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ENERGY TECHNOLOGY INNOVATION POLICY

eRD3

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Uncertainty: Funding levels and technology costs

Staff Workshop, Benefits Assessment
Energy Research and Development Division (ERDD)
California Energy Commission

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Innovation in energy and the role of government

Objective of the ERD3 Policy Project:

to make recommendations to the U.S. federal government

to accelerate energy innovation

to meet energy-related environmental, economic, and security challenges

- Public, private sectors, and citizens all have roles to play in innovation, with the private sector being the main actor.
- Role of government is to address market failures:
  - Companies can capture only a fraction of the value of their innovations
  - Environmental impacts of energy system (local pollution, GHG emissions) not valued in market
  - National security not valued in market
- Major challenges in energy innovation
  - Uncertainty of results of innovation investments
  - Uncertainty of climate damages
  - Inertia of multi-trillion dollar infrastructure, decades of policies built around incumbent technologies

Calls for more energy innovation in the United States are becoming more frequent

Year	Recommendation
1997	PCAST recommended $2.8 billion/year in by 2003, which represented a doubling in “as spent” dollars from 1997, for efficiency, fission and fusion, fossil, and renewables.
1999	Schock *et al*. (mainly from national labs) estimated the value of U.S. low-carbon energy R&D to reduce climate change mitigation costs to $6.4-$9 billion/year (about 3X).
2004	NCEP recommended an increase from $2.0 billion 2010$ in 2004 to $3.7 billion in 2010 (almost a doubling) for oil, efficiency, advanced coal, nuclear energy, and renewables.
2005	Nemet and Kammen recommended that $6.7-30.1 billion/year be invested in low-carbon technology R&D using Schock et al. results from 550 ppmv CO_2 stabilization scenario.
2007	Nemet and Kammen recommended a 5-10 fold increase in energy RD&D from 2005 levels ($21-$41 billion/year) using analogies with Manhattan and Apollo projects.
2008	APS recommended $250 million per year for buildings efficiency.
2010	▪ Brookings Institution, American Enterprise Institute, and Breakthrough Institute recommended $25 billion/year for a national network of innovation institutions, expanded U.S. DOD energy technology procurement, ARPA-E, and nuclear power ▪ American Energy Innovation Council recommended $16 billion/year in energy RD&D. ▪ PCAST also recommended annual expenditures on energy RDD&D of $16 billion.
All figures are in 2010$	

From expert elicitations to uncertainty around RD&D portfolio investment benefits

Step 1

Expert elicitations

RD&D $ ➔ $/kWh

- Estimate uncertainty around technology performance and cost in 2030 with BAU RD&D investments
- Recommend RD&D budget through 2030
- New estimates with enhanced RD&D in 2030

→

Step 2

Setting up MARKAL Simulation

- Three types of input on cost and performance for each technology area
- Estimate correlation between technologies and over time
- Intra- and interpolate for data over time

→

Step 3

Impact of policies & market conditions

$/kWh ➔ e.g. ton CO_2

- Different investment portfolios and amounts
- Different oil and natural gas prices
- Construct key policy and market scenarios including carbon caps, clean electricity standards, and CAFE

- Our approach is to incorporate technical uncertainty to quantify the uncertainty around the benefits and use decision metrics such as:
  - Probability of CO_2 price below a certain level, e.g., $30/ton$CO_2$
  - Mean and standard deviation of a resulting oil imports, etc.

  … under a range of investment portfolios and assumptions

Technologies covered

- 4 supply side technology areas
  - *Nuclear energy*: Gen III, Gen IV, modular reactors
  - *Fossil energy*: coal with and without CCS, natural gas with and w/o CCS
  - *Bioenergy:* gasoline, diesel, and jet fuel production through thermochemical and biochemical conversion pathways, and electricity
  - *Photovoltaic energy*: residential, commercial, and utility scale
- 1 enabling technology area
  - *Utility scale energy storage*: compressed air storage, 2 types of batteries, flow batteries
- 2 demand side technology areas
  - *Vehicle types*: advanced ICE, electric vehicle, plug-in electric vehicle, hybrid vehicle, and fuel cell vehicle
  - *Buildings*: commercial buildings, 6 levels of energy efficiency for heating and cooling

➔ *We covered 25 technologies under 4 budget scenarios*

➔ *Insights from 100 technical experts and 23 high-level reviewers*

Allocation of recommended budgets: Energy storage
(Average percentage of budget, Annual to 2030)

	Pumped Hydro	Compressed Air Energy	Batteries	Flow Batteries	Thermal	Fuel Cells	Superconducitng Magnetic Energy	Flywheels	Electrochemical Capacitors	Other
Basic Research	0.2	1.8	4.5	4.0	0.5	1.3	1.9	1.5	2.3	1.1
Applied Research	0.7	3.7	4.9	4.9	1.4	1.1	1.1	2.5	2.4	1.7
Experiments and Pilots	0.7	3.7	4.2	7.1	2.0	0.6	0.4	2.2	2.3	2.4
Commercial Demonstration	1.4	8.3	4.6	7.8	1.6	0.7	0.6	1.9	2.1	1.7
Total	3.2	18.2	18.1	24.0	5.7	3.9	3.6	7.3	8.7	7.3

Budget recommendations: Energy storage

DOE Energy Storage Budget

FY2009		FY2010	
$208 million		$63 million	
$185 million ARRA	$23 million EFRCs, OE R&D	$31 million ARPA-E	$32 million EFRCs, OE R&D

Experts' Recommended Budgets	
(millions 2010$)	Expert(s)
50	5, 6
70-80	15, 14, 19
100	7, 16, 17, 20, 21, 24
120	2, 10, 12
200-250	11, 23, 8, 13
500	4, 9
2,000-20,000	3

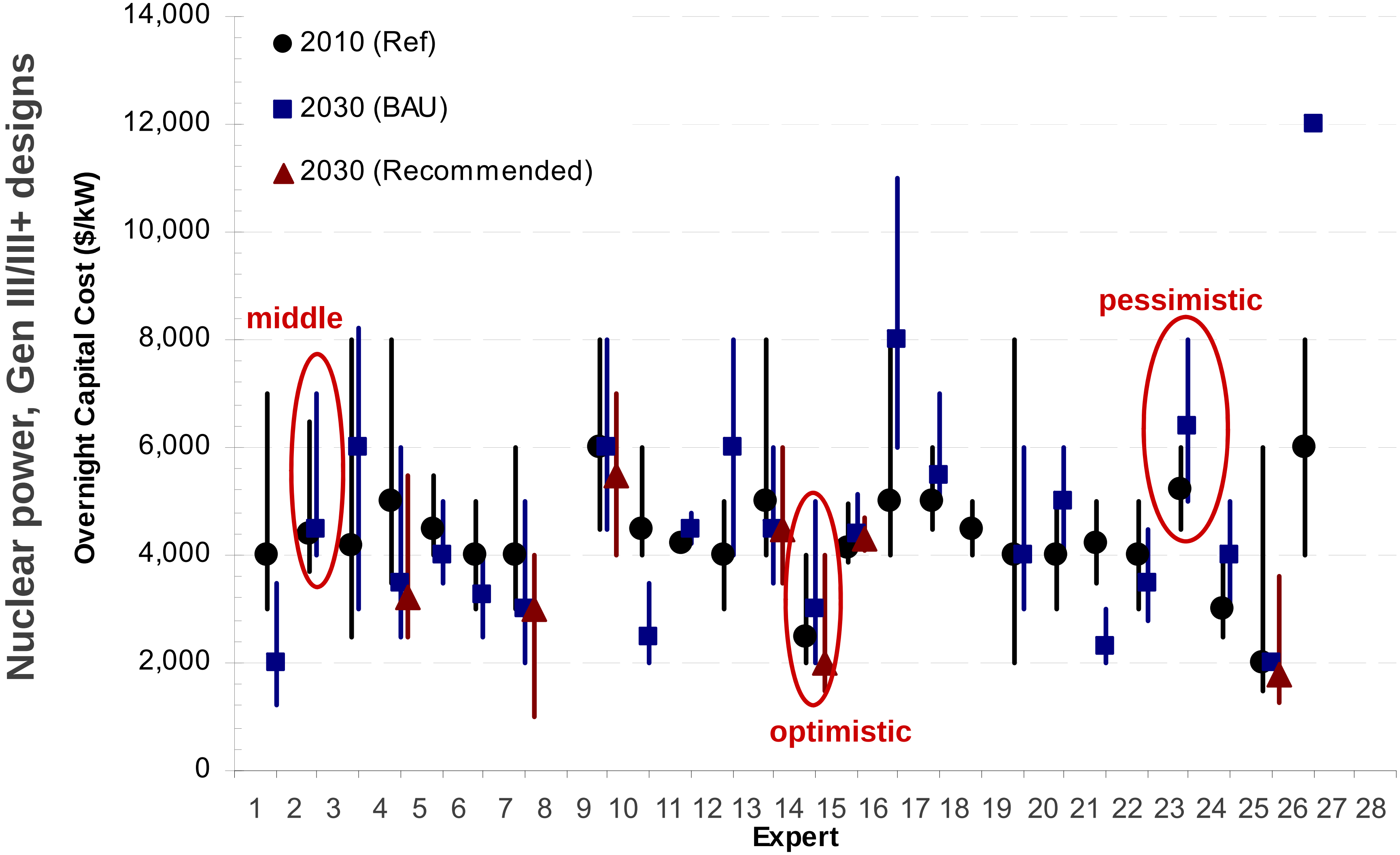
Scenarios to evaluate benefits of different budgets by "expert type" and policy & market conditions

Parameter	Variations
Funding level	Business-as-usual, ½ recommended, recommended, 10X recommended
Expert types*	Optimistic, middle, pessimistic
Energy prices	•Annual Energy Outlook 2010 (AEO2010) reference case •Reference case oil price (AEO2010), low gas price (AEO2011 reference case) •High oil price, high gas price (AEO2010)
Climate/energy policy	•Cap: 17% below 2005 levels by 2020, 83% below by 2050; Domestic offsets only; Banking and borrowing •Clean Electricity Standard of 80% by 2035; 30% improvement in commercial building shell efficiency; increase in CAFE standard to 75 miles per gallon by 2050

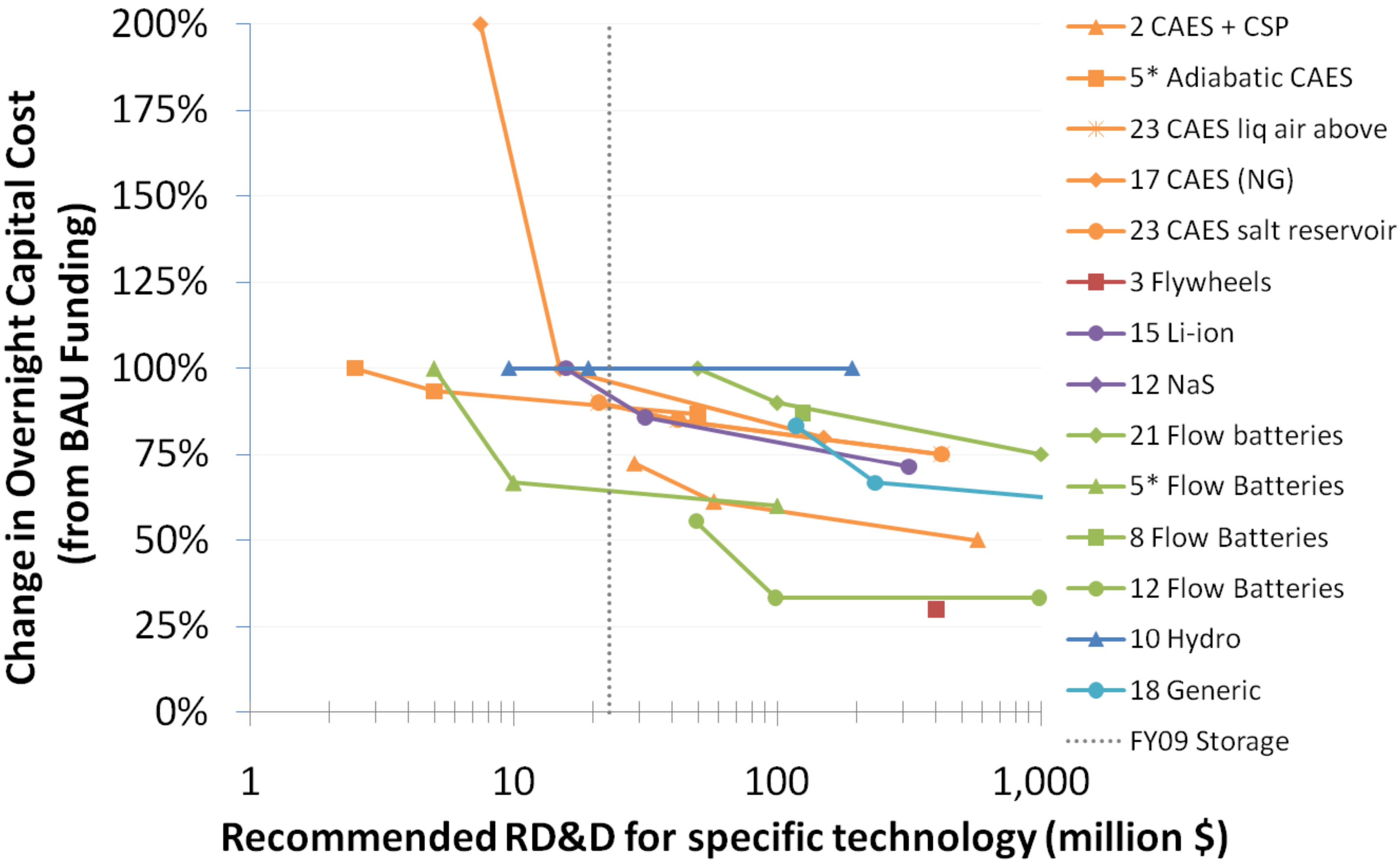
* Selected with the help of qualitative interviews

400 model runs per scenario

Picking representative experts to model wide range of uncertainty: Nuclear energy



Technology cost at different funding levels: Energy storage



Clusters of technologies where improvements are likely to be related

Cluster 1

Liquid fuels and electricity from coal and biomass through thermochemical processes

Cluster 2

Liquid fuels from biomass using biochemical processes

Cluster 3

Nuclear Gen III/III+, Gen IV technologies and modular nuclear reactors

Cluster 4

Photovoltaic for residential commercial, and utility scale applications

Cluster 5

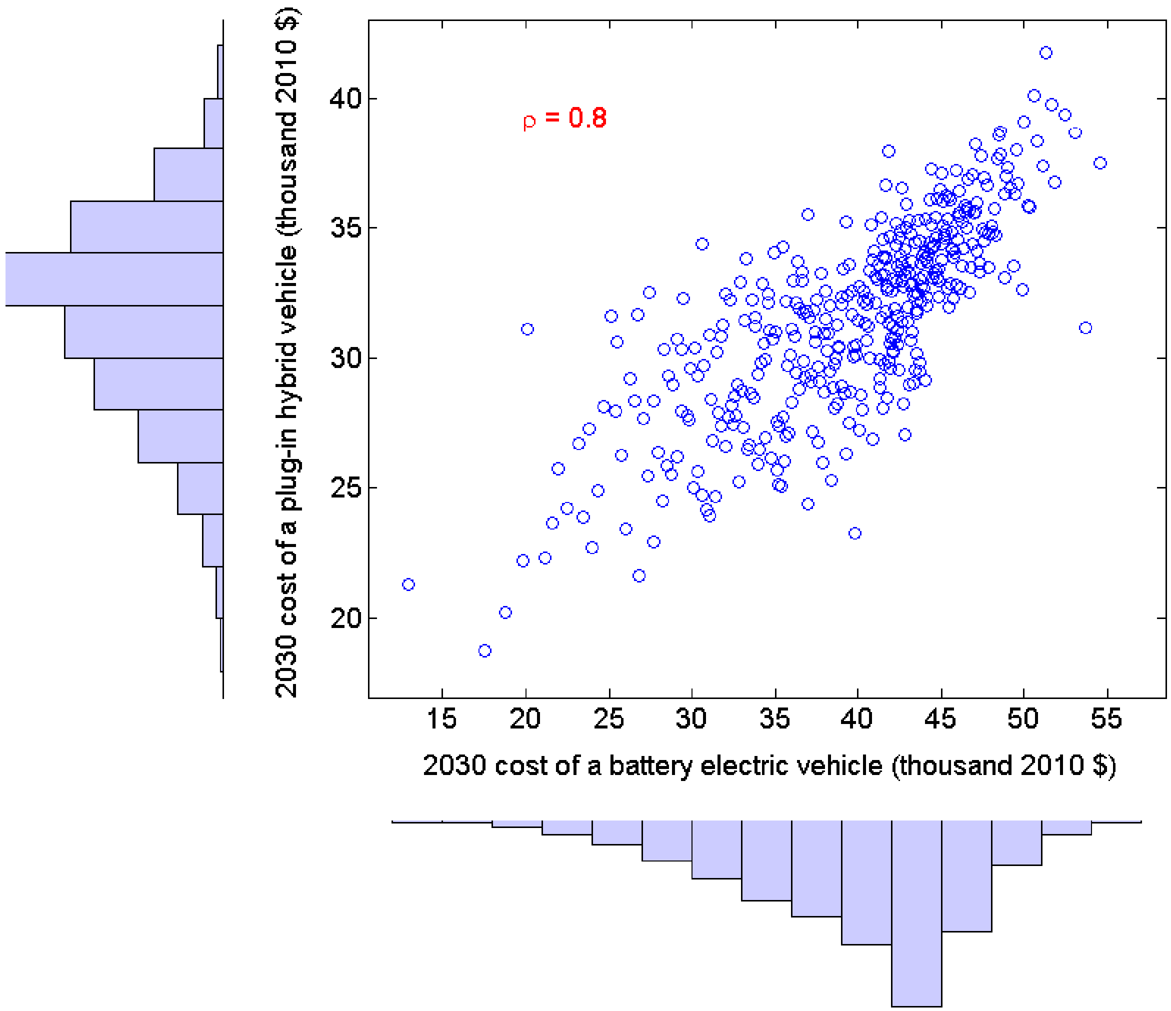
Different types of compressed air energy storage technologies

Cluster 6

Vehicles and batteries for utility scale energy storage

Latin Hypercube Sampling & correlations across technologies implemented

Accounting for the fact that improvements in some technologies are likely to be related

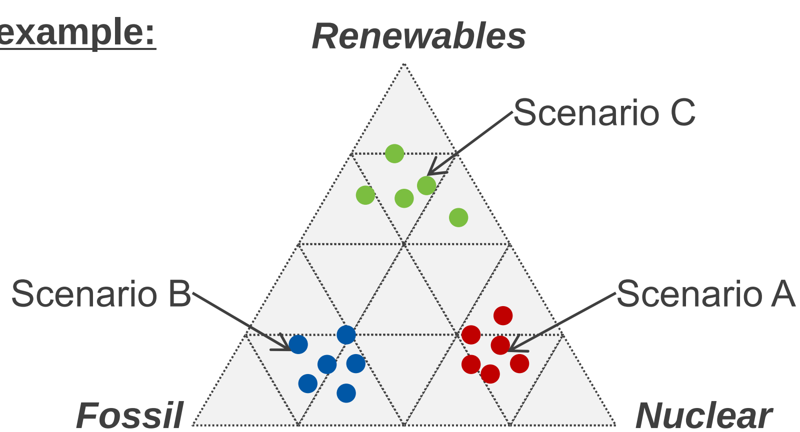


- Sampling distribution for electric and plug-in hybrid vehicles
  - Drawn using Latin hypercube sampling with Iman and Connover method to induce Gaussian copula dependence for $\rho = 0.8$
  - Marginal distributions (provided by experts) are preserved

Metrics: Quantifying benefits of portfolios accounting for uncertainty

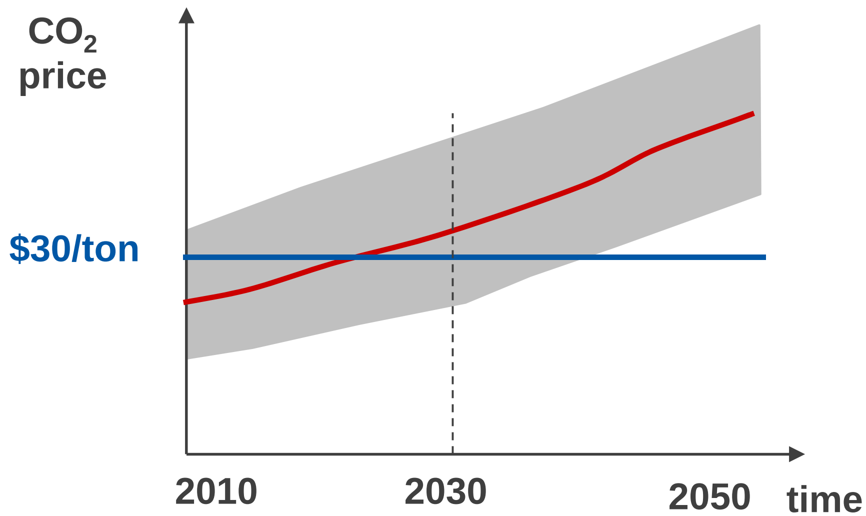
Metric
Distribution of CO2 emissions (tonnes) vs. Time (2010-2050)
Distribution of CO2 price ($/tonne) vs. Time (2010-2050)
Distribution of oil imports vs. Time (2010-2050)
Probability (%) vs. Technology deployment (GW)
Distribution of technology deployment (GW) vs. Technology cost ($/kW)
Distribution of share of technology types (renewables, nuclear, fossil)

For example:



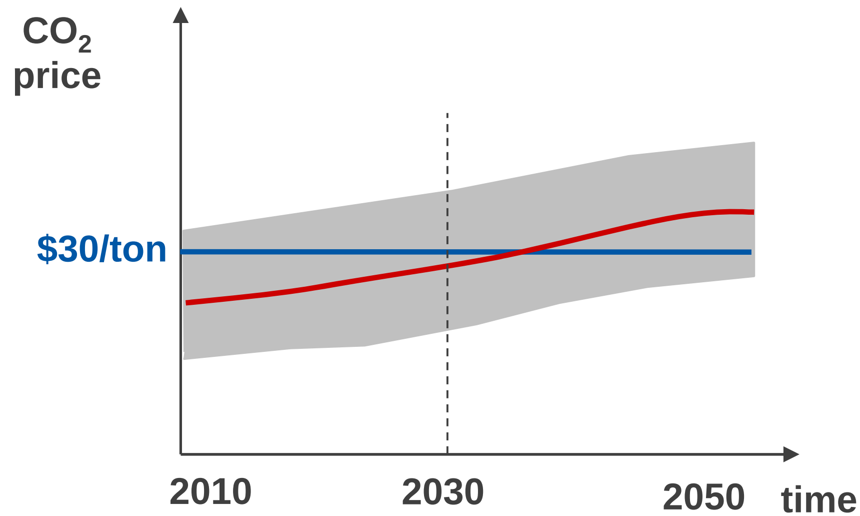
Quantifying benefits of portfolios accounting for uncertainty

Business as usual RD&D scenario



e.g.,30% probability of carbon price in 2030 below $30/ton$CO_2$

Enhanced RD&D scenario



e.g., 70% probability of carbon price in 2030 below $30/ton$CO_2$

- Same analysis results in uncertainty around CO_2 emissions in a scenario without a carbon policy

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