The Role of Solar in the Long-Term Outlook of Electric Power Generation in the U.S.

Robert Margolis (NREL) and
Frances Wood (OnLocation)

Presentation at
24th USAEE/IAEE North American Conference
Washington, DC
July 8-10, 2004

Objective

- To perform an analysis of solar energy market potential through 2050
  - Used the EIA's Annual Energy Outlook 2003 High Renewables and Technology Demand Cases as a starting point (through 2025).
  - Extended the relevant portions of EIA's National Energy Modeling System (NEMS) to 2050 so that the longer term potential of solar technologies could be assessed.
  - Ran a series of scenarios to determine key factors driving solar technology adoption.
  - Evaluated sensitivities to assumptions and limitations of the model.

Developed Four Solar Focused Scenarios

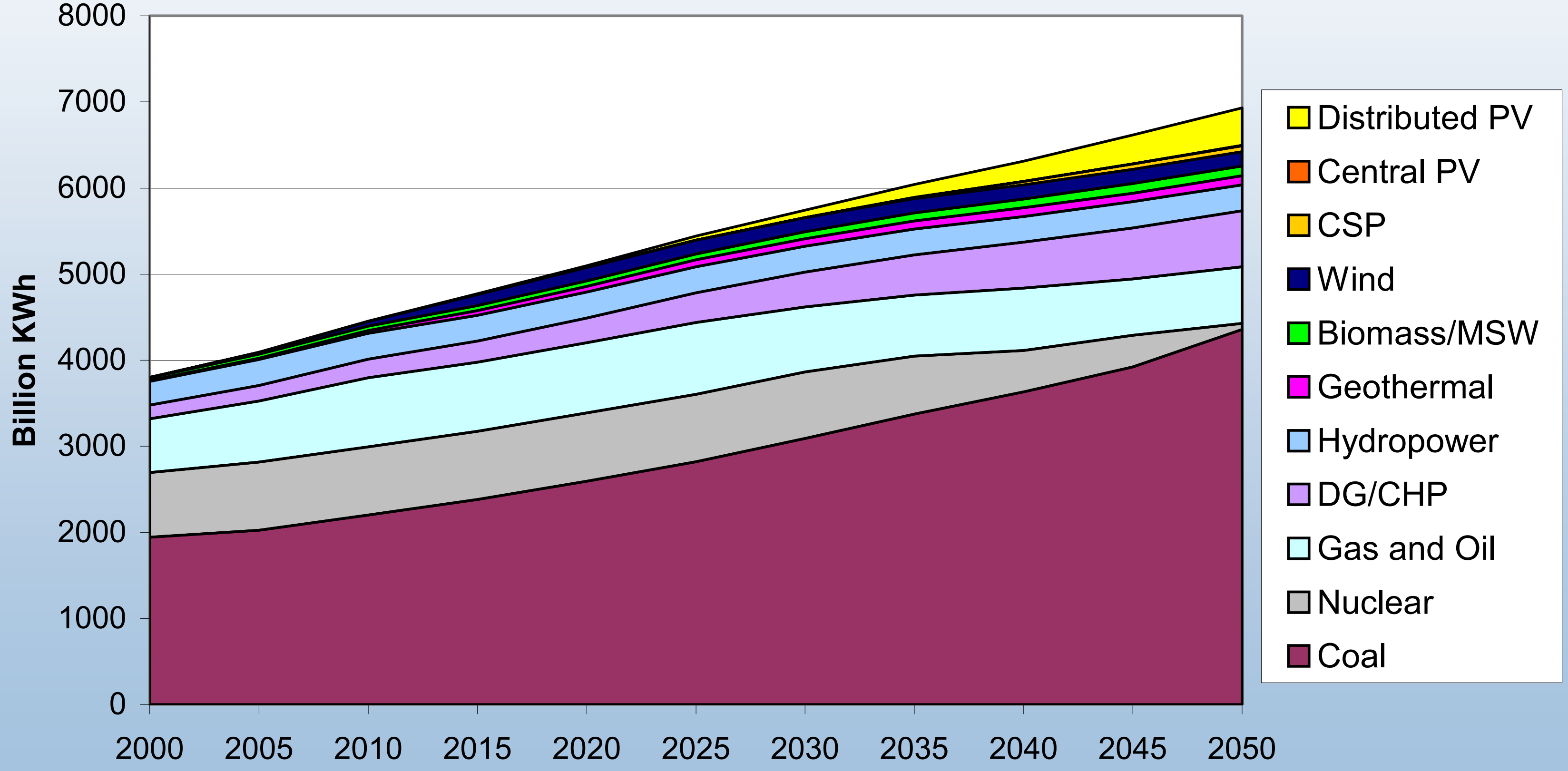
1) ***Solar Baseline Scenario***: Based on existing DOE solar program targets with EIA's high technology assumptions for energy efficiency and non-solar renewable energy technologies (extended to 2050). For other technologies used EIA's reference scenario assumptions.
2) ***Solar Baseline with Carbon Value***: Imposed a carbon value rising linearly from $0 per ton carbon in the 2015, to $100 per ton carbon in 2040.
3) ***Solar Advanced R&D with Moderate Policies***: Enhanced solar R&D and moderate policies added to (2).
4) ***Solar Advanced R&D with Aggressive Policies***: Enhanced solar R&D and aggressive policies added to (2).

Scenario Assumption Matrix

	Solar Baseline	Carbon Value	Enhanced R&D with Moderate Policies	Enhanced R&D with Aggressive Policies
Central Station Solar				
Technology Characteristics	Existing Program Targets	Existing Program Targets	Accelerated Targets	Accelerated Targets
Investment Tax Credit and 5-year Depreciation	Yes	Yes	Yes	Yes
Production Tax Credit	None	None	1.8 cents/kWh for 10 years phased out by 2030	2.7 cents/kWh for 20 years phased out by 2030
Financing Period	20 Years	20 Years	20 Years	30 Years
Distributed PV				
Technology Characteristics	Existing Program Targets	Existing Program Targets	Accelerated Targets	Accelerated Targets
System Capacity Size	Residential: 4 kW Commercial: 100kW	Residential: 4 kW Commercial: 100kW	Average size increases by 50% by 2030	Average size increases by 100% by 2030
5-year Depreciation	Commercial: Yes	Commercial: Yes	Commercial: Yes	Commercial: Yes
Investment Tax Credit	Commercial: 10%	Commercial: 10%	30% in 2005, declining to 10% by 2030	30% in 2005, declining to 10% by 2030
Adoption Rate for Existing Buildings	1/50 of New Buildings	1/50 of New Buildings	1/50 of New Buildings	1/30 of New Buildings
Solar Water and Space Heating				
Technology Characteristics	Existing Program Targets	Existing Program Targets	Accelerated Targets	Accelerated Targets
Investment Tax Credit	None	None	30% in 2005, declining to 10% by 2030	30% in 2005, declining to 10% by 2030

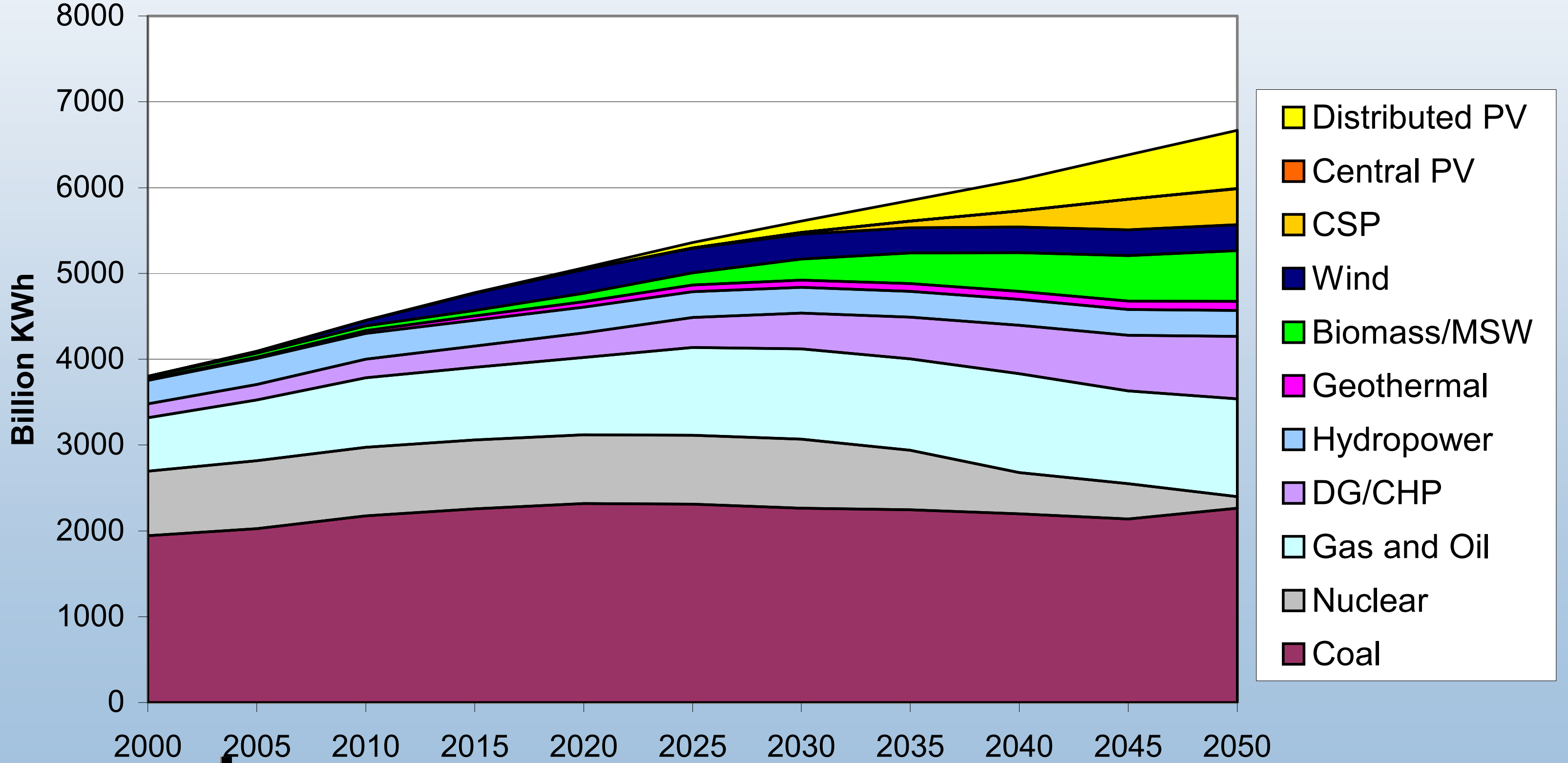
Baseline Electricity Generation by Fuel

- Without further initiatives, solar is projected to provide 7 percent of electricity generation by 2050.
- Coal continues to dominate U.S. supply under this scenario.



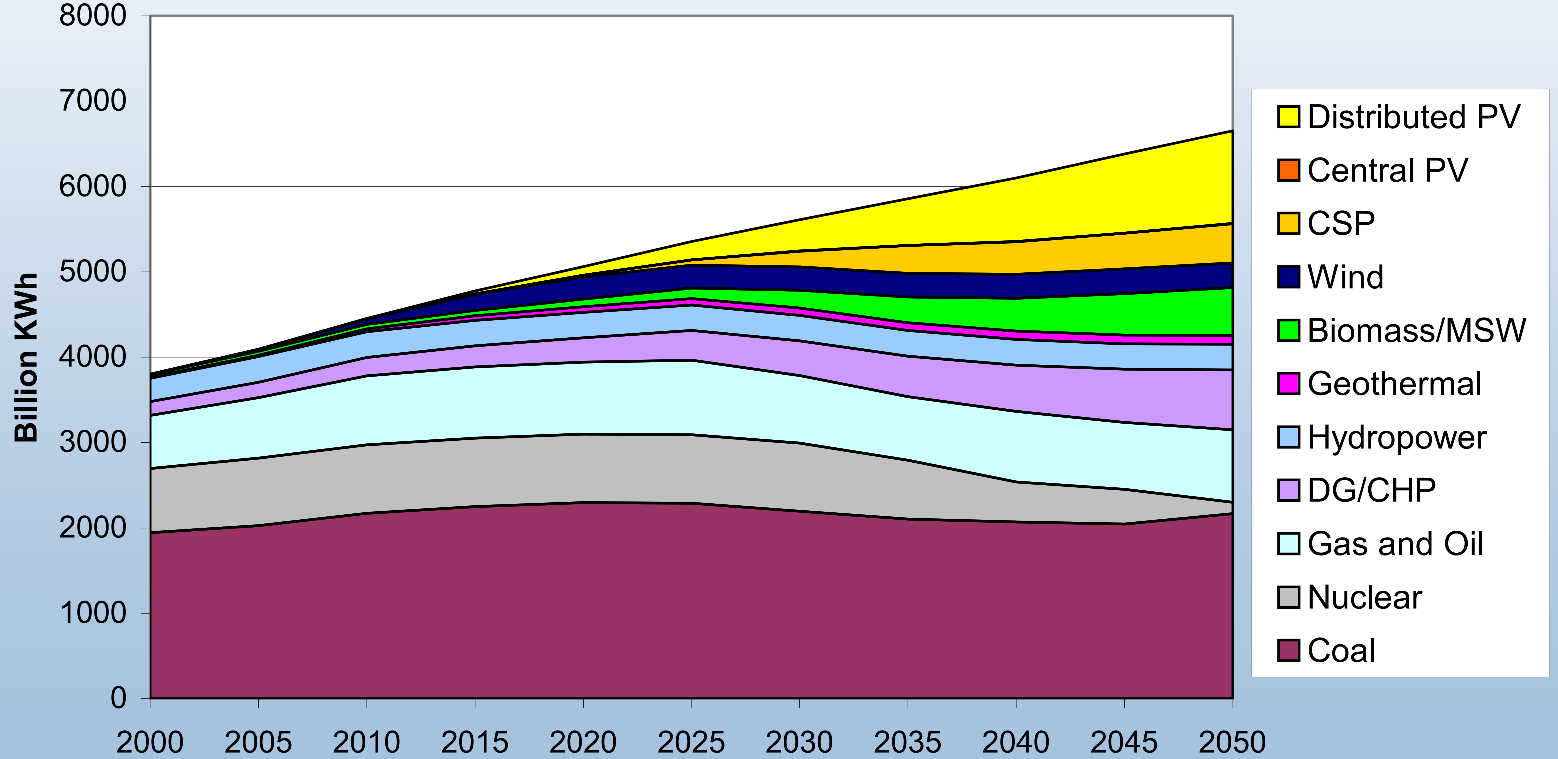
Baseline with Carbon Value Electricity Generation by Fuel

- With a $100 per ton carbon value, the solar share of electricity generation increases to 17 percent by 2050.
- Share of generation from other renewables increase substantially.
- Coal generation moderates.



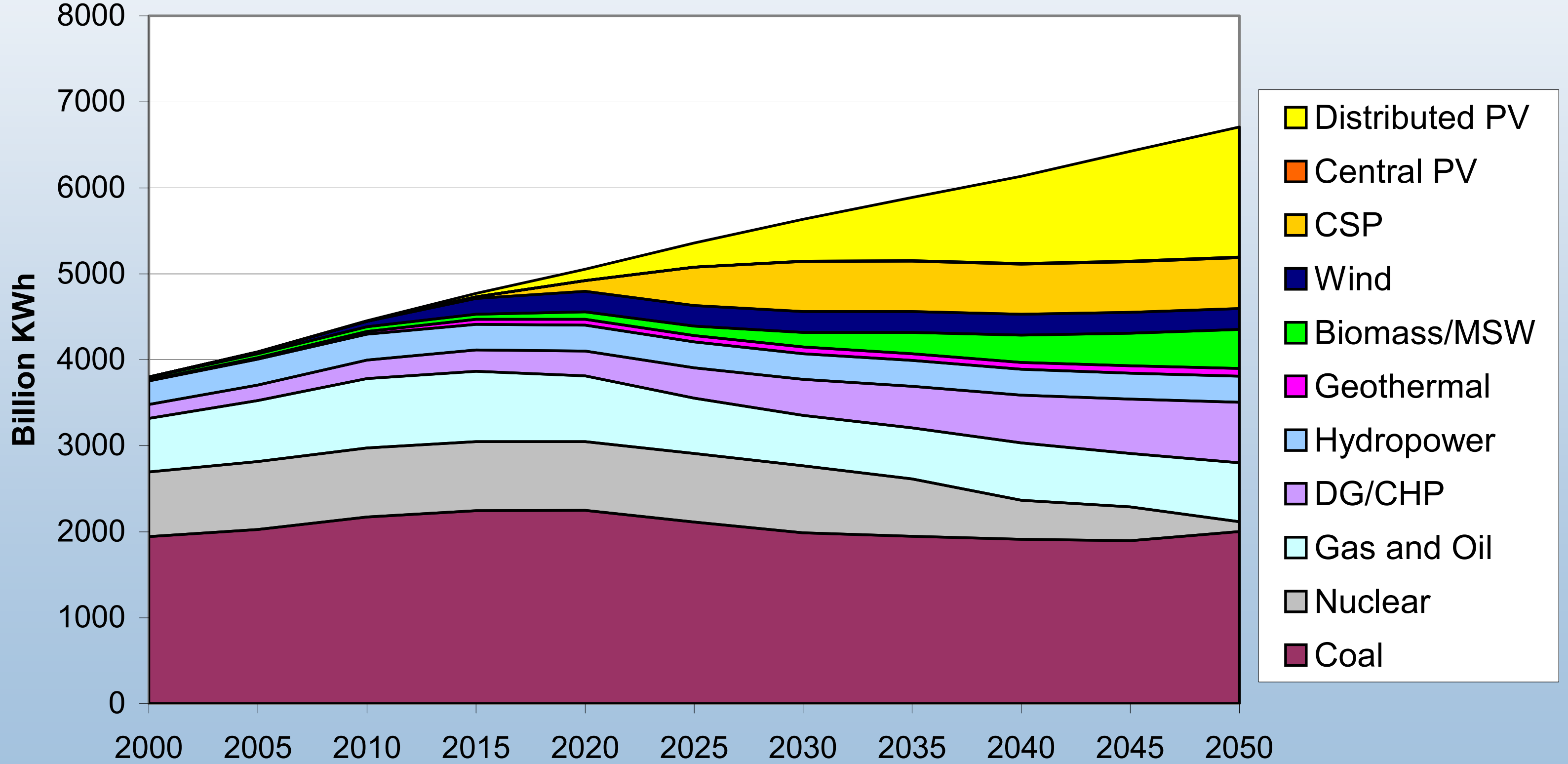
R&D and Moderate Policies Electricity Generation by Fuel

- With additional R&D and moderate policies, the solar share of generation could increase to 23 percent by 2050.
- Distributed generation could supply 30 percent of demand by 2050 under this scenario.



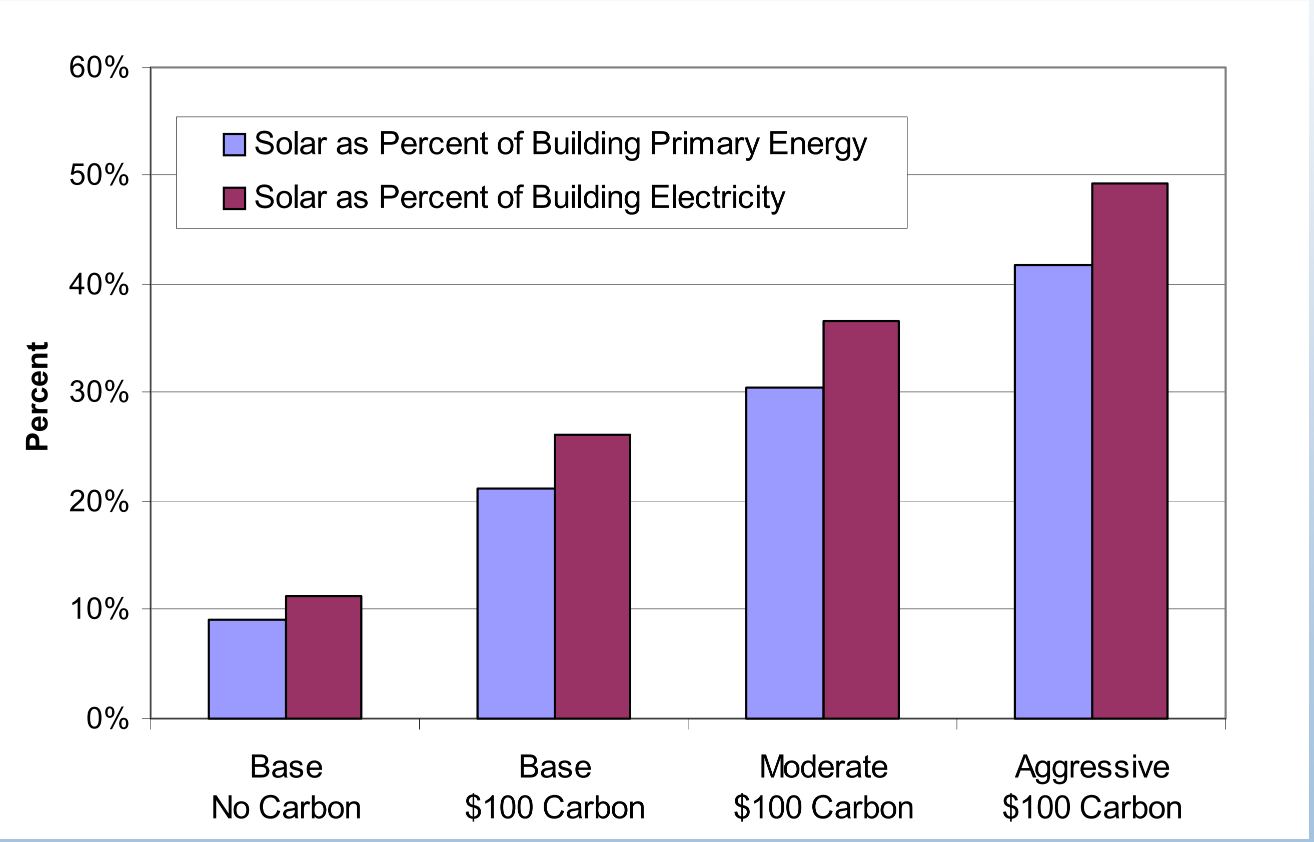
R&D and Aggressive Policies Electricity Generation by Fuel

- With more aggressive policies the solar share of generation might increase to 32 percent by 2050.
- Distributed generation might supply one third of electricity demand by 2050.



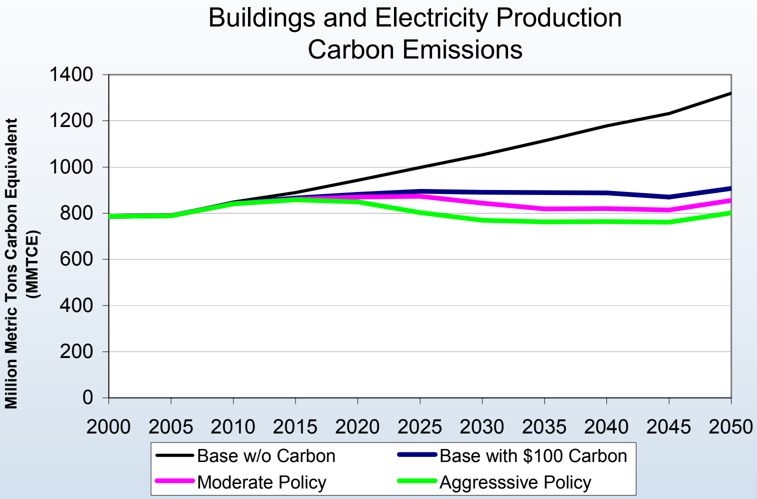
Solar Contribution in 2050

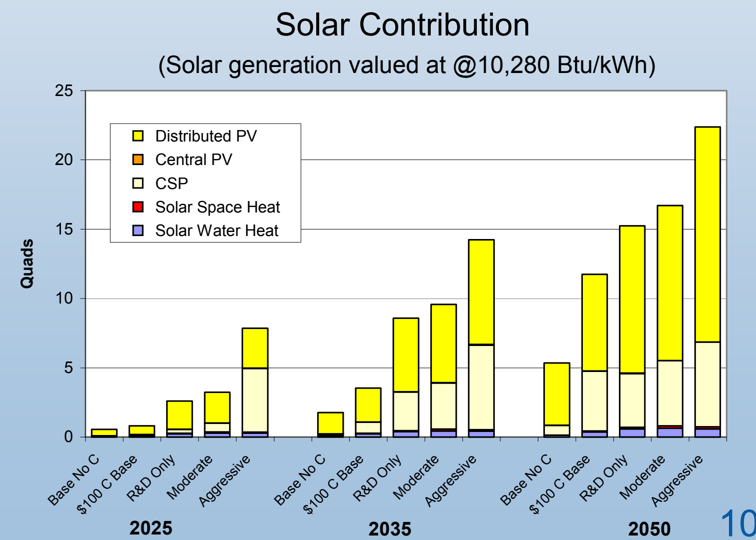
- With aggressive policies to promote solar technologies, solar could supply roughly half of the electricity demand in buildings by 2050.



Benefits

- With Enhanced R&D and Policies
  - Solar makes a significant contribution to lower carbon emissions (and other air pollutants).
  - Solar technologies displace 17 quads (moderate case) and 22 quads (aggressive case) of conventional energy by 2050.
  - Expanding the use of this domestic resource and distributed generation makes our power system more reliable and secure.





EAO Energy Analysis Office Understanding Energy Issues

NREL National Renewable Energy Laboratory

Conclusions

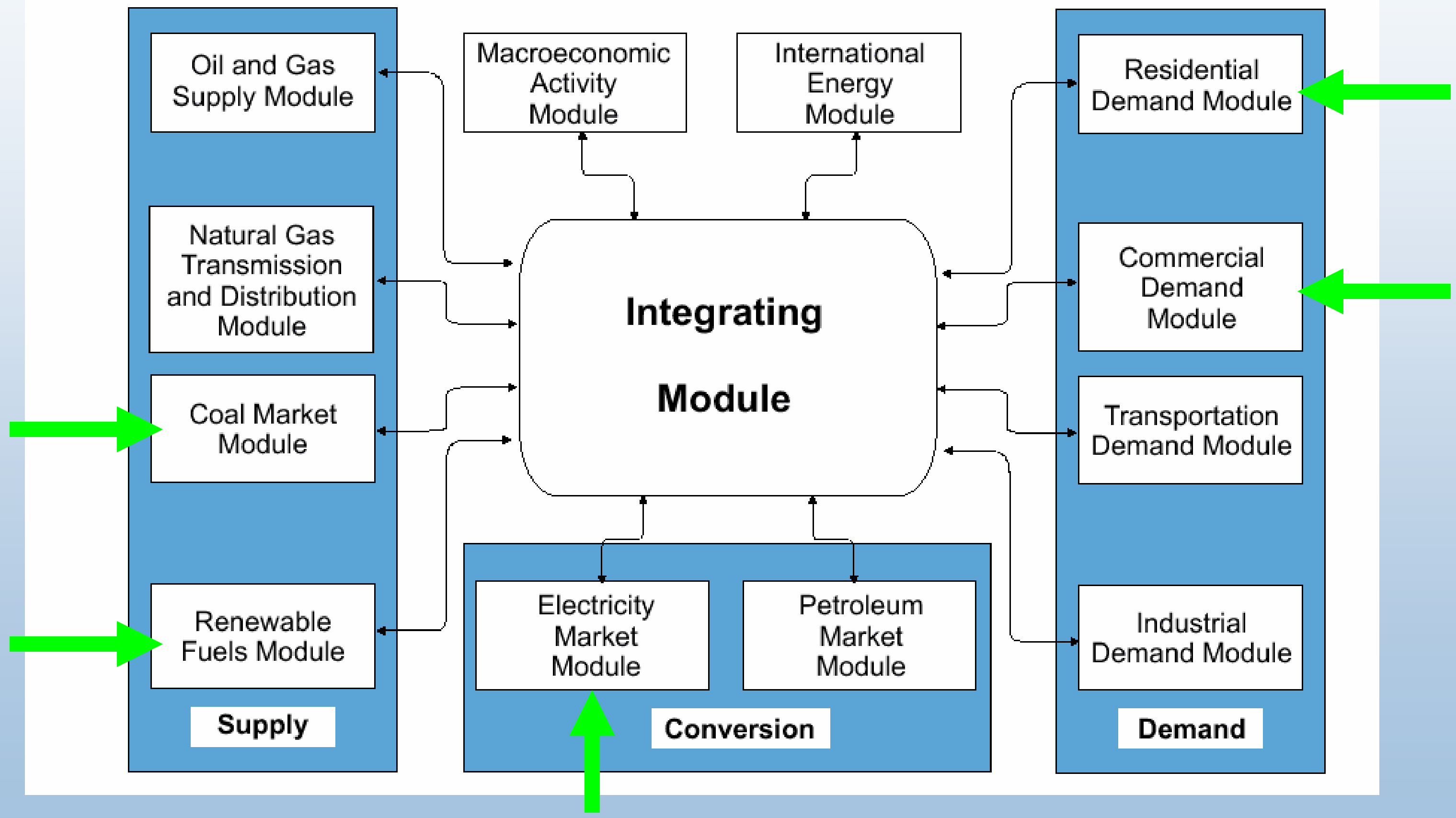
- Our analysis indicates that
  - An enhanced solar R&D program with moderate or aggressive policy initiatives could result in a dramatic increase in solar market share (40% or 50% of buildings electricity demand).
  - Placing a modest value on carbon ($100 per ton carbon) could provide solar with increased market opportunities.
  - The incremental costs of pursuing an aggressive vs. moderate set of policies are significant (NPV of $70 billion vs. $22 billion).
  - The vision presented here could result in a significant shift towards a distributed electricity system, with up to a third of all electricity provided outside the central grid.
  - There are no fundamental technical constraints that we are currently aware of that would limit the proposed large-scale implementation of solar energy.

Areas for Further Analysis

- Non-rooftop PV applications (i.e., facades, parking lots).
- Improvements to the transmission system (low-cost transmission over long distances, microgrids with storage).
- Analysis (outside of NEMS) for hydrogen.
- Analysis of Energy Storage (24/7).
- Explore impacts of alternative fossil fuel prices; environmental constraints on fossil fuels, financial assumptions, etc.
- Detailed analysis of materials requirements.

Background Material

Extended Relevant Portions of NEMS to 2050



NEMS Extension Assumptions

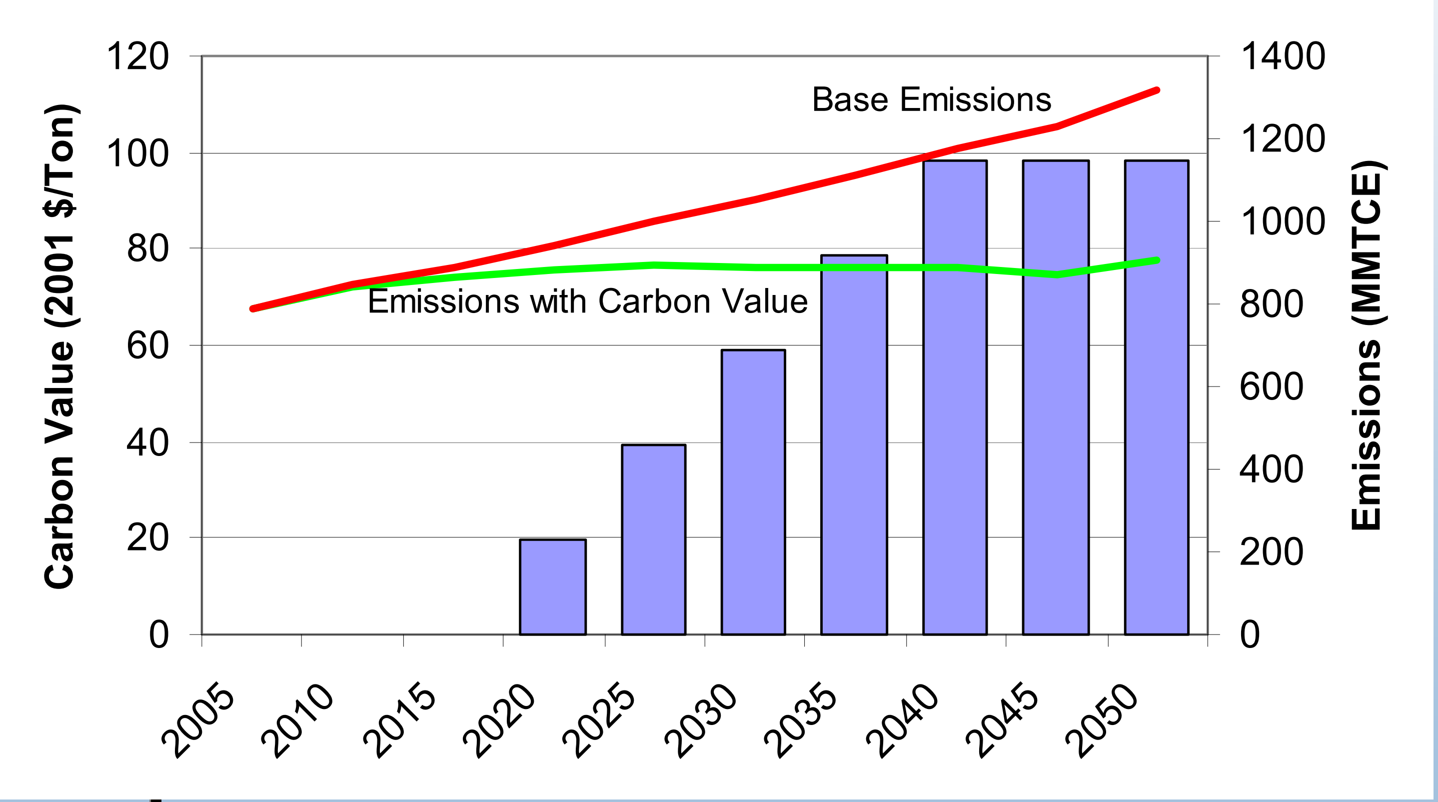
- Technologies with endogenous learning (central generation) continue to improve based on cumulative installed capacity.
- Costs for carbon sequestration for fossil generation plants were based on data from Herzog at MIT.
- Nuclear plants must retire at age 60 (one re-licensing allowed).
- All generation plants assumed to face an additional $25/kW-year cost at age 60.
- Coal mining productivity improvements saturate.

Key NEMS Modifications

- Ran a very low-cost solar scenario to test the limits of the NEMS model. This led to the following model changes, i.e., in the baseline scenario:
  - CSP:
    - Raised capacity credit value to accurately reflect storage capabilities.
  - Residential PV:
    - Increased average system size from 2kW to 4kW,
    - Increased maximum penetration level for single family homes from 30% to 70%, and added multi-family homes
    - Modified algorithm for adoption rates.
  - Commercial PV:
    - Increased average system size from 10kW to 100kW,
    - Increased maximum penetration level from 30% to 55%,
    - Modified algorithm for adoption in existing buildings.
  - SWH
    - Modified model to allow SWH to compete in the new homes and increased market replacement market (set max at 50%).
  - Solar Space Heat
    - Added technology

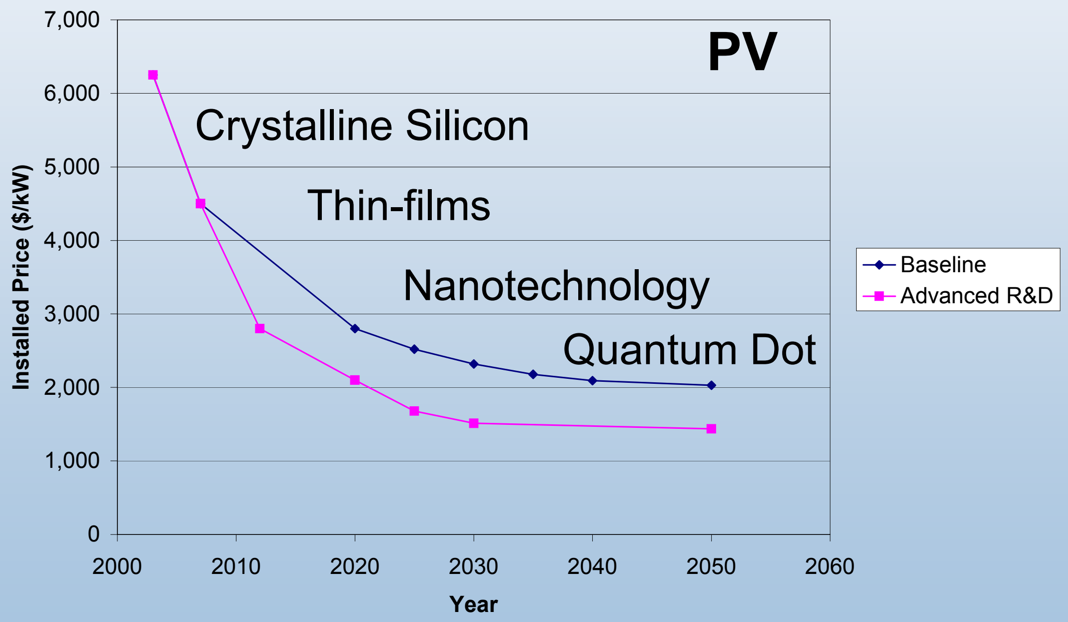
Carbon Value

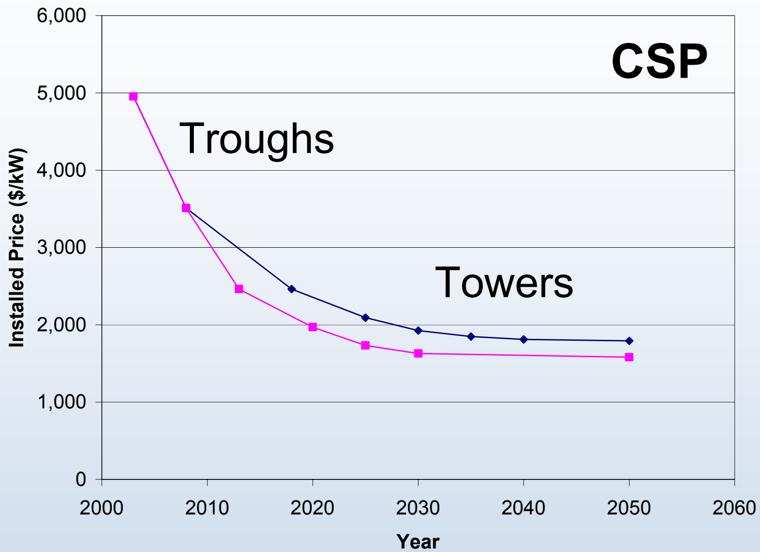
- The carbon value rises linearly from $0 per ton carbon in 2015, to $100 per ton carbon in 2040 for this scenario.
- This carbon value roughly stabilizes buildings and electricity carbon emissions.

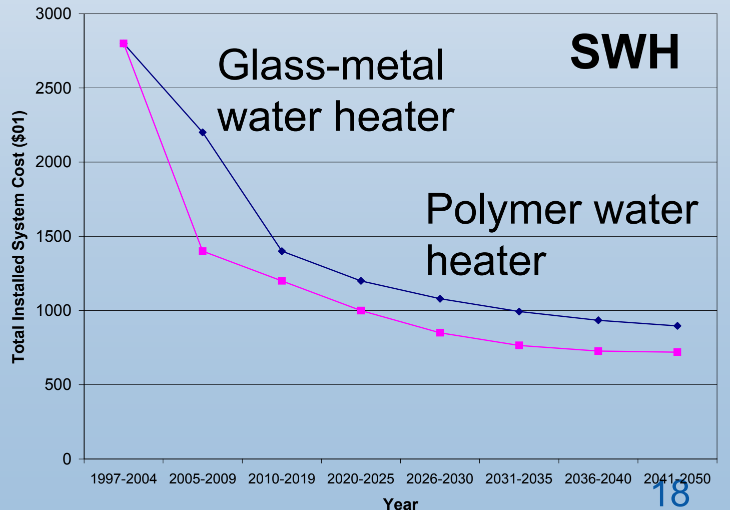


Expected Impact of Enhanced R&D on Costs

- Enhanced R&D accelerates the expected decline in cost for each of the solar technologies under these scenarios

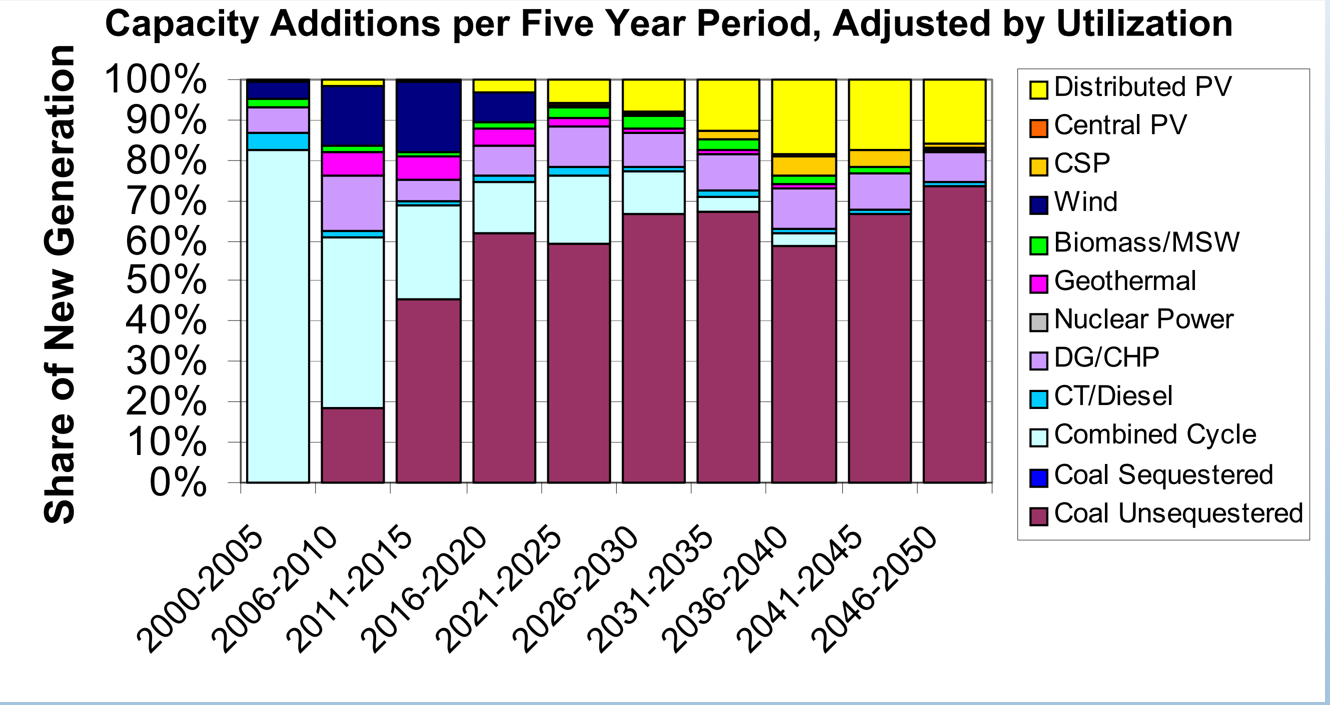






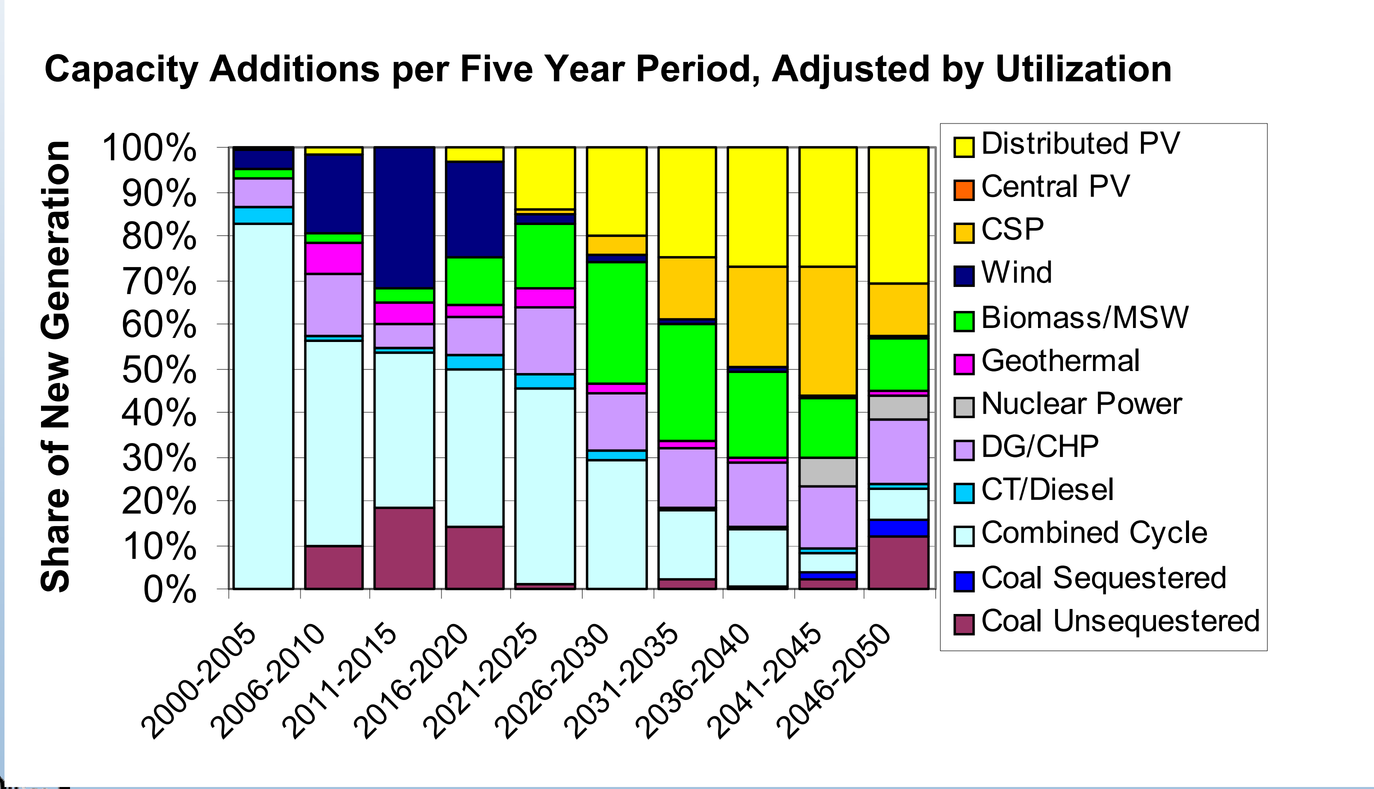
Baseline Shares of New Generation

- Through 2010 new capacity is primarily supplied by gas technologies.
- Post-2020, coal dominates new additions.
- Wind and geothermal provide a significant share of new generation in the period to 2025, while distributed PV and CSP contribute more in the later period.



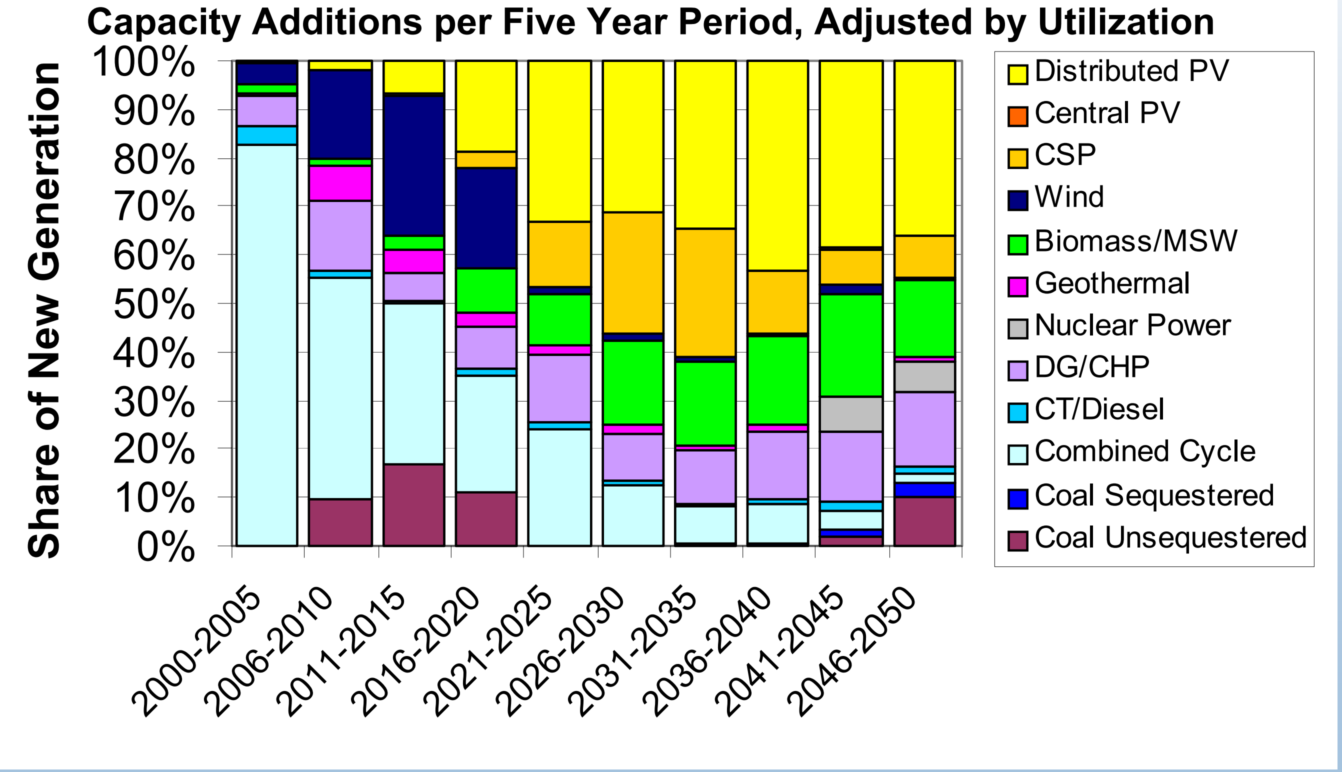
Baseline with Carbon Value Shares of New Generation

- Through 2025 new capacity is dominated by gas technologies.
- Wind is the first renewable to expand rapidly. By 2020 wind reaches a saturation of sites (with fewer constraints, wind might contribute more). After 2020 biomass and solar begin to gain (as the technology improves and carbon value increases).
- After 2040, sequestered coal and nuclear plants begin to enter the mix.



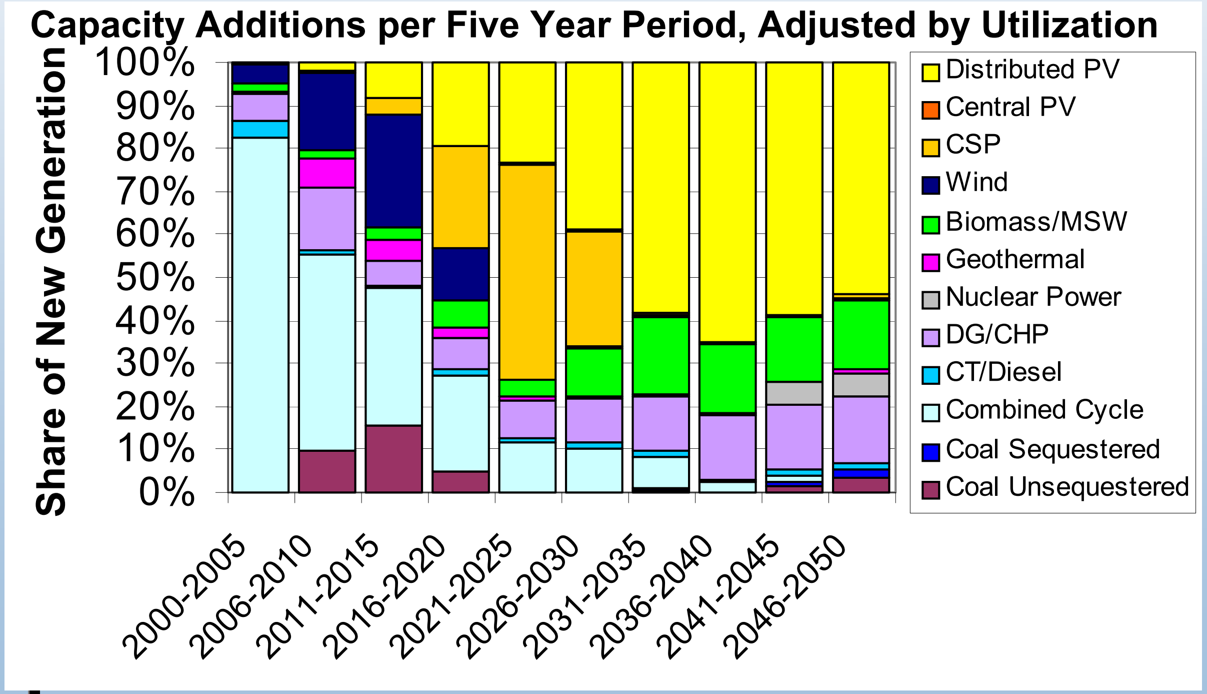
R&D and Moderate Policies Shares of New Generation

- With additional R&D and moderate policies, PV and CSP might begin to capture a significant share of new generation after 2020.
- After 2035, distributed generation additions might be over half of the total.



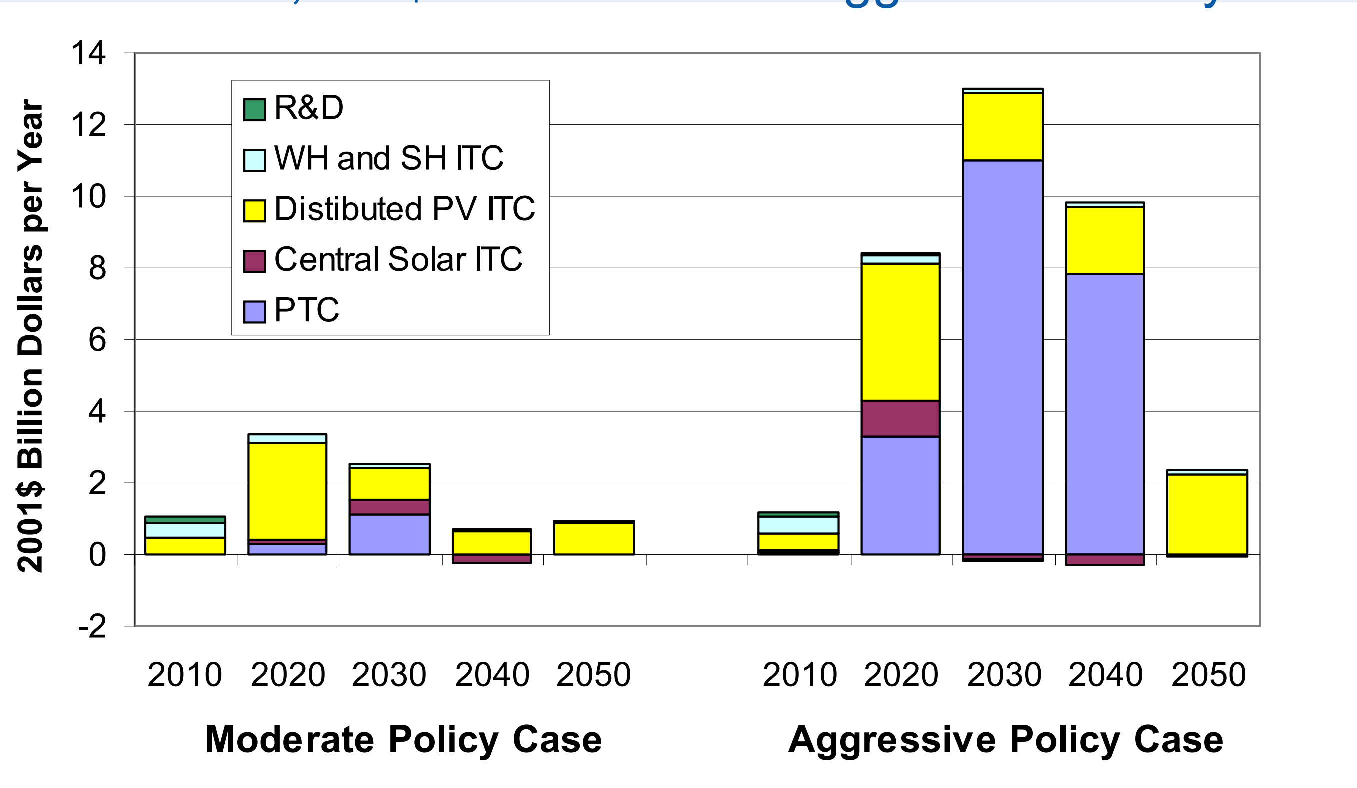
R&D and Aggressive Policies Shares of New Generation

- With more aggressive policies, solar begins to capture a significant share of new generation by 2015 in this scenario.
  - CSP accounts for roughly half of new generation between 2021-2025.
  - PV dominates additions after 2030.
- Distributed generation accounts for 70 to 80 percent of additions after 2030 in this scenario.



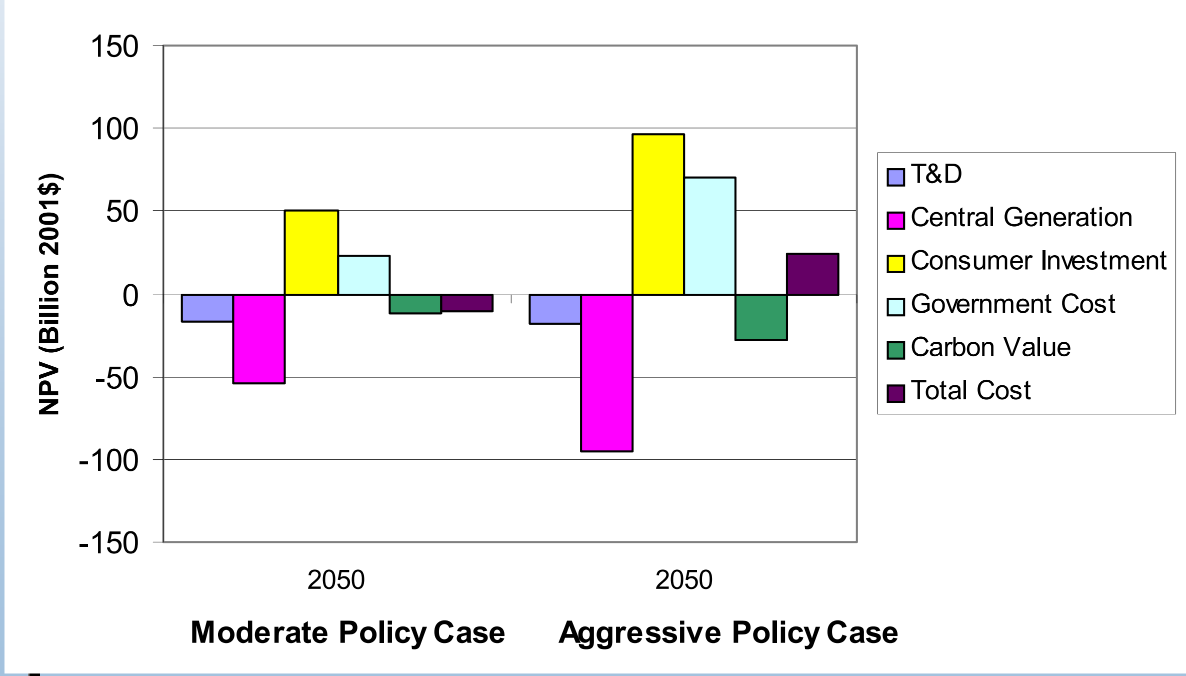
Incremental Annual Government Costs

- Government costs are significantly higher in the Aggressive Policy Case, especially in the early period when the ITC and PTC are at their greatest values.
- The incremental cost (policy case minus carbon case) between 2005 and 2050 has a NPV (at 7%) equal to $22 Billion in the moderate case, vs. $70 Billion in the Aggressive Policy Case.



Total System Costs

- With Enhanced R&D and Policies the total system costs are slightly positive in the Moderate Case and roughly $50 billion in the Aggressive Case through 2050 (on an NPV basis).
- When the value of carbon abatement is included the cost of the Aggressive Case is only $24 billion.
- Other environmental and security externalities, as well as lower natural gas prices, provide additional benefits not measured here.



Note: NPV from 2005 to 2050 calculated using a 7 percent discount rate.

Energy Analysis Office
Understanding Energy Issues

NREL National Renewable Energy Laboratory

Integration Issues

- An underlying assumption of the analysis presented here is that the electricity grid is likely to evolve in a manner that will make solar an increasingly attractive option.
- An increased emphasis on reliability, security, and environmental concerns could drive a number of new technologies into the marketplace:
  - Emerging storage technologies,
  - New load management techniques,
  - Dispatch of conventional technologies to “firm up” solar,
  - Smart metering/time of use pricing, and
  - Intelligent control systems.
- While not fully analyzed here, these factors could enable solar to become an integral part of the grid.

Key Energy/Finance Assumptions

- EIA forecast to 2025 trended to 2050, except natural gas prices which are roughly $0.50 higher.

Energy Prices (2001 Dollars)

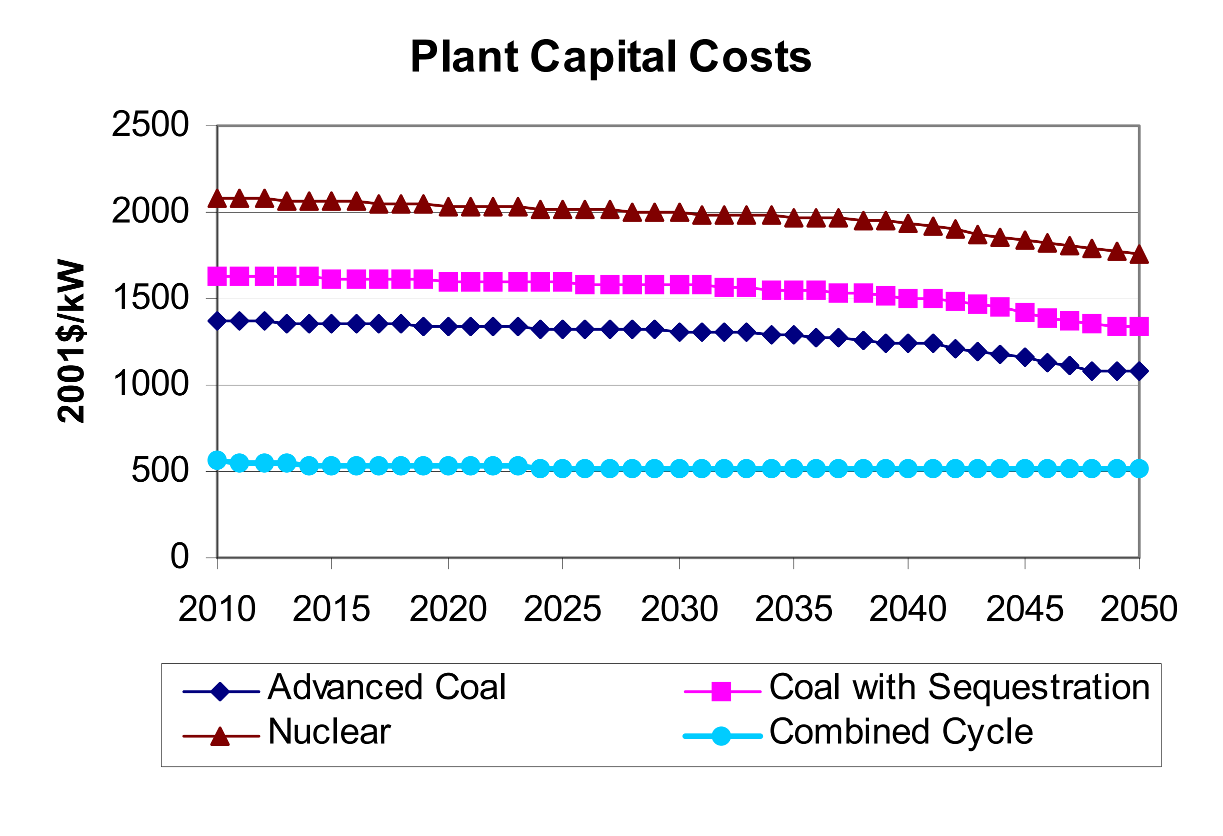
	2010	2020	2030	2040	2050
World Oil Price ($ per bbl)	24.00	25.48	27.50	29.45	31.52
Gas Wellhead Price($/Mcf)	3.80	4.15	4.49	4.80	5.14
Coal Minemouth Price ($/ton)	14.99	14.57	14.53	14.65	15.35
Gas Delivered to Electric Generators ($/MMBtu)	4.36	4.83	5.26	5.57	5.90

Selected Inflation and Interest Rates

	2000-10	2010-20	2020-30	2030-40	2040-50
Annual Inflation	2.0	2.4	2.9	3.0	3.0
AA Utility, Nominal	7.5	8.2	9.9	10.5	10.5
30 Year Mortgage Rate, Nominal	7.6	8.5	10.1	10.3	10.3
3 Month Treasuries, Nominal	4.1	5.7	6.2	6.2	6.2

Power Plant Cost Assumptions

- The cost of fossil generation technologies is projected to decline modestly over time.



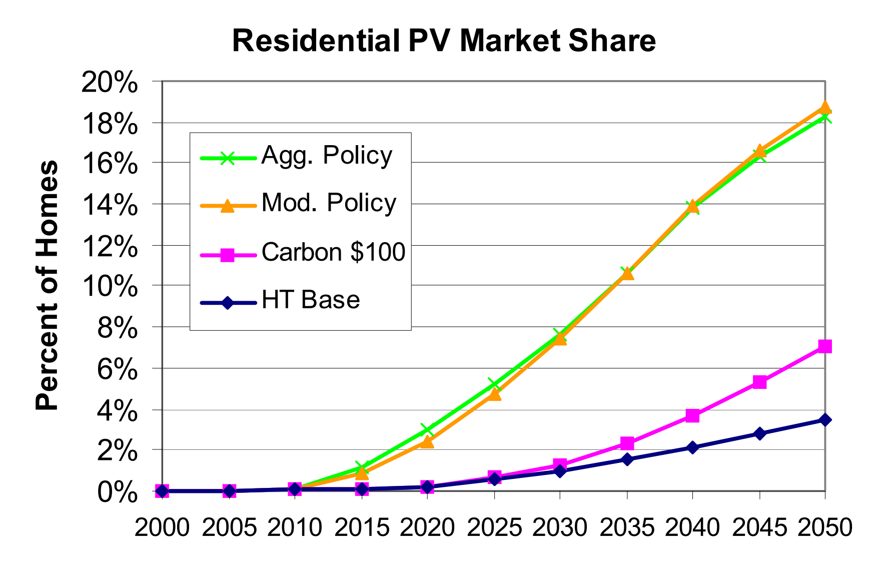
Aggressive Policy Case Regional CSP Share

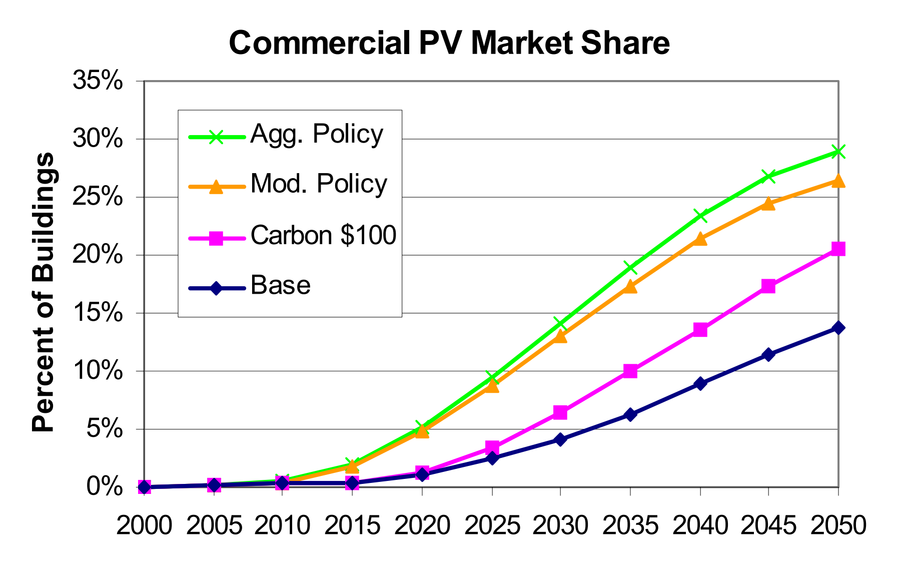
- In 4 regions, the majority of new central capacity built between 2015 and 2050 is CSP in the Aggressive Policies Case.

	CSP			CSP as a Percent of total		
	Capacity in 2050 (GW)	Generation in 2050 (bkWh)	New Additions 2015 to 2050 (GW)	Central Capacity in 2050	Central Generation in 2050	New Additions 2015 to 2050
ECAR	0.0	0.0	0.0	0%	0%	0%
ERCOT	35.3	194.3	35.3	35%	57%	73%
MAAC	0.0	0.0	0.0	0%	0%	0%
MAIN	0.0	0.0	0.0	0%	0%	0%
MAPP	0.7	3.2	0.7	1%	1%	7%
NYPP	0.0	0.0	0.0	0%	0%	0%
Neng	0.0	0.0	0.0	0%	0%	0%
FL	0.0	0.0	0.0	0%	0%	0%
SERC	0.0	0.0	0.0	0%	0%	0%
SPP	14.3	74.6	14.3	22%	29%	65%
NWP	0.1	0.3	0.1	0%	0%	0%
RA	16.2	103.4	16.2	25%	46%	83%
CA	34.9	219.2	31.6	26%	57%	54%
Total	101.6	595.0	98.2	9%	13%	29%

PV Market Share

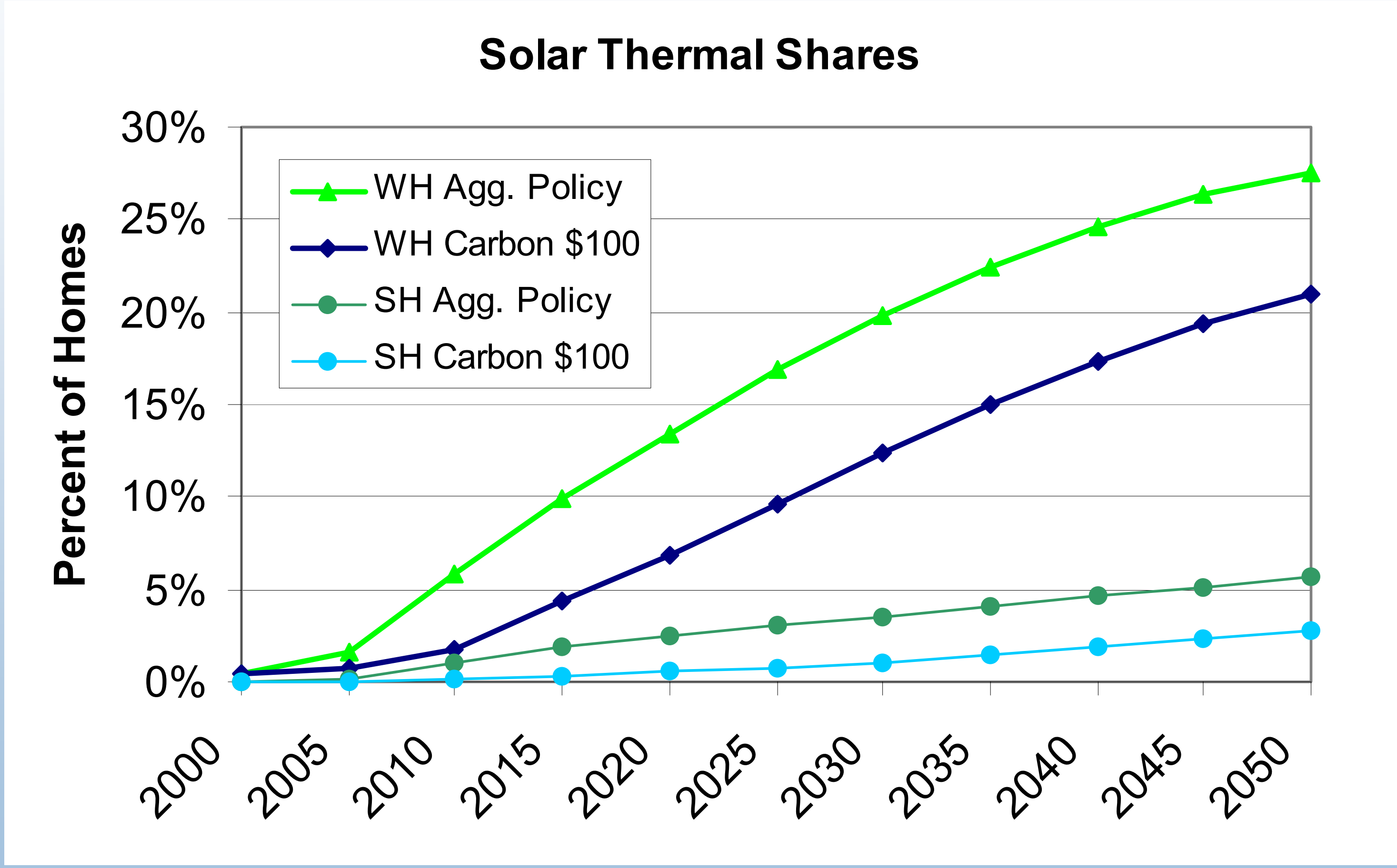
- The share of PV increases with the policy scenarios, but are very similar in the moderate and aggressive cases.
- Increasing the size of the systems makes them somewhat less economic, although the stock share increases more rapidly due to the assumption about greater penetration in existing buildings.





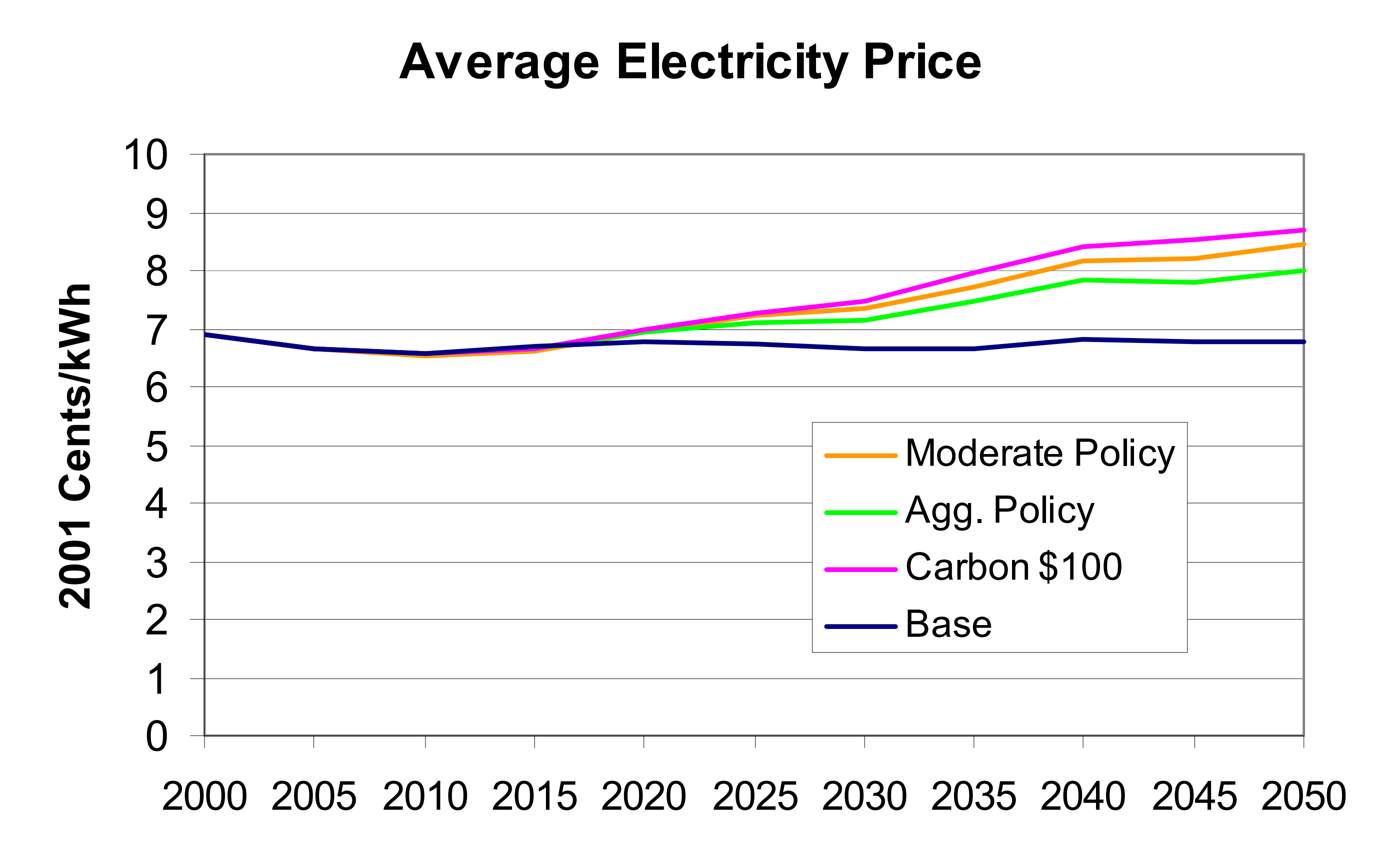
Solar Thermal Shares

- Solar water and space heat share increase in the policy cases.



Electricity Prices

- Including a $100 per ton carbon value increases the average price of electricity by roughly 28 percent in 2050.
- The Aggressive policy case reduces this increase to 18 percent.



2050 Summary

	Base	Base with $100 Carbon	Moderate Policies	Aggressive Policies
Capacity (GW)				
CSP	11.3	66.9	75.4	100.3
Central PV	0.8	0.8	1.7	4.5
Distributed PV	212.6	333.2	537.7	750.4
Total Solar Capacity	224.7	400.8	614.8	855.1
Generation (BkWh)				
CSP	69	419	458	589
Central PV	2	2	4	9
Distributed PV	437	678	1088	1511
Total Solar Generation	508	1099	1550	2110
as percent of total generation	7%	17%	23%	32%
Number of residential PV systems (millions)	5.5	11.3	30.2	29.3
as percent of homes	3%	7%	19%	19%
Number of commercial PV systems (millions)	1.3	1.9	2.5	2.7
as percent of commercial buildings	14%	20%	26%	29%
Solar Water Heaters (millions)	31.9	33.1	43.5	43.5
as percent of homes	20%	21%	28%	28%
Residential solar SH systems (millions)	4.36	4.46	8.86	8.85
as percent of homes	3%	3%	6%	6%
Solar as Percent of Building Primary Energy	9%	21%	30%	42%
Solar as Percent of Building Electricity	11%	26%	37%	49%
NPV PTC cost (Billion $)	0.00	0.00	2.83	38.21
NPV Solar ITC Cost (Billion $)	0.15	0.94	2.33	6.56
NPV Distibuted PV ITC Costs (Billion $)	3.49	8.14	25.18	32.85
NPV of Total Government Subsidy (Billion $)	3.64	9.85	32.31	79.58