the economy of CO_2 emissions constraints is still substantially reduced by the availability of the full portfolio. RD&D that results in more technology options, with earlier availability and lower deployment costs will reduce the GDP losses associated with a CO_2 constraint.

The scenario analysis illustrates the importance of performing RD&D in several key areas simultaneously. The relative share of technologies forming an optimal generation mix at a given time varies depending upon technology costs and availability. Natural gas and demand reduction, including end-use efficiency, will play particularly important roles over the next decade as other technologies emerge and deploy. A consistent finding is that the optimal mix includes substantial baseload generation combining nuclear, advanced coal with CCS, and non-hydro renewables. Figure 2-1 demonstrates the above points by comparing selected scenarios from the sixteen scenarios analyzed. In the scenarios shown, non-hydro renewables represent roughly 28% of generation. Either nuclear or coal with CCS can be the dominant baseload technology, but the combination of the two consistently represents 45%-58% of generation. However, note that the GDP impact of these scenarios varies substantially. It therefore becomes important to have the technology options needed for these scenarios and to increase the probability of lower cost scenarios. Figure 2-2 presents the same four scenarios' generation mix as it evolves over time.

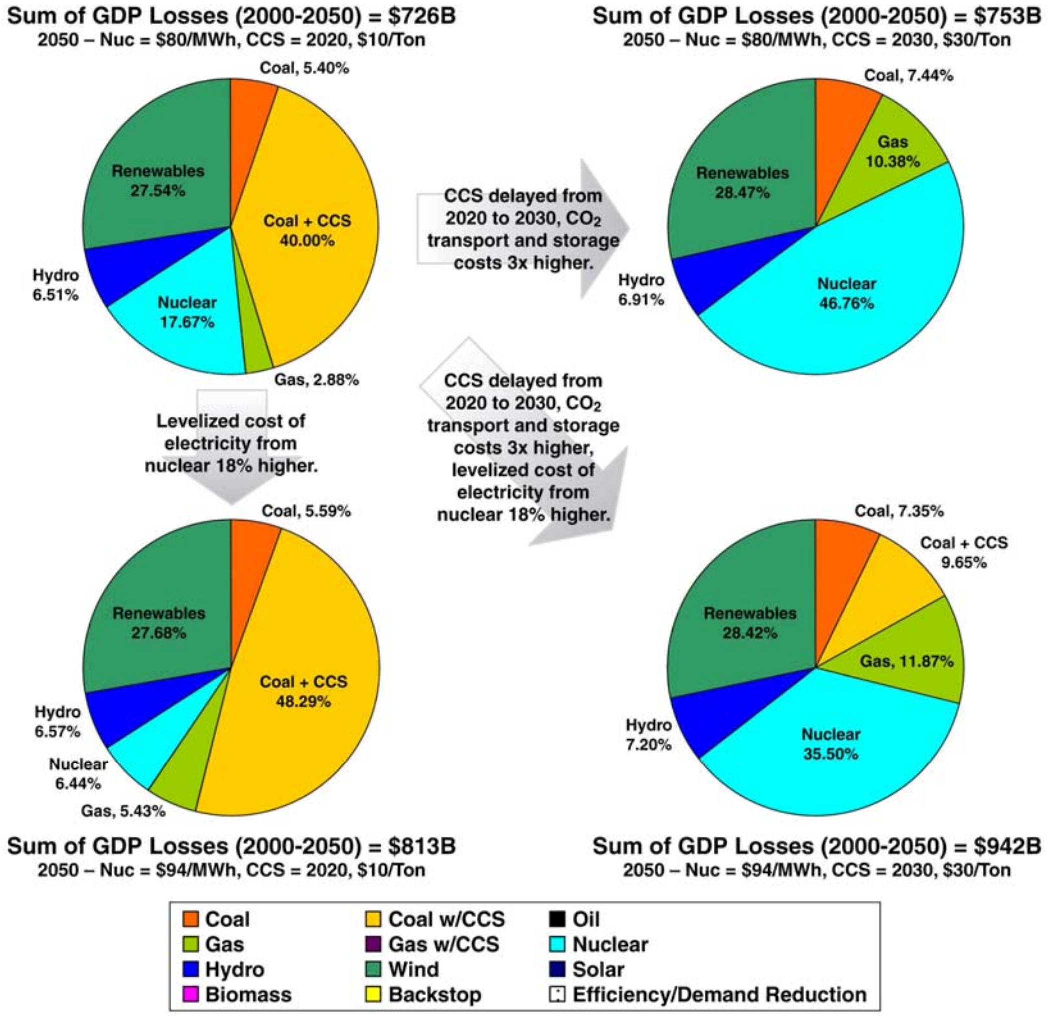
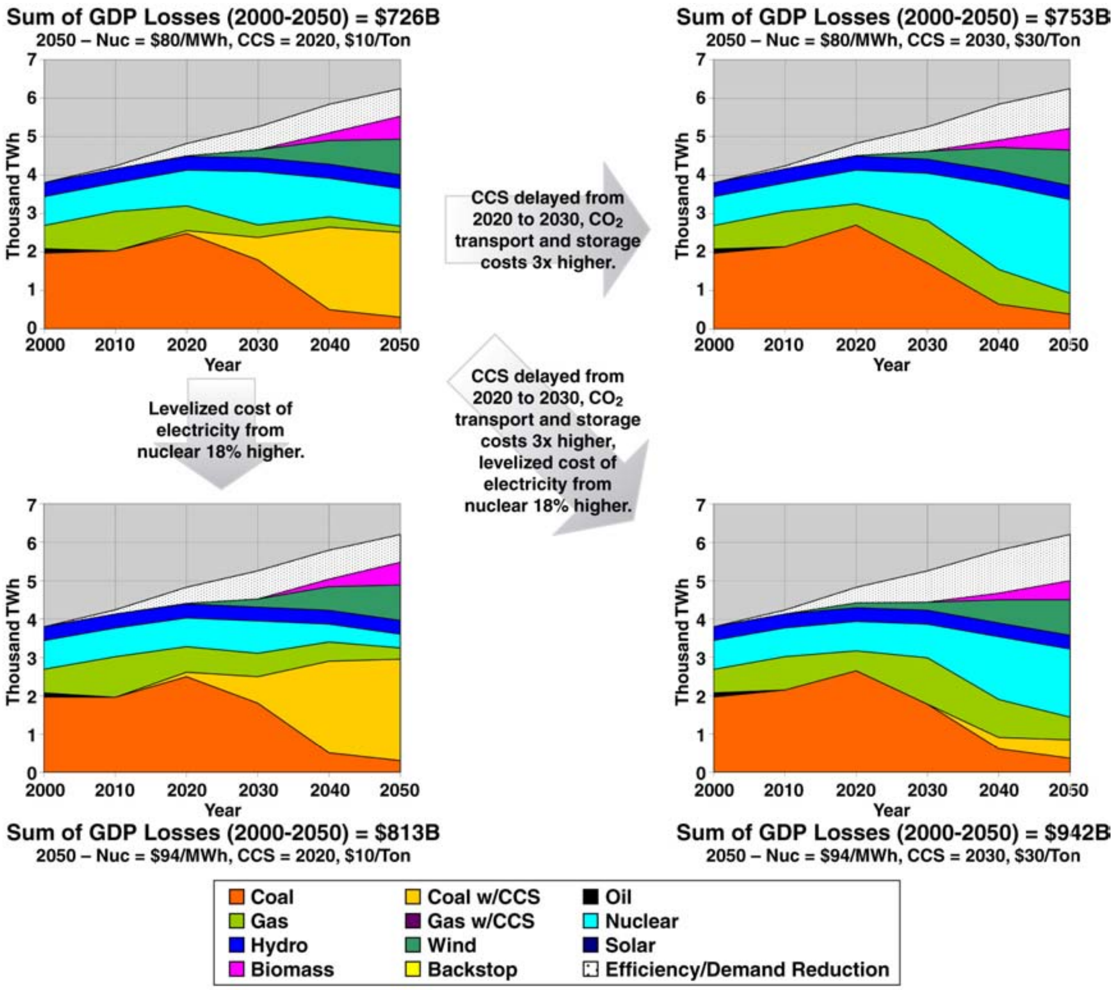


Figure 2-1
2050 generation mix - contrasting scenarios
This chart shows the importance of RD&D to achieve technology optionality by comparing different scenarios. The discounted sum of GDP losses under a CO_2 emissions reduction constraint can be reduced by enabling lower cost portfolios.



Sum of GDP Losses (2000-2050) = $726B
2050 – Nuc = $80/MWh, CCS = 2020, $10/Ton

Sum of GDP Losses (2000-2050) = $753B
2050 – Nuc = $80/MWh, CCS = 2030, $30/Ton

CCS delayed from 2020 to 2030, CO_2 transport and storage costs 3x higher.

Levelized cost of electricity from nuclear 18% higher.

CCS delayed from 2020 to 2030, CO_2 transport and storage costs 3x higher, levelized cost of electricity from nuclear 18% higher.

Sum of GDP Losses (2000-2050) = $813B
2050 – Nuc = $94/MWh, CCS = 2020, $10/Ton

Sum of GDP Losses (2000-2050) = $942B
2050 – Nuc = $94/MWh, CCS = 2030, $30/Ton

Figure 2-2
Generation mix over time - contrasting scenarios
This chart shows the importance of RD&D to achieve technology optionality. Different generation technology portfolios may be important, and the discounted sum of GDP losses under a CO_2 emissions reduction constraint can be reduced by enabling lower cost portfolios.

Price-Induced Efficiency and Electrification Increase the Value of the Smart Grid

Electricity consumption is a function of many variables, including technology costs, technology capabilities, and the presence or absence of a CO_2 emissions constraint. The scale of demand reduction observed in the scenario analyses is significant. For example, 2030 electricity consumption would be roughly 600-900 TWh lower with a modeled CO_2 emissions constraint than without an emission constraint under the same technology assumptions.

The demand reduction impact is complex and cannot be explained without taking an economy-wide perspective. Much of the electricity "demand reduction" observed in scenarios with an emission constraint results from price-induced efficiency: as prices rise, technologies that improve load management and demand response become more attractive. But at the same time, electrification (substituting electricity for carbon-based fuels in other sectors) will limit the drop in electricity demand. Indeed, the opportunity for electricity to provide low-carbon energy throughout the economy is an important insight from the 2007 analysis [1] (see Figure A-3, Appendix A).

Finally, a technology-driven component of the demand reduction also emerges. Reductions in consumption also result from technological progress. As noted in EPRI's 2006 work [6], for example, the smart grid creates the platform for deploying smart technologies that improve load management and demand response.

Nuclear and Advanced Coal with CCS Are Essential

While significant deployments of new nuclear plants and advanced coal plants with CO_2 capture and storage are unlikely until after 2020, substantial RD&D for these technologies must proceed between now and then. Large-scale baseload generation plays a key role in meeting demand and supporting grid reliability. Demonstration projects will be vital to the development and availability of technologies required to achieve mandated reductions.

Advanced nuclear and coal technologies supply large amounts of electricity in the analyzed scenarios (see Appendix B), representing 19%-42% of the generation mix in 2030 and 45%-64% by 2050. These results demonstrate that large baseload technologies with little or no emissions are central elements of the future generation mix. Therefore, emissions reductions requirements make it important to successfully demonstrate CO_2 storage on a commercial scale and to construct new nuclear plants.

Non-Hydro Renewables Will Play a Large Role

Non-hydro renewables, which represent about 1.8% of U.S. electricity generation in 2006 (as reported by the EIA [5]), are projected to represent 4-5% of generation in nearly all scenarios by 2030. However, by 2050, they are projected to grow to 28% of total generation across the range of scenarios analyzed. The renewables generation calculated in these analyses consists of about 60% wind and 40% biomass. The economically optimal electricity technology portfolio includes significant generation from non-hydro renewables. Relative to current levels, renewables generation will have to grow by roughly a factor of three by 2030 in these scenarios, and by more than a factor of 15 by 2050.

3
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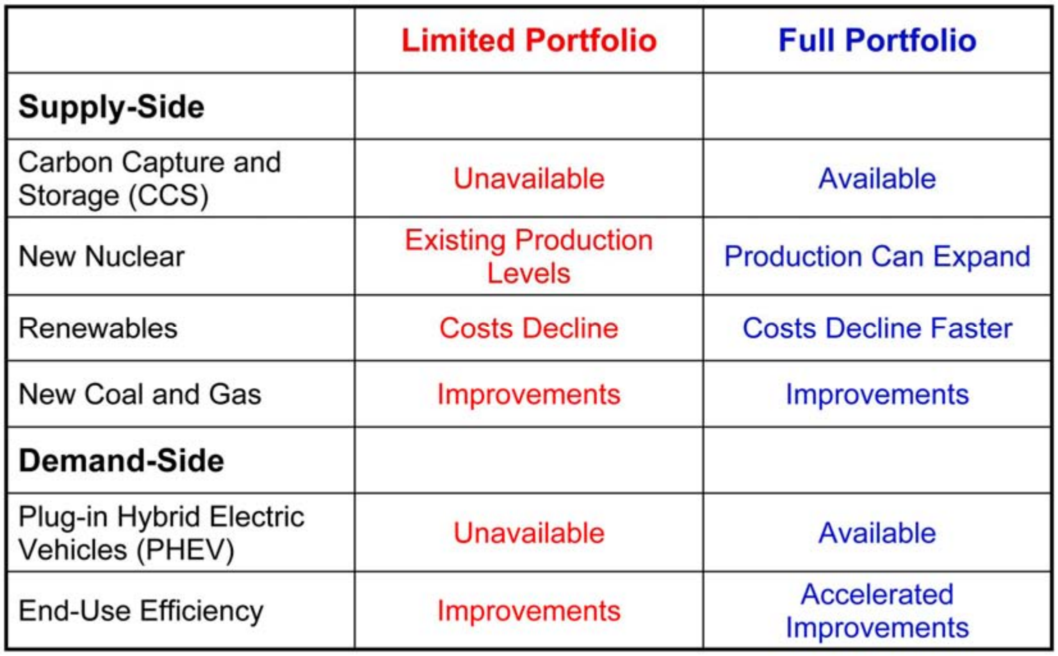
A

SUMMARY OF 2007 EPRI ECONOMIC ANALYSIS

The 2007 EPRI analysis [1] assessed the economic impact of different electricity sector technology portfolios under an assumed CO_2 emissions constraint, using the MERGE modeling system. MERGE [2] is a general equilibrium economic model that has been used for more than a decade to analyze the cost of CO_2 emissions mitigation as a function of technology cost, availability, and performance. MERGE models long time horizons to capture economic effects of potential climate change and encompasses all major greenhouse gases and all emitting sectors of the economy. Using technology descriptions and policy constraints as inputs, the model outputs not only energy production by technology, but also prices for wholesale electricity and carbon emissions. The MERGE analysis clearly showed the enormous economy-wide benefit of investing in the RD&D needed to commercialize a full portfolio of technologies.

Conceptually, MERGE estimates the least-cost combination of technologies necessary to provide the economy's energy services with or without a CO_2 emissions constraint. In the 2007 analysis, two technology scenarios were contrasted: a "Limited Portfolio" scenario representing incremental technology improvements, and a "Full Portfolio" scenario representing the electricity technology advances consistent with those used in EPRI's "Prism" analysis (Table A-1). Comparing the economy-wide cost of meeting a CO_2 constraint between these two scenarios provides a basis for assessing the value of the RD&D investment needed to assure the levels of technology performance described in the PRISM analysis.

Table A-1
2007 EPRI economic analysis technology scenarios



	Limited Portfolio	**Full Portfolio**
Supply-Side		
Carbon Capture and Storage (CCS)	Unavailable	Available
New Nuclear	Existing Production Levels	Production Can Expand
Renewables	Costs Decline	Costs Decline Faster
New Coal and Gas	Improvements	Improvements
Demand-Side		
Plug-in Hybrid Electric Vehicles (PHEV)	Unavailable	Available
End-Use Efficiency	Improvements	Accelerated Improvements

The results of the 2007 analysis clearly indicated that CO_2 emissions reductions policies will create a cost to the U.S. economy. Reducing CO_2 emissions will require fundamental changes in how energy is produced, transformed and used. Emissions abatement costs will be a combination of investments today to ensure ample supplies of low-cost, low-emissions-intensity energy alternatives in the future and reliance on higher cost substitutes in the interim. The key criterion in choosing a technology strategy is minimizing these costs.

The 2007 analysis demonstrated that under a representative economy-wide CO_2 emissions constraint (flat from 2010-2020, 3%/year decline beyond 2020), development and deployment of the Full portfolio of technologies would reduce the negative impact on U.S. GDP by $1.0 trillion, relative to the Limited Portfolio. Figure A-1 shows the economic benefits of the individual technologies and the cumulative effect of implementation of the Full portfolio. The first bar shows the $1.5 trillion aggregate economic impact without the implementation of advanced technologies. Moving to the right, the red portions of the bars illustrate the economic benefit of incorporating each technology individually. Note that the relationship between these individual benefits and the benefit of implementing all technologies is not additive, due to complex interactions between different economic sectors and how they use energy.

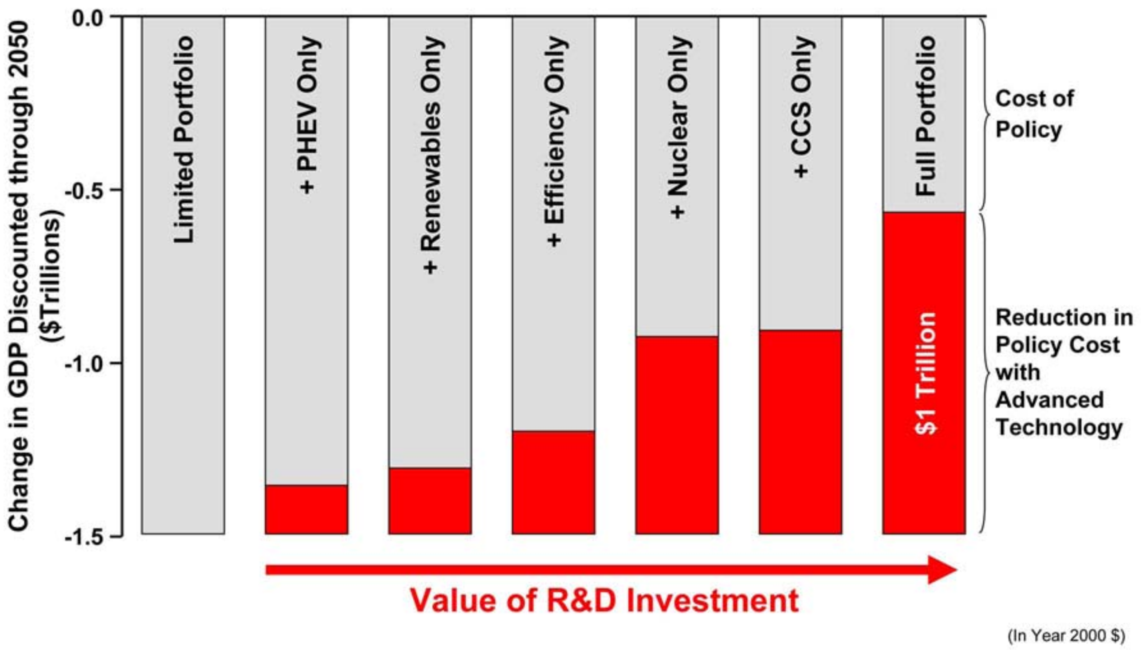


Figure A-1
Economic benefits of advanced technology

The economic benefits of adopting a full portfolio technology strategy were also evident in lower projected CO_2 allowance and wholesale electricity prices.

The MERGE analysis also projected the mix of technologies over time that would maximize U.S. GDP while meeting the specified emissions constraint. Figure A-2 below compares the generation mix calculated in the 2007 EPRI MERGE analysis for the Limited Portfolio and Full portfolio scenarios. Each of these results represents the economic optimum mix of technologies given technology availability, costs, and the emissions constraint. In the Limited Portfolio scenario, emissions reductions require large reductions in electricity demand, which places severe constraints on economic growth. In contrast, for the Full portfolio scenario, the availability of CCS and nuclear generation provide large-scale, supply-side emissions reductions so that the electricity market is preserved and constraints on economic growth are limited. The availability of advanced generation technologies results in a substantially lower projection for wholesale electricity costs (expressed in 2000 $) – reaching $65/MWh in 2050 compared to $160/MWh if emissions reductions are met under the Limited Portfolio scenario (note that the 2000 average U.S. wholesale electricity cost was $44/MWh).

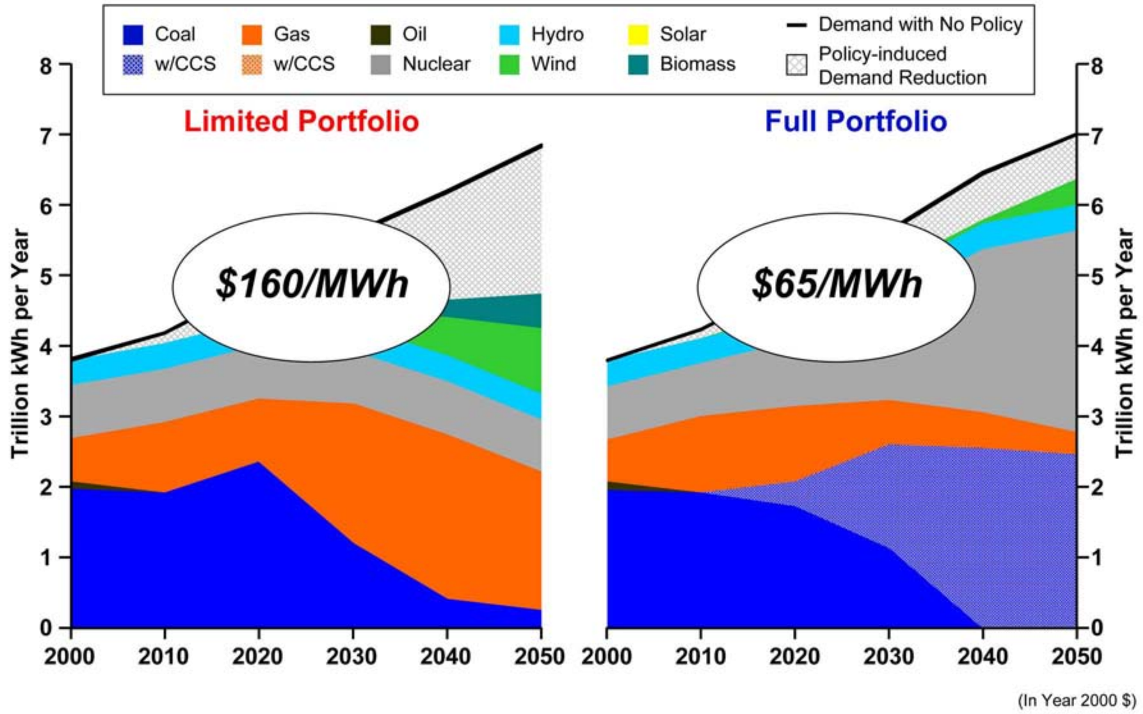


Figure A-2
Technology mix over time under the 2007 limited and full portfolio scenarios

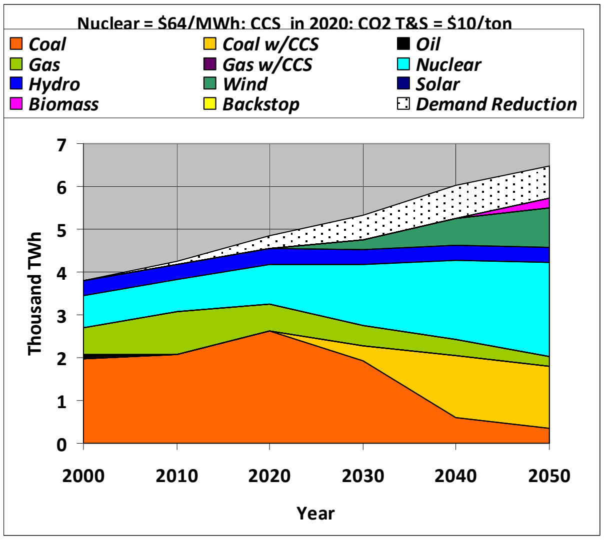
Another important insight of the MERGE analysis is the opportunity for electricity to provide low carbon energy throughout the economy. In particular, advanced technology allows the electricity price to remain relatively stable while CO_2 prices continue to rise, providing incentives for decarbonization of the overall economy.

B
2008 SENSITIVITY STUDIES

This appendix presents detailed results for the analysis of 16 separate cases representing the different combinations of nuclear electricity production costs, timing of CO_2 capture/storage (CCS) availability, and costs of CO_2 transport and storage described above. Results from these analyses are presented in two ways.

The initial set of charts shows the level of electricity generation and the economically optimal composition of the generation technology mix between 2000 and 2050 under the assumed CO_2 emissions constraint. These charts also show the difference in the level of electricity demand for the same set of technology assumptions between cases with and without CO_2 emissions constraints (see also discussion under Demand Reduction in section 2 of this report). For each of the four nuclear cost cases, a panel of four charts is shown depicting electricity generation vs. time for each combination of the timing of CCS and the cost of CO_2 transport and storage.

Given the significance of these technologies within the generation portfolio, the second set of charts compares the variation of generation shares over the range of different scenarios for nuclear and coal with CCS. Two panels of four charts show the generation share in percentage terms for each of the CCS timing and CO_2 transport and storage combinations. Each chart contains four curves representing the four nuclear cost cases.


Nuclear = $64/MWh; CCS in 2020; CO2 T&S = $10/ton
Coal
Gas
Hydro
Biomass
Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
Solar
Demand Reduction
Thousand TWh
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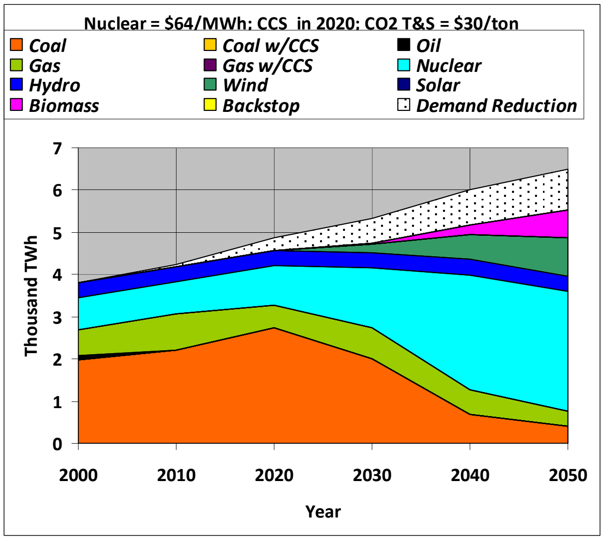
Nuclear = $64/MWh; CCS in 2020; CO2 T&S = $30/ton
Coal
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Biomass
Coal w/CCS
Gas w/CCS
Wind
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Oil
Nuclear
Solar
Demand Reduction
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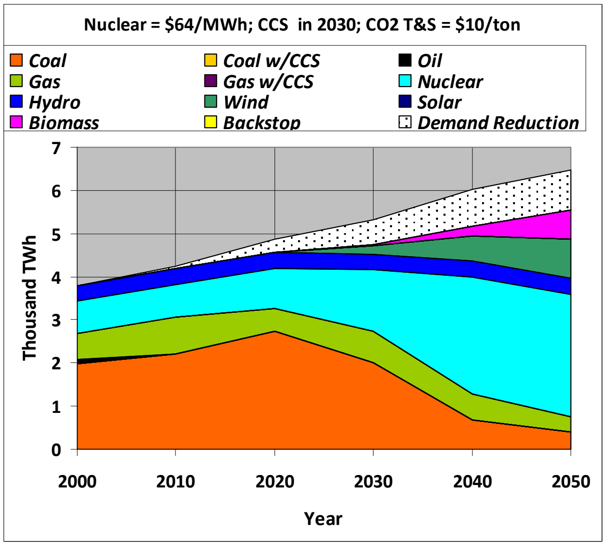
Year


Nuclear = $64/MWh; CCS in 2030; CO2 T&S = $10/ton
Coal
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Hydro
Biomass
Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
Solar
Demand Reduction
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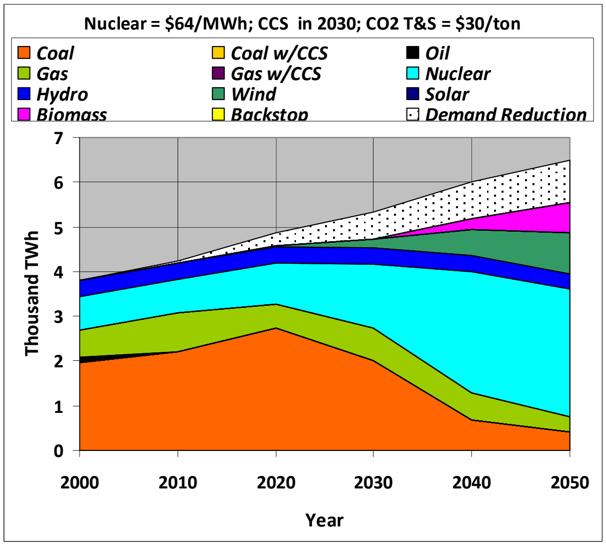
Nuclear = $64/MWh; CCS in 2030; CO2 T&S = $30/ton
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Gas w/CCS
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Nuclear
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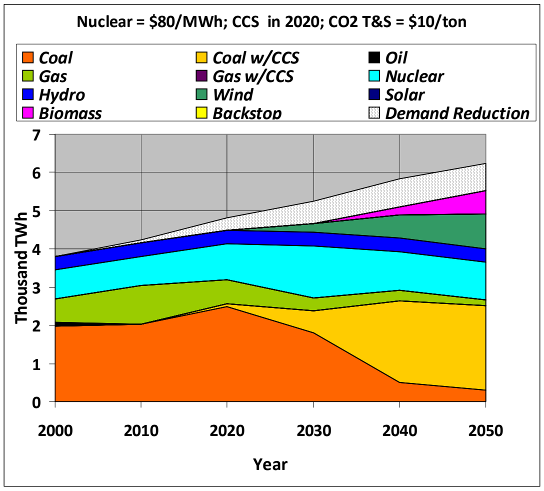
Nuclear = $80/MWh; CCS in 2020; CO2 T&S = $10/ton
Coal
Gas
Hydro
Biomass
Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
Solar
Demand Reduction
Thousand TWh
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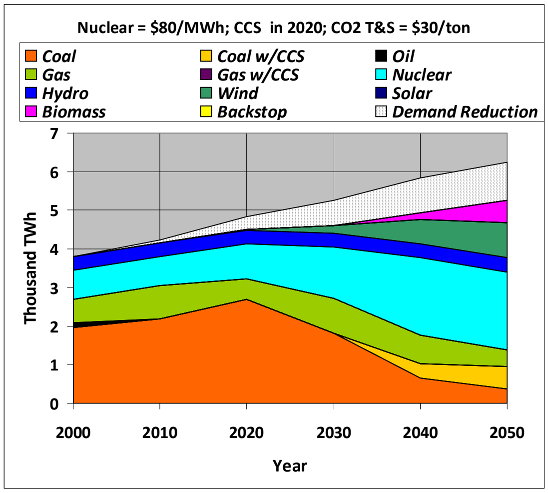
Year


Nuclear = $80/MWh; CCS in 2020; CO2 T&S = $30/ton
Coal
Gas
Hydro
Biomass
Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
Solar
Demand Reduction
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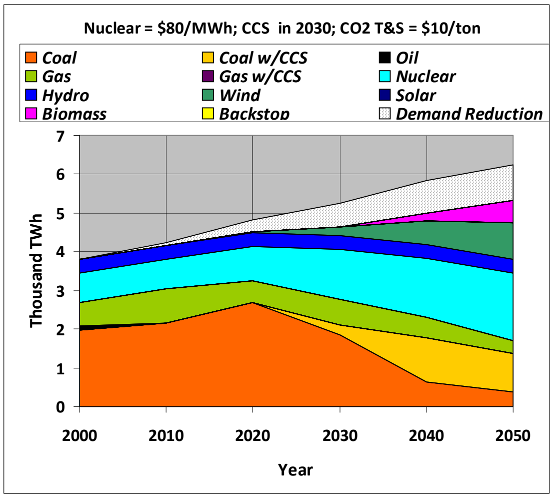
Nuclear = $80/MWh; CCS in 2030; CO2 T&S = $10/ton
Coal
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Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
Solar
Demand Reduction
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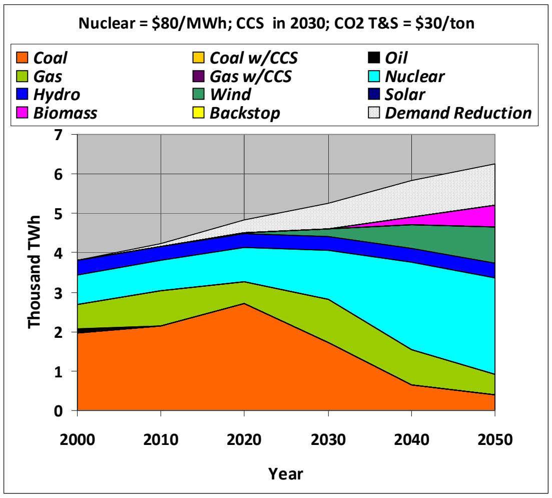
Nuclear = $80/MWh; CCS in 2030; CO2 T&S = $30/ton
Coal
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Biomass
Coal w/CCS
Gas w/CCS
Wind
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Oil
Nuclear
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Demand Reduction
Thousand TWh
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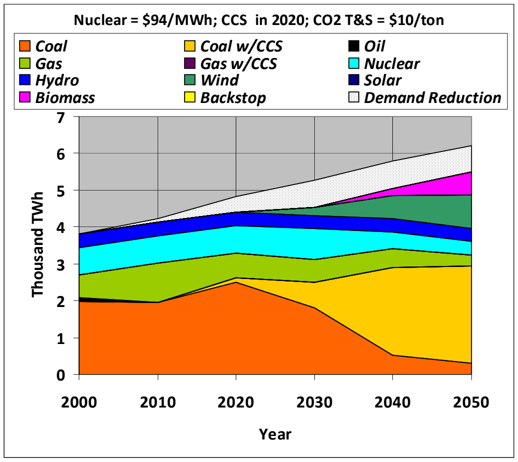
Year


Nuclear = $94/MWh; CCS in 2020; CO2 T&S = $10/ton
Coal
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Hydro
Biomass
Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
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Demand Reduction
Thousand TWh
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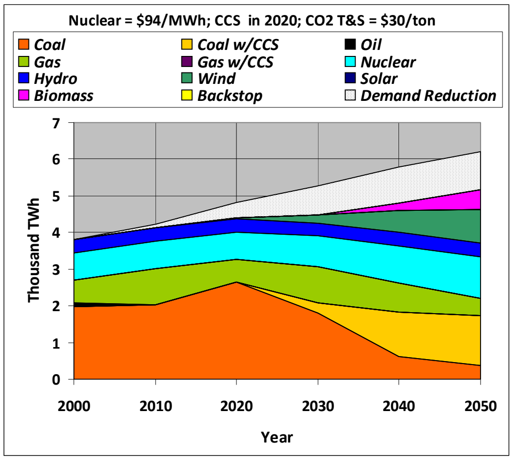
Nuclear = $94/MWh; CCS in 2020; CO2 T&S = $30/ton
Coal
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Biomass
Coal w/CCS
Gas w/CCS
Wind
Backstop
Oil
Nuclear
Solar
Demand Reduction
Thousand TWh
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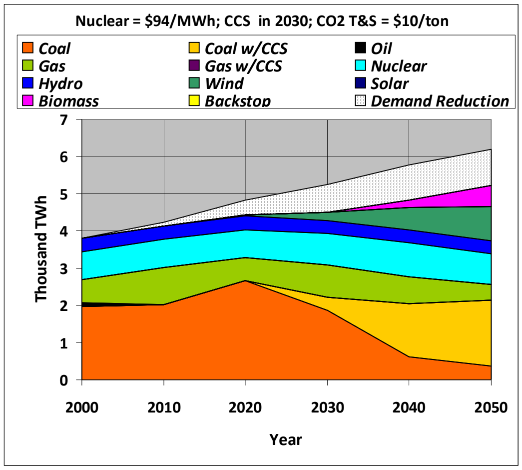
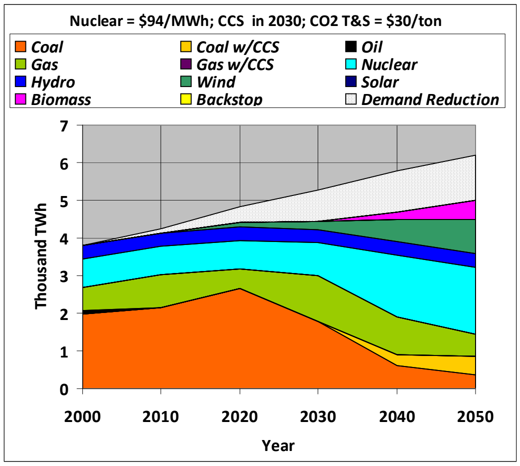
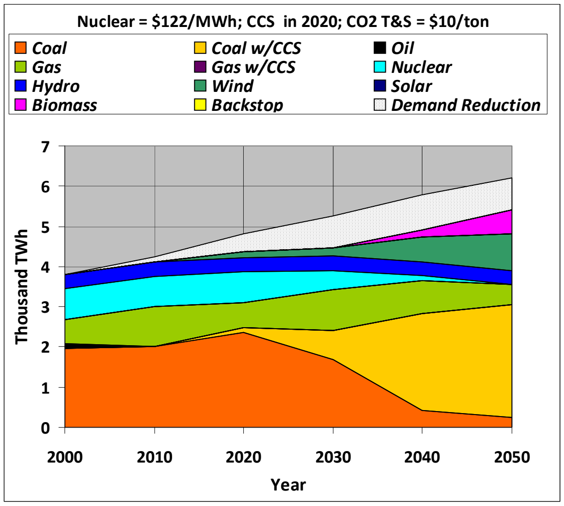
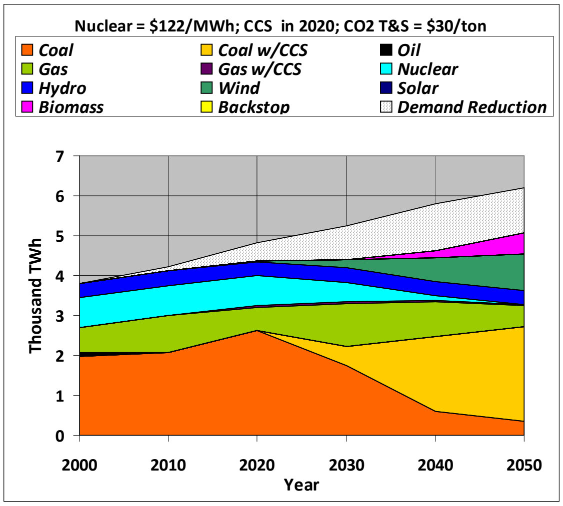
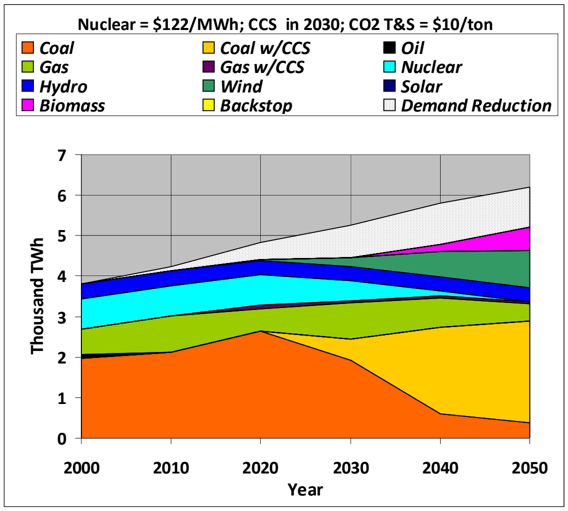
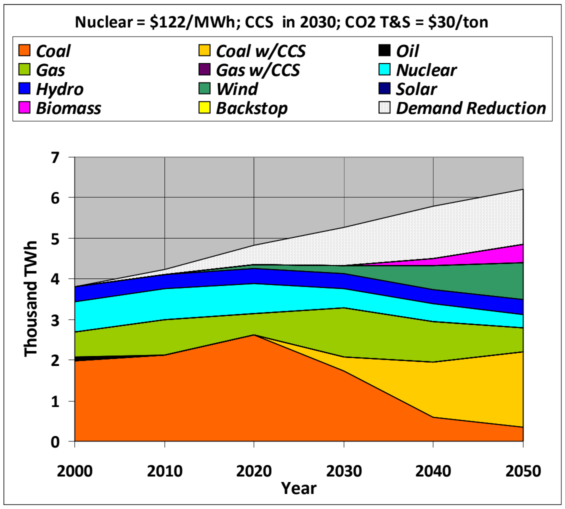

Nuclear = $94/MWh; CCS in 2030; CO2 T&S = $10/ton

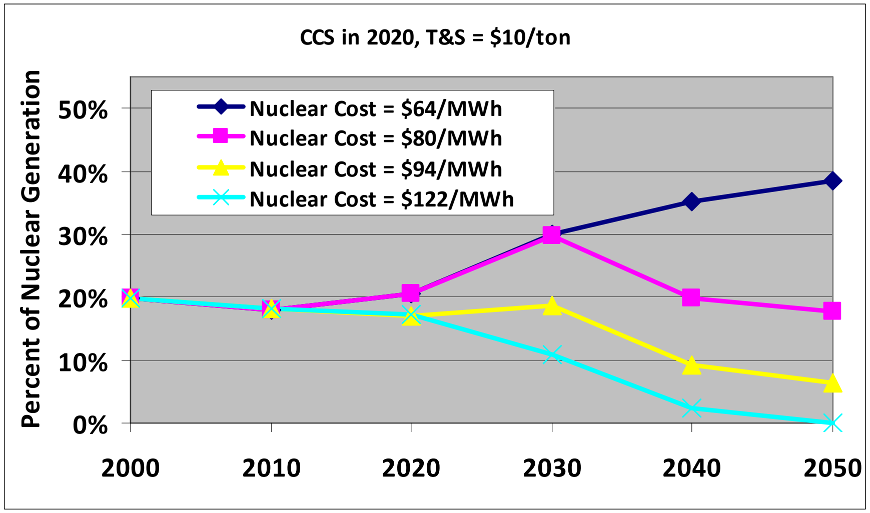

Nuclear = $94/MWh; CCS in 2030; CO2 T&S = $30/ton

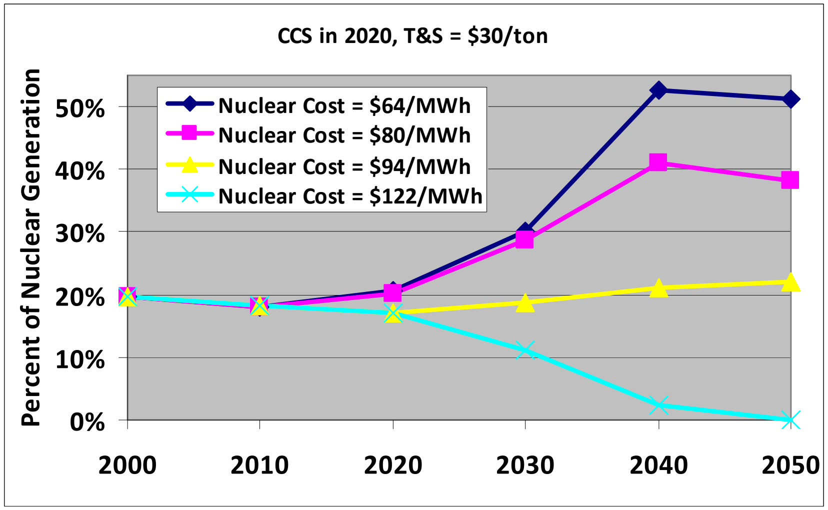

Nuclear = $122/MWh; CCS in 2020; CO2 T&S = $10/ton

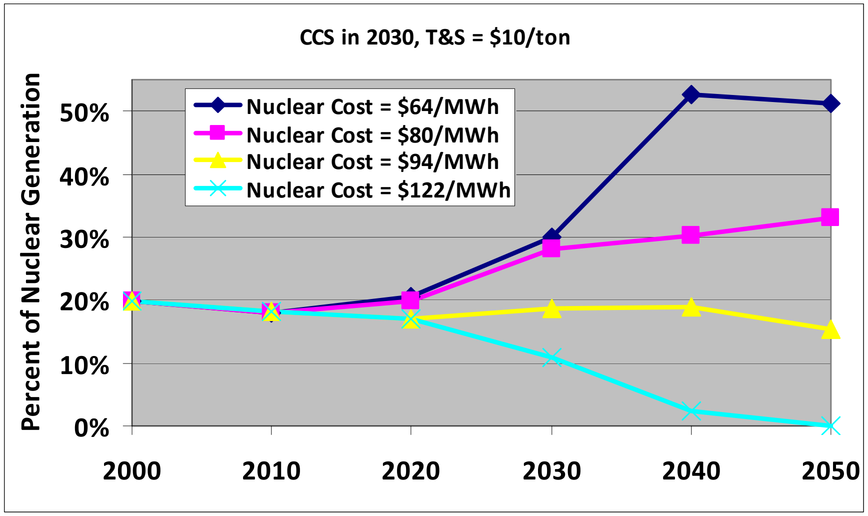

Nuclear = $122/MWh; CCS in 2020; CO2 T&S = $30/ton

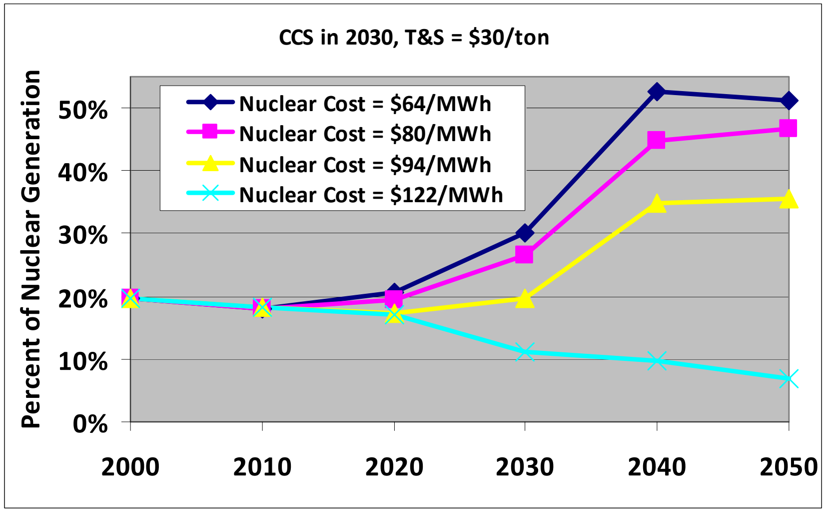

Nuclear = $122/MWh; CCS in 2030; CO2 T&S = $10/ton

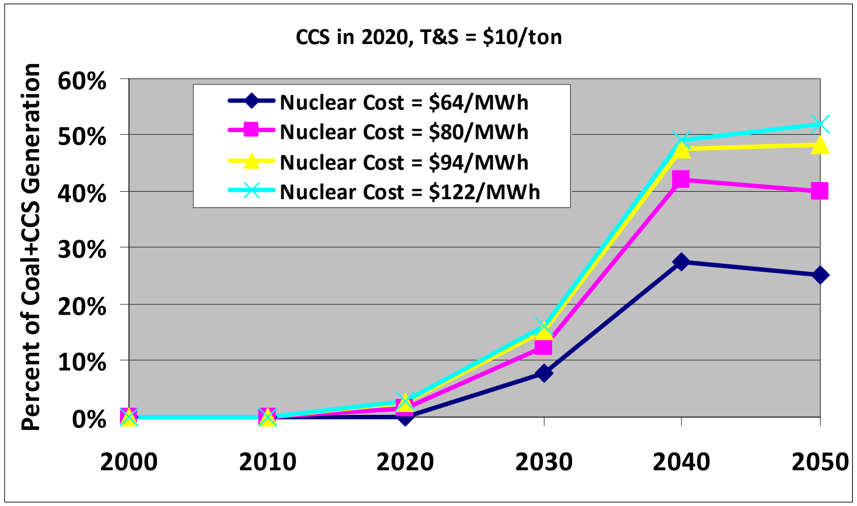

Nuclear = $122/MWh; CCS in 2030; CO2 T&S = $30/ton


CCS in 2020, T&S = $10/ton


CCS in 2020, T&S = $30/ton


CCS in 2030, T&S = $10/ton


CCS in 2030, T&S = $30/ton


CCS in 2020, T&S = $10/ton
Percent of Coal+CCS Generation
60%
50%
40%
30%
20%
10%
0%
2000
2010
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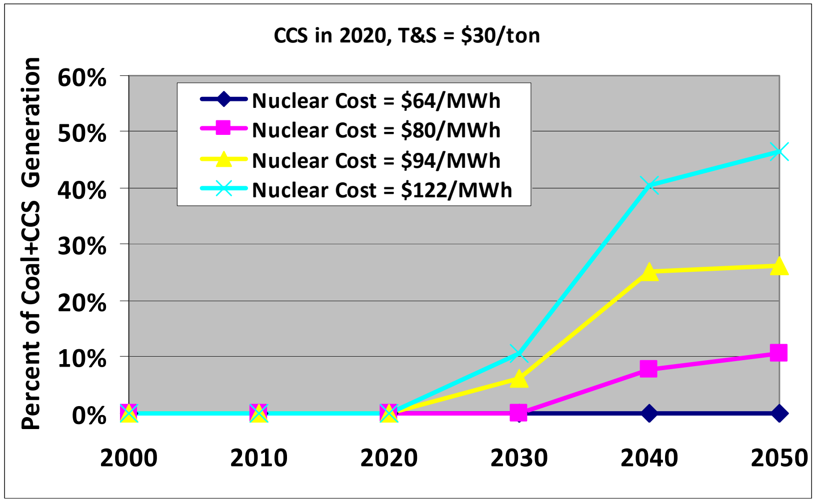
2040
2050
Nuclear Cost = $64/MWh
Nuclear Cost = $80/MWh
Nuclear Cost = $94/MWh
Nuclear Cost = $122/MWh


CCS in 2020, T&S = $30/ton
Percent of Coal+CCS Generation
60%
50%
40%
30%
20%
10%
0%
2000
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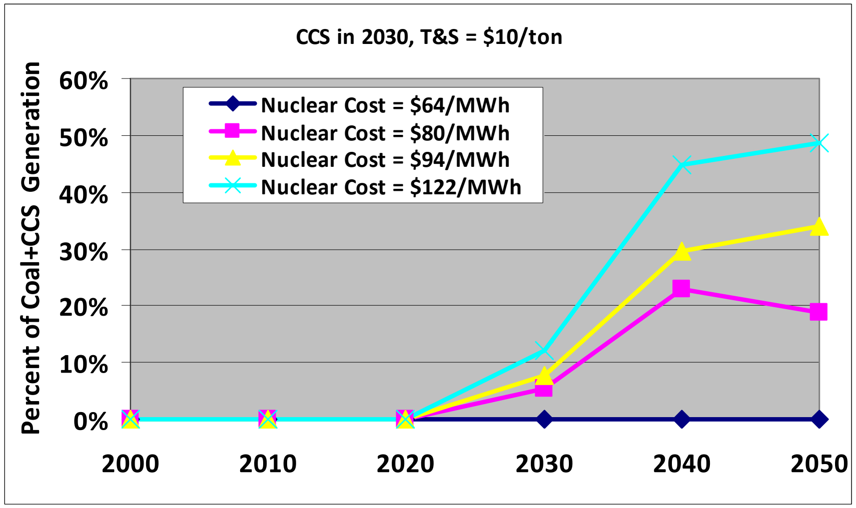
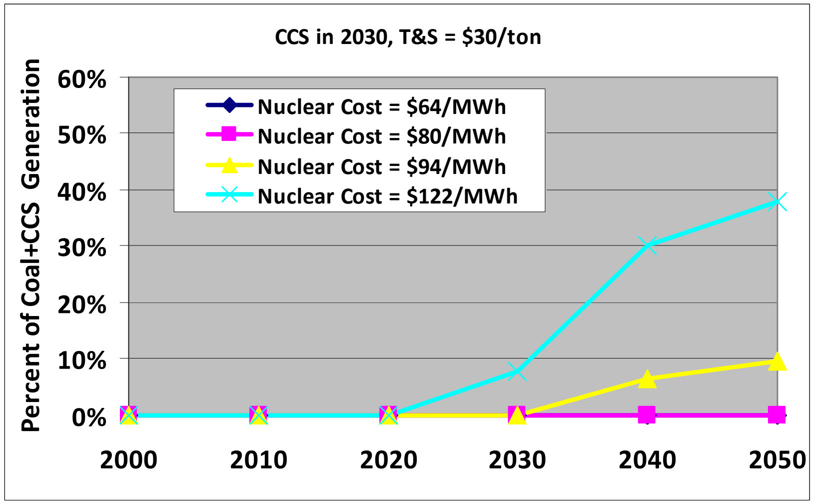
Nuclear Cost = $64/MWh
Nuclear Cost = $80/MWh
Nuclear Cost = $94/MWh
Nuclear Cost = $122/MWh


CCS in 2030, T&S = $10/ton
Percent of Coal+CCS Generation
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Nuclear Cost = $64/MWh
Nuclear Cost = $80/MWh
Nuclear Cost = $94/MWh
Nuclear Cost = $122/MWh


CCS in 2030, T&S = $30/ton
Percent of Coal+CCS Generation
60%
50%
40%
30%
20%
10%
0%
2000
2010
2020
2030
2040
2050
Nuclear Cost = $64/MWh
Nuclear Cost = $80/MWh
Nuclear Cost = $94/MWh
Nuclear Cost = $122/MWh

C
2008 SENSITIVITY STUDY ASSUMPTIONS

Beyond the assumptions regarding nuclear and coal with CCS described in Appendix B, the 2008 scenario analyses assumed updated technology costs based on data from EPRI's Technology Assessment Guide (TAG) research program as documented in the EPRI study "Generation Options under a Carbon-Constrained Future" (October 2007). In addition, assumptions regarding technology growth consistent with those from the 2007 EPRI analysis1 were also made. All of these assumptions are summarized here.

General assumptions:

- An economy-wide CO_2 emissions constraint requiring no growth in annual emissions from 2010-2020 followed by a 3%/year decline.
- Retirements of existing coal and nuclear plants are modeled in this analysis; nuclear and coal plants are assumed to have 60 year lifetimes.
- Other generic assumptions regarding the economic modeling are described in Reference 1.

Table C-1
Technology capital cost assumptions (all figures in 2006 $)

Technology	Timeframe			Notes
	2010	**2020**	**2030–2050**	
Coal	$43/MWh 38% efficiency	$39/MWh 42% efficiency	$37/MWh 46% efficiency	• Average of pulverized coal, integrated gasification combined cycle • Excludes fuel cost (~$13-$14/MWh)
Coal + CO_2 capture and storage (CCS)	Not available	$64/MWh 31% efficiency	2030: $58/MWh 33% efficiency 2040: $50/MWh 37% efficiency 2050: $44/MWh 42% efficiency	• Average of pulverized coal, integrated gasification combined cycle • Excludes fuel cost (~$16-$19/MWh) • Excludes CO_2 transport/storage cost. • For cases where CCS is delayed until 2030, the costs shown at left are shifted 10 years into the future.
Natural Gas	$14.5/MWh 47% efficiency	$13/MWh 47% efficiency	$13/MWh 51% efficiency	• Excludes fuel cost
Natural Gas + CO_2 capture and storage (CCS)	Not available	$29/MWh 39% efficiency	$29/MWh 42% efficiency	• Excludes fuel cost
Nuclear Scenarios				• Capacity factor = 90% • Efficiency = 33% • Plant life = 60 years • Added non-market cost = ~$10/MWh (at current generation share for nuclear); scales with increasing nuclear generation share.

Table C-1 (continued)
Technology capital cost assumptions (all figures in 2006 $)

Technology	Timeframe			Notes
	2010	2020	2030–2050	
Nuclear Scenarios (continued)	$64/MWh	$64/MWh	2030: $62/MWh 2040: $60/MWh 2050: $58/MWh	• Inclusive of fuel cost • Ranges represent different scenarios.
	$80/MWh	$80/MWh	2030: $78/MWh 2040: $75/MWh 2050: $73/MWh	• Inclusive of fuel cost • Ranges represent different scenarios.
	$94/MWh	$94/MWh	2030: $91/MWh 2040: $88/MWh 2050: $86/MWh	• Inclusive of fuel cost • Ranges represent different scenarios.
	$122/MWh	$122/MWh	2030: $118/MWh 2040: $115/MWh 2050: $111/MWh	• Inclusive of fuel cost • Ranges represent different scenarios.
Wind	$96/MWh	$75/MWh	2030: $73/MWh 2040: $71/MWh 2050: $69/MWh	• 2010: 32% capacity factor • 2020-2050: 42% capacity factor • Limited to maximum 20% of total U.S. generation
Biomass	$107/MWh	$90/MWh	2030: $87/MWh 2040: $85/MWh 2050: $82/MWh	• 85% capacity factor • Combined with wind, limited to 30% of total U.S. generation
Solar thermal	$190/MWh	$190/MWh	2030: $184/MWh 2040: $180/MWh 2050: $173/MWh	• 34% capacity factor

Table C-1 (continued)
Technology capital cost assumptions (all figures in 2006 $)

Technology	Timeframe			Notes
	2010	**2020**	**2030–2050**	
Solar photovoltaic	$250/MWh	$220/MWh	2030: $194/MWh 2040: $170/MWh 2050: $173/MWh	
Plug-in Hybrid Electric Vehicles	• $4000 price premium/ vehicle • Maximum 3% vehicle fleet	• $3000 price premium/ vehicle • Maximum 16% vehicle fleet	• $2000 price premium/ vehicle declining by $1000/decade. • 2030: maximum 16% vehicle fleet • 2040: maximum 60% of vehicle fleet • 2050: maximum 100% of vehicle fleet	

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