US Technology Choices, Costs and Opportunities under the Lieberman-Warner Climate Security Act:

Assessing Compliance Pathways

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Project for:

Natural Resources Defense Council
Climate Center
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US-NM50: A Comprehensive Energy System Planning Model

- **Extended and improved US EPA national MARKAL model**
- **Base period is 2000 and final period is 2050, with 2000 and 2005 calibrated to historical data**
- **Resource supply curves based on AEO2006**
- **Full depiction of all demand sectors (commercial, residential, industrial and transportation)**
- **Demand projections adjusted to recently released AEO2008**
- **Reference or business-as-usual (BAU) case 2010-2030 compares closely to AEO2008**
- **Renewable, carbon capture and sequestration (CCS), advance nuclear and hydrogen production technologies subject to endogenous technology learning**
- **All demands endogenously adjusted based upon own-price elasticities**
- **Compares energy use and prices, technology choice, system cost, security of supply, CO_2 marginal costs, etc.**

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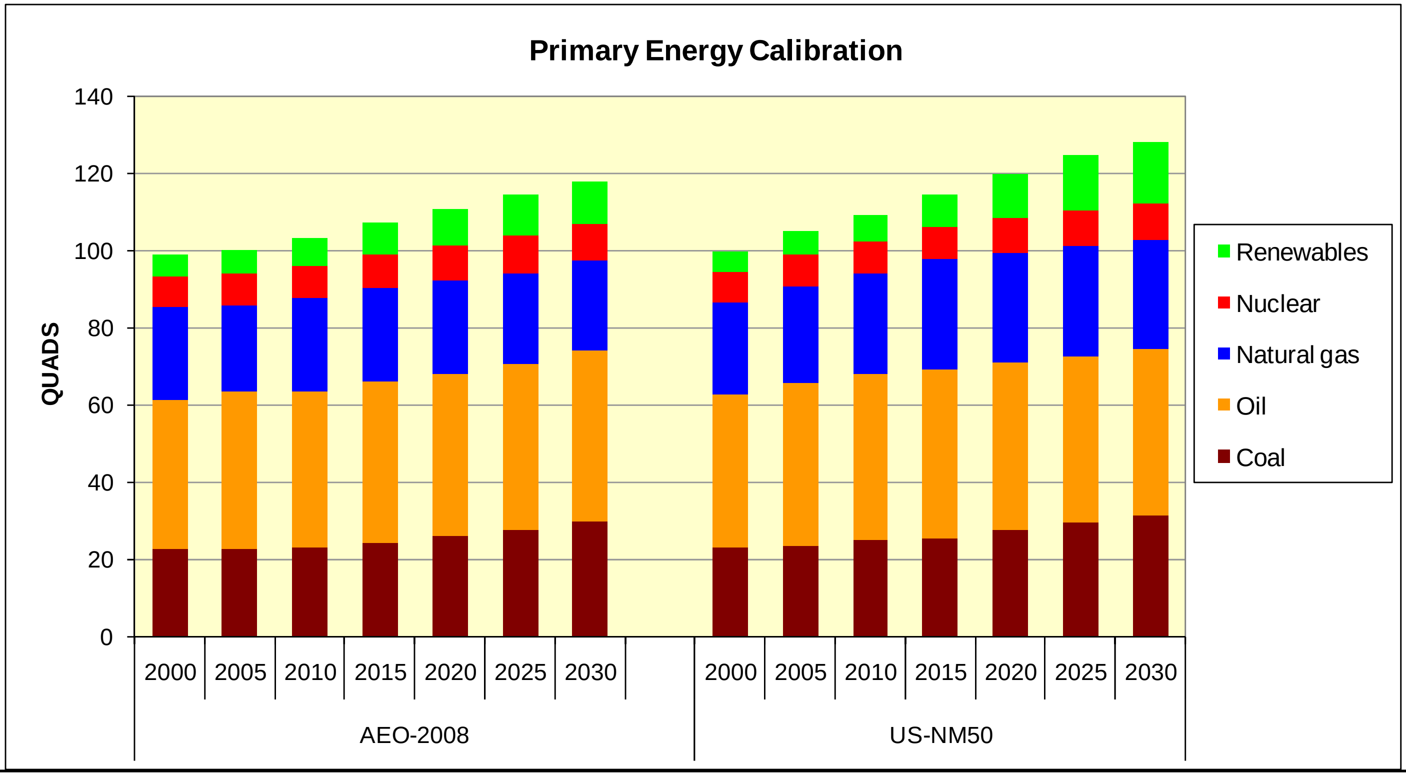
MARKAL finds the least-cost evolution of the energy system utilizing available resources and technologies to meet the energy service demands, subject to physical limitations, policies and market constraints imposed on the system

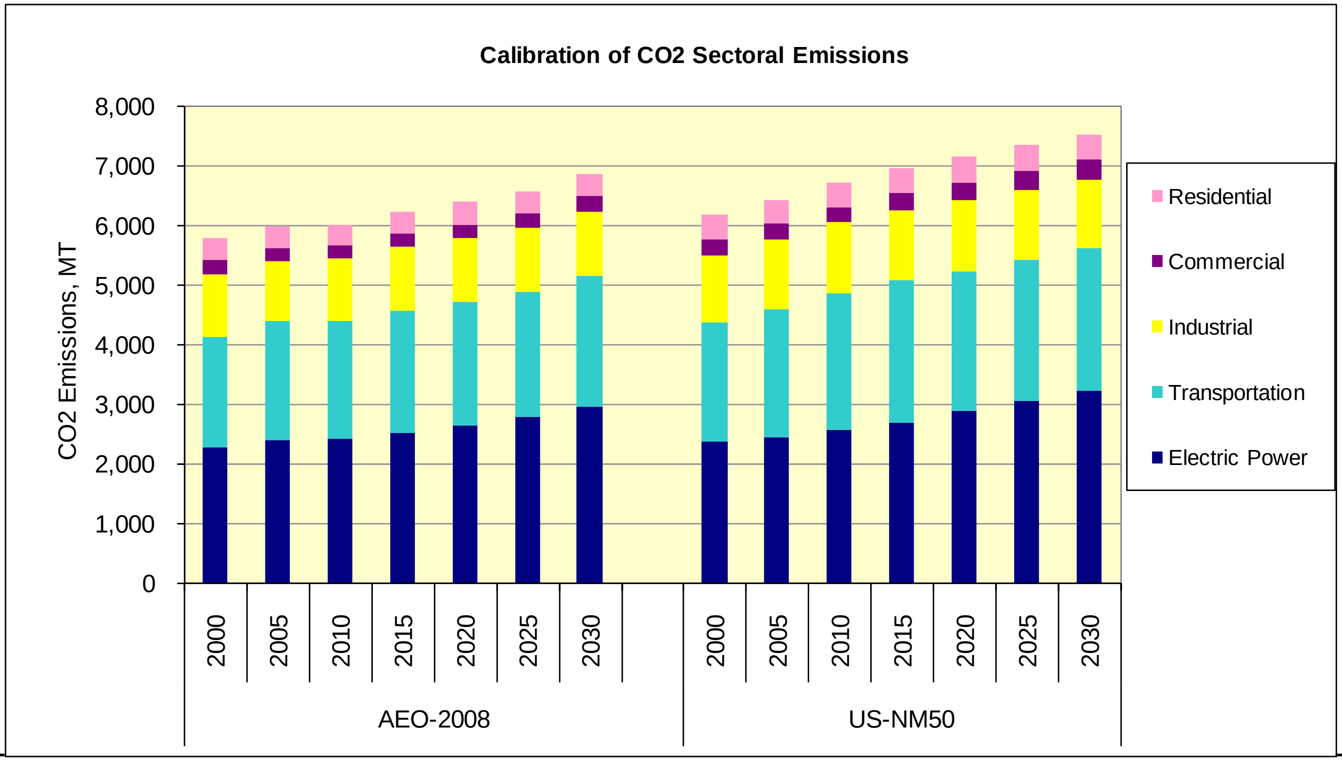
PRIMARY ENERGY SUPPLY	CONVERSION TECHNOLOGIES	END-USE TECHNOLOGIES	DEMAND FOR ENERGY SERVICE
(PRIMARY ENERGY)	(FINAL ENERGY)	(USEFUL ENERGY)	
Renewables, e.g. • Biomass • Hydro • Solar • Wind Mining, e.g. • Crude oil • Natural gas • Coal Imports, e.g. • Crude oil • Oil products Exports, e.g. • Oil products • Coal Stock changes	Fuel Processing Plants, e.g. • Oil refineries • Hydrogen prod. • Ethanol prod. Power Plants, e.g. • Conventional fossil fueled • IGCC • Solar • Wind • Nuclear • CCGT • Fuel cells • Combined heat and power	Industry, e.g. • Steam boilers • Machinery Services, e.g. • Air conditioners • Light bulbs Households, e.g. • Space heaters • Refrigerators Agriculture, e.g. • Irrigation pumps Transport, e.g. • Gasoline car • Fuel cell bus	Industry, e.g. • Process steam • Motive power Services, e.g. • Cooling • Lighting Households, e.g. • Space heat • Refrigeration Agriculture, e.g. • Water supply Transport, e.g. • Person-km

US-NM50 BAU Primary Energy Use is 5 to 9% higher than AEO2008



Comparison of Primary Energy Consumption: 2000 to 2030 (Quads)							
	2000	2005	2010	2015	2020	2025	2030
AEO-2008	99.38	100.08	103.34	107.26	110.85	114.54	118.01
US-NM50 BAU	99.62	105.04	109.26	114.26	119.87	124.72	127.97
Difference	0.2%	5.0%	5.7%	6.5%	8.1%	8.9%	8.4%

US-NM50 BAU Projections of CO_2 Emissions are 6 to 11% higher than AEO-2008



Comparison of CO_2 Emissions: 2000 to 2030 (Million tons)							
	2000	2005	2010	2015	2020	2025	2030
AEO 2008	5,787	5,982	6,011	6,226	6,384	6,571	6,851
US-NM50 BAU	6,104	6,362	6,644	6,890	7,081	7,272	7,449
Difference	5.5%	6.4%	10.5%	10.7%	10.9%	10.7%	8.7%

US Legislative Policy Scenarios Examined

- **Reference (BAU) Scenario - in line with EIA projections**
- **Energy Efficiency & Renewable Energy (EE&RE)**
  - **Energy efficiency incentives**
  - **Expanded renewable energy resources**
- **Lieberman-Warner (L-W) cap & trade bill**
  - **Modeled as cumulative limit on 2000-2050 CO_2 emissions**
  - **15% limits on domestic and international offsets each**
  - **13 billion tons of carbon capture & sequestration (CCS) incentives**
- **Two scenarios of energy system evolution under L-W**
  - **Case A: Least-cost given assumed technology learning rates**
  - **Case B: Case A with intensive role for CCS allowing greater coal use**

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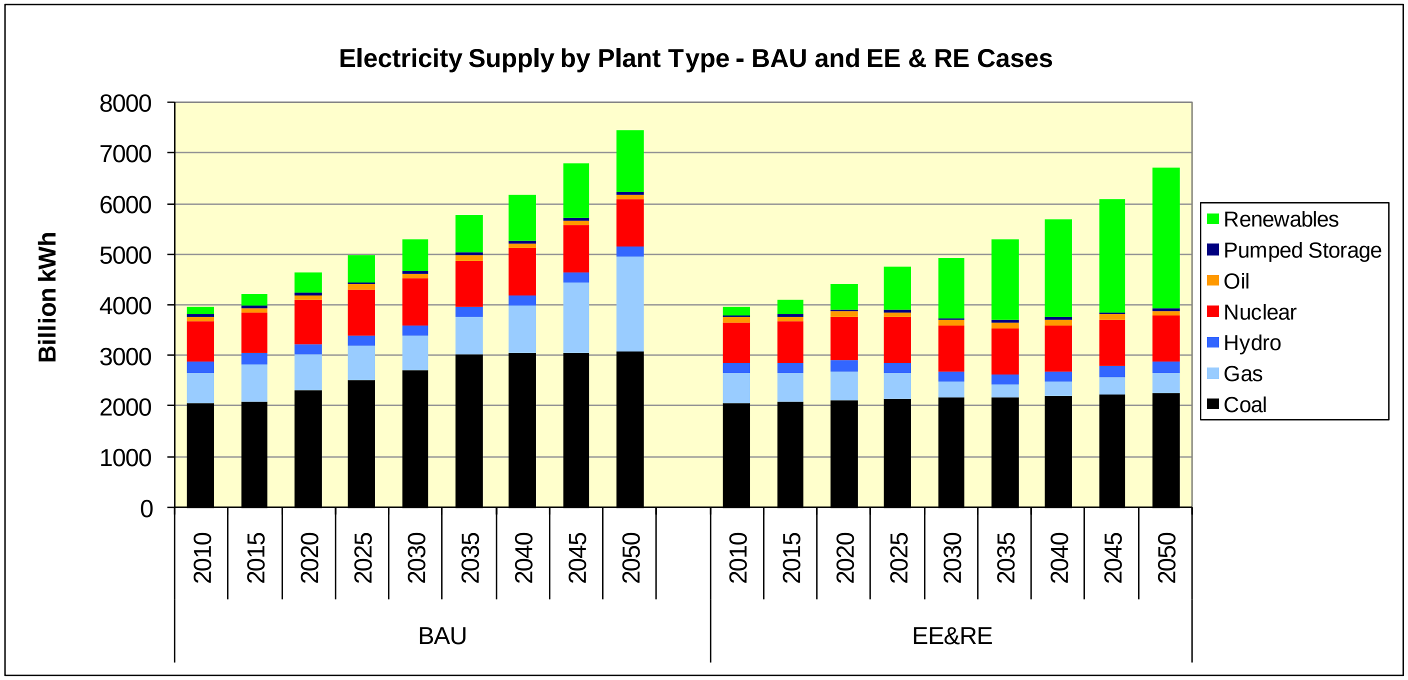
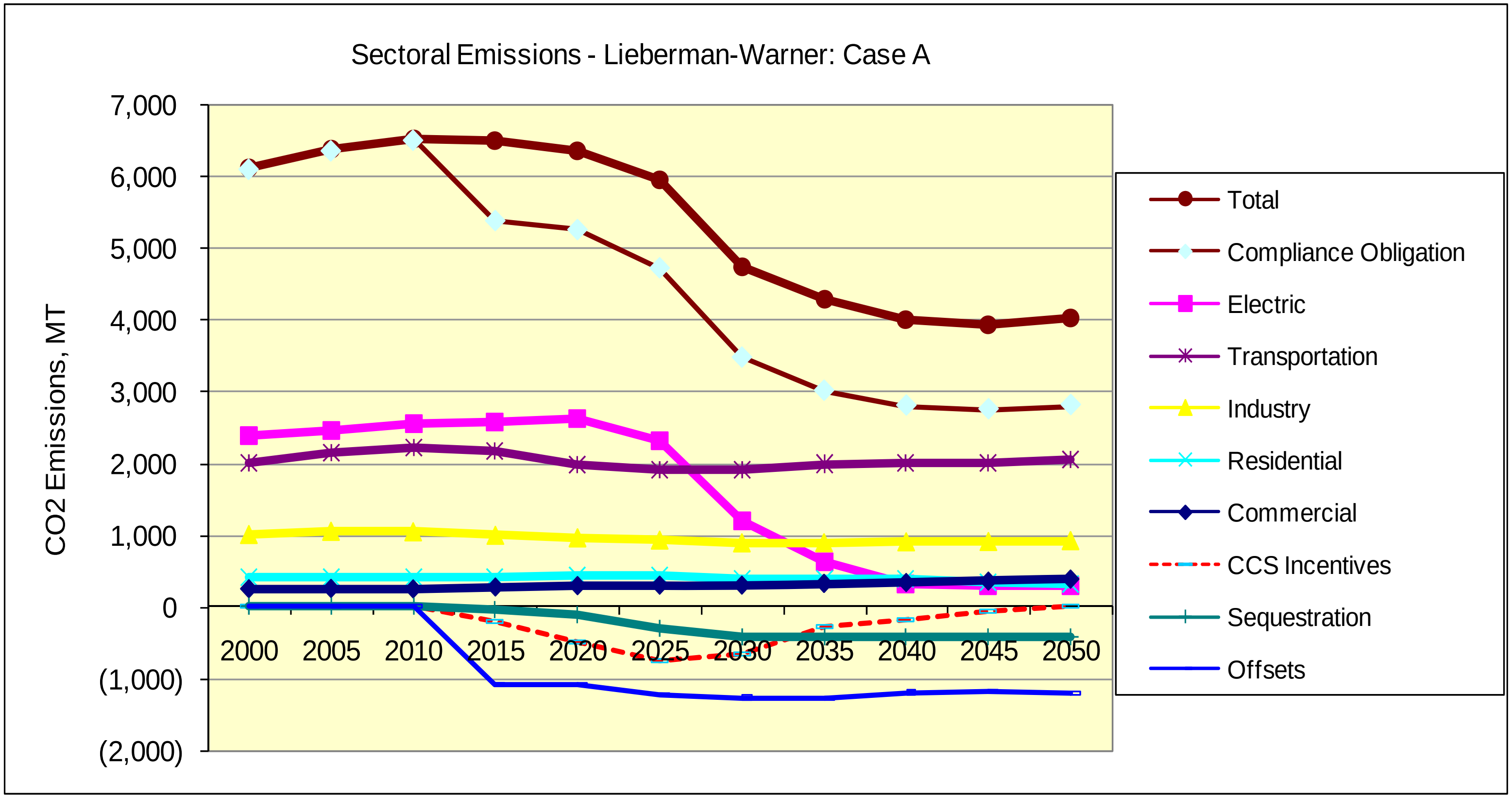
Policies to improve energy efficiency and promote renewable energy resources will achieve significant CO_2 emission reductions and reduce the total energy system cost, but they will not produce the necessary deep reductions called for in Lieberman-Warner.

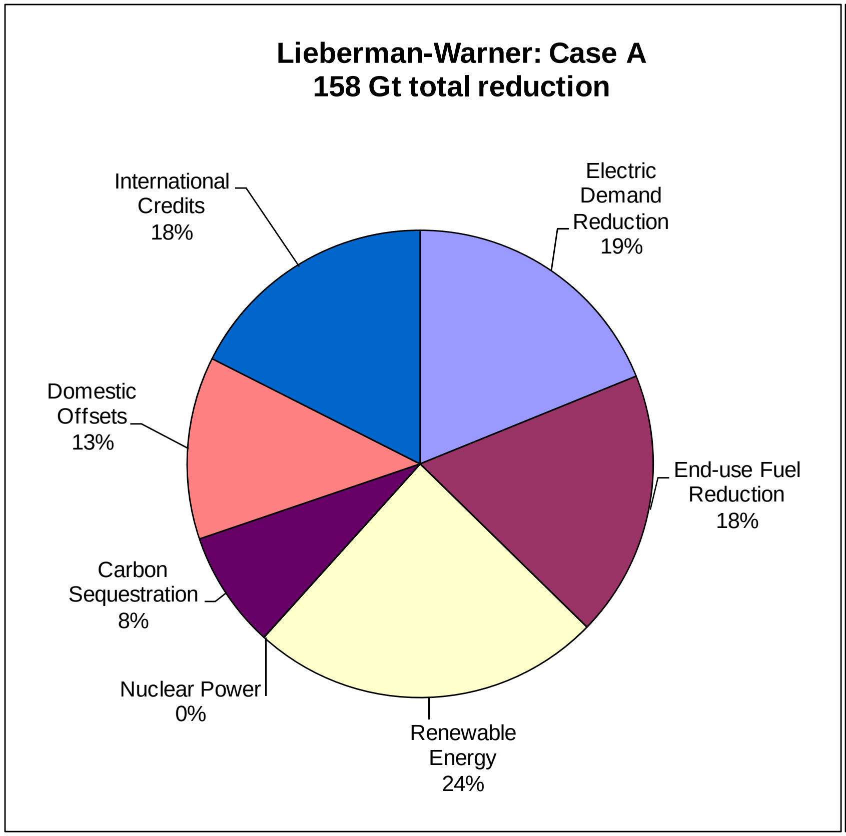
	Change in System Cost	Change in Cumulative Emissions
Business as Usual (BAU)	**0.0%**	**0.0%**
Enhanced Efficiency	**-1.3%**	**-7.5%**
Expanded Renewables	**-0.9%**	**-6.1%**
Combined Efficiency & Renewables (EE&RE)	**-1.9%**	**-11.9%**

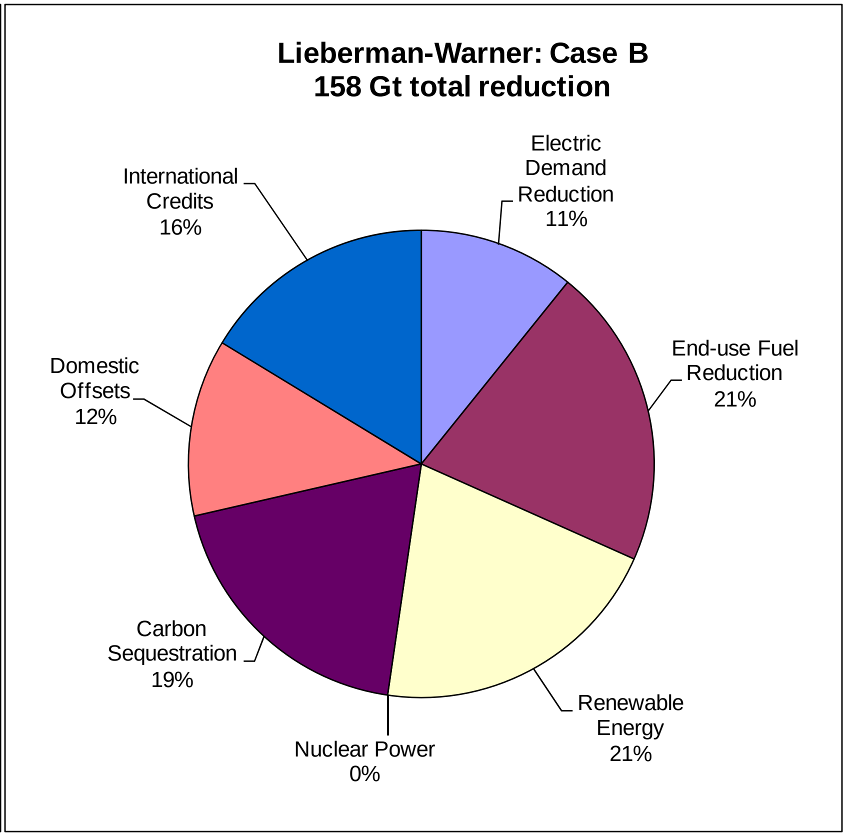


Lieberman-Warner: Case A - Most CO_2 reductions come from the electric sector through a combination of end-use efficiency improvements, renewable energy use and carbon capture and sequestration. Demand sector direct emissions are flat – with reductions offsetting growth. CCS grows to about 460 Mt/yr. CO_2 offsets average almost 1.2 Bt/yr.

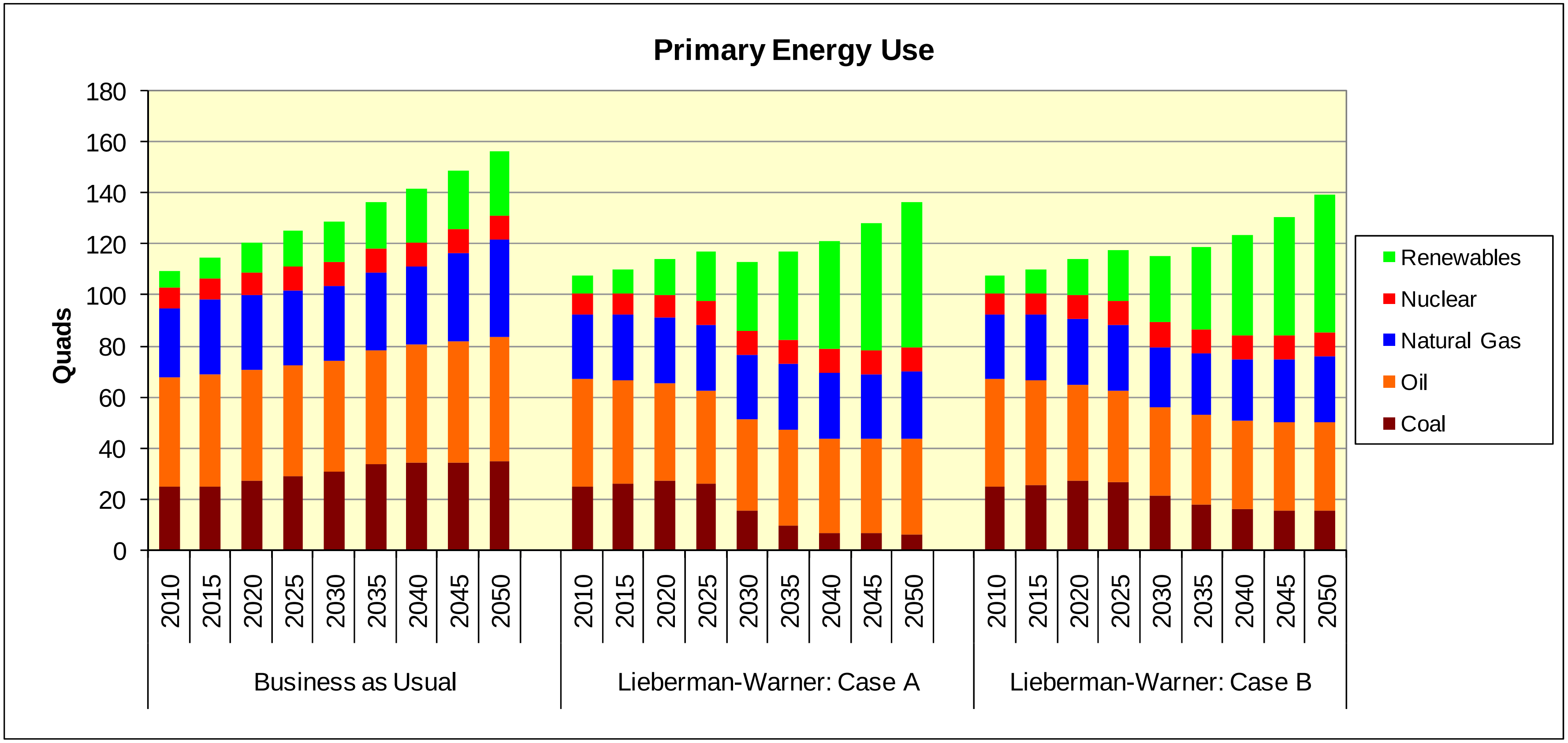


Source of emission reductions in Lieberman-Warner Cases A and B: In Case B intensive use of CCS technologies limits annual decline in coal power generation to 1%. Most CO_2 reductions continue to come from the electric sector and CCS increases to over 1.2 Bt/yr. Electric demand reduction, renewable energy and CO_2 offset use decline slightly compared to Case A.

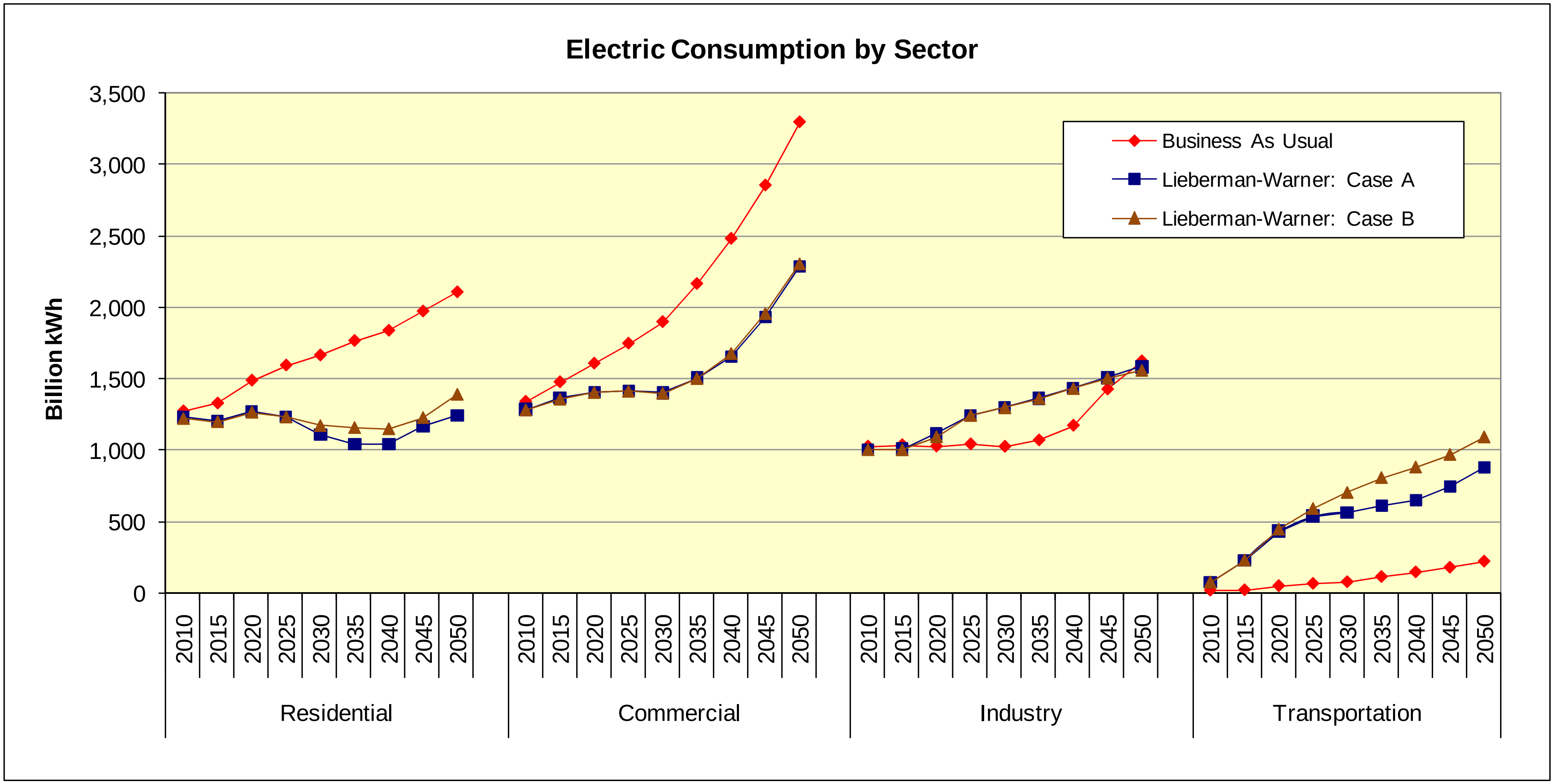




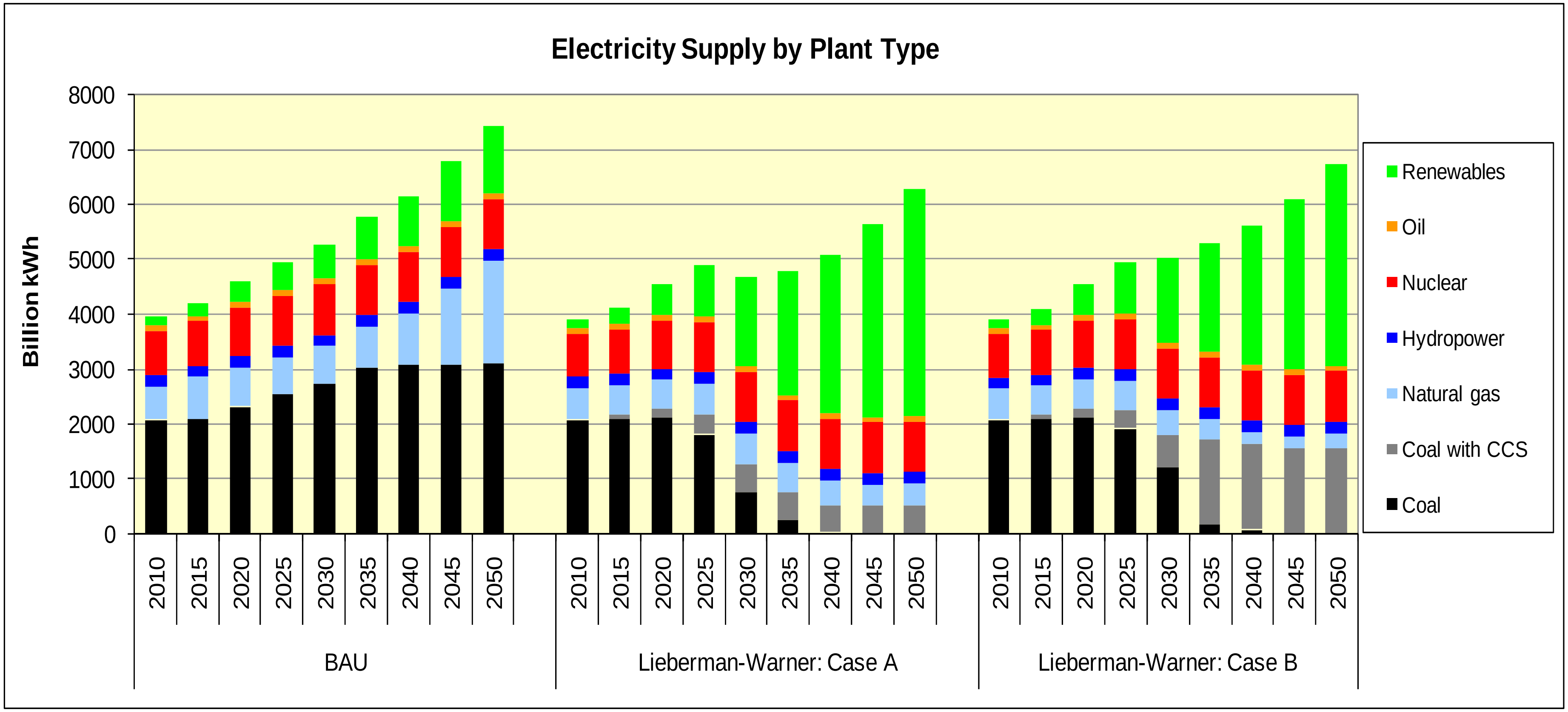
Primary energy use is 12% lower under Lieberman-Warner than in the BAU. Coal use grows to about 27 quads in 2025 and then declines to between 7 and 16 quads by 2050. Oil and natural gas use are reduced from the BAU case. Nuclear use remains constant, and renewable energy use increases to 26 quads in 2030 and to between 50 and 56 quads by 2050.



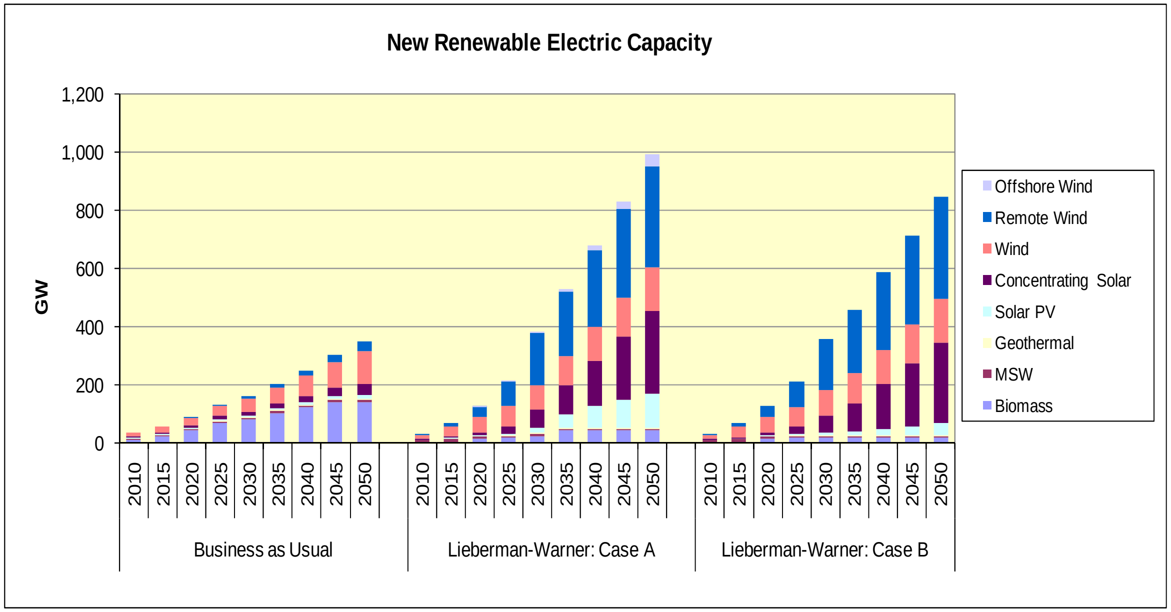
Electricity consumption shows significant reductions for the commercial and residential sectors compared to the BAU. Industrial electricity use increases above BAU as savings in machine drive and electrochemical use are offset by fuel switching in other areas. Transport electricity consumption increases dramatically to supply plug-in hybrids.



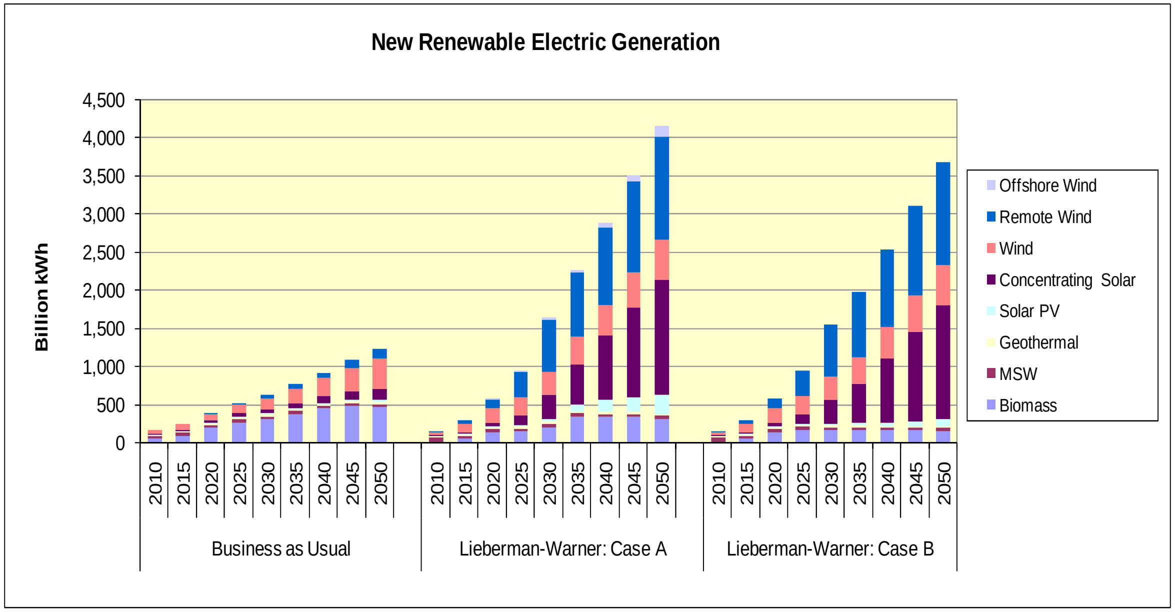
Electricity generation increases, but demand is 16% and 9% below the BAU case – with more consumption in Case B to supply plug-in hybrids. Power plant fuel mix shows the transition from coal combustion to coal with CCS starting in 2020; Natural gas is replaced with renewables, except for peaking considerations, and nuclear power grows slightly due to upgrades at existing plants only. Renewables grow to between 50 and 60% of supply.



Renewables are a mix of biomass, geothermal, concentrating solar power, solar photovoltaic (PV) and wind technologies and grow to between 800 an 1000 GW of installed capacity.

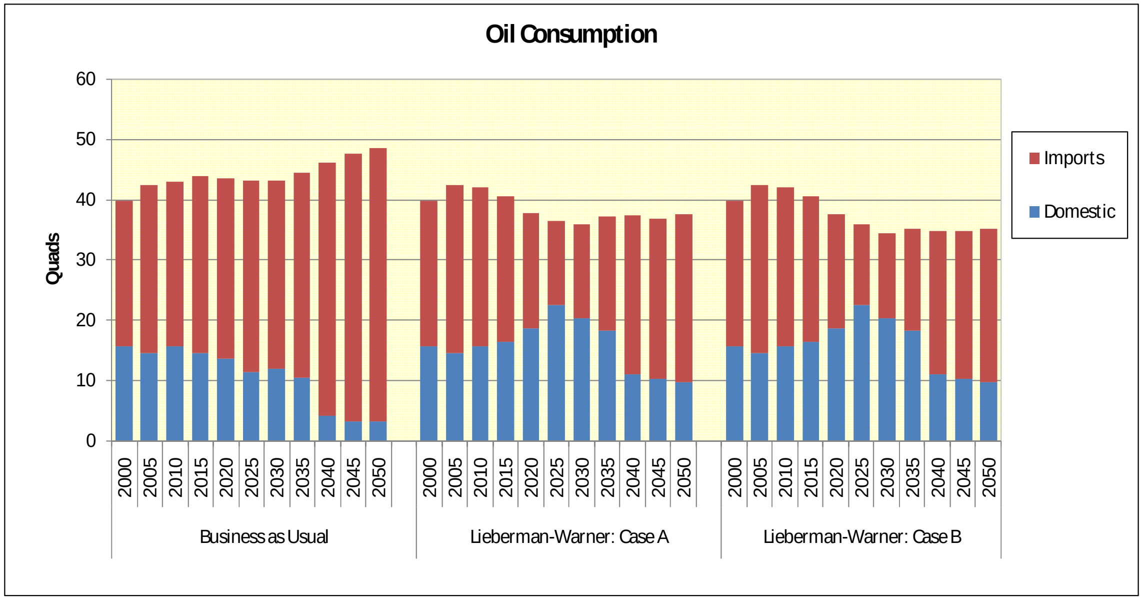


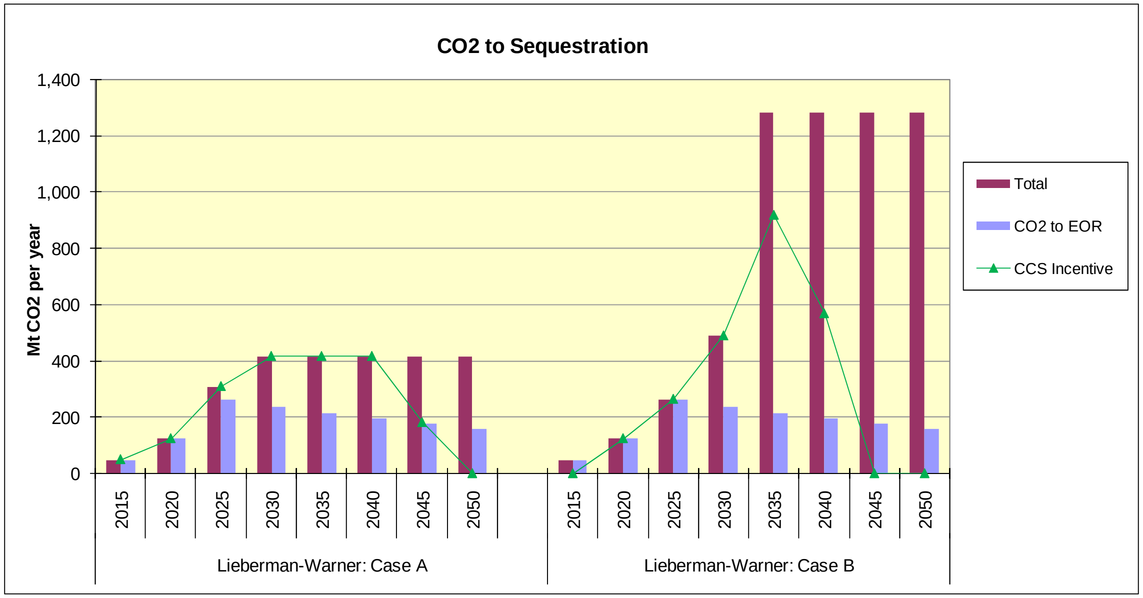
Electric output from new renewables comes mostly from large remote wind farms with dedicated transmission to load centers, and concentrating solar power with integrated energy storage.



Oil imports drop to about 35% of total oil supply in the 2030 and 2035 periods due to both the lower demand and the use of CCS for Enhanced Oil Recovery (EOR), then rise after this resource (50 billion barrels) begins to deplete, although staying under 60% of total oil supply compared to over 80% in the BAU.

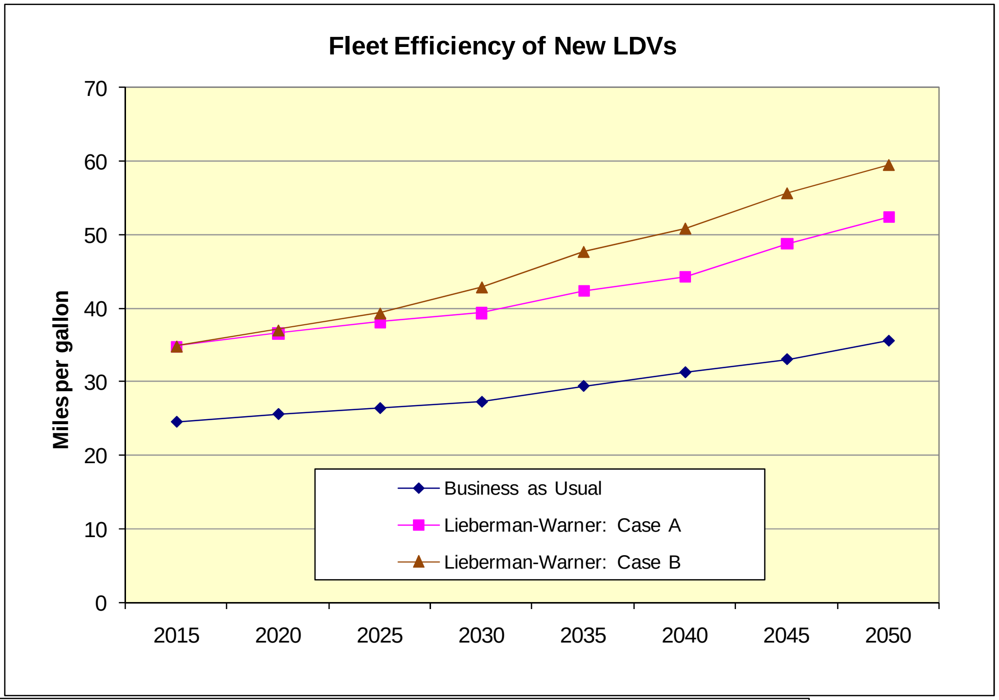
Incentives in Lieberman-Warner help to stimulate the implementation of CCS technology and result in a deployment of CCS above the level that can be used for EOR.

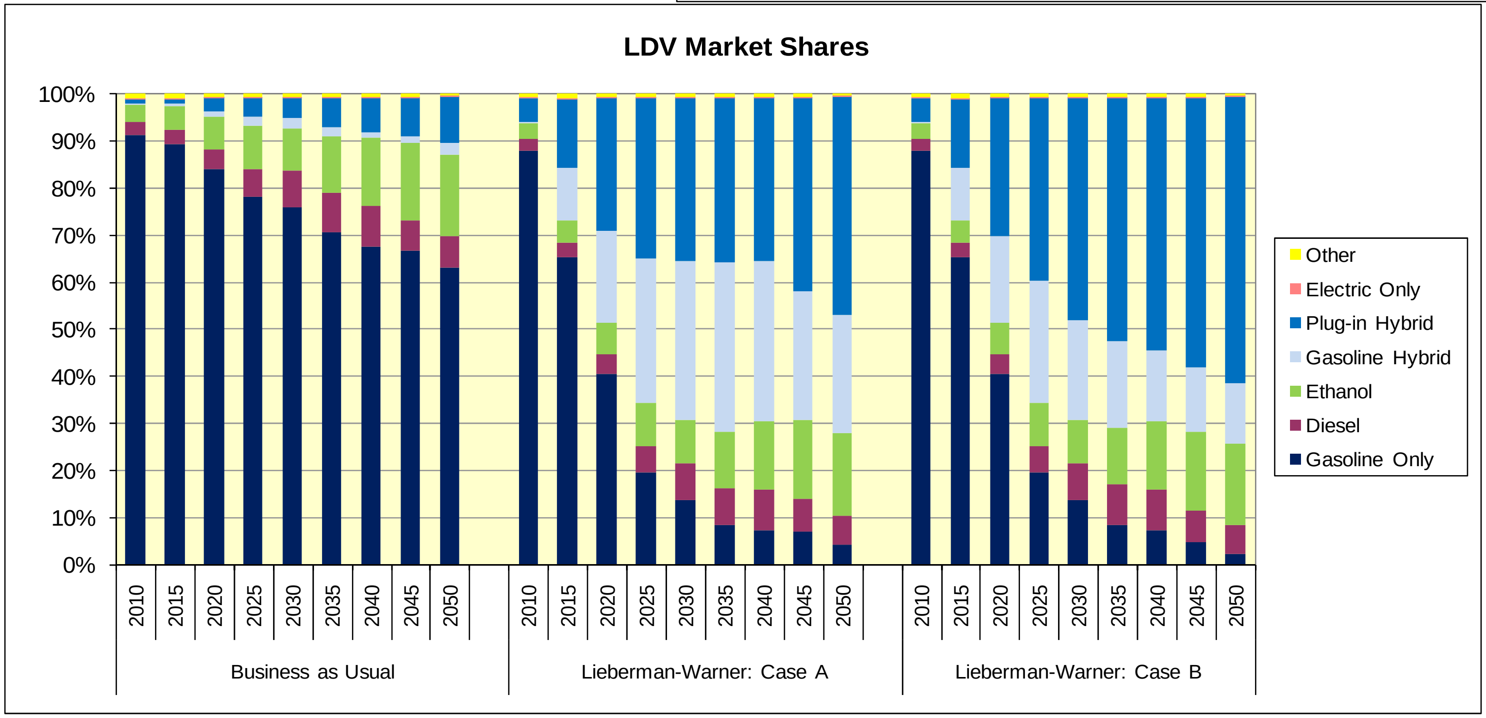




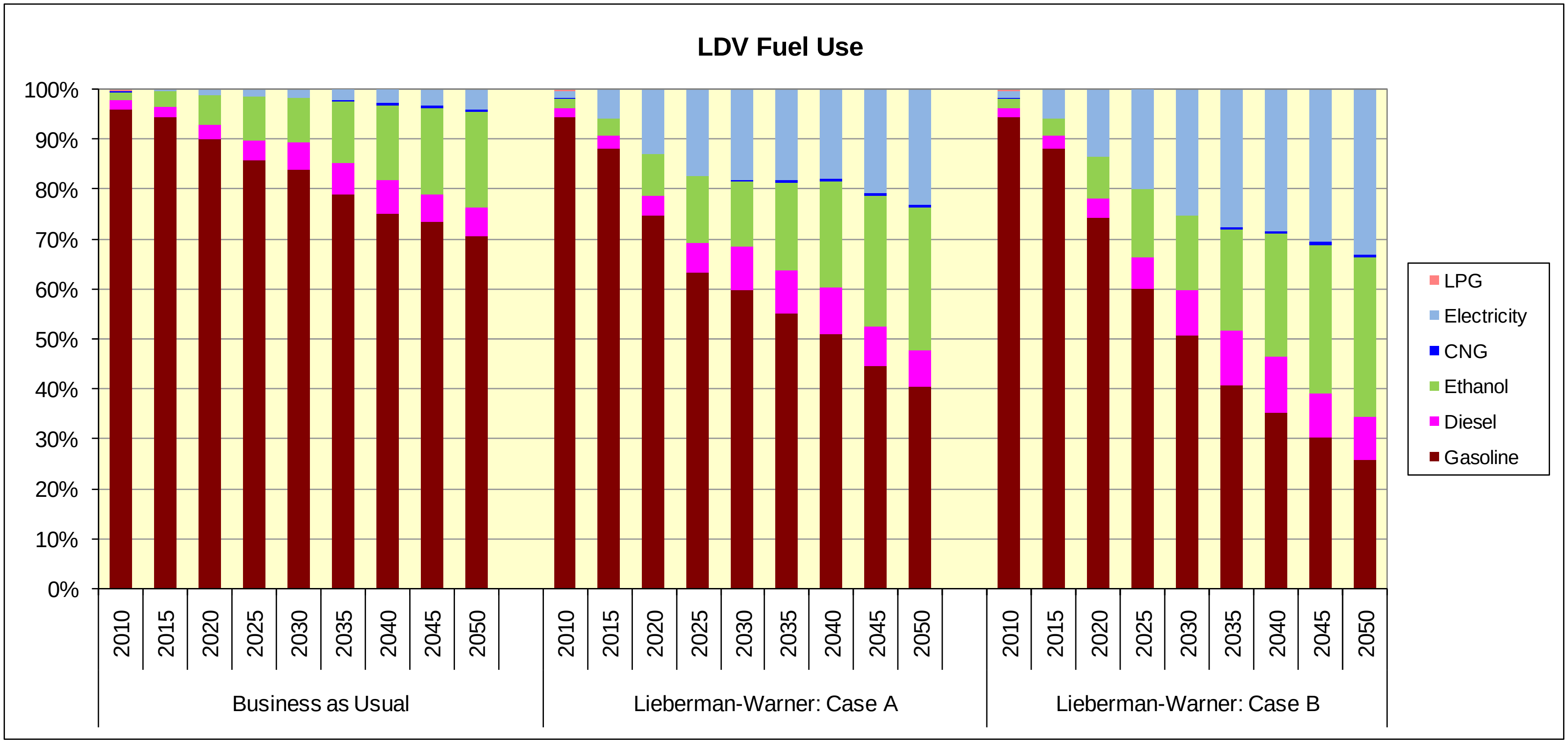
Fleet efficiency for new Light Duty Vehicle (LDV) improves to about 35 mpg in the BAU case, but increases to 52 and 60 mpg in the two Lieberman-Warner cases.

The LDV fleet converts to hybrids and plug-ins running flexibly on ethanol and gasoline. CCS-intensive case produces more electricity to fuel more plug-ins.





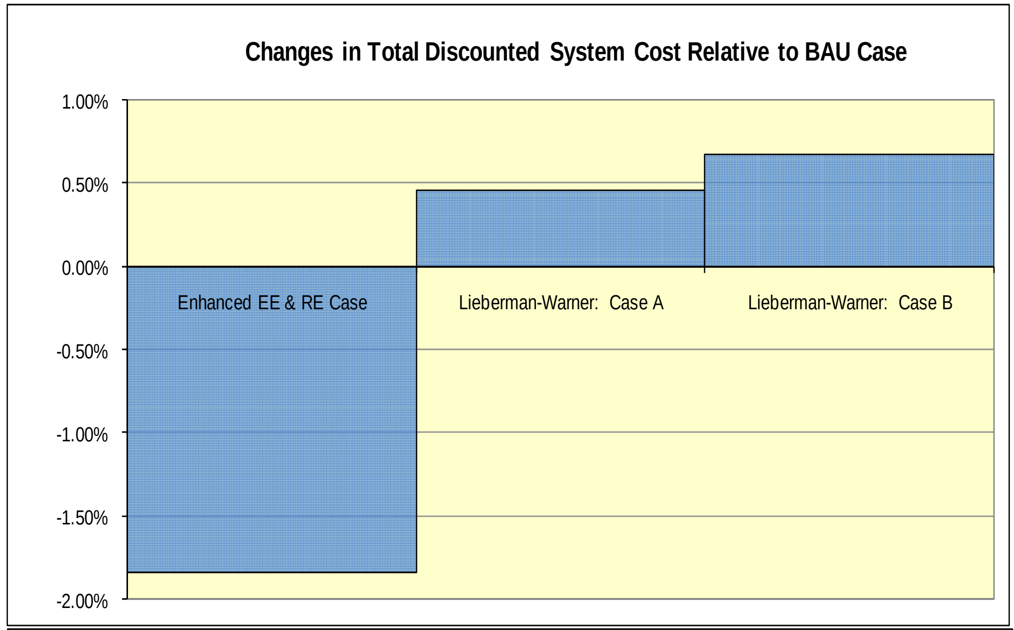
Gasoline use decreases to about 40% of all LDV fuel in Case A and 25% of all LDV fuel in Case B. Ethanol fuel share is 25% to 30%, and the electricity fuel share is between 24% and 34% for Cases A and B, respectively.

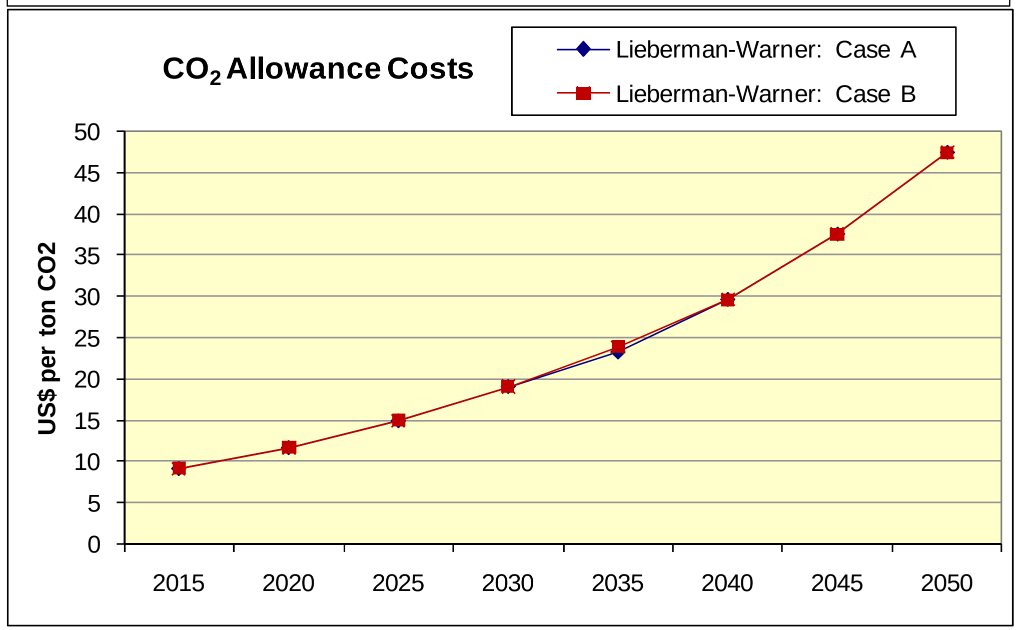


Policies to improve energy efficiency and promote renewable energy resources decrease the total energy system cost by about 1.8% relative to the BAU over the 2000 to 2050 period.

The CO_2 emission reductions in Lieberman-Warner increase the energy system cost, but the net cost increase relative to the BAU case is only 0.45% in Case A. Case B has a 0.65% increase in the total system cost, given the lower learning rate assumed for CCS relative to renewable energy systems.

In both cases CO_2 allowance prices are $12/ton in 2020, increasing to $20/ton in 2030 and almost $50 per ton in 2050.





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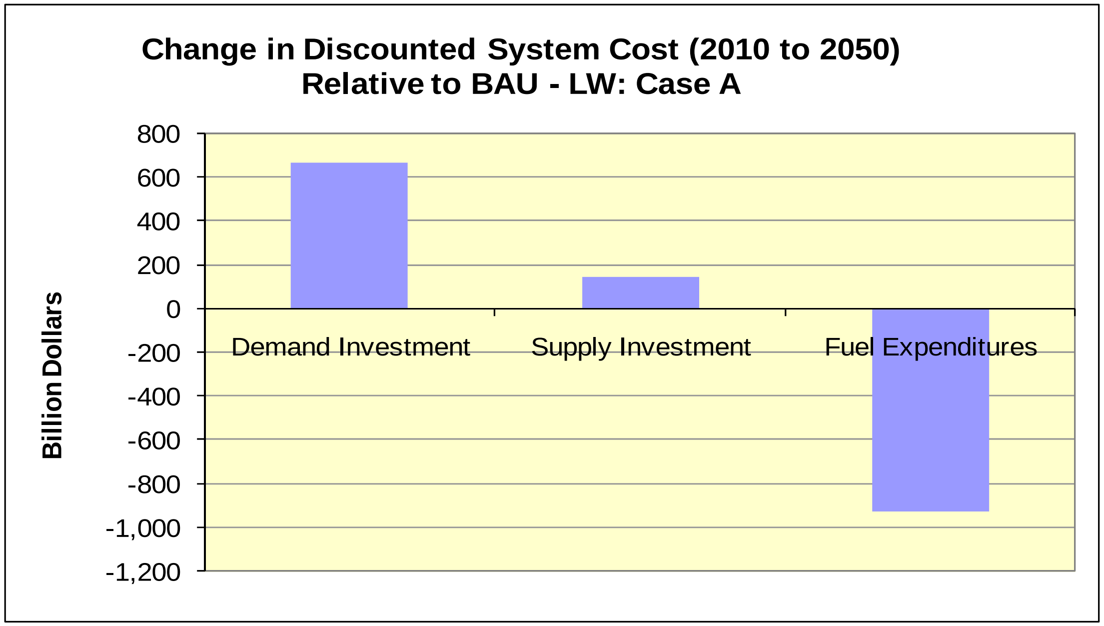
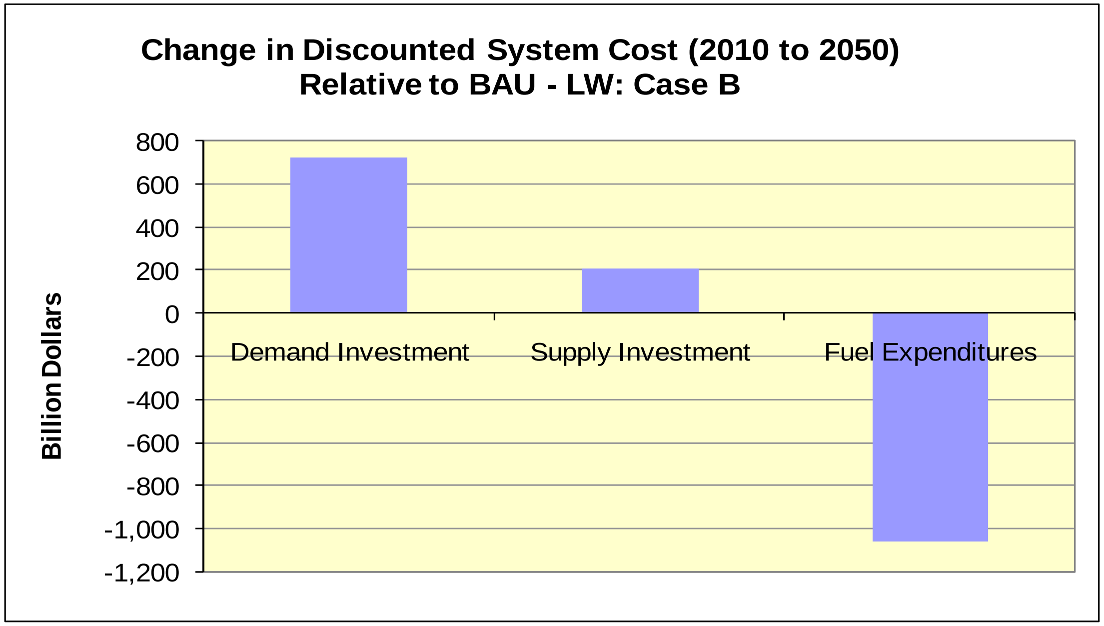
To achieve deep CO_2 emission reductions, increased investment in demand technologies is needed.

Supply investments are similar to those required in the BAU case because reduced electricity demand offsets the cost of the more expensive generation technologies.

Overall cost impacts are mitigated by savings in fuel expenditures.

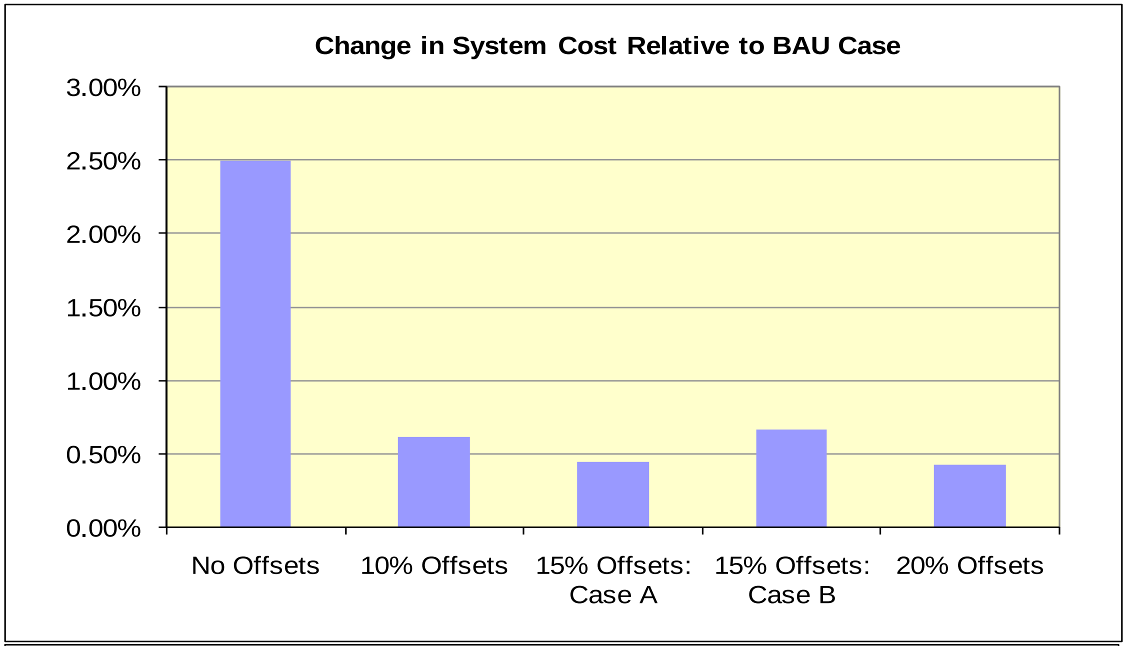


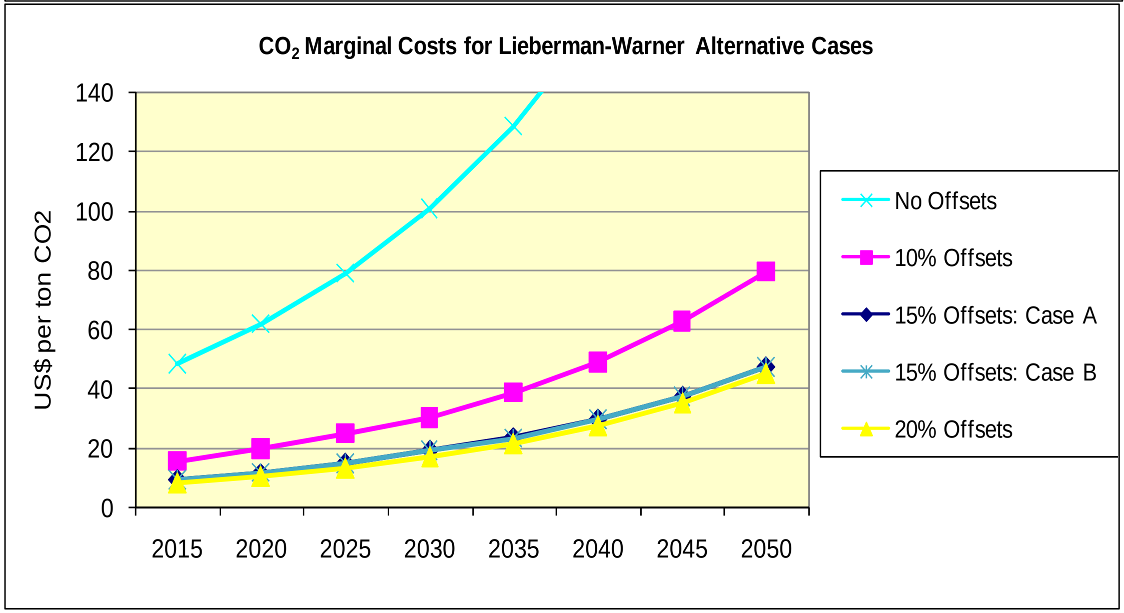


Decreasing CO_2 Offsets from domestic and international sources leads to steeper CO_2 reductions in the electric sector, through earlier retirement of existing stock, increased CCS and renewables, and decreased demand.

System cost impacts of limiting offsets are small, but the increase in CO_2 marginal costs is significant.

Additional offsets beyond 15% are of little benefit.

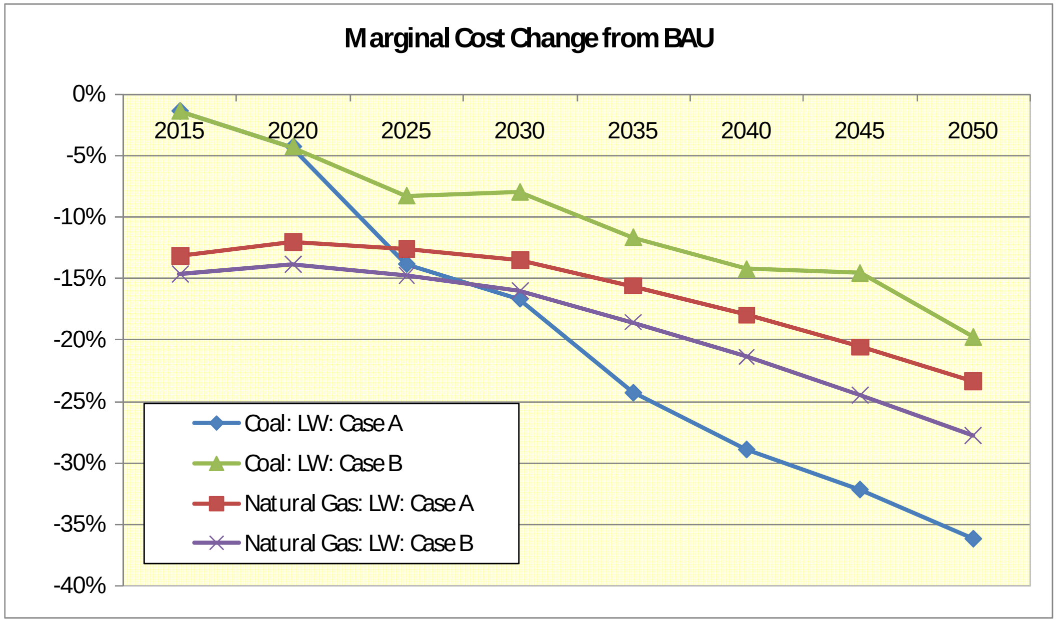


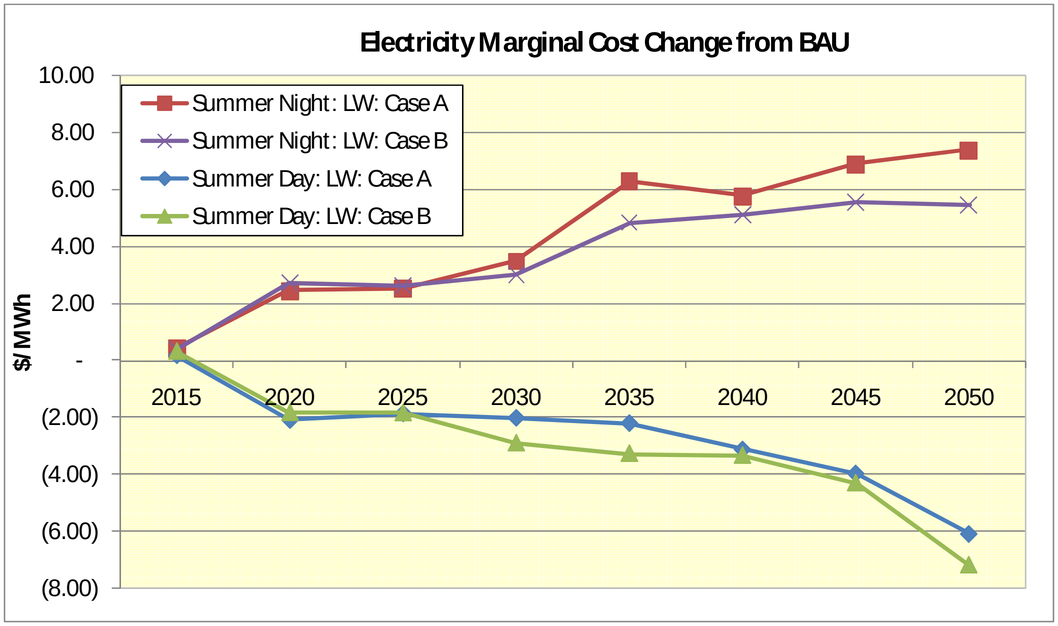


Marginal energy costs for coal and natural gas are lower relative to the BAU case due to decreased demand.

In Case B, the relative decline in coal prices is only 20% in 2050 due to higher coal use compared to Case A.

Electricity prices for summer days decrease due to decreased demand, but summer night prices increase as the use of plug-in hybrids grows.

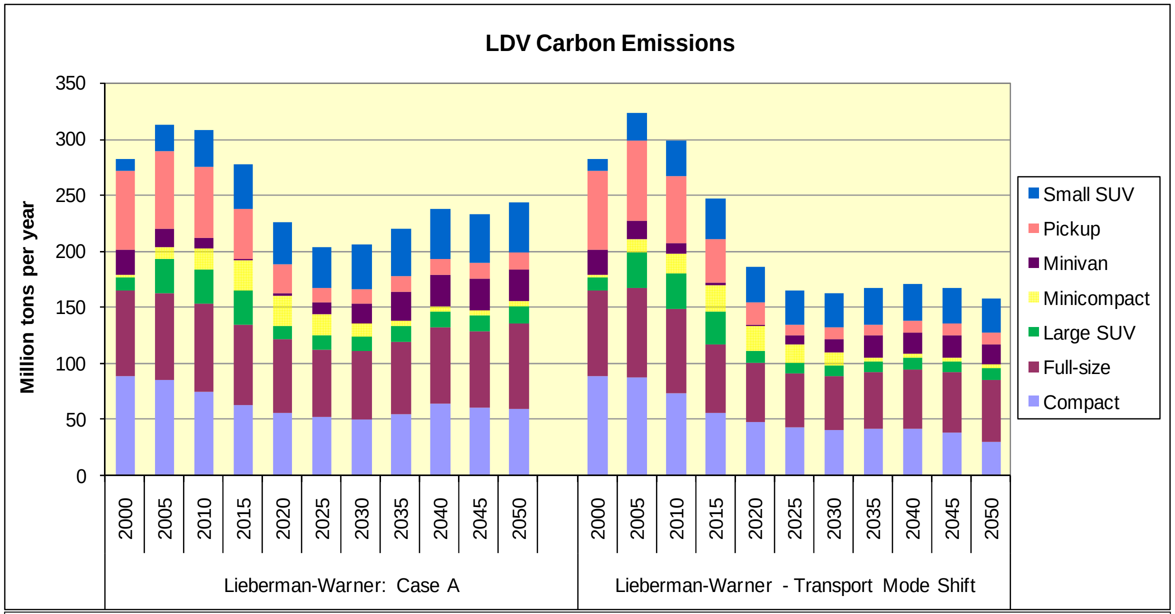


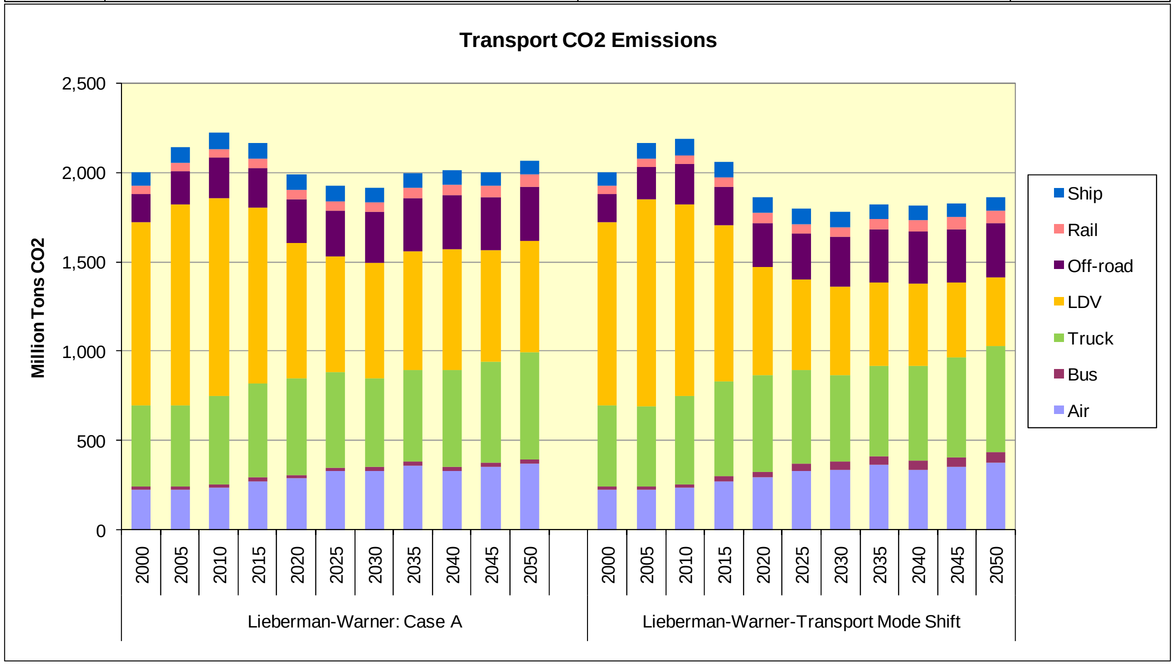


Transport Mode Sensitivity:

Policies and programs to shift 24% of LDV passenger travel demand to bus and rail by 2050 reduce transport sector CO_2 emissions by 8% in 2030 and 12% in 2050.

Total system cost decreases by 5% and CO_2 allowance prices by 7% when LDV miles are reduced.

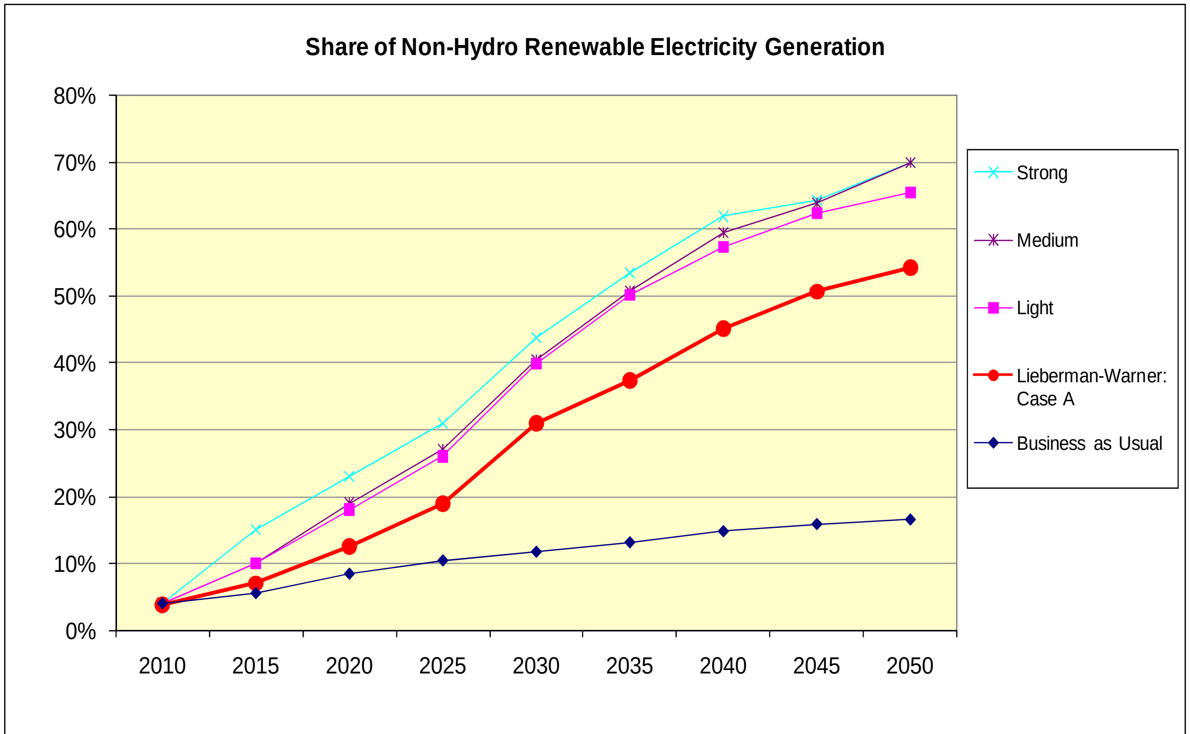




RPS Sensitivity:

Faster ramp-up of renewable electricity generation can help to lower CO_2 marginal costs with relatively small increases in the total system cost.

The faster ramp-up shows greater relative benefits in 2030.



	Change in System Cost relative to Lieberman-Warner	Change in CO_2 Marginal cost - 2030	Change in CO_2 Marginal cost - 2050
Light RPS	0.12%	-9%	-6%
Medium RPS	0.12%	-9%	-6%
Strong RPS	0.29%	-15%	-9%

Conclusions

- Lieberman-Warner CO_2 reduction targets are achievable with minimal increase in total discounted energy system cost, but major technology transitions are required.
- Least-cost reduction paths focus on early and steady reductions in the electric sector through rapid promotion of energy efficiency, early development of renewable energy and strong deployment of CCS technology starting in 2020.
- The nation's LDV fleet must transition to hybrid and plug-in vehicles running flexibly on ethanol, gasoline and electricity.
- Limited use of domestic offsets and international credits significantly reduce compliance costs but additional offsets are of little benefit.
- Achieving Lieberman-Warner targets through energy efficiency, renewables and CCS-supplied Enhanced Oil Recovery has the added benefit of substantially reducing dependence on foreign oil.

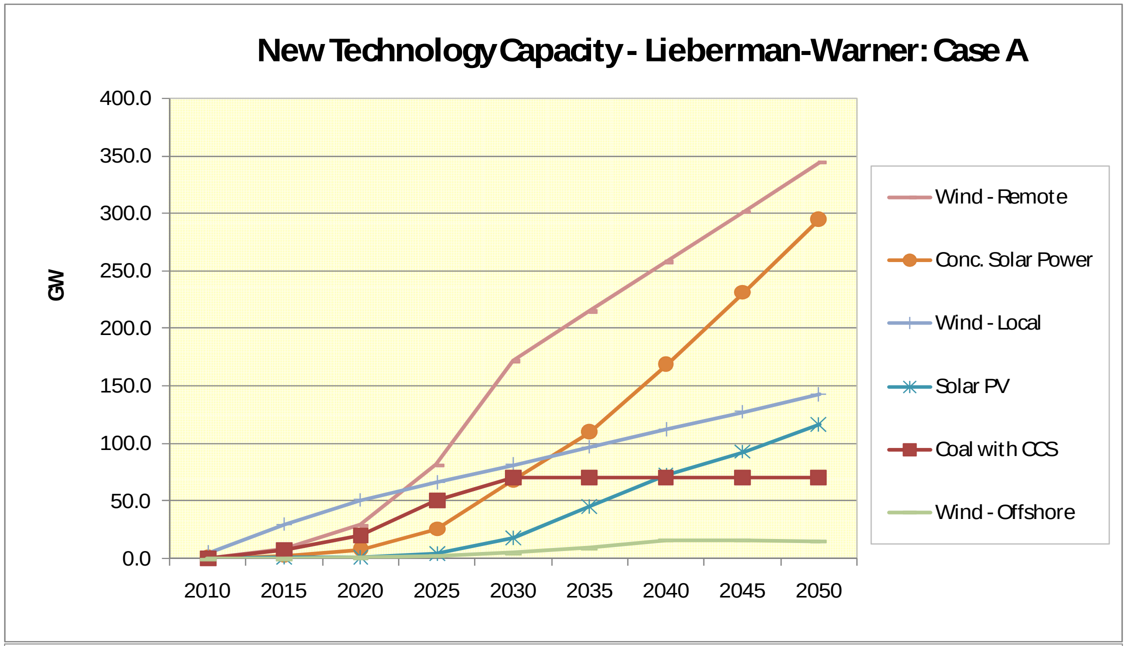
Appendix:
Technology Learning Details

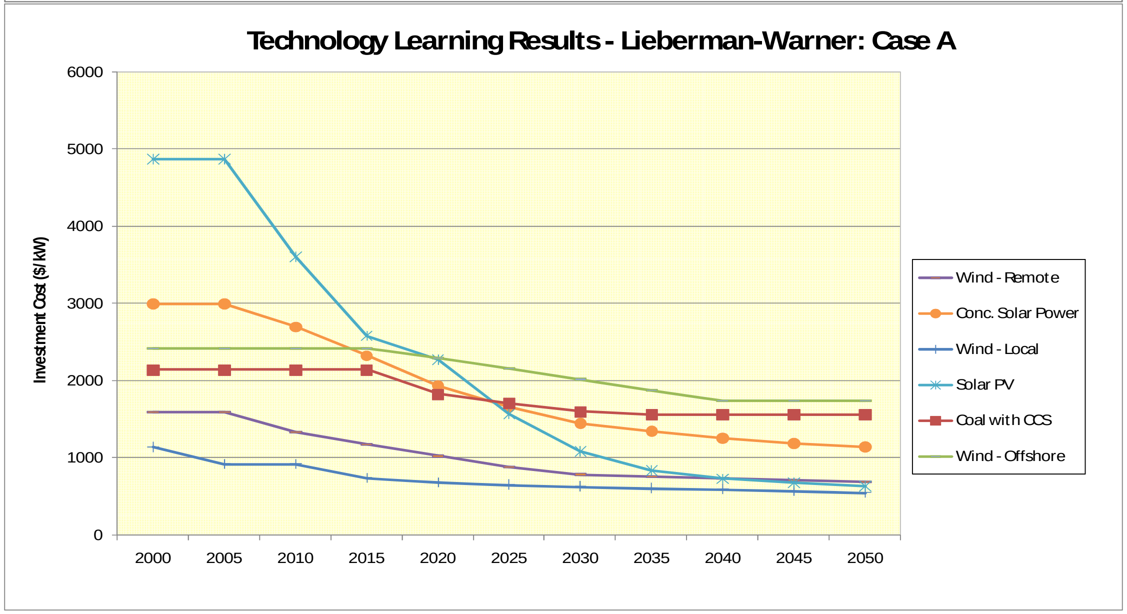
Technology	Initial Investment Cost, $/kW	Fixed O&M Cost, $/kW-yr	Variable O&M Cost, $/kW	Progress ratio
Biomass Gasification Combined Cycle	1,873	40.91	0.75	0.89
Power and Fischer-Tropsche Liquid from Biomass	2,459	0.00	4.14	0.89
Atmospheric Fluidized Bed	1,570	38.11	0.86	
Pulverized Coal to Coal Fired Power -- 2010	1,311	21.48	0.86	
Integrated Coal Gasif. Combined Cycle -- 2015	1,860	29.98	0.20	0.95
Integrated Coal Gasif. Combined Cycle -- CO2 Capt.	2,144	41.44	1.12	0.95
Geothermal Binary Cycle and Flashed Steam	1,896	91.02	0.00	0.89
Geothermal Enhanced Hydraulic Geo-Stimulation	3,000	91.00	0.00	0.9
Hydroelectric	929	12.90	1.13	
Hydroelectric Pumped Storage	1,615	15.18	0.67	
Natural Gas Advanced Combined Cycle--2010	602	13.27	0.13	
Natural Gas Advanced Combustion Turbine--2010	403	8.07	0.71	
Distributed Generation--Base--2010	887	12.29	1.61	
Natural Gas Combined Cycle -- CO2 Capture	1,190	18.12	0.74	
Pebble Bed Modular Reactor	2,875	0.00	0.69	0.95
Gas Turbine - Modular Helium Reactor	2,683	26.48	0.18	0.95
New Conventional Nuclear (LWR)	2,000	63.00	0.00	
Advanced LWR available 2010	2,440	0.00	1.39	
Central Photovoltaic	4,158	8.96	0.00	0.8
Photovoltaic--Commercial	4,870	12.00	0.00	0.8
Photovoltaic--Residential	7,519	30.00	0.00	0.8
Solar Central Thermal	2,757	36.00	0.00	0.9
Solar Central Thermal-Storage	3,000	24.00	0.00	0.9
Wind Central Electric	1,226	23.24	0.00	0.89
Wind Central Electric-Land-Remote	1,597	23.44	0.00	0.89
Wind Central Electric-Offshore-Local	2,423	29.30	0.00	0.89
Wind Central Electric-CAES Hybrid	2,770	23.44	0.00	0.89

Technology Learning: Case A

New power plant technology choices are modeled using endogenous technology learning based on initial technology cost and progress ratio data.

In Case A most capacity additions and cost reductions occur for renewable technologies although coal gasification with CCS has modest penetration and cost reduction.





Technology Learning: Case B

New power plant technology choices are modeled using endogenous technology learning based on initial technology cost and progress ratio data.

In Case B coal gasification with CCS has much greater penetration and cost reduction, while solar PV penetration is significantly decreased and offshore wind is not used.