HARVARD Kennedy School
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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<br>▪ American Energy Innovation Council recommended $16 billion/year in energy RD&D.<br>▪ 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 |

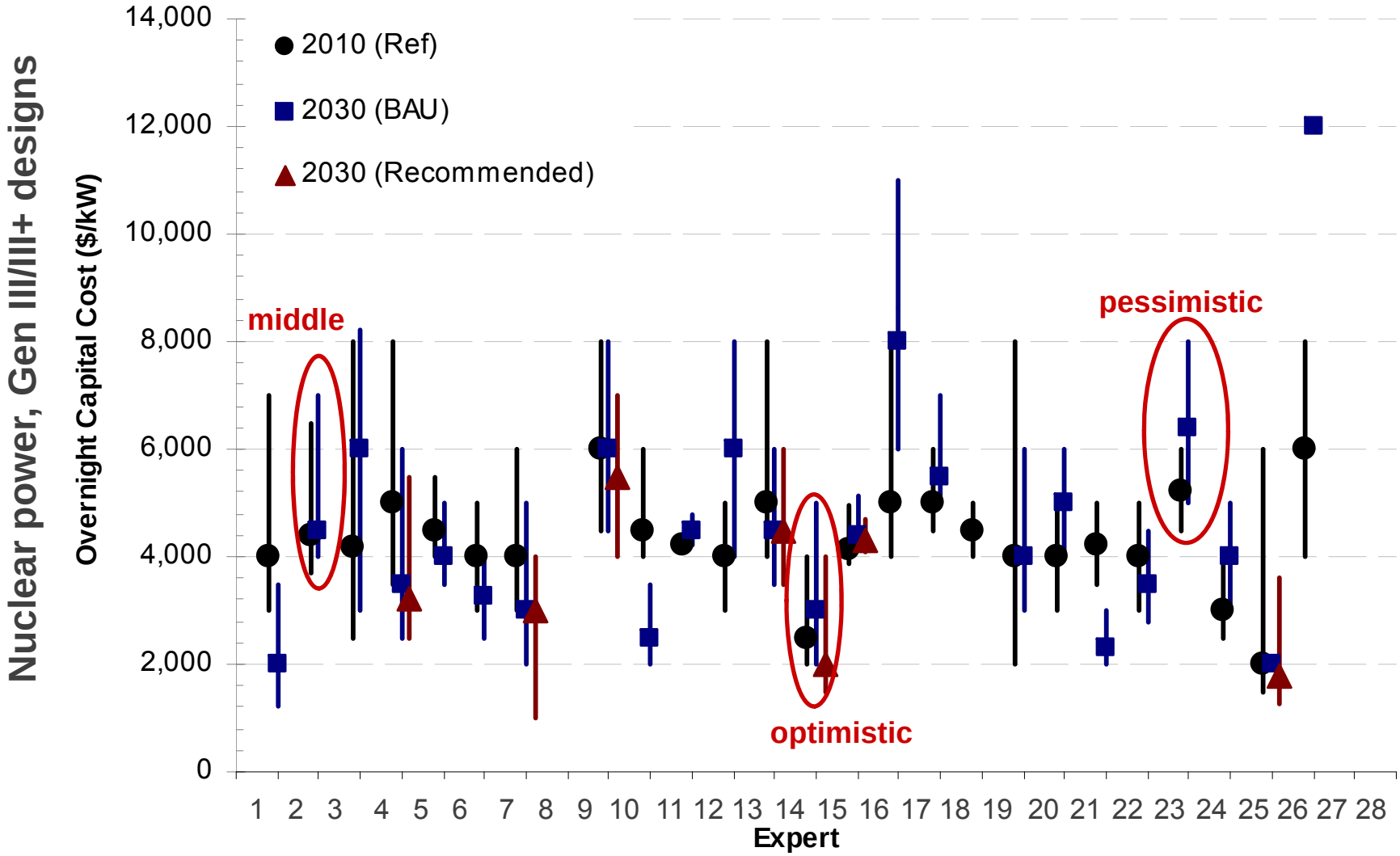
# Scenarios to evaluate benefits of different budgets by "expert type" and policy & market conditions

| 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<br>•Reference case oil price (AEO2010), low gas price (AEO2011 reference case)<br>•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<br>•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 |

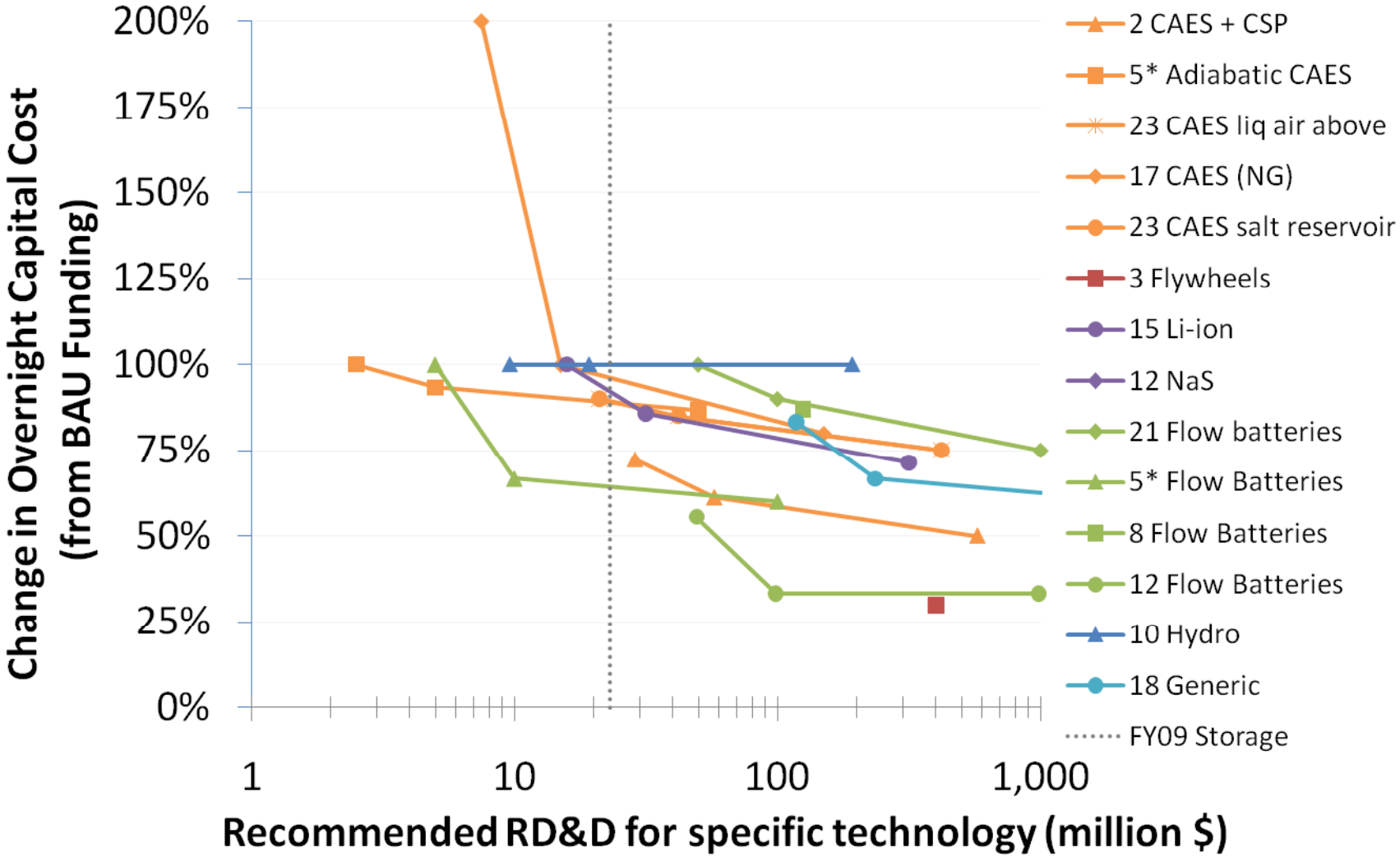
* Selected with the help of qualitative interviews

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**

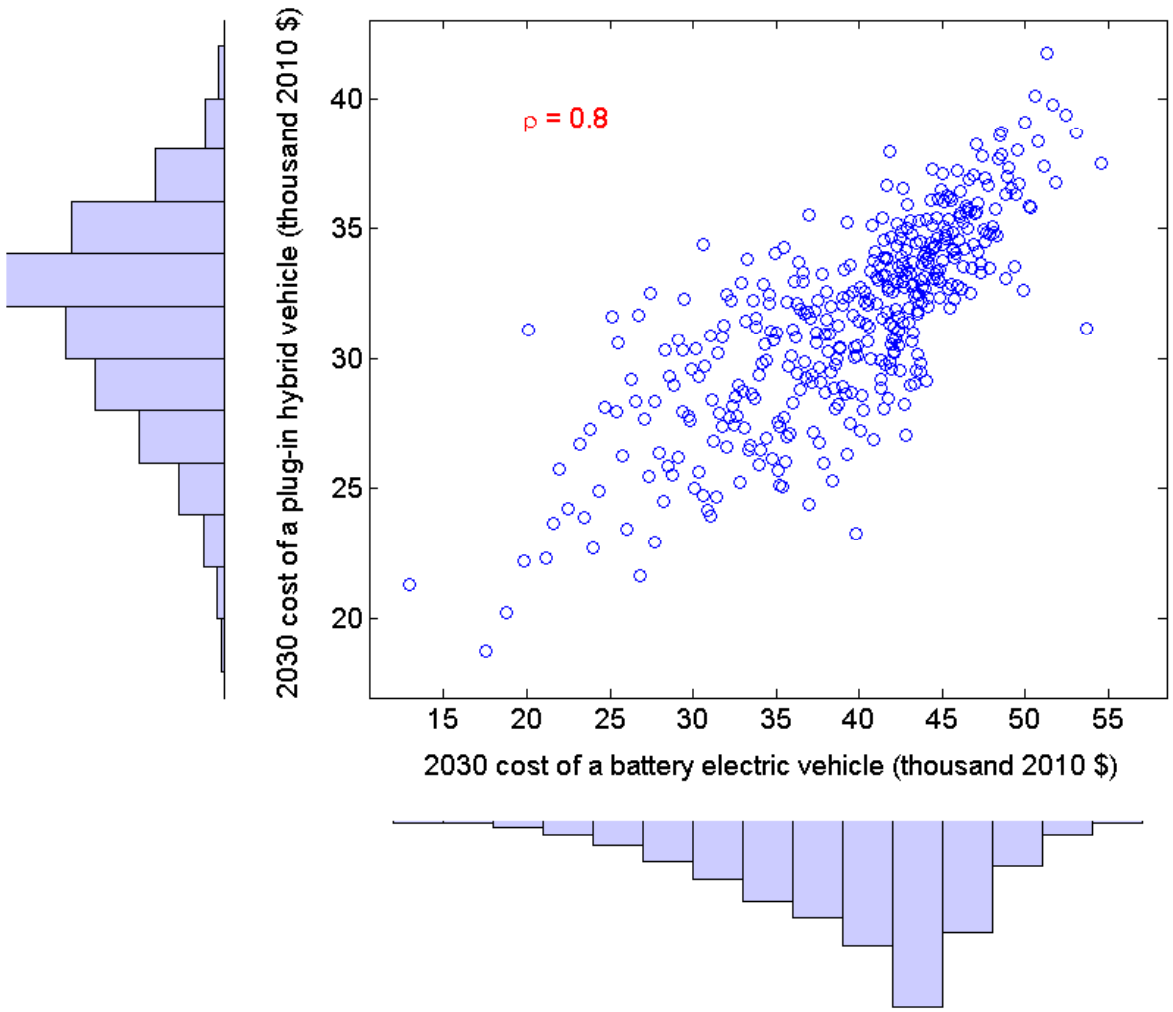
Different types of compressed air energy storage technologies

**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

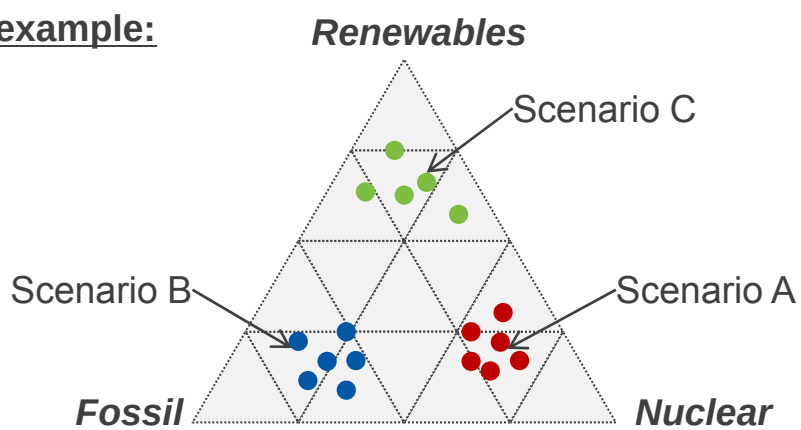



- Sampling distribution for electric and plug-in hybrid vehicles
  - Drawn using Latin hypercube sampling with Iman and Connover method to induce Gaussian copula dependence for ρ= 0.8
  - Marginal distributions (provided by experts) are preserved

# Metrics: Quantifying benefits of portfolios accounting for uncertainty

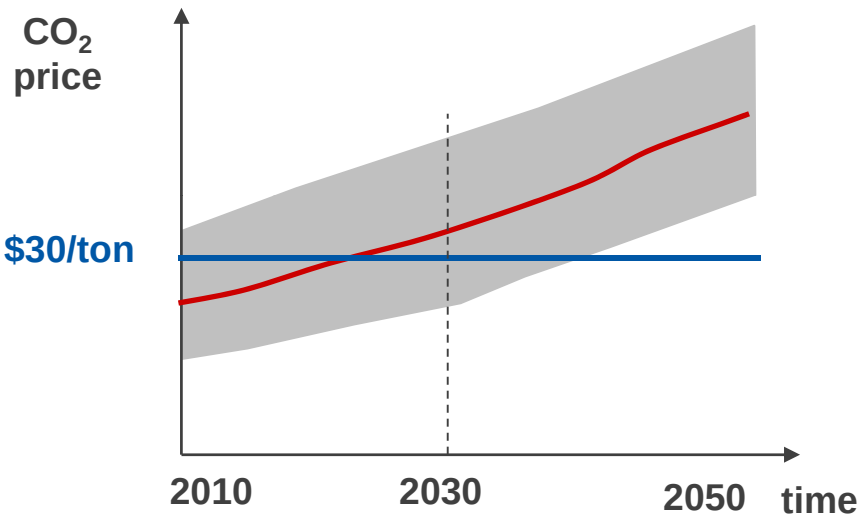
| Metric |
| --- |
| Distribution of CO2 emissions (tonnes) vs. Time (2010-2050) |
| Distribution of CO2 price ($/tonne) vs. Time (2010-2050) |
| Distribution of oil imports vs. Time (2010-2050) |
| Probability (%) vs. Technology deployment (GW) |
| Distribution of technology deployment (GW) vs. Technology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

**For example:**



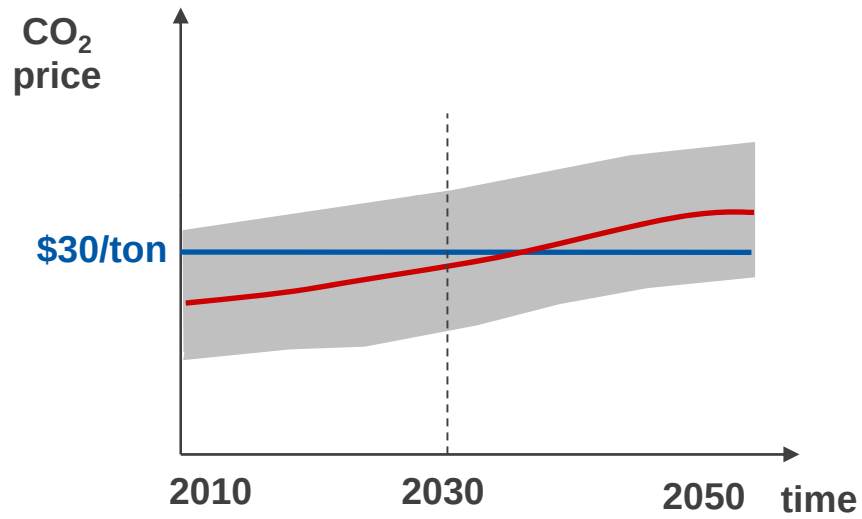
# Quantifying benefits of portfolios accounting for uncertainty

**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

# Energy Research, Development, Demonstration & Deployment (ERD3) Policy Project Team

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