POLICY BRIEF

The Lieberman-Warner America's Climate Security Act: A Preliminary Assessment of Potential Economic Impacts

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October 2007

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FOR ENVIRONMENTAL POLICY SOLUTIONS
DUKE UNIVERSITY

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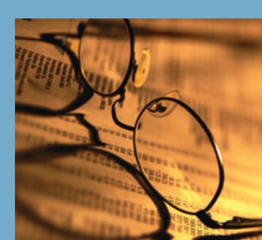
NI PB 07-04







The Lieberman-Warner America's Climate Security Act: A Preliminary Assessment of Potential Economic Impacts

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BACKGROUND

On August 2, 2007 Senator Lieberman and John Warner (R-VA) introduced a framework for *Lieberman-Warner America's Climate Security Act of 2007*. The proposal, which we refer to here as the "Lieberman-Warner" bill, calls for the United States to make substantial cuts in greenhouse gas (GHG) emissions below current levels by 2050. Such GHG emissions cuts will contribute to global efforts aimed at reducing atmospheric concentrations of GHG and mitigating harm to our climate system. The most recent assessment report of the *Intergovernmental Panel on Climate Change* provides a scientific basis for the world's countries to take strong action to mitigate the threats of climate change.

The stated purpose of the GHG cuts out to 2050 in the Lieberman-Warner bill is to "avert catastrophic impacts of climate change, and to do so while preserving robust economic growth in the US economy and avoiding the imposition of hardship on US citizens." Toward that end, this paper briefly summarizes how the actions necessary to meet the requirements of the proposed Lieberman-Warner bill might affect general and specific economic indicators using a model of the U.S. economy. Actions to fight the risks of climate change require a commitment of resources and investment and deployment of low-carbon technologies that cut across virtually all sectors of the economy. Because these resources are diverted from other uses in the economy, they entail opportunity costs, which are estimated and described below. It is important to recognize that our

[1] We acknowledge the research assistance of Kevin Fritze, Duke University. The analysis herein was done collaboratively by the two authors under a strategic alliance between Duke University and RTI International. All opinions are their own and should not be interpreted as the views or positions of their research institutions.

analysis does not consider or monetize the many potential economic benefits from successfully addressing climate change risks, including foregone damages to human health, ecosystems and human infrastructure, all of which are important to consider along with the costs evaluated here.

PROPOSED POLICY

The Lieberman-Warner framework issued in August, 2007 called for the electric power, transportation, and industrial sectors of the economy to cut emissions to 70% below 2005 levels by 2050, according to the following periodic benchmarks along the way (Table 1).

Table 1. Emission Reduction Benchmarks: Lieberman-Warner

Year	Emissions below 2005 levels
2012	0%
2020	-10%
2030	-30%
2040	-50%
2050	-70%

Small entities within the three sectors are exempt from coverage subject to the following size thresholds in Table 2:

Table 2: Coverage Size Thresholds by Sector: Lieberman-Warner

Sector	Coverage Size Threshold
Electric power	10 megawatts
Transportation	10,000 tons, CO2 equivalent
Industry	10,000 tons, CO2 equivalent

To determine the emissions trajectory allowed under the Lieberman-Warner bill, we set the 2012 emissions cap equal to the 2005 GHG emissions from the US EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005 (US EPA 2007a). We further reduced the cap to account for entities falling below the thresholds indicated in Table 2. The electric power and transportation sectors have virtually all of their emissions covered by the cap, the industrial sector has approximately 84% of its emissions covered, which is consistent with a recent estimate by the Nicholas Institute (2007). Netting out uncovered sectors and entities gives a target covered emissions rate of approximately 5,450 million tons of CO_2 equivalent emissions capped in 2012. Together the covered entities account for just over 75 percent of the GHG emissions in the U.S. economy.

Figure 1 depicts the capped emissions trajectory, following the benchmarks defined in Table 1, as well as reference case emissions under "Business-as-Usual" (BAU), estimated by the ADAGE model used for this analysis (see below).

The L-W targets to 2050 are contrasted with the expected emissions under a BAU reference case presented in Exhibit 1.

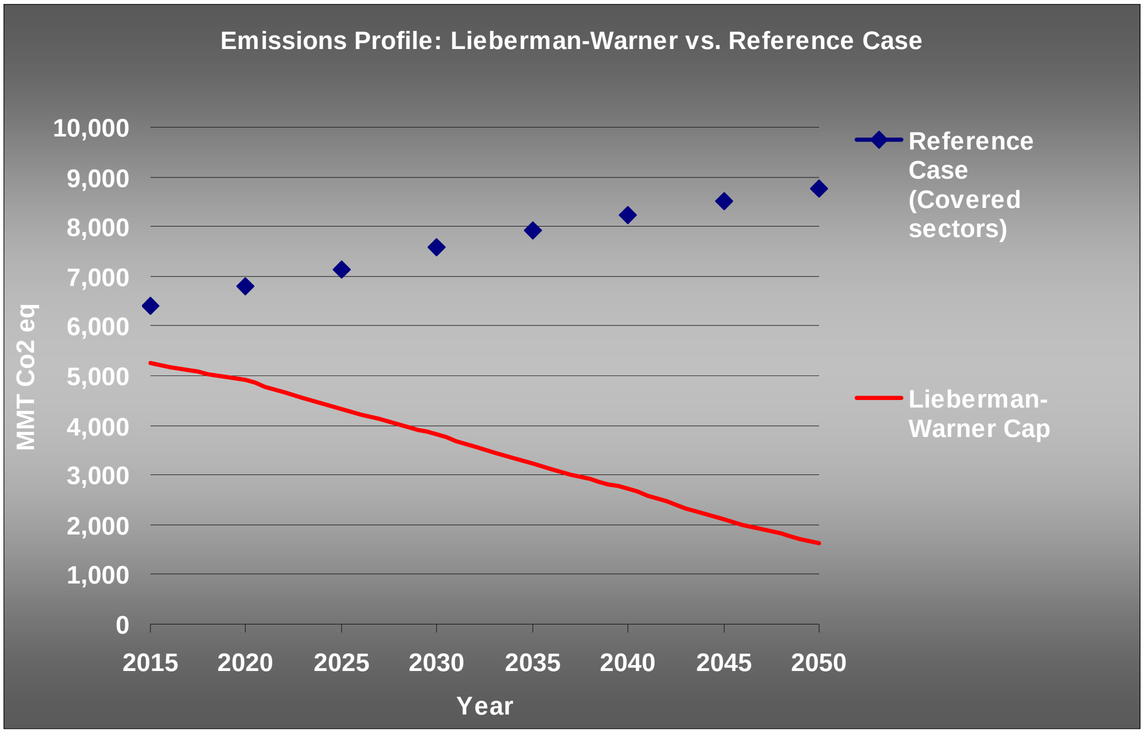


Figure 1. Emissions Profile: Lieberman-Warner Cap vs. Reference Case

While the analysis prepared here is based on the emissions targets defined in the August, 2007 framework proposal, we recognize that a detailed version of the proposal was released on October 18, 2007 with somewhat different targets than those outlined here. We expect that more comprehensive analyses of that detailed proposal will be conducted by the economic modeling community in the months to come. This analysis, therefore, can be best viewed as a preliminary quick glance at the potential impacts of the legislation, serving as a point of departure for the more detailed analyses to follow.

ADAGE MODEL

To examine the potential impacts of the Lieberman-Warner proposal, we use the ADAGE economic model developed by RTI International (Ross, 2007). The *Applied Dynamic Analysis of the Global Economy* (ADAGE) model is a dynamic computable general equilibrium (CGE) model capable of examining many types of economic, energy, environmental, climate-change mitigation, and trade policies at the international, national, U.S. regional, and U.S. state levels. The focus of this analysis is at the national level for the U.S. To investigate policy effects, the CGE model combines a consistent theoretical structure with economic data covering all interactions among businesses and households in the economy. Economic data in ADAGE come from the Global Trade Analysis Project (GTAP) and IMPLAN model databases, and energy data and various growth forecasts come from the International Energy Agency and Energy Information

Administration of the U.S. Department of Energy. Emissions estimates and associated abatement costs for six types of greenhouse gases (GHG) are also included in the model. For more detail on the ADAGE model including data sources, see Ross (2007).

ADAGE is also used by US EPA to provide economic analysis of proposed climate legislation and policy (see, for example, US EPA, 2007(b) analysis of The Climate Stewardship and Innovation Act of 2007, http://www.epa.gov/climatechange/downloads/s280fullbrief.pdf) and thereby provides an appropriate frame of reference for analyzing provisions of newly introduced legislation, such as the Lieberman-Warner bill.

MODELING RESULTS SUMMARY

The ADAGE model was run to generate reference case (BAU baseline) and policy scenarios for the Lieberman-Warner bill. The difference between a baseline run and a policy run is that in the latter, the economy is constrained to meet its emission target, whereas in the former, there are no constraints imposed on the economy and no incentives to cut GHGs. Detailed results are found in both tabular and graphic form in the appendix for a whole range of economic variables tracked by the model, with a special emphasis on the following variables over the time period 2015-2050

- GHG emissions
- Allowance prices
- Gross Domestic Product (GDP)
- Primary Energy Use (fossil and non-fossil)
- Energy Prices (fuels and electricity)
- Electricity generation mix

The key results are highlighted here, first for the core run of the Lieberman-Warner scenario, then for variations on the core run that tighten the stringency and expand the scope of coverage, then comparatively to the results for the economic analysis done by EPA for *The Climate Stewardship and Innovation Act of 2007* (S.280).

Core Lieberman-Warner Scenario

The core scenario holds the covered sectors to the target outlined above, while allowing entities to achieve these targets through allowance trading, offsets from domestic offsets and international credits to the full extent allowed, and banking and borrowing over time as needed. The key results from this scenario are briefly summarized below.

- **The policy generates substantial emissions reductions across the economy**. Total U.S. GHG emissions (including capped and uncapped sectors) are projected to be approximately 27% lower than Reference Case emissions in 2030, and 44% lower in 2050.
- **The capped sectors rely significantly on domestic offsets and international credits to achieve their net emission reduction targets**. Offsets bring in less expensive emission reductions from uncapped sources and thereby allow

compliance at a lower cost than could be achieved by the covered sectors acting alone.

- **Allowance prices** are projected at $18/t CO2e in 2015, $38 /tCO2e in 2030, and $101 /tCO2e in 2050.
- **Compliance with the targets has a small effect on rising GDP**. By 2030 GDP is projected to increase 112% from 2005 levels in the Reference Case, and by 2050 the projected increase in GDP from 2005 levels is 238%. Under Lieberman-Warner, GDP is estimated by the model to be 0.5% ($75 billion) lower in 2015, 0.9% ($245 billion) lower in 2030 and 1.5% ($658 billion) lower in 2050 than in the Reference Case.
- **Mitigation involves a heavy switch from fossil to non-fossil energy in the near term, but a return of fossil energy as carbon capture and storage (CCS) becomes viable.** Coal use drops substantially in the early years of the policy (42% below baseline in 2020) but recovers from 2030-2050 as CCS networks are assumed to develop. Natural gas consumption stays roughly on its baseline track in the early years, as direct reduced demand is buffeted by fuel-switching from coal. But in the long run, natural gas use falls below the reference case as the energy sector becomes more decarbonized. Nuclear generation rises substantially over the course of the policy.
- **By 2045, 90 percent of CO_2 emissions from the electricity sector are being captured through CCS technologies.** Thus, additional reductions must come from other sectors, where abatement comes at a higher cost.
- **Fossil energy "demand" (or consumer) prices all rise once the GHG allowance price is incorporated. "Supply" (or producer) prices may fall in response to reduced demand.** For example, in 2030 the final demand price for petroleum is about 9% higher than the Reference Case, but the market supply price declines by about 4%.
- **Electricity prices are expected to rise.** As the electric power moves to decarbonized electricity, the price per kilowatt hour (kwh) will rise over time – 18% above the reference case in 2015, 30% above in 2030, and 27% above in 2050.

Sensitivity to changes in stringency and scope

We considered variations on the Lieberman-Warner cap that accelerates the pace of required reductions between 2012 and 2020 ("tighter cap") as well as the possibility of including the residential and commercial sectors under the cap (they are not covered in the main results). Results from these sensitivity runs are:

- **A tighter cap moderately raises the allowance price** from $18 to $20/t CO2e in 2015, from $38 to $42 in 2030, and from $101 to $111 in 2050.
- **Expanding coverage to include emissions in residential and commercial sectors reduces the allowance price somewhat, but raises the GDP impact.** Expanding the cap to include emissions from natural gas and heating oil used in homes and buildings provides more mitigation options and therefore reduces the marginal cost of allowances, yielding allowance price of $16/t CO2e in 2015, $33

in 2030, and $88 in 2050. GDP effects, though, would be slightly higher than in the core scenario: -0.51% vs -0.45% in 2015, -1.00% vs. -0.93% in 2030, and -1.59% vs -1.54% in 2050.

Comparison to EPA Results for S280

The results in this analysis are compared to the results from the EPA analysis (US EPA, 2007) using the ADAGE model to evaluate the effects of *The Climate Stewardship and Innovation Act of 2007* (S.280). The key differences are highlighted here.

- **Lieberman-Warner emission cuts are deeper than S.280.** Sector coverage under the proposed Lieberman-Warner cap is somewhat different than under S.280, and cumulative emissions allowed under the cap are around 10% less than S.280, in large part due to the requirement of a steadily declining cap under Lieberman-Warner, rather than the ratcheted or "stair step" cap under S280.
- **Projected allowance prices are higher under Lieberman-Warner.**

	2015	2030	2050
Lieberman-Warner	$18	$38	$101
S.280	$13	$27	$70

- **GDP impacts are larger, but still small relative to rising GDP levels in the economy.** GDP effects relative to the GDP Reference Case are

	2015	2030	2050
Lieberman-Warner	-0.45%	-0.93%	-1.54%
S.280	-0.22%	-0.55%	-1.07%

- **Under Lieberman-Warner, the pace of adoption of CCS accelerates and the scale expands relative to S.280.** CCS is not expected to be commercially viable at a large scale until around 2025. Starting in 2025, the adoption of CCS is more aggressive under the Lieberman-Warner proposal due to the more stringent target.

CONCLUSIONS

The draft framework for *Lieberman-Warner America's Climate Security Act of 2007*, proposed on August, 2, 2007 calls for substantial cut in GHG emissions, with a target of 2005 emissions levels by 2012 and 70% below that level by 2050. Though modeled in many ways after The *Climate Stewardship and Innovation Act of 2007* (S.280), the targets go a bit deeper. As a result, the economic impacts are expected to be somewhat more pronounced than under S.280, thought still small relative to the scale of economic activity in the economy. Because meeting these targets is largely an energy sector task, energy price effects are larger proportionally than overall GDP effects, but this is the price signal that drives increases in energy efficiency necessary to meet the targets. Achieving these emission reductions will require a substantial shift in the way that energy is produced and used in this country, for instance requiring an almost completely decarbonized electric power sector by 2050. Cuts in the rest of the economy are a bit more difficult to achieve and there is likely to be a heavy reliance on offsets from uncapped sectors to attain national compliance. If these offsets do not materialize, costs would go up. On the other hand, if offsets – or any form of mitigation in the capped sectors - are cheaper than the models estimate, compliance costs would go down. The actual realized cost of the policy will depend significantly on the development and deployment of low-carbon technologies that are not widely in use today. Indeed, it may involve deployment of technologies not yet on the drawing board. It is difficult to predict and model how these developments will occur, but some mix of public and private investment will likely be necessary to further develop the portfolio of options. Moreover, complementary policies focused on accelerating the pace of adoption may also be considered. Capturing these factors in the long-term economic assessment of climate policy remains the focus of the economic modeling community's continued efforts.

REFERENCES

Nicholas Institute. 2007. *Size Thresholds for Greenhouse Gas Regulation: Who Would be Affected by a 10,000-ton CO2 Emissions Rule?* Policy Brief NI PB 07-02. Nicholas Institute for Environmental Policy Solutions, Duke University. http://www.nicholas.duke.edu/institute/10Kton.pdf

Ross, Martin T. 2007. *Documentation of the Applied Dynamic Analysis of the Global Economy (ADAGE) Model.* Working paper 07-02. RTI International. http://www.rti.org/pubs/adage-model-doc_ross_apr07.pdf

US EPA. 2007a. *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005.* USEPA #430-R-07-002. US Environmental Protection Agency, Washington,DC. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

US EPA. 2007b. EPA Analysis of the Climate Stewardship and Innovation Act of 2007: S.280 in 110'th Congress. Briefing available online at http://www.epa.gov/climatechange/downloads/s280fullbrief.pdf

APPENDIX OF DETAILED RESULTS

TABLES

FIGURES

Lieberman-Warner Core Scenarios

Sensitivity Cases

Comparison to S.280

Table A-1. Reference Case

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Macroeconomic									
Population *(millions)*	308.9	322.4	335.8	349.4	363.6	373.8	383.1	391.6	399.6
GDP *(billion 2005$)*	$14,620	$16,910	$19,819	$22,953	$26,438	$30,046	$33,958	$38,171	$42,697
% Change in GDP	--	--	--	--	--	--	--	--	--
Consumption *(bill 2005$)*	$10,783	$12,398	$14,638	$17,030	$19,721	$22,418	$25,350	$28,505	$31,887
% Change in Consump	--	--	--	--	--	--	--	--	--
Allowance Price - $/t$CO_2$e	--	--	--	--	--	--	--	--	--
Energy Prices - delivered (with allowance price)									
Coal *($ per MMBtu)*	$1.59	$1.53	$1.54	$1.59	$1.67	$1.68	$1.70	$1.71	$1.73
Electricity *($ per kWh)*	$0.071	$0.069	$0.071	$0.072	$0.073	$0.074	$0.075	$0.076	$0.078
Natural Gas *($ per MMBtu)*	$7.16	$6.55	$6.89	$7.46	$7.99	$8.10	$8.21	$8.32	$8.42
Petroleum *($ per MMBtu)*	$15.38	$15.84	$16.15	$16.43	$16.69	$16.61	$16.53	$16.44	$16.34
% Change in Coal	--	--	--	--	--	--	--	--	--
% Change in Electricity	--	--	--	--	--	--	--	--	--
% Change in Natural Gas	--	--	--	--	--	--	--	--	--
% Change In Petroleum	--	--	--	--	--	--	--	--	--
GHG Emissions - mmt CO_2e									
CO_2	6,342.5	6,678.4	7,024.1	7,376.6	7,827.5	8,206.9	8,555.0	8,864.2	9,133.4
CH_4	526.4	532.2	546.5	552.7	560.6	560.8	561.6	554.3	547.4
N_2O	374.4	383.1	394.2	403.3	412.7	403.7	395.1	377.2	360.3
HFC	154.3	212.7	275.9	269.8	263.9	256.7	249.7	248.3	246.8
PFC	11.7	10.8	10.6	11.0	11.4	11.8	12.2	12.3	12.3
SF_6	14.2	13.3	13.0	12.9	12.8	12.5	12.3	12.2	12.1
Total	**7,423**	**7,830**	**8,264**	**8,626**	**9,089**	**9,452**	**9,786**	**10,068**	**10,312**
% Change	--	--	--	--	--	--	--	--	--
Primary Energy Use - Quadrillion Btu									
Coal	24.6	25.1	26.5	28.5	31.5	32.8	33.9	34.8	35.5
Natural Gas	24.3	27.1	28.3	28.2	27.9	29.3	30.7	31.9	33.0
Petroleum	43.0	45.3	47.7	50.2	53.2	56.0	58.7	61.2	63.5
Nuclear	8.5	8.7	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Renewable Elec.	4.2	4.3	4.5	4.7	4.9	4.9	5.0	5.1	5.2
Total *	**104.6**	**110.5**	**116.1**	**120.8**	**126.5**	**132.2**	**137.4**	**142.1**	**146.3**
% Change	--	--	--	--	--	--	--	--	--
Energy Intensity - total *									
1000 btu per $ of GDP	7.16	6.53	5.86	5.26	4.79	4.40	4.05	3.72	3.43
Electricity Generation - billion kWh									
Fossil Fuels w/o CCS	2,936	3,208	3,449	3,676	3,981	4,265	4,536	4,787	5,017
Nuclear	816	837	879	879	879	879	879	879	879
Other Non-Fossil	408	414	433	452	470	477	484	491	499
Fossil with CCS	0	0	0	0	0	0	0	0	0
Total	**4,160**	**4,460**	**4,761**	**5,007**	**5,330**	**5,621**	**5,898**	**6,157**	**6,395**
% Change	--	--	--	--	--	--	--	--	--

* Note: only renewable energy used in electricity generation is included.

Emissions		2010	2015	2020	2025	2030	2035	2040	2045	2050
	Total	**7,423.5**	**7,830.5**	**8,264.2**	**8,626.3**	**9,088.9**	**9,452.5**	**9,785.7**	**10,068.4**	**10,312.4**
	CO_2	6,342.5	6,678.4	7,024.1	7,376.6	7,827.5	8,206.9	8,555.0	8,864.2	9,133.4
	CH_4	526.4	532.2	546.5	552.7	560.6	560.8	561.6	554.3	547.4
USA (total)	N_2O	374.4	383.1	394.2	403.3	412.7	403.7	395.1	377.2	360.3
	HFC	154.3	212.7	275.9	269.8	263.9	256.7	249.7	248.3	246.8
	PFC	11.7	10.8	10.6	11.0	11.4	11.8	12.2	12.3	12.3
	SF_6	14.2	13.3	13.0	12.9	12.8	12.5	12.3	12.2	12.1
	Total	**6,039.9**	**6,408.8**	**6,805.7**	**7,146.2**	**7,582.8**	**7,924.3**	**8,236.7**	**8,518.1**	**8,762.5**
	CO_2	5,764.9	6,080.9	6,412.8	6,757.7	7,198.5	7,549.3	7,870.9	8,156.3	8,404.7
	CH_4	51.1	46.4	46.4	46.0	45.7	44.6	43.6	43.3	43.0
USA (covered)	N_2O	43.8	44.7	47.0	48.8	50.5	49.3	48.1	45.7	43.5
	HFC	154.3	212.7	275.9	269.8	263.9	256.7	249.7	248.3	246.8
	PFC	11.7	10.8	10.6	11.0	11.4	11.8	12.2	12.3	12.3
	SF_6	14.2	13.3	13.0	12.9	12.8	12.5	12.3	12.2	12.1
	Total	**1,383.5**	**1,421.7**	**1,458.5**	**1,480.1**	**1,506.1**	**1,528.2**	**1,549.0**	**1,550.4**	**1,550.0**
	CO_2	577.6	597.5	611.3	618.9	629.0	657.6	684.1	707.8	728.7
	CH_4	475.3	485.8	500.1	506.6	514.9	516.2	518.0	511.0	504.4
USA (uncovered)	N_2O	330.6	338.4	347.1	354.6	362.1	354.5	347.0	331.5	316.8
	HFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SF_6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A-2. Lieberman-Warner Core Scenario

Note: all percent change is from reference case

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Macroeconomic									
Population *(millions)*	308.9	322.4	335.8	349.4	363.6	373.8	383.1	391.6	399.6
GDP *(billion 2005$)*	$14,583	$16,835	$19,672	$22,749	$26,193	$29,743	$33,578	$37,689	$42,039
% Change in GDP	-0.25%	-0.45%	-0.74%	-0.89%	-0.93%	-1.01%	-1.12%	-1.26%	-1.54%
Consumption *(bill 2005$)*	$10,776	$12,311	$14,514	$16,894	$19,562	$22,229	$25,119	$28,255	$31,567
% Change in Consump	-0.07%	-0.70%	-0.85%	-0.80%	-0.80%	-0.85%	-0.91%	-0.88%	-1.00%
Allowance Price - $/t$CO_2$e		$18.1	$23.1	$29.6	$37.8	$48.4	$61.8	$78.9	$100.7
Energy Prices - delivered (with allowance price)									
Coal *($ per MMBtu)*	$1.59	$3.17	$3.64	$4.30	$5.16	$6.19	$7.53	$9.23	$11.33
Electricity *($ per kWh)*	$0.072	$0.082	$0.086	$0.090	$0.095	$0.100	$0.104	$0.097	$0.098
Natural Gas *($ per MMBtu)*	$7.16	$7.55	$8.15	$8.85	$9.70	$10.16	$10.76	$11.62	$12.88
Petroleum *($ per MMBtu)*	$15.34	$16.77	$17.32	$17.61	$18.25	$18.73	$19.37	$20.27	$21.47
% Change in Coal	-0.2%	106.4%	137.2%	171.2%	209.7%	267.7%	343.3%	438.9%	556.1%
% Change in Electricity	0.6%	18.2%	21.5%	24.7%	29.6%	34.8%	38.1%	26.7%	27.0%
% Change in Natural Gas	-0.1%	15.3%	18.4%	18.7%	21.3%	25.4%	31.1%	39.7%	52.9%
% Change In Petroleum	-0.3%	5.9%	7.3%	7.2%	9.4%	12.8%	17.2%	23.3%	31.3%
GHG Emissions - mmt CO_2e									
CO_2	6,345.9	5,697.2	5,809.3	5,762.5	5,698.4	5,438.8	5,001.9	4,879.1	4,913.0
CH_4	491.2	497.9	508.5	500.4	503.6	493.7	474.7	451.8	438.6
N_2O	395.3	396.9	404.6	397.1	405.8	396.5	387.5	369.9	352.8
HFC	13.0	39.0	45.7	40.3	35.7	31.5	27.8	25.0	22.6
PFC	5.3	6.3	6.0	6.0	6.0	6.0	6.0	5.9	5.7
SF_6	4.8	6.1	5.6	5.3	5.0	4.7	4.3	4.2	4.0
Total	**7,255**	**6,643**	**6,780**	**6,712**	**6,654**	**6,371**	**5,902**	**5,736**	**5,737**
% Change	-2.3%	-15.2%	-18.0%	-22.2%	-26.8%	-32.6%	-39.7%	-43.0%	-44.4%
Primary Energy Use - Quadrillion Btu									
Coal	24.6	15.9	15.2	14.7	15.3	16.2	20.8	25.7	25.5
Natural Gas	24.2	27.0	28.1	27.4	26.3	25.5	22.9	21.5	21.5
Petroleum	43.2	43.7	45.6	47.8	50.1	51.8	53.1	54.0	54.6
Nuclear	8.6	9.5	10.2	12.0	14.2	16.7	18.6	20.1	22.2
Renewable Elec.	4.2	4.4	4.6	4.9	5.2	5.4	5.6	5.5	5.6
Total *	**104.8**	**100.5**	**103.8**	**106.9**	**111.0**	**115.7**	**120.9**	**126.9**	**129.5**
% Change	0.1%	-9.0%	-10.6%	-11.5%	-12.3%	-12.5%	-12.0%	-10.7%	-11.5%
Energy Intensity - total *									
1000 btu per $ of GDP	7.18	5.97	5.27	4.70	4.24	3.89	3.60	3.37	3.08
Electricity Generation - billion kWh									
Fossil Fuels w/o CCS	2,923	2,843	2,989	2,814	2,509	1,816	613	0	0
Nuclear	825	918	979	1,154	1,362	1,606	1,787	1,935	2,138
Other Non-Fossil	407	425	449	477	507	526	538	534	546
Fossil with CCS	0	0	0	147	443	1,061	2,261	3,112	3,089
Total	**4,155**	**4,186**	**4,417**	**4,593**	**4,822**	**5,009**	**5,200**	**5,582**	**5,773**
% Change	-0.1%	-6.1%	-7.2%	-8.3%	-9.5%	-10.9%	-11.8%	-9.3%	-9.7%

* Note: only renewable energy used in electricity generation is included.

Emissions		2010	2015	2020	2025	2030	2035	2040	2045	2050
	Total	**7,255.5**	**6,643.4**	**6,779.7**	**6,711.5**	**6,654.4**	**6,371.1**	**5,902.2**	**5,735.9**	**5,736.7**
	CO_2	6,345.9	5,697.2	5,809.3	5,762.5	5,698.4	5,438.8	5,001.9	4,879.1	4,913.0
	CH_4	491.2	497.9	508.5	500.4	503.6	493.7	474.7	451.8	438.6
USA (total)	N_2O	395.3	396.9	404.6	397.1	405.8	396.5	387.5	369.9	352.8
	HFC	13.0	39.0	45.7	40.3	35.7	31.5	27.8	25.0	22.6
	PFC	5.3	6.3	6.0	6.0	6.0	6.0	6.0	5.9	5.7
	SF_6	4.8	6.1	5.6	5.3	5.0	4.7	4.3	4.2	4.0
	Total	**5,834.9**	**5,194.2**	**5,299.2**	**5,234.6**	**5,150.8**	**4,847.3**	**4,368.5**	**4,215.1**	**4,221.0**
	CO_3	5,764.0	5,094.1	5,192.5	5,133.3	5,054.0	4,757.4	4,284.5	4,136.8	4,149.0
	CH_5	4.2	5.9	4.9	3.9	3.3	2.9	3.2	3.5	3.0
USA (covered)	N_2O	43.6	42.8	44.5	45.8	46.8	44.8	42.7	39.7	36.7
	HFC	13.0	39.0	45.7	40.3	35.7	31.5	27.8	25.0	22.6
	PFC	5.3	6.3	6.0	6.0	6.0	6.0	6.0	5.9	5.7
	SF_7	4.8	6.1	5.6	5.3	5.0	4.7	4.3	4.2	4.0
	Total	**1,420.6**	**1,449.2**	**1,480.5**	**1,477.0**	**1,503.6**	**1,523.8**	**1,533.7**	**1,520.8**	**1,515.6**
	CO_4	581.9	603.2	616.8	629.2	644.4	681.4	717.5	742.2	764.0
	CH_6	487.0	492.0	503.6	496.5	500.3	490.7	471.5	448.3	435.5
USA (uncovered)	N_2O	351.7	354.1	360.1	351.3	359.0	351.7	344.7	330.2	316.1
	HFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SF_8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A3: Lieberman-Warner Residential-Commercial Scenario

Note: all percent change is from reference case

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Macroeconomic									
Population (millions)	308.9	322.4	335.8	349.4	363.6	373.8	383.1	391.6	399.6
GDP (billion 2005$)	$14,581	$16,823	$19,653	$22,729	$26,173	$29,720	$33,551	$37,654	$42,016
% Change in GDP	-0.26%	-0.51%	-0.84%	-0.98%	-1.00%	-1.09%	-1.20%	-1.36%	-1.59%
Consumption (bill 2005$)	$10,769	$12,306	$14,509	$16,889	$19,558	$22,224	$25,112	$28,231	$31,549
% Change in Consump	-0.13%	-0.75%	-0.88%	-0.83%	-0.83%	-0.86%	-0.94%	-0.96%	-1.06%
Allowance Price - $/tCO2e		$15.7	$20.1	$25.7	$32.9	$42.1	$53.7	$68.6	$87.6
Energy Prices - delivered (with allowance price)									
Coal ($ per MMBtu)	$1.59	$2.94	$3.35	$3.94	$4.69	$5.59	$6.75	$8.24	$10.08
Electricity ($ per kWh)	$0.072	$0.080	$0.084	$0.088	$0.092	$0.097	$0.101	$0.098	$0.097
Natural Gas ($ per MMBtu)	$7.16	$7.34	$7.89	$8.56	$9.35	$9.76	$10.25	$11.03	$12.05
Petroleum ($ per MMBtu)	$15.35	$16.66	$17.17	$17.42	$18.00	$18.40	$18.93	$19.68	$20.68
% Change in Coal	-0.2%	91.8%	118.5%	148.2%	181.7%	232.3%	297.6%	380.8%	483.4%
% Change in Electricity	0.6%	15.8%	18.7%	21.5%	26.0%	30.6%	34.5%	28.2%	25.7%
% Change in Natural Gas	0.0%	12.1%	14.6%	14.8%	16.9%	20.4%	24.9%	32.6%	43.1%
% Change In Petroleum	-0.2%	5.2%	6.4%	6.0%	7.9%	10.8%	14.5%	19.7%	26.6%
GHG Emissions - mmt CO2e									
CO2	6,344.1	5,750.1	5,867.5	5,844.5	5,801.1	5,577.9	5,168.1	4,881.8	4,883.7
CH4	491.2	497.5	507.6	499.5	502.8	494.2	478.4	447.2	429.4
N2O	395.5	397.2	405.0	397.5	406.2	397.0	388.0	370.2	353.3
HFC	13.0	41.3	48.3	42.6	37.8	33.3	29.4	26.4	23.8
PFC	5.3	6.4	6.1	6.1	6.1	6.1	6.1	6.0	5.8
SF6	4.8	6.3	5.8	5.5	5.2	4.8	4.5	4.3	4.1
Total	**7,254**	**6,699**	**6,840**	**6,796**	**6,759**	**6,513**	**6,074**	**5,736**	**5,700**
% Change	-2.3%	-14.5%	-17.2%	-21.2%	-25.6%	-31.1%	-37.9%	-43.0%	-44.7%
Primary Energy Use - Quadrillion Btu									
Coal	24.6	16.5	15.9	15.2	15.5	15.8	19.0	25.1	25.9
Natural Gas	24.2	26.8	27.9	27.4	26.3	25.8	23.8	20.9	20.4
Petroleum	43.1	43.7	45.7	47.9	50.2	52.1	53.4	54.4	55.0
Nuclear	8.6	9.5	10.1	11.9	14.1	16.6	18.5	20.2	22.2
Renewable Elec.	4.2	4.4	4.6	4.9	5.2	5.4	5.5	5.5	5.6
Total *	**104.7**	**101.0**	**104.2**	**107.3**	**111.3**	**115.7**	**120.3**	**126.0**	**129.1**
% Change	0.1%	-8.6%	-10.2%	-11.2%	-12.0%	-12.5%	-12.5%	-11.4%	-11.7%
Energy Intensity - total *									
1000 btu per $ of GDP	7.18	6.00	5.30	4.72	4.25	3.89	3.59	3.35	3.07
Electricity Generation - billion kWh									
Fossil Fuels w/o CCS	2,922	2,879	3,033	2,915	2,668	2,110	1,071	93	0
Nuclear	825	913	973	1,147	1,354	1,597	1,778	1,939	2,133
Other Non-Fossil	407	423	447	474	502	519	535	535	544
Fossil with CCS	0	0	0	99	348	844	1,874	3,001	3,143
Total	**4,154**	**4,215**	**4,453**	**4,635**	**4,872**	**5,070**	**5,258**	**5,569**	**5,821**
% Change	-0.1%	-5.5%	-6.5%	-7.4%	-8.6%	-9.8%	-10.9%	-9.5%	-9.0%

* Note: only renewable energy used in electricity generation is included.

Emissions		2010	2015	2020	2025	2030	2035	2040	2045	2050
	Total	**7,254.0**	**6,698.8**	**6,840.2**	**6,795.6**	**6,759.1**	**6,513.3**	**6,074.5**	**5,735.9**	**5,700.2**
	CO_2	6,344.1	5,750.1	5,867.5	5,844.5	5,801.1	5,577.9	5,168.1	4,881.8	4,883.7
	CH_4	491.2	497.5	507.6	499.5	502.8	494.2	478.4	447.2	429.4
USA (total)	N_2O	395.5	397.2	405.0	397.5	406.2	397.0	388.0	370.2	353.3
	HFC	13.0	41.3	48.3	42.6	37.8	33.3	29.4	26.4	23.8
	PFC	5.3	6.4	6.1	6.1	6.1	6.1	6.1	6.0	5.8
	SF_6	4.8	6.3	5.8	5.5	5.2	4.8	4.5	4.3	4.1
	Total	**6,360.3**	**5,800.4**	**5,925.3**	**5,899.0**	**5,849.7**	**5,615.9**	**5,196.6**	**4,901.3**	**4,893.9**
	CO_3	6,289.3	5,697.1	5,815.1	5,794.7	5,750.1	5,523.5	5,110.4	4,820.9	4,819.7
	CH_5	4.2	6.5	5.3	4.2	3.6	3.0	3.1	3.6	3.3
USA (covered)	N_2O	43.6	42.9	44.6	46.0	47.1	45.2	43.2	40.1	37.1
	HFC	13.0	41.3	48.3	42.6	37.8	33.3	29.4	26.4	23.8
	PFC	5.3	6.4	6.1	6.1	6.1	6.1	6.1	6.0	5.8
	SF_7	4.8	6.3	5.8	5.5	5.2	4.8	4.5	4.3	4.1
	Total	**893.8**	**898.5**	**915.0**	**896.6**	**909.4**	**897.4**	**877.9**	**834.6**	**806.4**
	CO_4	54.8	53.1	52.3	49.8	51.0	54.4	57.8	60.9	64.0
	CH_6	487.1	491.0	502.3	495.3	499.2	491.1	475.3	443.6	426.2
USA (uncovered)	N_2O	351.9	354.4	360.4	351.5	359.1	351.8	344.8	330.1	316.2
	HFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SF_8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A4: Lieberman-Warner Tighter Cap Scenario

Note: all percent change is from reference case

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Macroeconomic									
Population *(millions)*	308.9	322.4	335.8	349.4	363.6	373.8	383.1	391.6	399.6
GDP *(billion 2005$)*	$14,580	$16,828	$19,656	$22,735	$26,180	$29,724	$33,551	$37,656	$41,996
% Change in GDP	-0.27%	-0.48%	-0.82%	-0.95%	-0.98%	-1.07%	-1.20%	-1.35%	-1.64%
Consumption *(bill 2005$)*	$10,778	$12,307	$14,507	$16,884	$19,549	$22,210	$25,097	$28,235	$31,540
% Change in Consump	-0.05%	-0.74%	-0.89%	-0.86%	-0.87%	-0.93%	-1.00%	-0.95%	-1.09%
Allowance Price - $/t$CO_2$e		$20.0	$25.5	$32.6	$41.8	$53.4	$68.2	$87.1	$111.1
Energy Prices - delivered (with allowance price)									
Coal *($ per MMBtu)*	$1.59	$3.35	$3.87	$4.59	$5.53	$6.66	$8.14	$10.01	$12.33
Electricity *($ per kWh)*	$0.072	$0.083	$0.087	$0.092	$0.097	$0.103	$0.106	$0.097	$0.099
Natural Gas *($ per MMBtu)*	$7.16	$7.65	$8.28	$9.01	$9.90	$10.41	$11.09	$12.07	$13.46
Petroleum *($ per MMBtu)*	$15.34	$16.89	$17.47	$17.81	$18.51	$19.06	$19.80	$20.83	$22.18
% Change in Coal	-0.2%	118.0%	152.2%	189.7%	232.2%	296.2%	379.4%	484.6%	613.8%
% Change in Electricity	0.6%	19.9%	23.5%	27.0%	32.4%	38.0%	40.8%	27.2%	27.8%
% Change in Natural Gas	-0.1%	16.8%	20.3%	20.9%	23.9%	28.5%	35.2%	45.1%	59.7%
% Change In Petroleum	-0.3%	6.6%	8.2%	8.4%	10.9%	14.8%	19.8%	26.7%	35.7%
GHG Emissions - mmt CO_2e									
CO_2	6,345.9	5,634.1	5,738.3	5,685.2	5,614.4	5,346.1	4,909.6	4,813.9	4,830.8
CH_4	491.2	497.1	507.5	499.3	502.2	491.4	470.8	448.9	435.1
N_2O	395.2	396.3	403.9	396.2	404.7	395.3	386.2	368.6	351.4
HFC	13.0	37.5	43.9	38.7	34.3	30.2	26.7	24.0	21.7
PFC	5.3	6.2	5.9	5.9	5.9	5.9	5.9	5.8	5.6
SF_6	4.8	6.0	5.5	5.2	4.9	4.6	4.3	4.1	3.9
Total	**7,255**	**6,577**	**6,705**	**6,630**	**6,566**	**6,274**	**5,803**	**5,665**	**5,648**
% Change	-2.3%	-16.0%	-18.9%	-23.1%	-27.8%	-33.6%	-40.7%	-43.7%	-45.2%
Primary Energy Use - Quadrillion Btu									
Coal	24.6	15.4	14.7	14.1	14.7	15.9	20.7	25.6	25.3
Natural Gas	24.2	26.9	28.0	27.4	26.1	25.2	22.4	21.2	21.1
Petroleum	43.2	43.5	45.4	47.5	49.7	51.3	52.4	53.3	53.7
Nuclear	8.6	9.6	10.2	12.0	14.2	16.8	18.7	20.2	22.3
Renewable Elec.	4.2	4.4	4.7	5.0	5.3	5.5	5.6	5.5	5.7
Total *	**104.8**	**99.9**	**103.0**	**106.0**	**110.1**	**114.7**	**119.9**	**125.7**	**128.0**
% Change	0.1%	-9.6%	-11.3%	-12.2%	-13.0%	-13.3%	-12.8%	-11.5%	-12.5%
Energy Intensity - total *									
1000 btu per $ of GDP	7.19	5.93	5.24	4.66	4.20	3.86	3.57	3.34	3.05
Electricity Generation - billion kWh									
Fossil Fuels w/o CCS	2,923	2,816	2,956	2,774	2,459	1,742	529	0	0
Nuclear	825	921	982	1,158	1,368	1,613	1,793	1,938	2,142
Other Non-Fossil	407	426	451	480	511	532	542	536	547
Fossil with CCS	0	0	0	149	447	1,080	2,297	3,098	3,063
Total	**4,155**	**4,163**	**4,390**	**4,561**	**4,784**	**4,966**	**5,161**	**5,571**	**5,753**
% Change	-0.1%	-6.7%	-7.8%	-8.9%	-10.2%	-11.7%	-12.5%	-9.5%	-10.0%

* Note: only renewable energy used in electricity generation is included.

Emissions		2010	2015	2020	2025	2030	2035	2040	2045	2050
	Total	**7,255.4**	**6,577.1**	**6,705.0**	**6,630.4**	**6,566.4**	**6,273.5**	**5,803.5**	**5,665.4**	**5,648.5**
	CO_2	6,345.9	5,634.1	5,738.3	5,685.2	5,614.4	5,346.1	4,909.6	4,813.9	4,830.8
	CH_4	491.2	497.1	507.5	499.3	502.2	491.4	470.8	448.9	435.1
USA (total)	N_2O	395.2	396.3	403.9	396.2	404.7	395.3	386.2	368.6	351.4
	HFC	13.0	37.5	43.9	38.7	34.3	30.2	26.7	24.0	21.7
	PFC	5.3	6.2	5.9	5.9	5.9	5.9	5.9	5.8	5.6
	SF_6	4.8	6.0	5.5	5.2	4.9	4.6	4.3	4.1	3.9
	Total	**5,834.8**	**5,128.4**	**5,225.2**	**5,154.4**	**5,064.1**	**4,751.8**	**4,273.9**	**4,149.0**	**4,138.1**
	CO_3	5,763.9	5,030.7	5,121.3	5,055.6	4,969.6	4,664.1	4,191.9	4,072.7	4,068.1
	CH_5	4.2	5.5	4.5	3.6	3.1	2.8	3.1	3.4	2.9
USA (covered)	N_2O	43.6	42.5	44.2	45.4	46.3	44.2	42.1	38.9	35.9
	HFC	13.0	37.5	43.9	38.7	34.3	30.2	26.7	24.0	21.7
	PFC	5.3	6.2	5.9	5.9	5.9	5.9	5.9	5.8	5.6
	SF_7	4.8	6.0	5.5	5.2	4.9	4.6	4.3	4.1	3.9
	Total	**1,420.6**	**1,448.7**	**1,479.8**	**1,476.0**	**1,502.3**	**1,521.7**	**1,529.6**	**1,516.4**	**1,510.4**
	CO_4	582.0	603.4	617.0	629.5	644.8	682.0	717.7	741.2	762.7
	CH_6	487.0	491.6	503.0	495.7	499.1	488.6	467.8	445.5	432.2
USA (uncovered)	N_2O	351.6	353.7	359.7	350.8	358.4	351.1	344.1	329.7	315.5
	HFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PFC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SF_8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

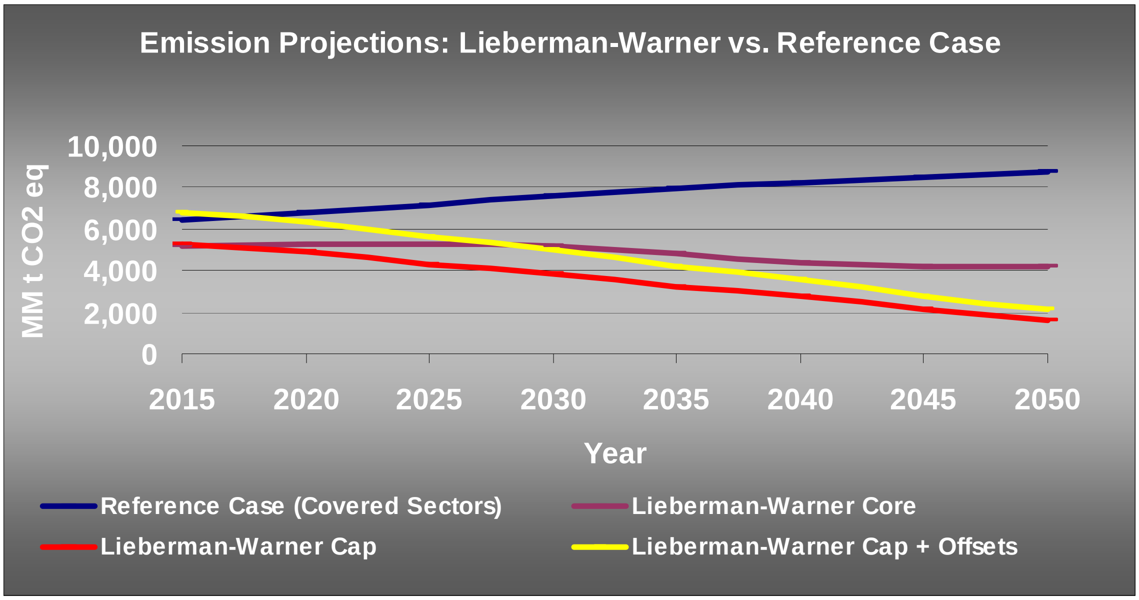


Figure A-1. Emission Projections: Lieberman-Warner vs Reference Case
Buying offsets from uncapped sources increases the amount that the covered sectors can emit.

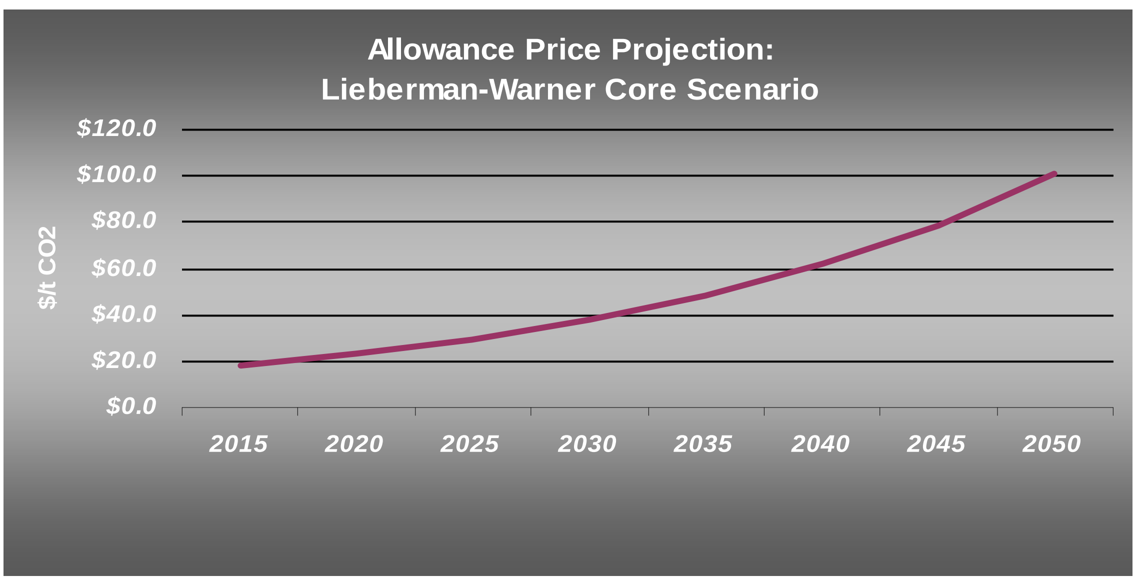


Figure A-2. Allowance Price: Warner-Lieberman

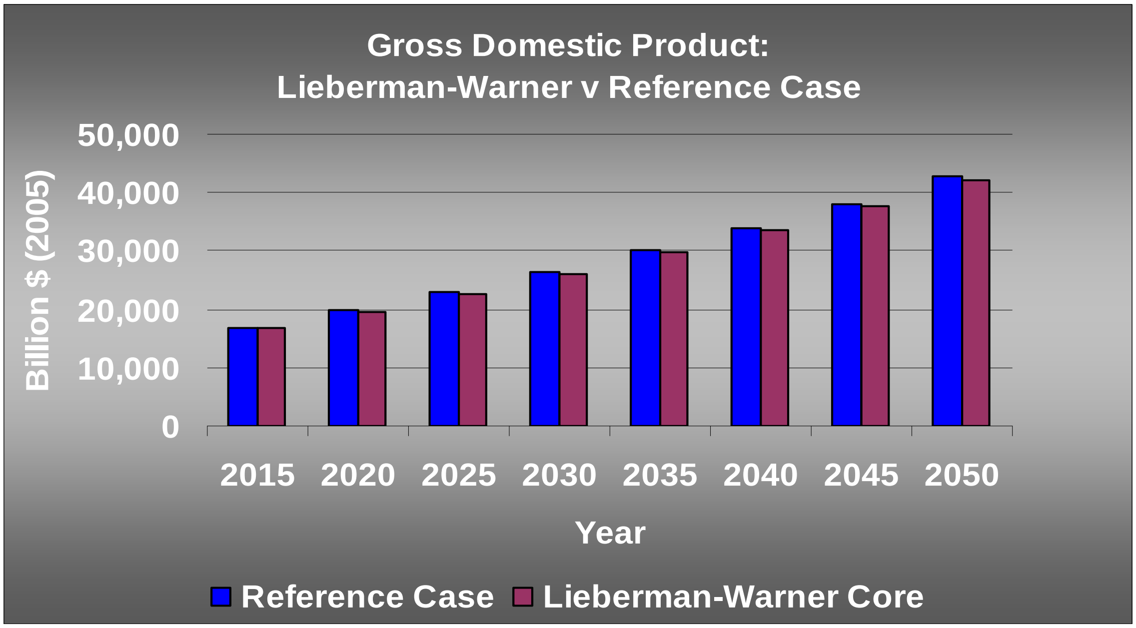
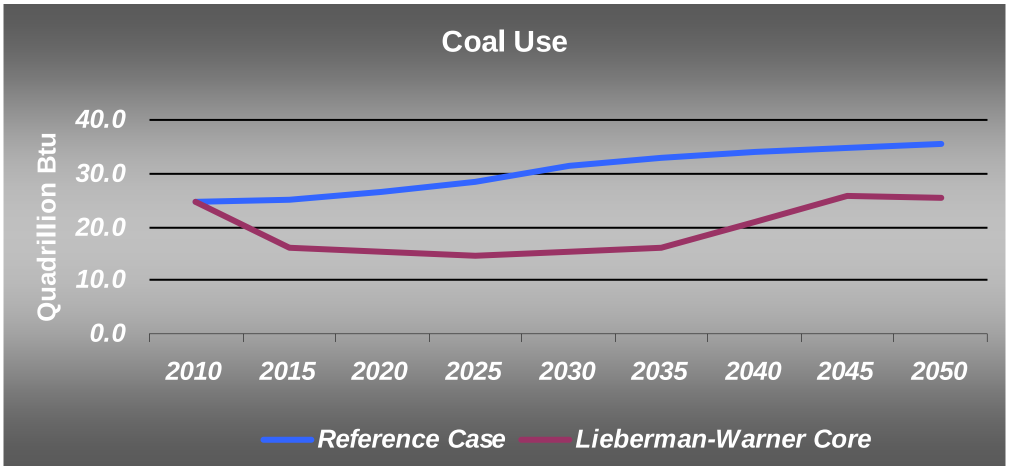
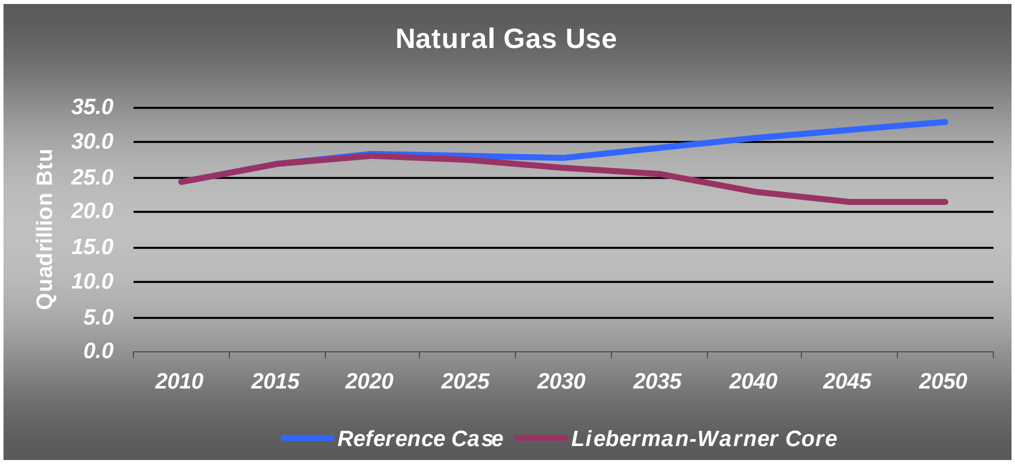


Figure A-3. GDP Effects: Lieberman-Warner





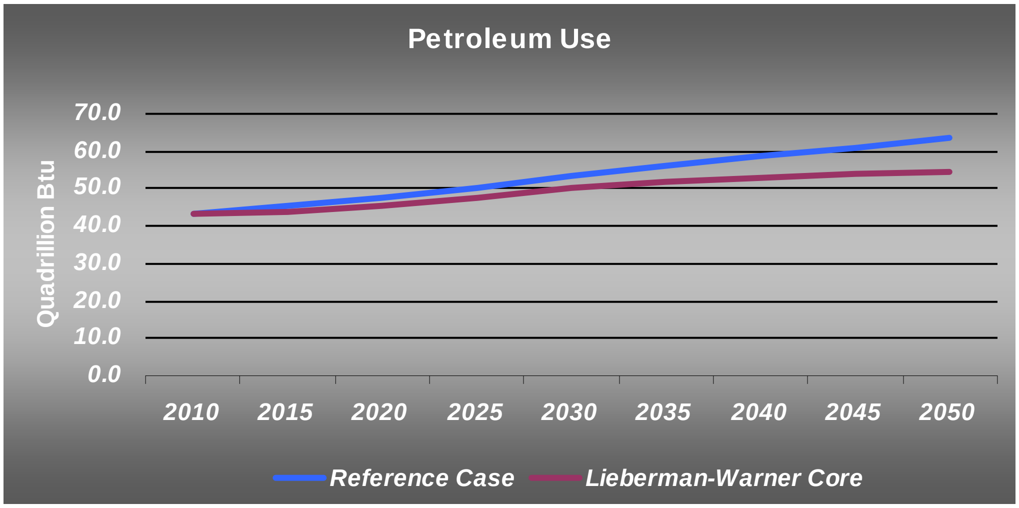
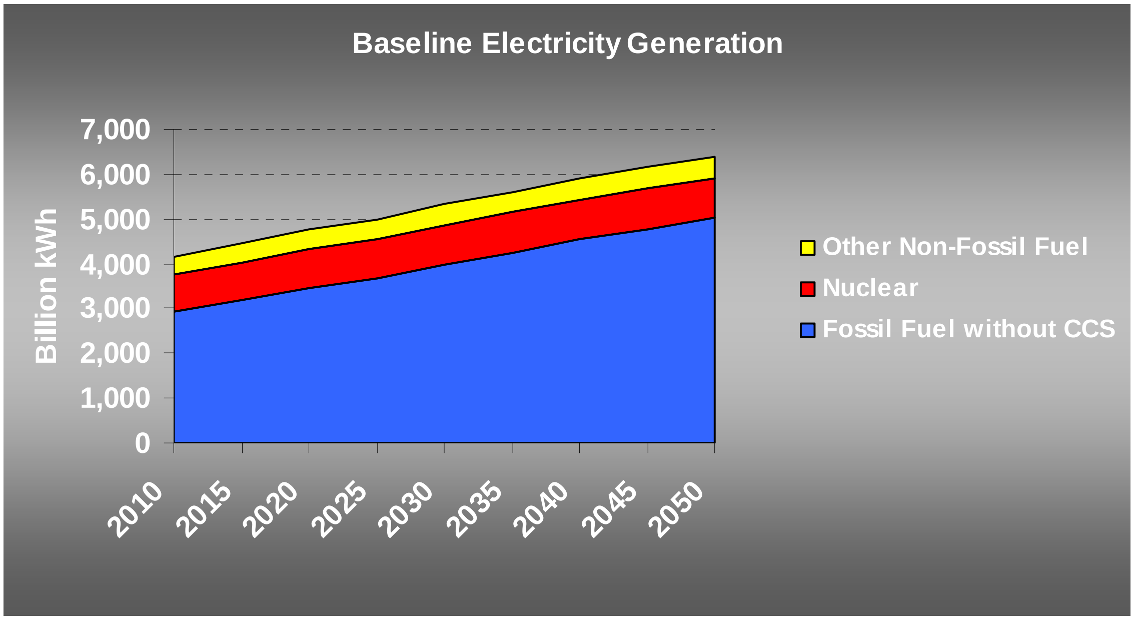


Figure A-4: Fossil Energy Use: Lieberman-Warner



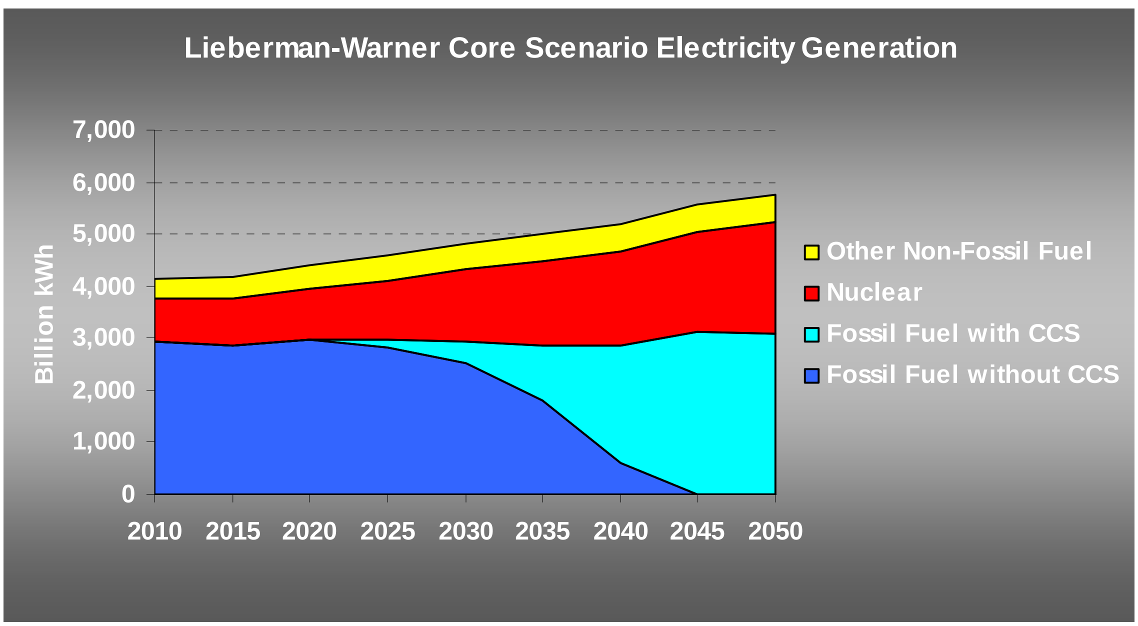


Figure A-5. Electricity Generation: Lieberman-Warner

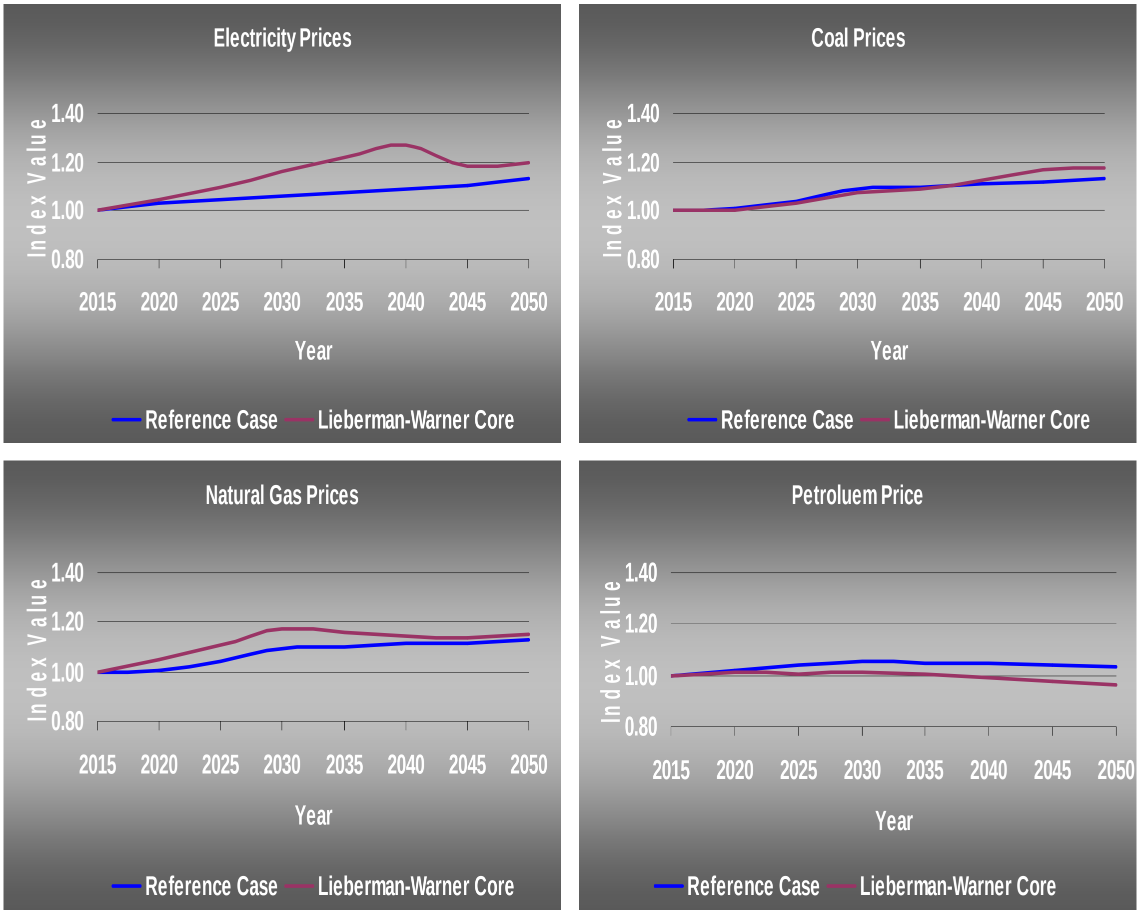


Figure A-6. Energy Price Indexes: Lieberman-Warner

Sensitivity Cases

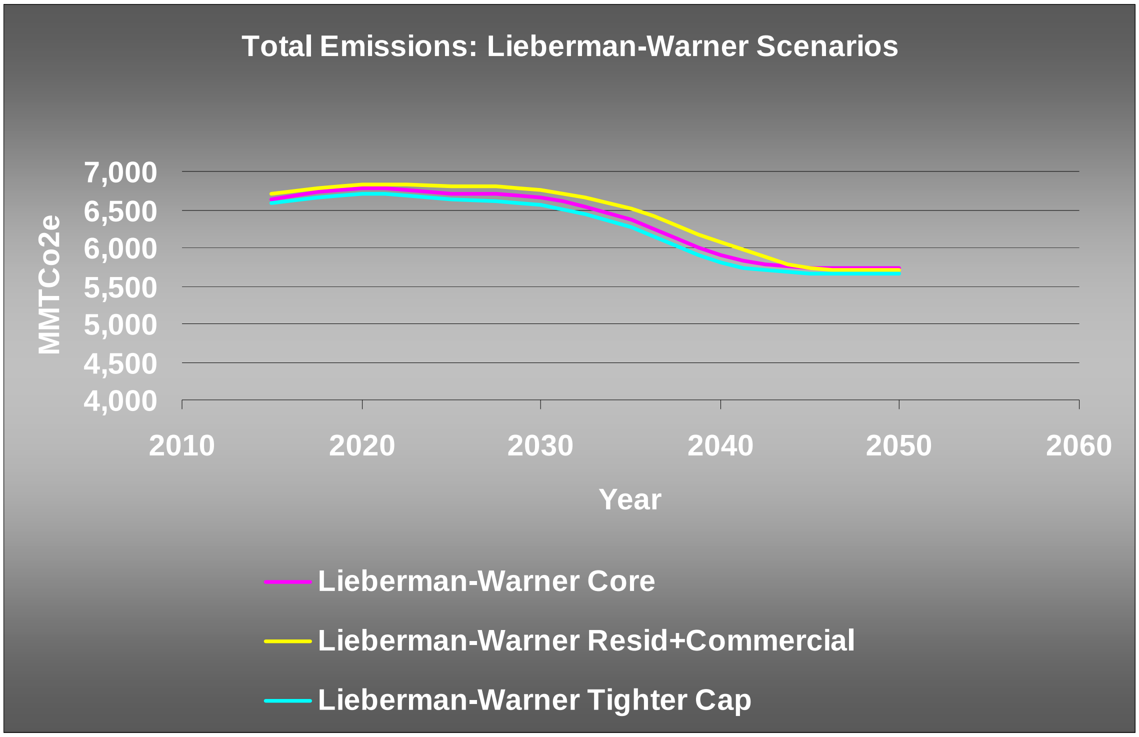


Figure A-7. Emissions: Lieberman-Warner Scenarios

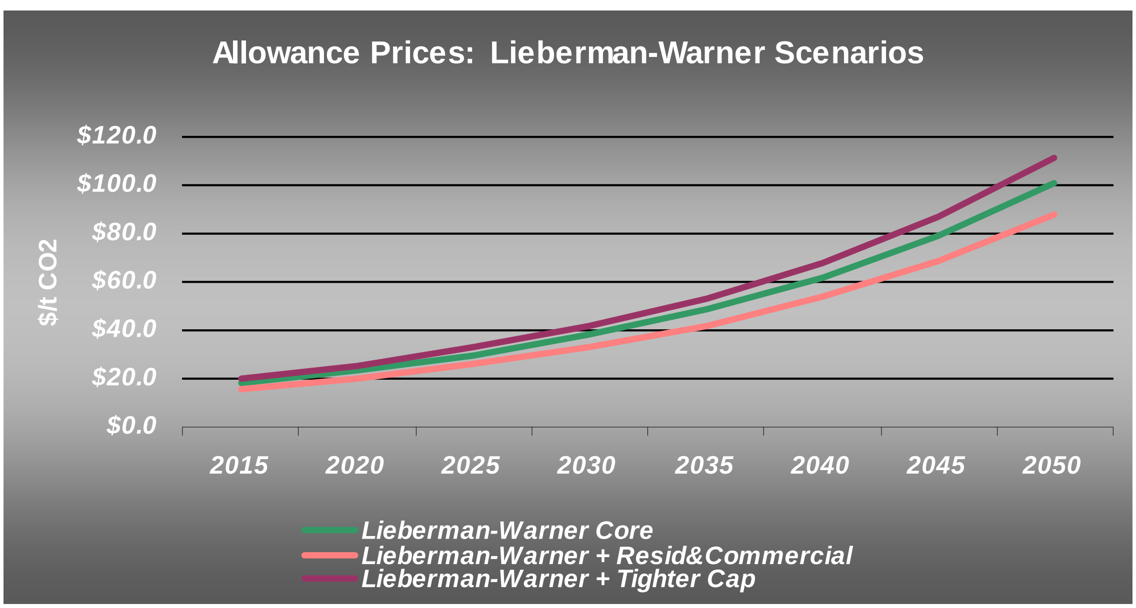


Figure A-8: Allowance Prices: Lieberman-Warner Sensitivity Cases

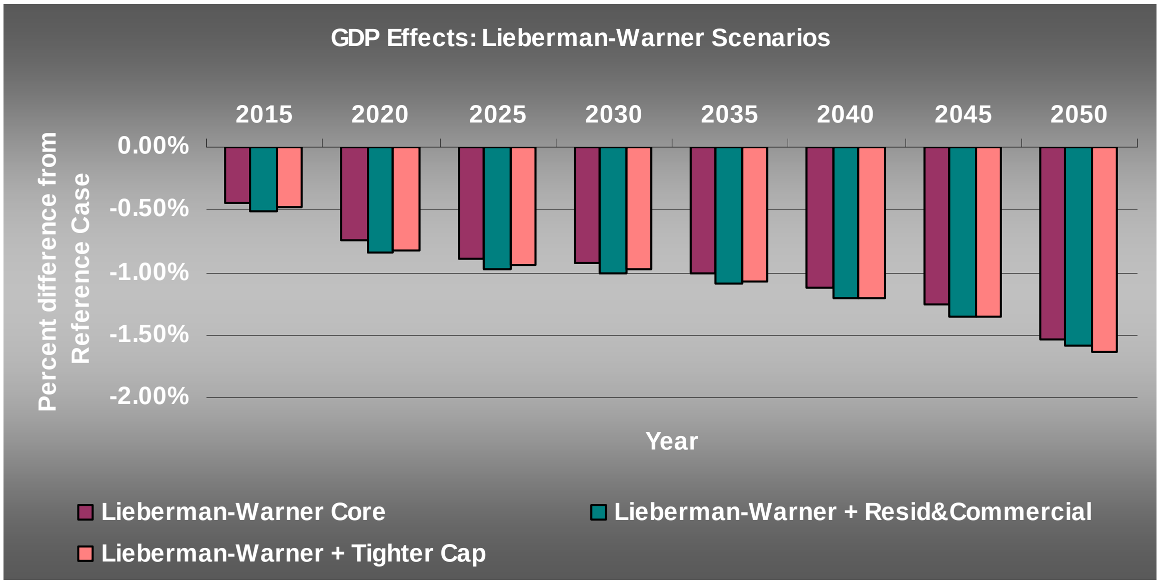


Figure A-9: GDP Effects: Lieberman-Warner Sensitivity Cases

<u>Comparison to S.280</u>

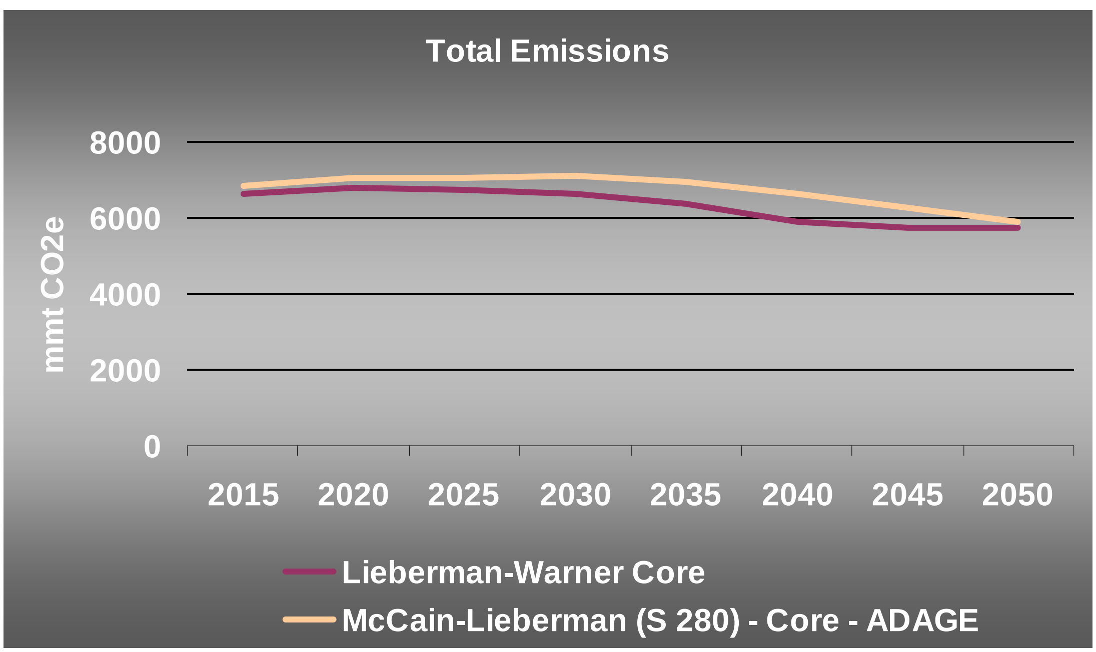


Figure A-10. Total Emissions: Lieberman-Warner vs S.280

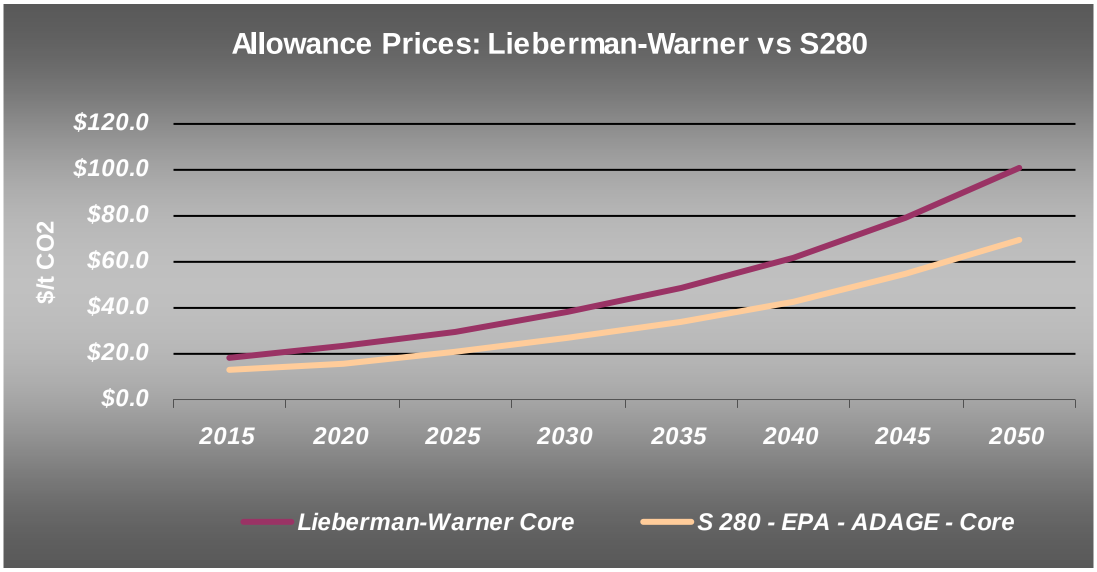


Figure A-11. Allowance Prices: Lieberman-Warner vs S.280

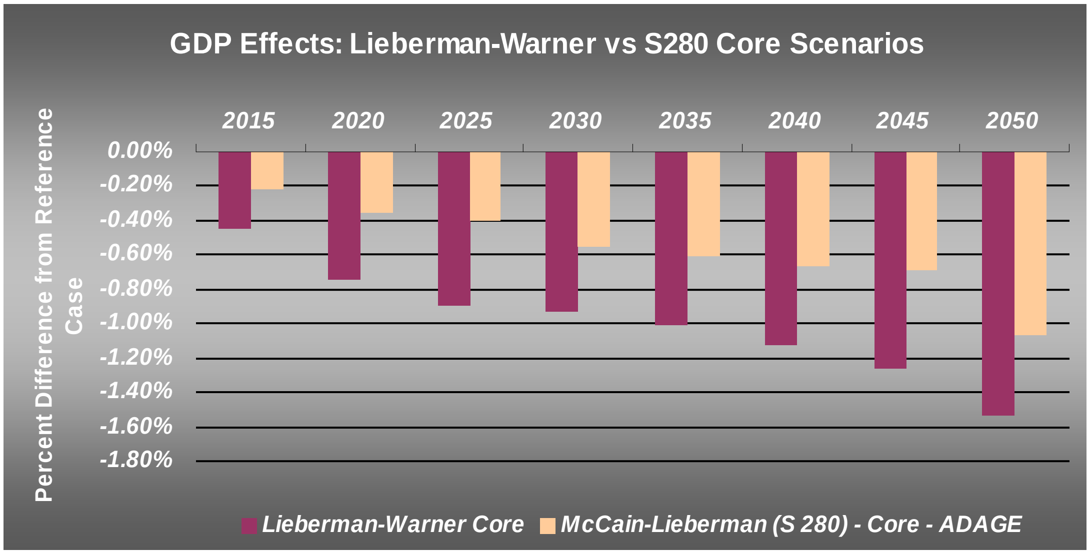


Figure A-12. GDP Effects: Lieberman-Warner vs S.280

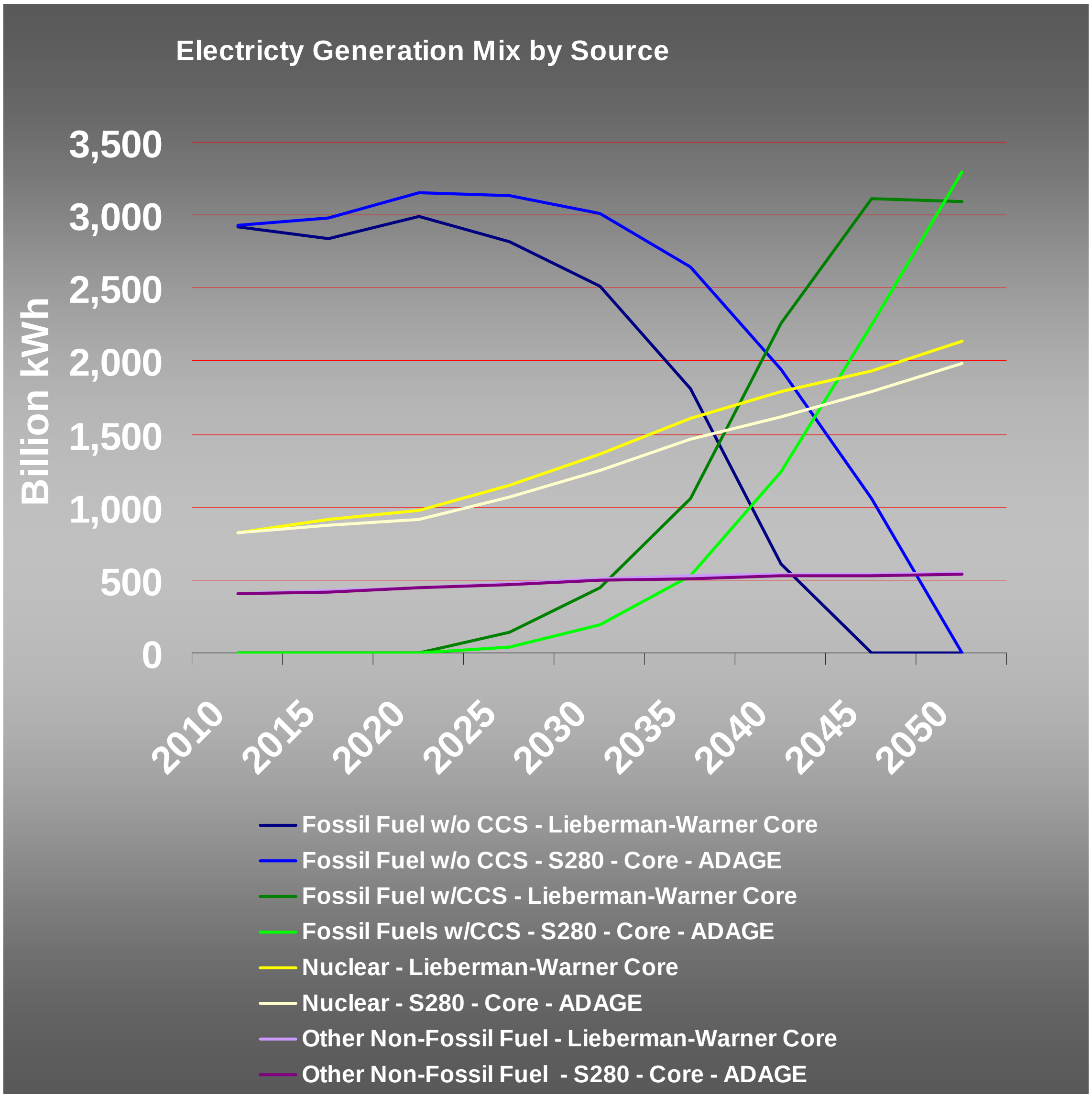


Figure A-13. Electricity Generation Mix over Time: Lieberman-Warner vs S.280

the Nicholas Institute

The Nicholas Institute for Environmental Policy Solutions at Duke University is a nonpartisan institute founded in 2005 to engage with decision makers in government, the private sector and the nonprofit community to develop innovative proposals that address critical environmental challenges. The Institute seeks to act as an "honest broker" in policy debates by fostering open, ongoing dialogue between stakeholders on all sides of the issues and by providing decision makers with timely and trustworthy policy-relevant analysis based on academic research. The Institute's staff leverages the broad expertise of Duke University as well as public and private partners nationwide.

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