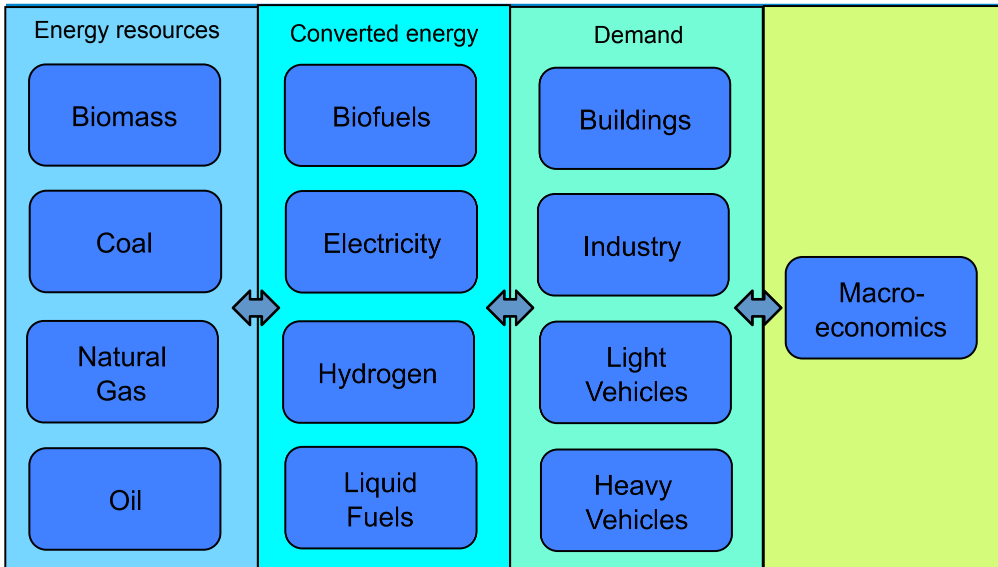
Stochastic Energy Deployment Systems Model for US Energy Economy

- DRAFT –

Discussion Document

Risk Working Group, DOE

SEDS: Stochastic Energy Deployment System



- SEDS provides projections of US energy markets to 2050, and effects on GHG emissions, energy costs, and oil imports
- Single-region model of all energy sectors within the U.S. economy
- Simulation horizon is 2005-2050 by 1-year time steps
- Its evaluates the effects of DoE's R&D programs on energy efficiency and renewable energy
- It assesses the uncertain effects of R&D on future improvements in technology performance.
- It treats uncertainties explicitly using probability and Monte Carlo
- It is developed seven national labs plus Lumina
- Built in Analytica

Typical Model Input/Output

- Input (probabilistic)
- Technology cost and performance
- Drivers of primary fuel prices (e.g., natural gas supply curves, timing of pipeline expansion, etc.)
- Energy-related policies
- Economic indicators

- Output
- Levels of technology deployment (e.g., electric generating capacity, vehicles, stock of building appliances, etc.)
- Energy demands by sector and in aggregate
- Energy prices by energy type
- CO_2 by sector, by energy type, and in aggregate
- Consumer expenditures

Uncertainty in Fuel Price and Macro Indicators

- Primary fuel prices
- Gas, coal, oil and biomass prices endogenously calculated using supply curves, where the gas, coal, and oil supply curves are largely derived from AEO results
- Supply curves vary depending on AEO supply scenarios such as high or low shale gas scenarios and high or low fossil scenarios and SEDS can randomly select a curve to apply
- Random supply shocks are applied to oil prices based on historically observed frequencies and magnitudes
- Macroeconomic indicators
- Indicators such as GDP, DPI, interest rates, population, etc., are exogenously bounded by AEO's high and low macroeconomic scenarios
- SEDS linearly interpolates between the bounds to produce distributions around these indicators
- No feedback from the energy sectors is applied to the macro indicators

Uncertainty in Policy

- Carbon policy
- SEDS can employ a carbon cap or a carbon tax
- The timing and magnitude can be defined by distributions
- SEDS cannot perfectly cap emissions, it merely adjusts CO2 allowance prices over time (using a PID-type control algorithm) in attempt to meet the CO2 targets
- Renewable fuel/electricity mandates
- The timing and magnitude of RES and RFS policies can be specified with uncertainty
- RFS is applied nationally and passes additional costs of biofuels onto all conventional gasoline consumers
- Tax incentives
- The magnitude and duration of tax incentives such as PTCs, ITCs, accelerated depreciation, and government-backed loans can be specified probabilistically

Uncertainty in Energy Demand

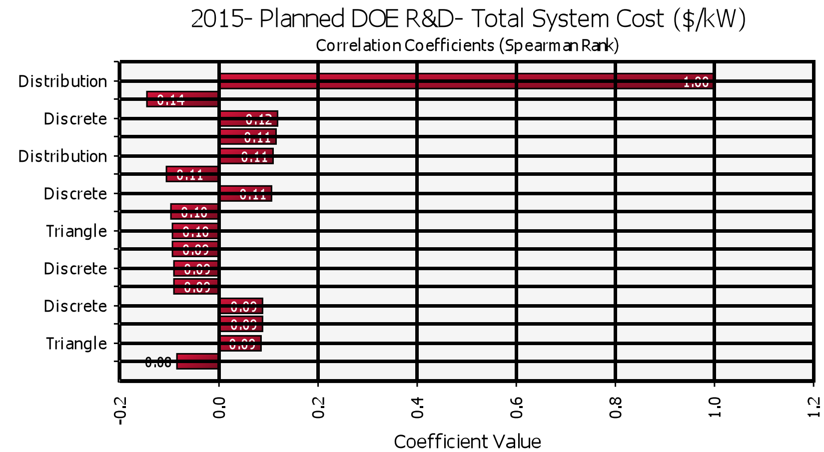
- Demand sectors track the physical stock of energy-consuming capital
- Demand elasticity to fuel prices along with macroeconomic indicators determine the need for energy-related services (e.g., space heating, vehicle-miles-traveled, industrial conveyance, etc)
- Demand for energy-related services is met by competing technologies against one-another by means of a logit market share formulation
- Uncertainty in demand is thus a function of uncertainty in fuel prices, policy, technology cost, and macroeconomic environment

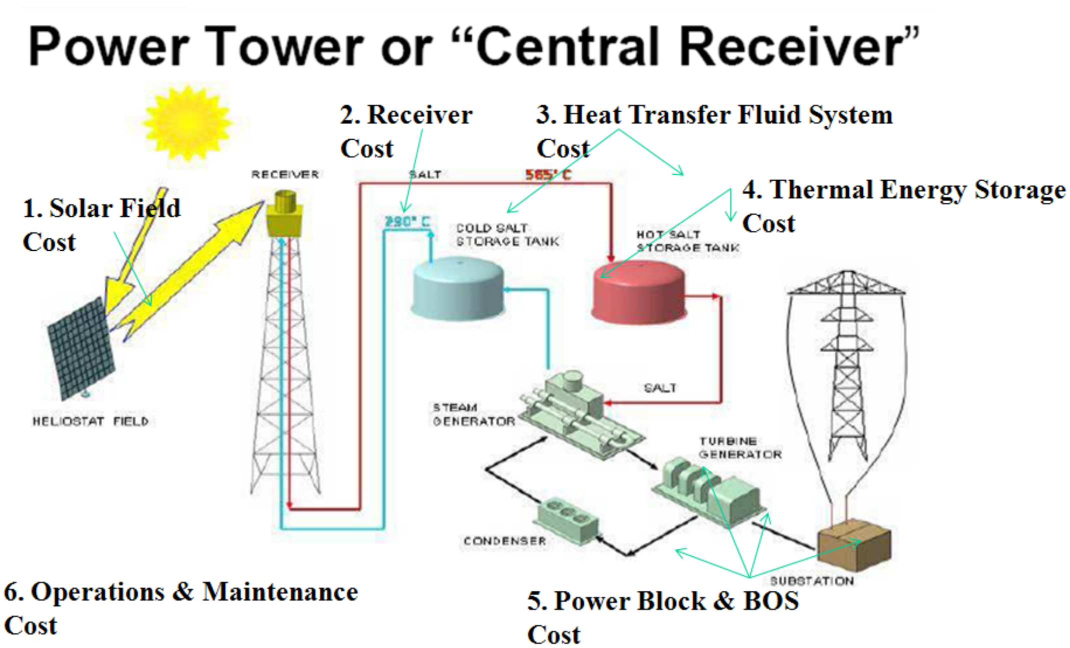
Technology subsystems: CSP and Power Tower

RISK ANALYSIS SCOPE – CSP Technologies – Power Tower

Power Tower

1. Solar Field Cost
2. Receiver Cost
3. Heat Transfer Fluid System Cost
4. Thermal Energy Storage Cost
5. Power Block & BOS Cost
6. Operations & Maintenance Cost





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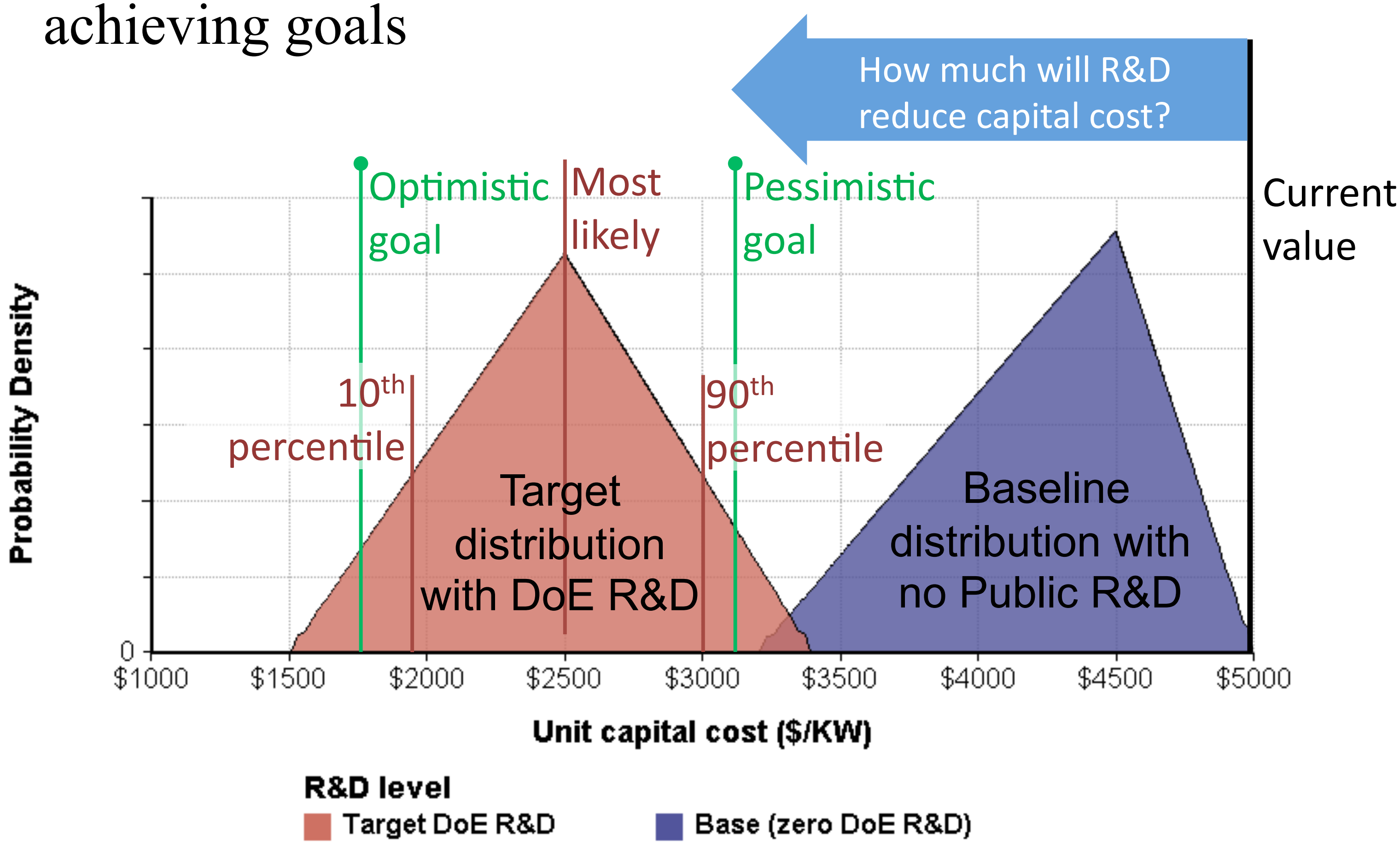
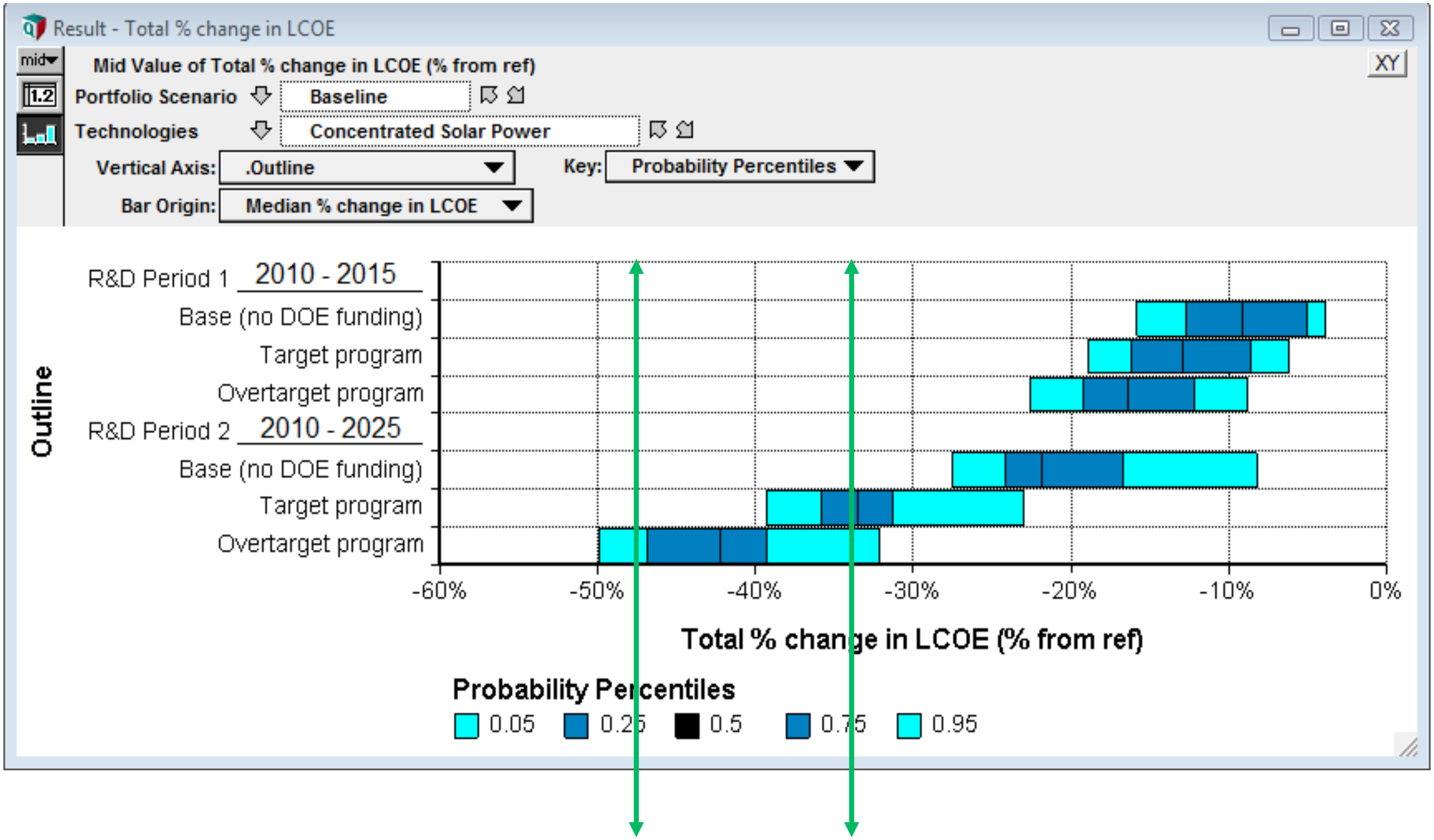
The probability of attaining technology goals

- Previously Programs provide performance Goals – with little consistency in degrees of optimism or pessimism
- Risk analysis lets us estimate the probability of achieving goals



Effect of R&D funding levels on LCOE for CSP, uncertainty as box plots



Aggressive 2025 Goal Example – less than 5% chance to achieve or do better than this value with overtarget R&D funding

Moderate 2025 Goal Example – about 50:50 chance to achieve or do better than this value with target R&D funding

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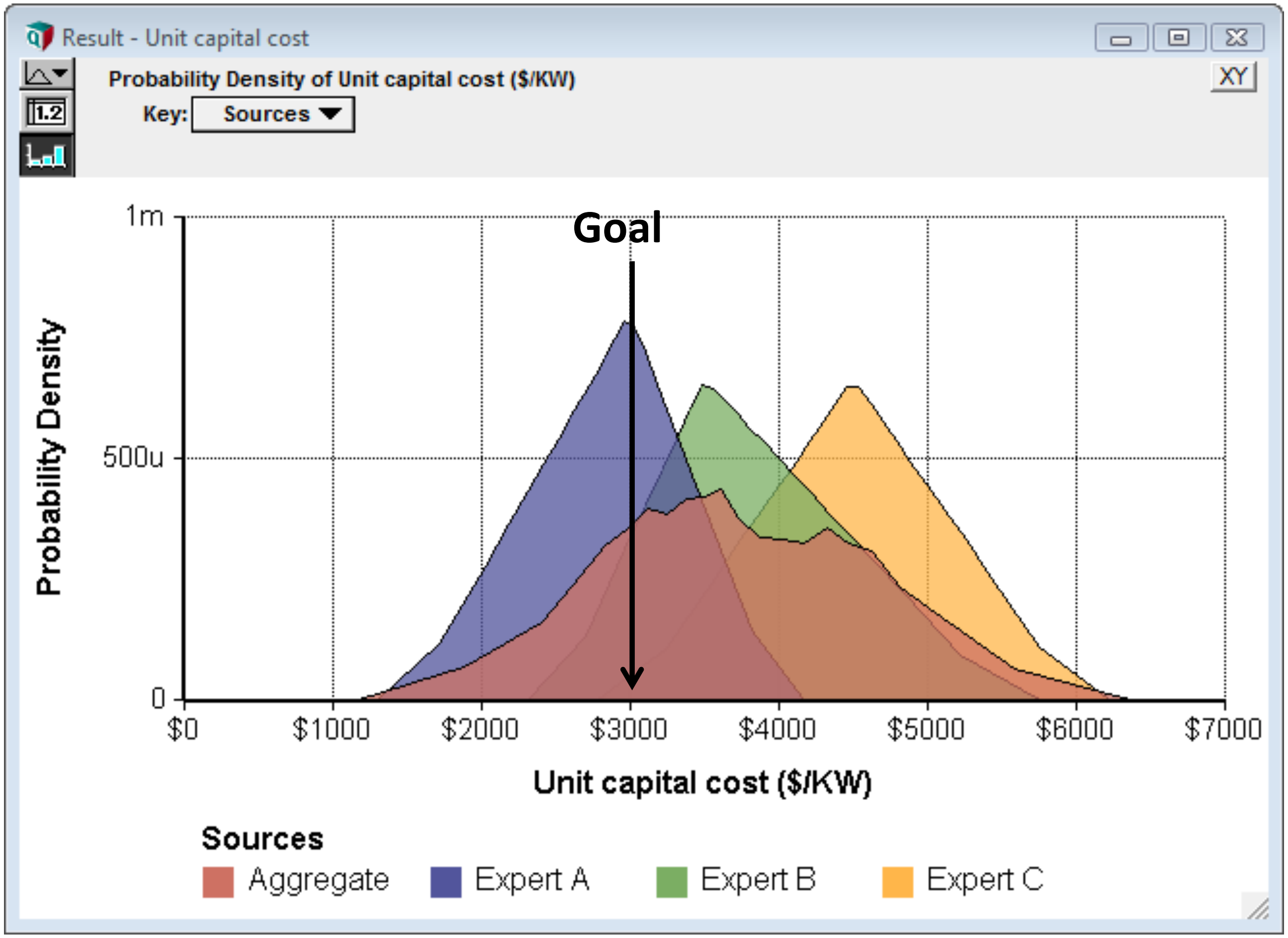
EERE Technologies assessed by expert risk panels in 2009 and 2010

- **Wind**: Onshore and offshore
- **Solar** [partly redone in 2010]
  - Photovoltaics
    - Crystalline silicon
    - Thin film
    - Concentrating PV
    - Rresidential, commercial, utility scale
  - Concentrating solar power
    - Parabolic trough
    - Power tower with 6 hrs thermal storage
- **Biomass**:
  - Ethanol: From corn and cellulosic
  - Electricity generation from biomass
- **Geothermal**
  - Enhanced Geothermal
    - Exploration
    - Wells/pumps/tools
    - Reservoir engineering
    - Power Conversion
  - Oil and Gas well production for on-site power
- **Industrial energy efficiency**
  - Partial implementation for 12 technologies aimed at reducing energy use.
- **Hydrogen**
  - Hydrogen fuel cell: PEM
  - Hydrogen production
    - Central natural gas
    - Distributed natural gas reformation
    - Central biomass gasification
    - Central wind electrolysis
    - Distributed ethanol reformation
    - Compression, storage, & dispensing
  - Hydrogen storage
    - 350 bar or 70 bar compression
    - Liquid
    - Cryogenic
    - Adsorbents
    - Metal hydrides
    - Chemical hydrides
- **Buildings**
  - Windows: Dynamic or highly insulating
  - LED lighting
  - Heat pumps
  - Photovoltaics for residential and commercial use
- **Vehicles**: including spark ignition, diesel, flex fuel, hybrid, plug-in hybrid, battery, hydrogen fuel cell, Batteries
- **Hydro and Ocean:** outstanding

Aggregating expert distributions

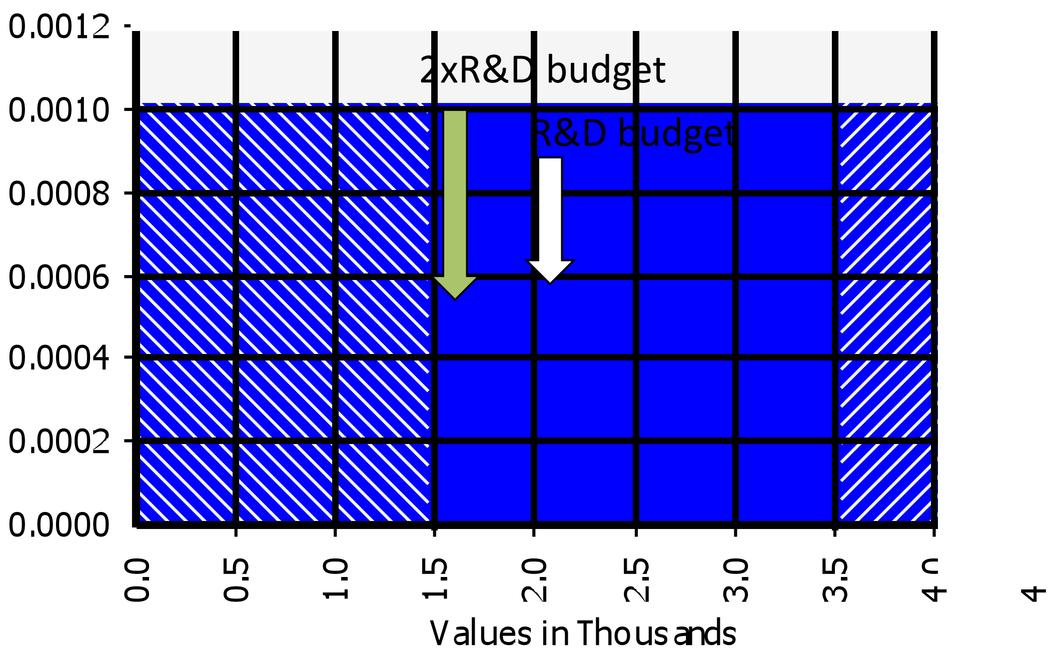


We aggregate the triangular distributions assessed by each expert, sampling from each using equal weights. The aggregate distribution is not (usually) triangular.

Changes in R&D funding can have a significant impact on likelihood of achieving a Goal

- Analysis indicated achieving program target of $1.50/W module cost by 2015 was about 1 in 3 under FY2009 budget levels; however
- Expanded funding on PV R&D (e.g., PV Manufacturing Initiative, Supply Chain) could improve that to better than 50:50.

2015 Planned vs Expanded DOE R&D- Module Cost ($/kW)



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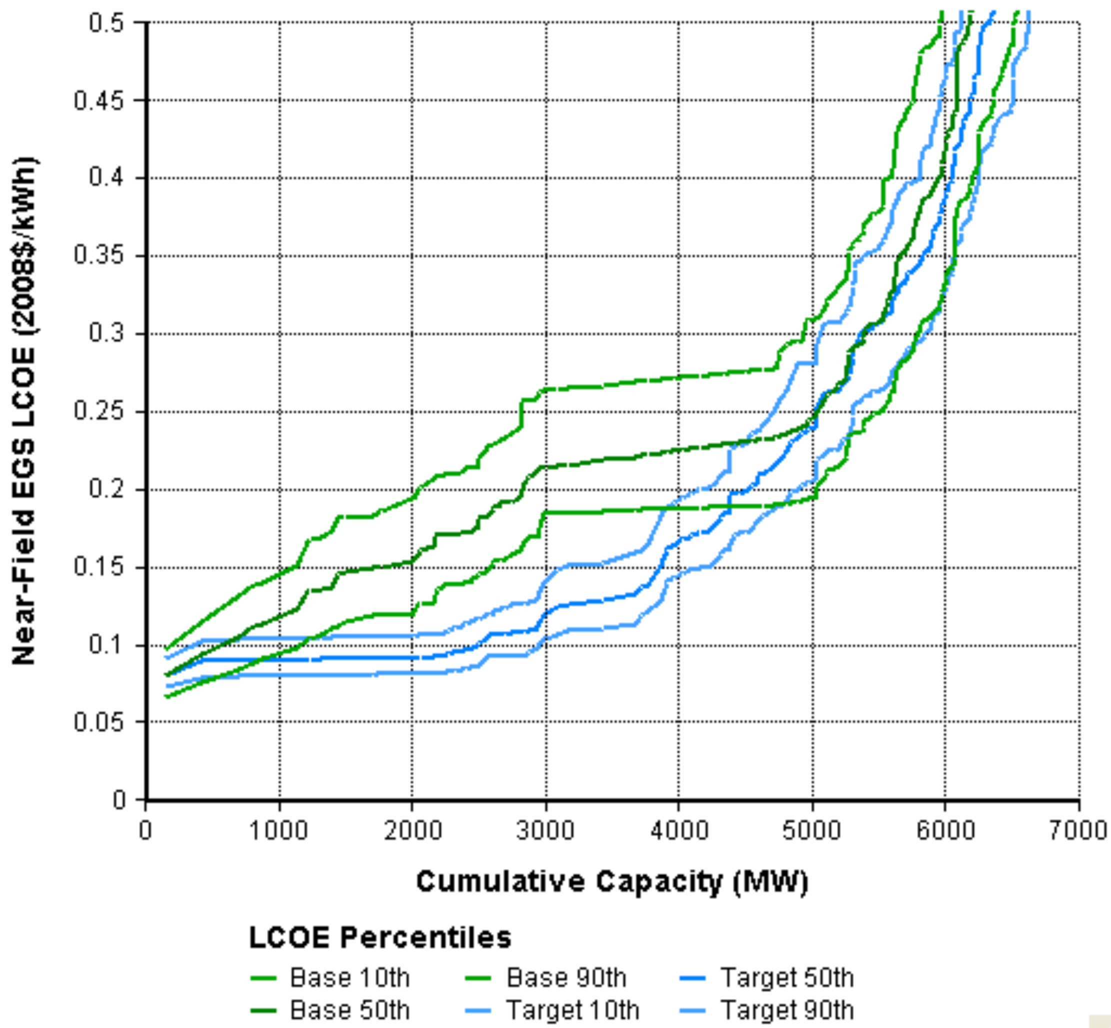
Uncertain supply curves: Geothermal
LCOE for EGS with Base and Target R&D funding

- LCOE will depend on both anticipated performance improvements and resource availability
- Without R&D expected about 3GW to be available at less than 20c/kWh
- R&D improves the expected cost to less than 12c/kWh for the same supply.

Near-field EGS Supply Curve



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Defining scenarios in SEDS

It takes just a few minutes to define and run a new scenario with SEDS. We show these scenarios in the following results:

1. **Base**: Business as usual. Similar to NEMS reference case.
2. **Nuclear**: 2% reduction in financing and hurdle rates for nuclear power plants.
3. **Low gas**: Gas prices fall to about $4/mmbtu (2009$)
4. **RPS**: 20% Renewable Portfolio Standard by 2020
5. **Overtarget R&D:** Double funding for all EERE technologies in SEDS.
6. **$60/ton CO2 tax:** Carbon tax starts in 2015 at $10/ton CO2e and ramps up to $60/ton by 2025.
7. **All but cap:** Combine scenarios 2 to 6.
8. **1.8 Gton Cap:** CO2 emissions cap begins in 2010 and ramps down to 1.8 billion tons CO2 equivalent in 2050*
9. **1.8 Gton Cap, Nuclear, RPS, R&D:** Combines scenarios 2, 4, 5, and 8*

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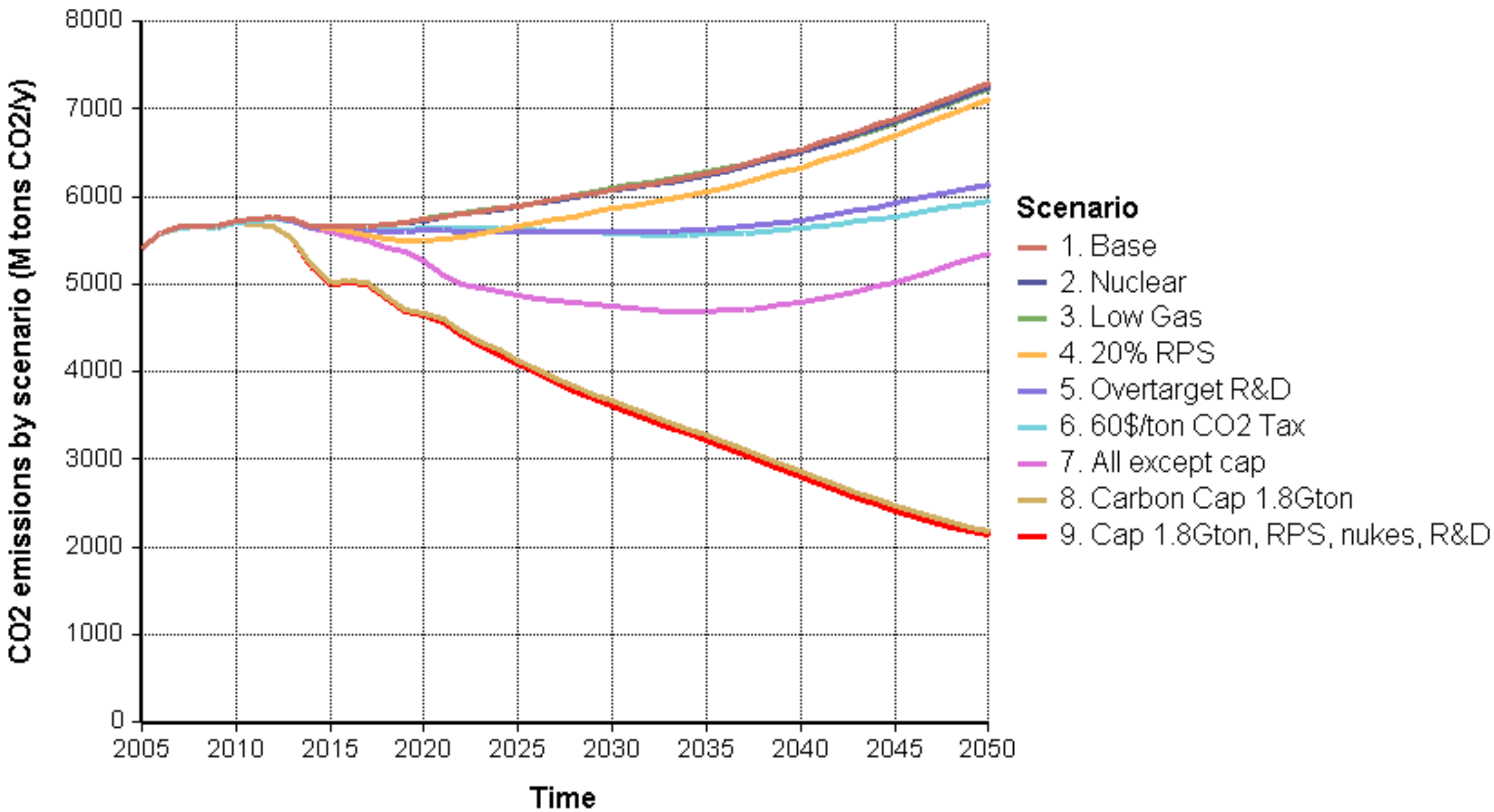
* SEDS does not quite reach 1.8 Gton CO2e cap, ending at about 2.2 Gton by 2050.

Comparing CO_2 emissions by scenario (mean values)



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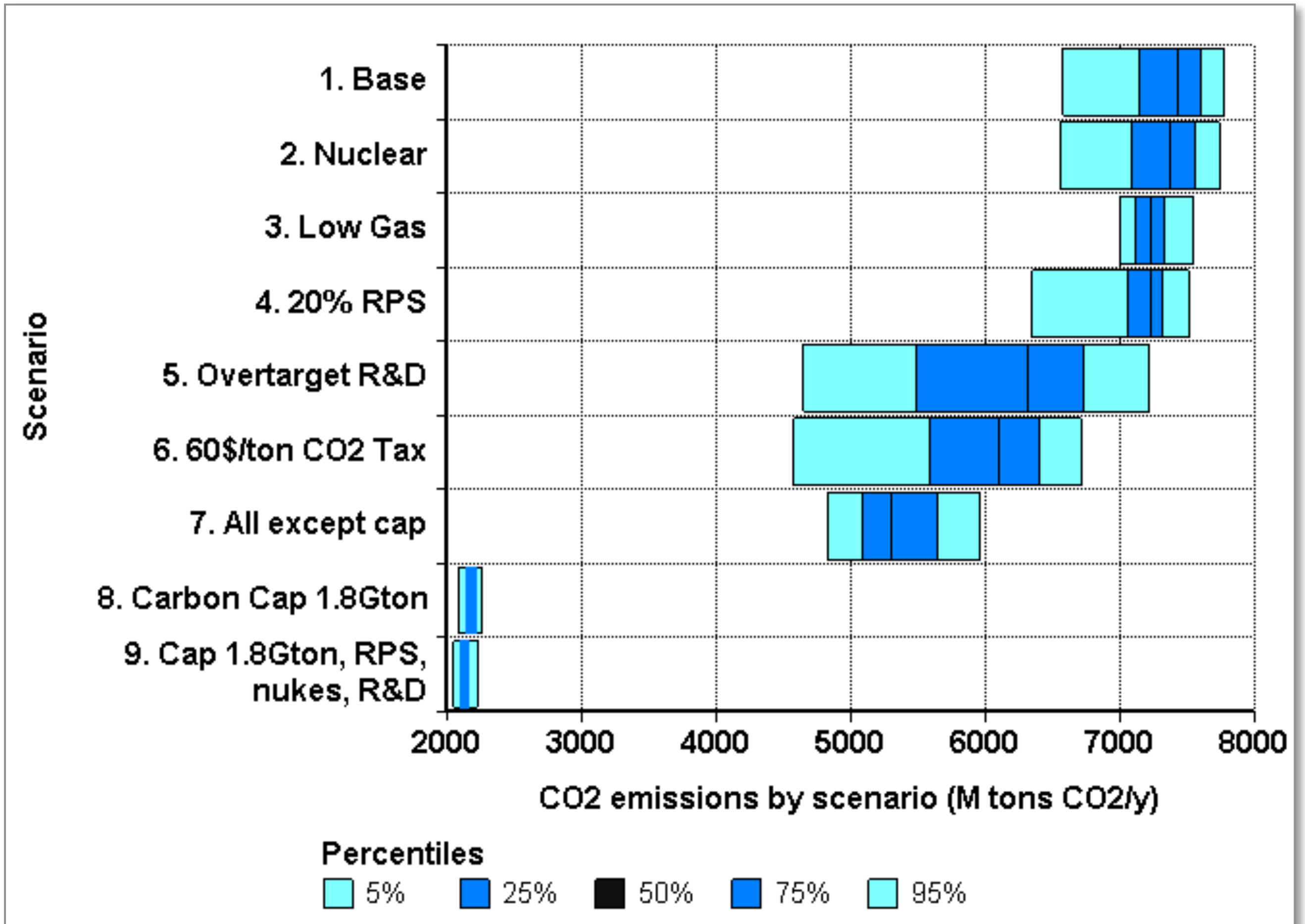
Comparing CO_2 emissions by scenario, with uncertainty in 2050



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Combining scenario and uncertainty analysis

Four scenarios for exploring impact of R&D

BAU: Business As Usual

Similar to AEO 2010 reference case.

Including crude oil rising $235/bbl in 2050 (2010$)

Base (zero) R&D by EERE

High Oil: Crude oil price rise to $248 in 2050

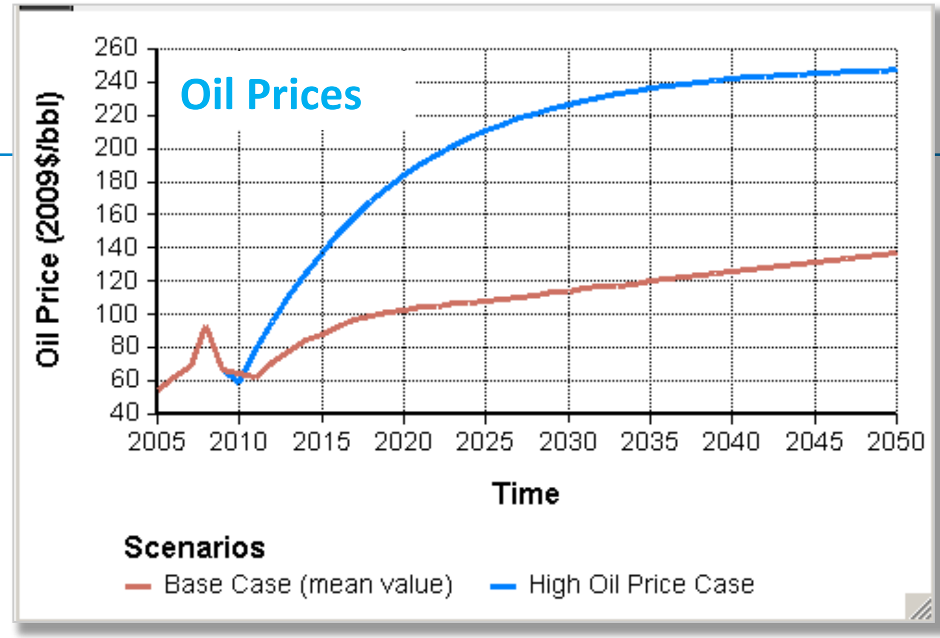
CO2: Carbon price

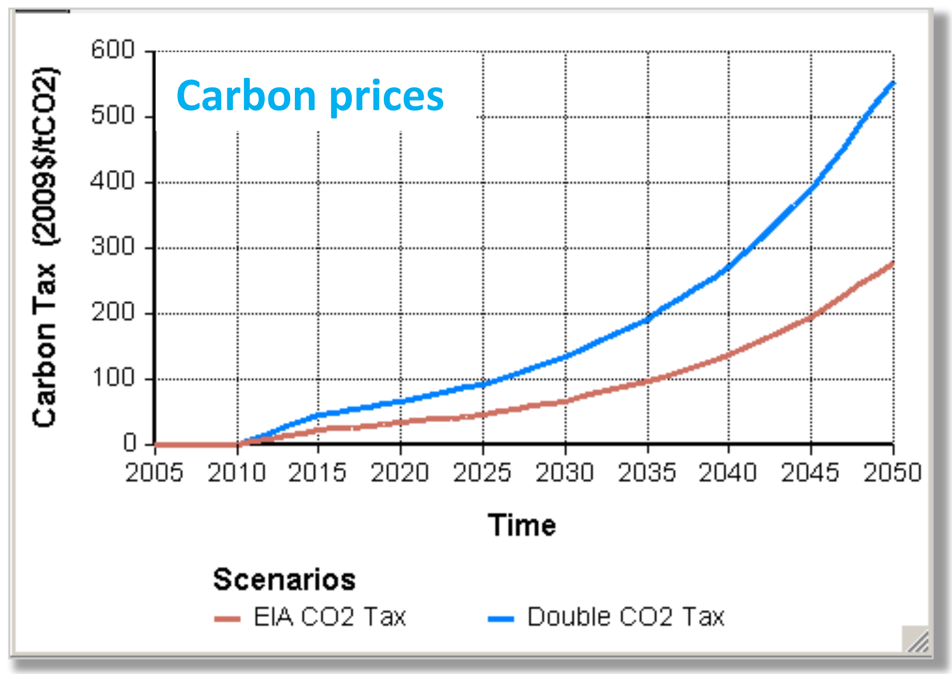
Rises to $275/tonne CO2 in 2050.

CO2 x 2: Double carbon price

Rises to $550/tonne CO2 in 2050.

We can view Carbon price as a proxy for Carbon tax or a Carbon cap and trading scheme.





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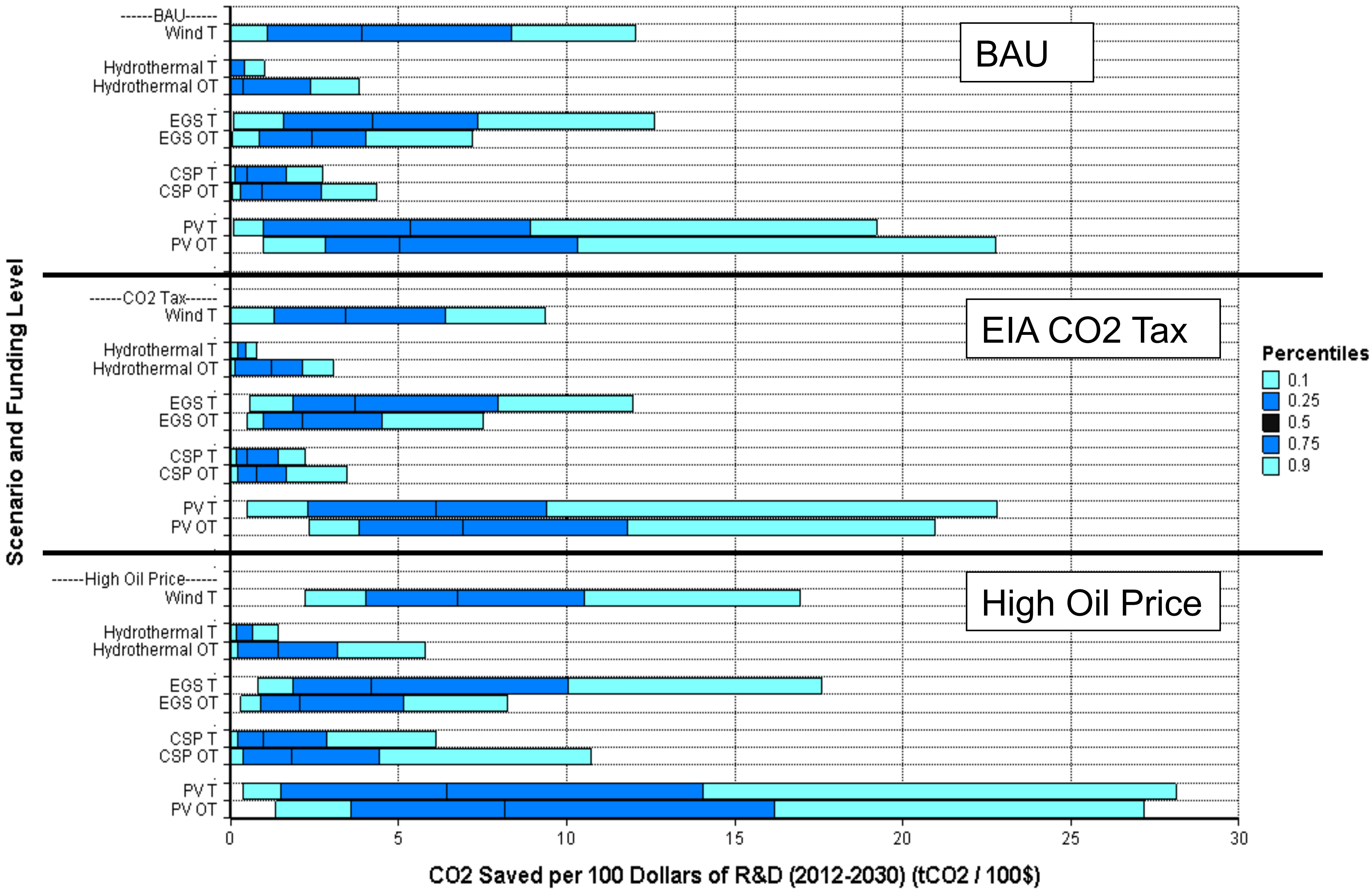
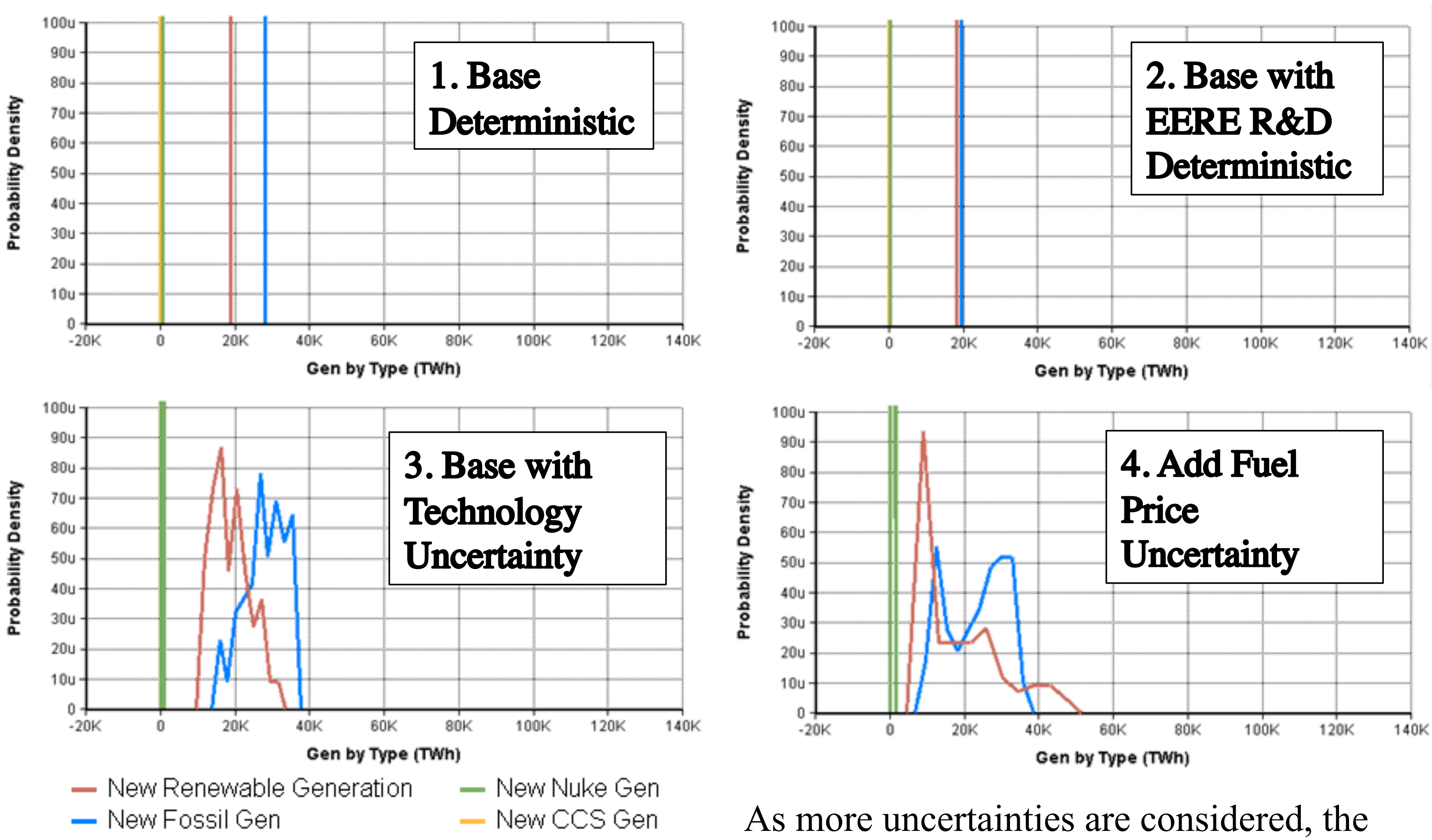
Evaluating the impact of R&D funding by technology

- Funding levels can be adjusted one technology at a time to look at the individual impact of that technology
- Funding levels for multiple technologies can be varied and run in combination to identify interactions
- Benefits of R&D related to consumer savings, energy security, and reduced emissions can be evaluated for numerous budgeting scenarios across the EERE portfolio

CO2 savings from 2012-2030 and CO2 abatement per $100 due to R&D for various market scenarios



Cumulative New Generation (2010-2050) by Technology Type: Adding Successive Uncertainties (1)



As more uncertainties are considered, the likelihood increases of having a significant renewable contribution

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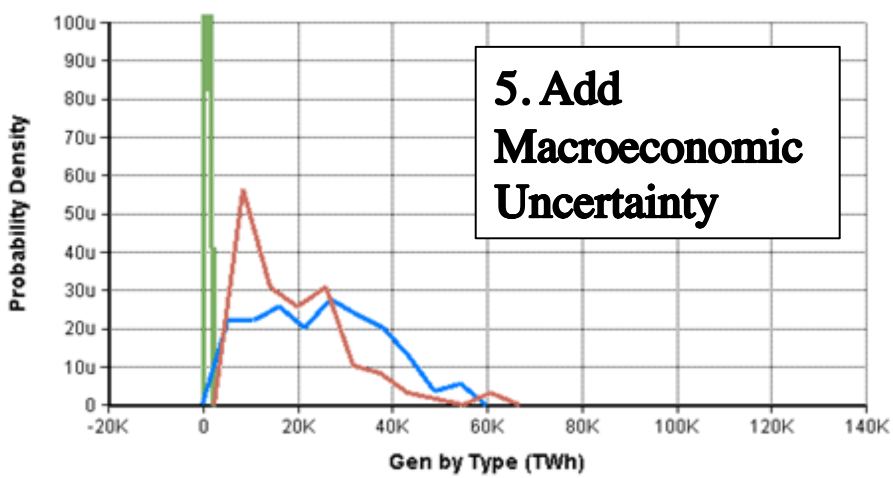
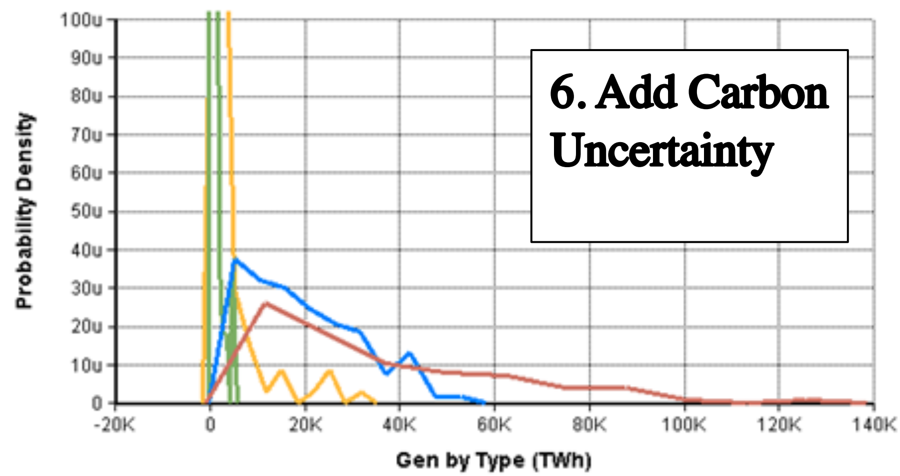
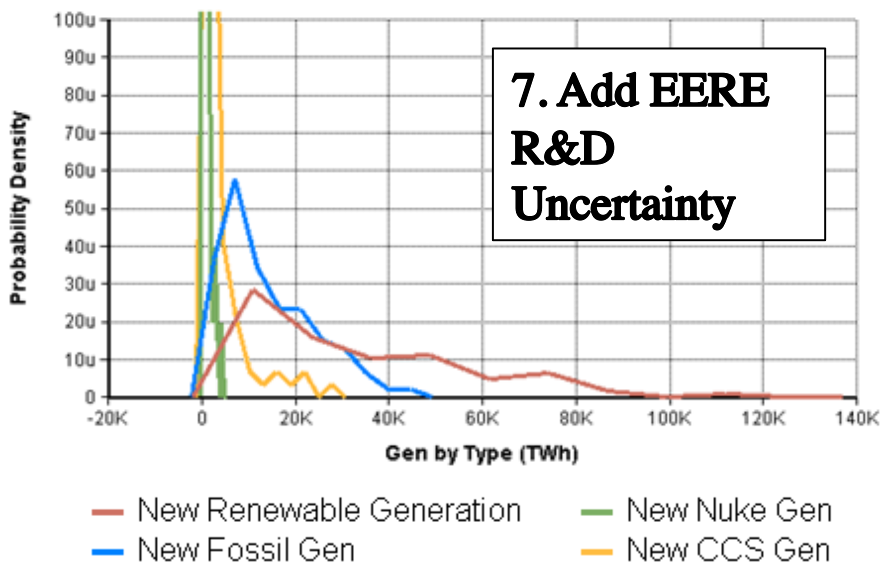
Cumulative New Generation (2010-2050) by Technology Type: Adding Successive Uncertainties (2)







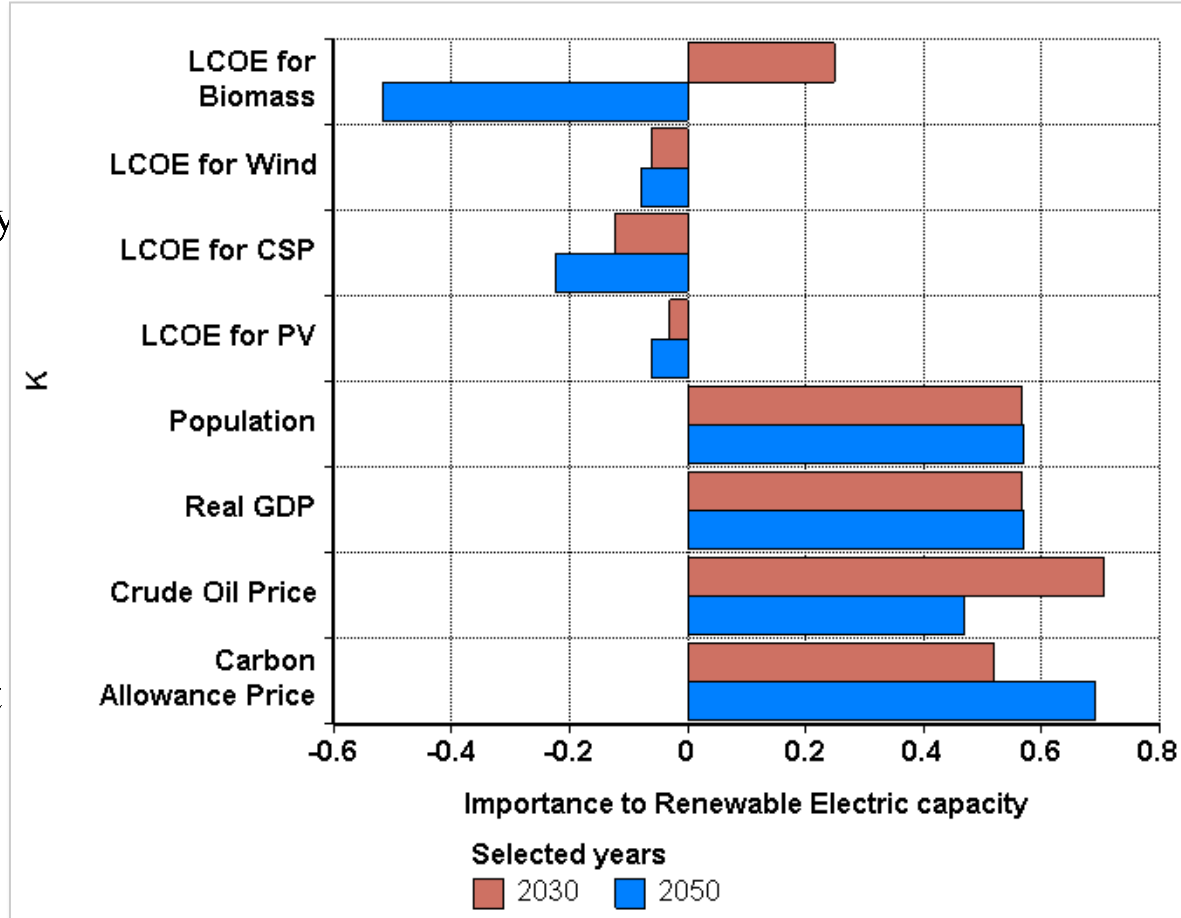
Including uncertainty into the analysis dramatically changes the results compared to the deterministic simulations.

Deterministically, fossils contributed much more than renewables to new electric generation.

Considering uncertainty, renewables proved to have a robust presence under the majority of the potential technology, market, and policy environments.

Which uncertainties contribute the most? Importance analysis of Renewable Electricity.

- This example shows the relative importance of key uncertain inputs to the renewable electricity capacity installed by year 2030 and 2030.
- Crude oil price is most important in 2030. Carbon price in 2050.
- Uncertainty in population, GDP, Oil, and Carbon prices are generally more important to renewable electricity capacity than LCOE for RE technologies



- *Importance* is estimated by rank-order regression coefficients of the Monte Carlo result sample against the samples for each input.

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