

What Can We Learn From Many Runs of Integrated Assessment Models?

Exploring Interactions Among Uncertain Low Carbon Energy Technologies

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Snowmass

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Overview of the Talk

- ▶ This talk covers recent research at JGCRI and in collaboration with RAND, looking at large sets of model runs exploring the impact of different combinations of technological advance.
- ▶ We hope to get some feedback on how to make this class of research more usable and more valuable.



Background and Context

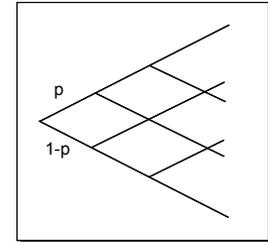
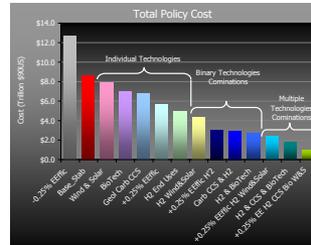



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The Normative R&D Strategy Challenge

Issues and Tools

How can we better inform R&D strategy:
(1) how much effort is appropriate?
(2) how should it be allocated?



ISSUES

Potential for Advance,
R&D Impact on Advance

Value of Technology

R&D Allocation Under
Uncertainty



TOOLS

Technology Assessments
Historical Analysis

Integrated Assessment
Models

Portfolio Models,
Decision Analysis



The Use of IAMs for Strategic Technology Planning

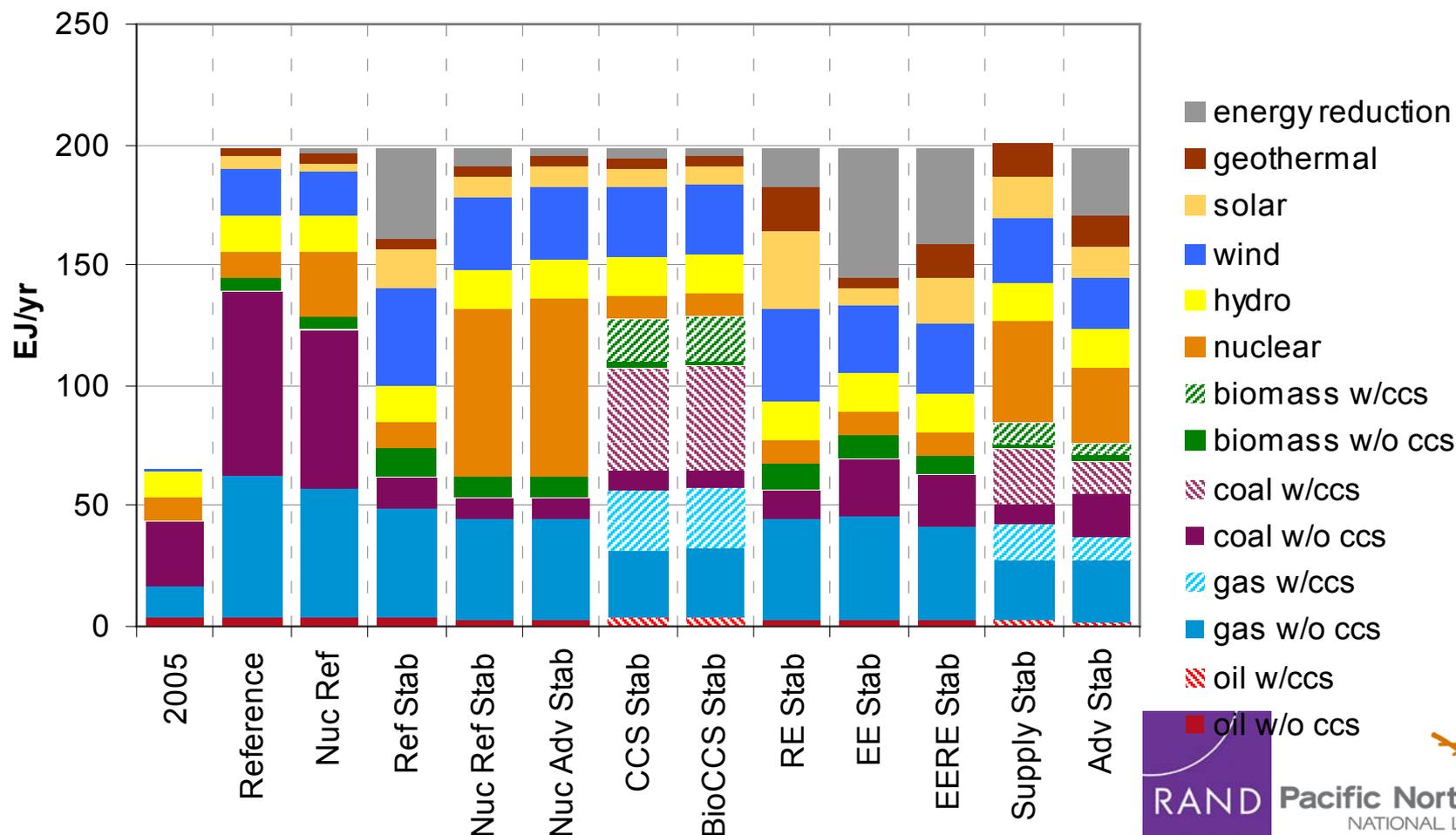
The U.S. Climate Change Technology Program (CCTP) uses integrated assessment analysis to inform strategic technology decision making.

Scenario & Naming Convention	Reference (Ref)	Nuclear Reference (Nuc Ref)	Nuclear Advanced (Nuc Adv)	CCS (CCS)	Bio and CCS (BioCCS)	Renewables (RE)	End Use (EE)	End Use & Renewables (EERE)	Hydrogen & Supply (Supply)	Advanced (Adv)
Transportation: Electric Vehicles	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Transportation: Fuel Cell Vehicles	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Advanced	Advanced
Transportation: Other	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Buildings	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Industry	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Electricity and Hydrogen CCS	No CCS	No CCS	No CCS	Advanced	Advanced	No CCS	No CCS	No CCS	Advanced	Advanced
Agricultural Productivity	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced	Advanced	Advanced
Hydrogen Production	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced
Wind Power	Reference	Reference	Reference	Reference	Reference	Advanced	Reference	Advanced	Advanced	Advanced
Solar Power	Reference	Reference	Reference	Reference	Reference	Advanced	Reference	Advanced	Advanced	Advanced
Nuclear Fission	No New Nuclear	Reference	Advanced	No New Nuclear	No New Nuclear	No New Nuclear	No New Nuclear	No New Nuclear	Advanced	Advanced
Geothermal	Reference	Reference	Reference	Reference	Reference	Advanced	Reference	Advanced	Advanced	Advanced

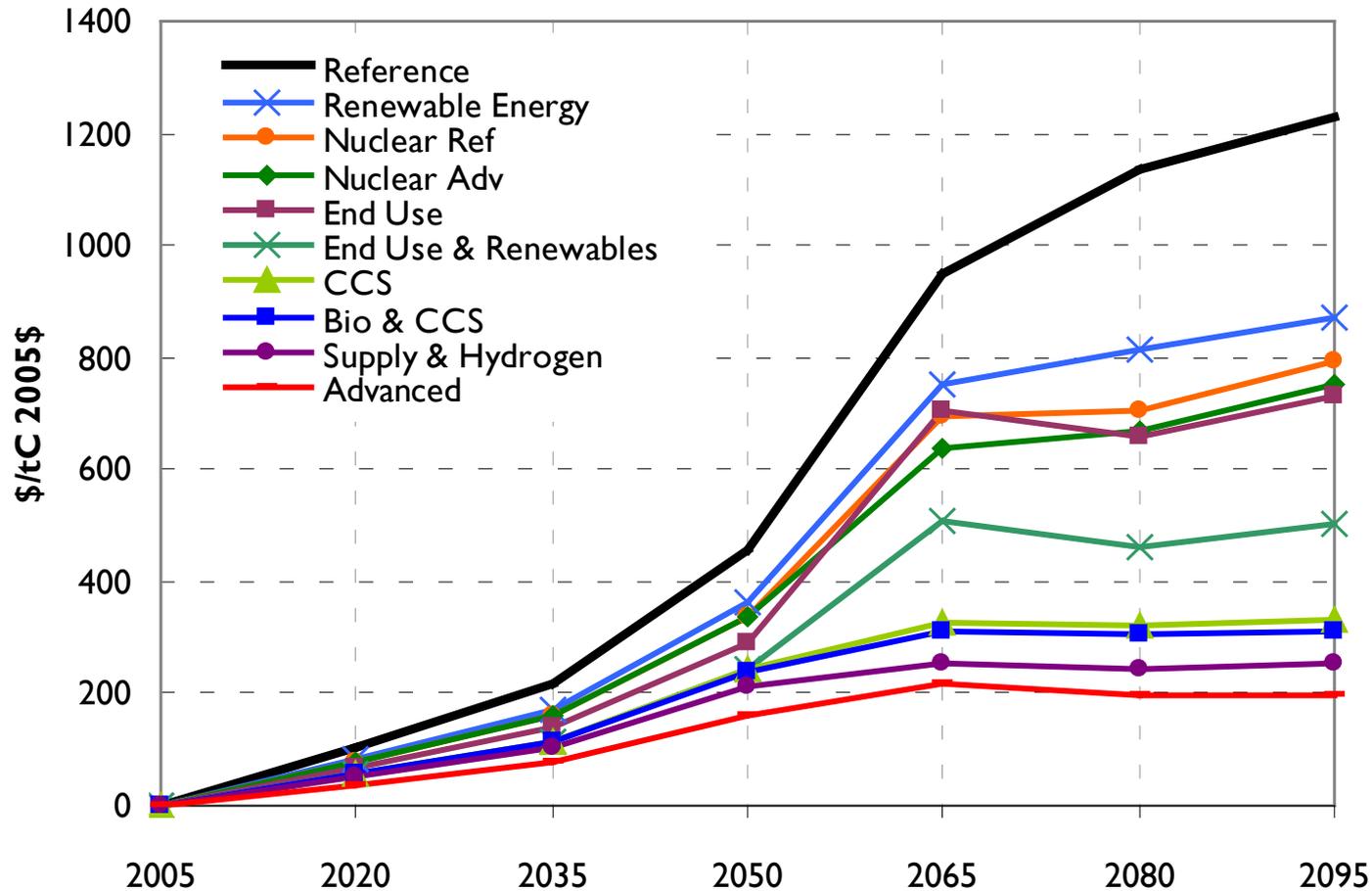


Technology scenario analysis provides insights into the composition and character of the energy system.

Electricity production by technology in 2050 across CCTP scenarios.



Technology scenarios can also provide insights into the economics of mitigation.



Where to Beyond Scenarios?

- ▶ Scenarios are valuable for understanding the nuances of key interactions between technologies and other factors that influence the costs and impacts of new technology.
- ▶ They provide discrete points by which to look at aggregate metrics such as cost.
- ▶ They are not, however, a robust assessment of the technology space. Are we missing something? What can we learn from a more robust assessment of the space.
- ▶ A Quick Bottom Line: These permutation-style analyses are a complement to scenarios, but not a substitute. They confirm many observations and insights from scenarios and bring forth several new sorts of insights.

One Option for Moving Beyond Scenarios: Exploring the Technology Space.



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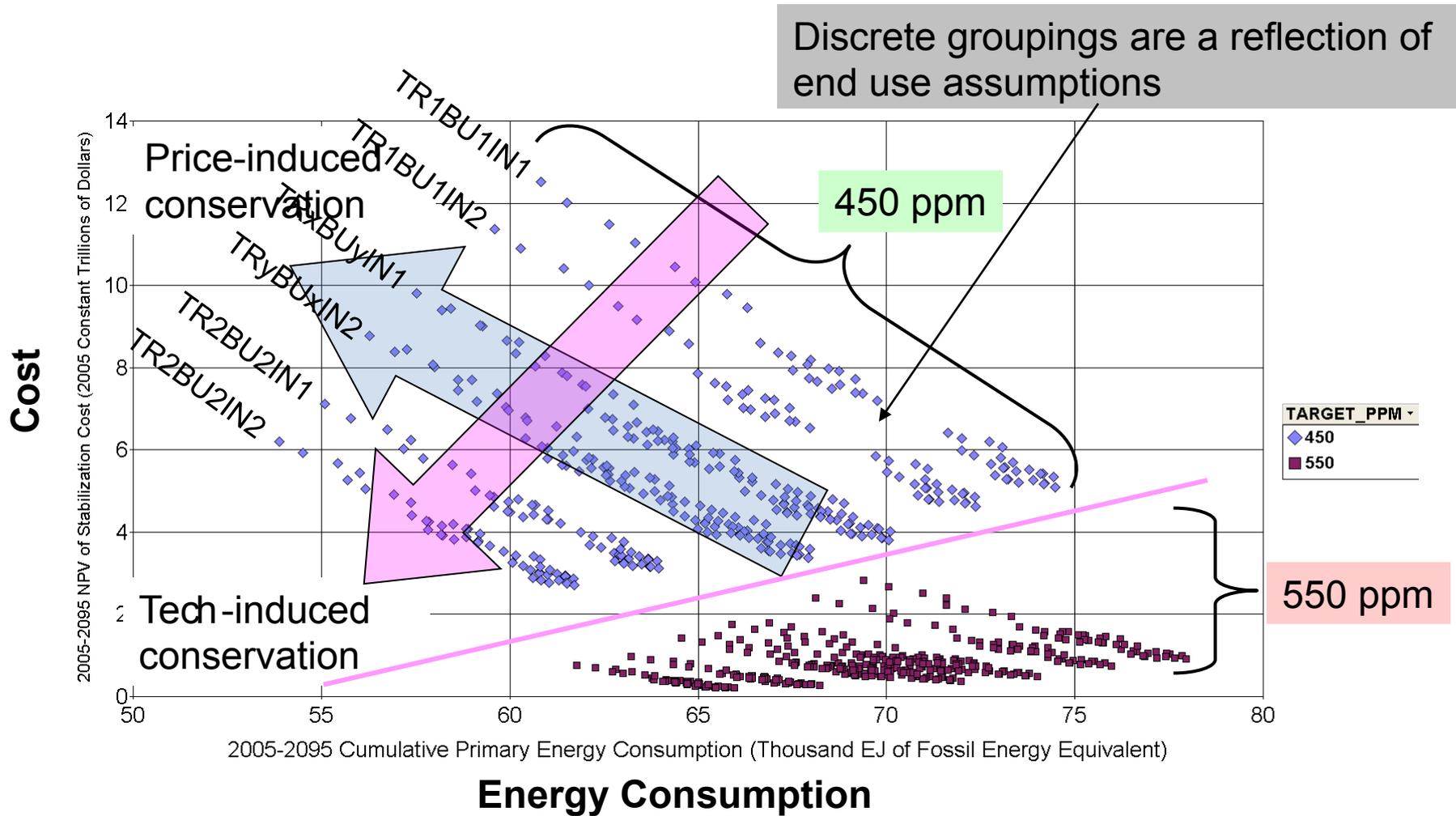
The study explores all permutations of one set of technology assumptions.

Full factorial combinations: $2^7 \cdot 3 = 384$ tech combinations per stabilization level

		0: FIXED	1: REF	2: ADV	
Supply Technology	Solar	N/A	Capital costs drop by 1%-2% per year 2005-2050	Capital costs drop by 2%-3.5% per year 2005-2050	2
	Wind	N/A	Capital costs drop by 0.25% per year 2005-2050	Capital costs drop by 0.5% per year 2005-2050	2
	CCS	No CCS in any applications	CCS available in electricity, hydrogen, and cement sectors (starting at about \$40 / t CO ₂)	N/A	2
	Nuclear	Nuclear power generation fixed at 2005 levels	Nuclear power available at \$2300/kW in 2020, decreasing at 0.1% per year	Nuclear power available at \$2300/kW in 2020, decreasing at 0.3% per year	3
End-Use Technology	Buildings	N/A	Improvement in building technologies and shells based on EIA (2007)	Accelerated improvement in costs and performance of energy-saving technologies and building shells	2
	Transport	N/A	Improvement in transportation technologies based on EIA (2007)	Accelerated improvements in conventional technologies, and availability of low-cost electric and fuel-cell light duty vehicles	2
	Industry	N/A	Technology efficiencies improve at 0.1% per year; process intensities improve at 0.35% per year	Boiler and motor system efficiencies improve by 10% and 25% by 2035; best available practices from IEA (2007) are in use by 2035	2
Other	Other	N/A	Long-term agricultural productivity improvement: 0.25% per year. Engineered geothermal systems (EGS) not available.	Long-term agricultural productivity: 0.5% per year. Accelerated improvements in hydrogen production. EGS available	2

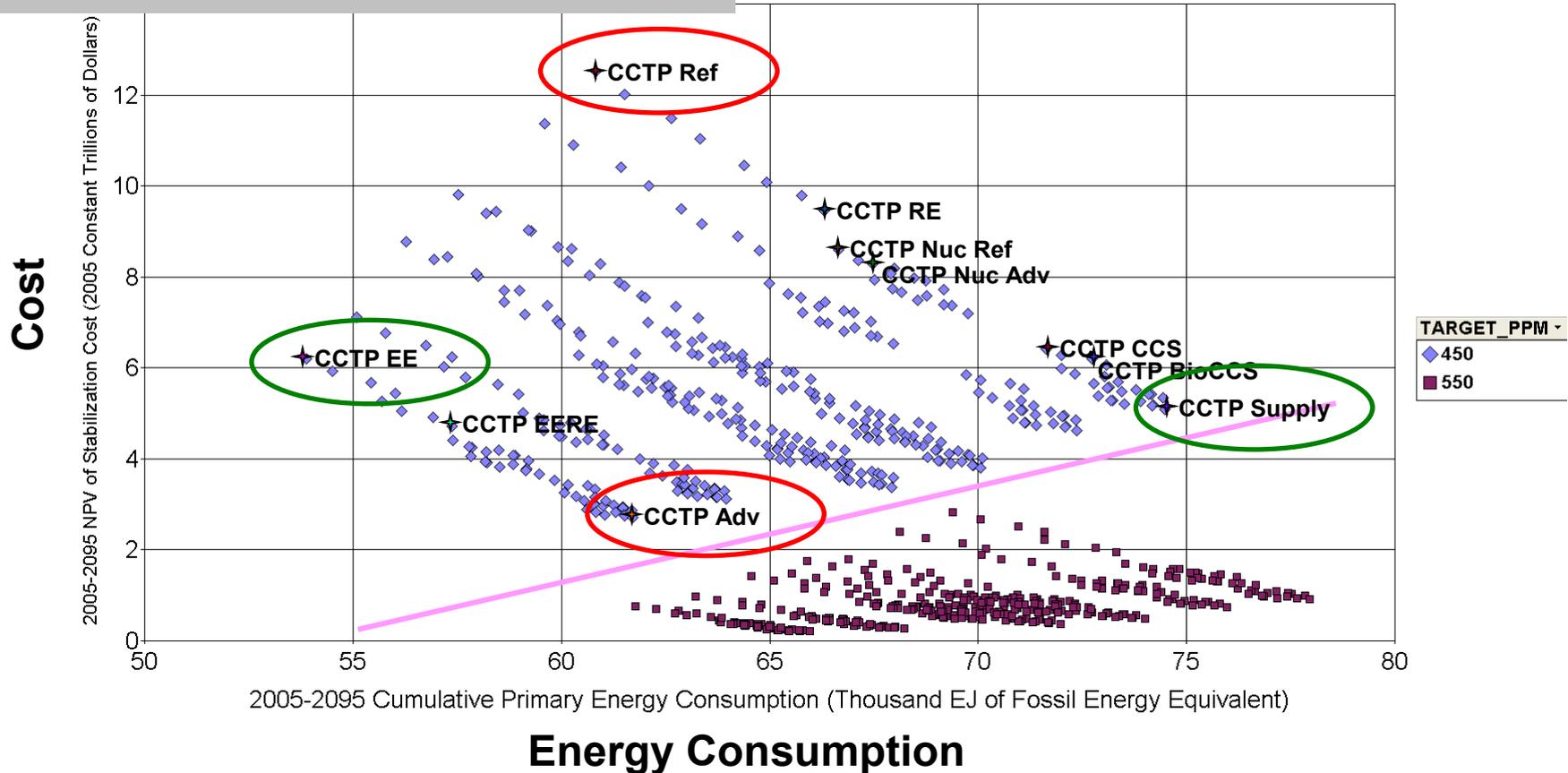
**384 combinations/level · 2 stabilization levels
= 768 total number of combinations considered**

A First Look at the 768 Runs

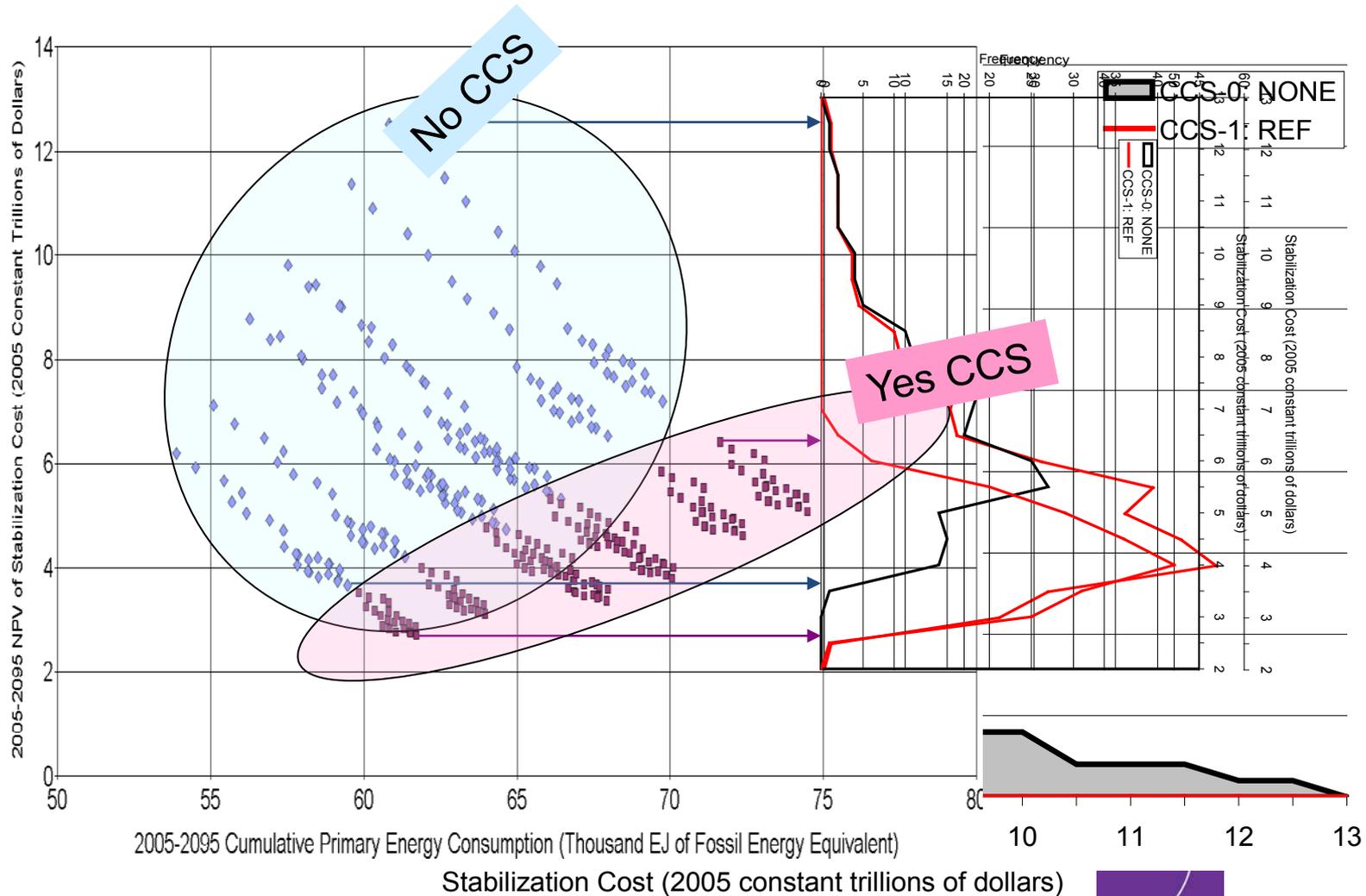


How well did the CCTP scenarios represent the full space of outcomes?

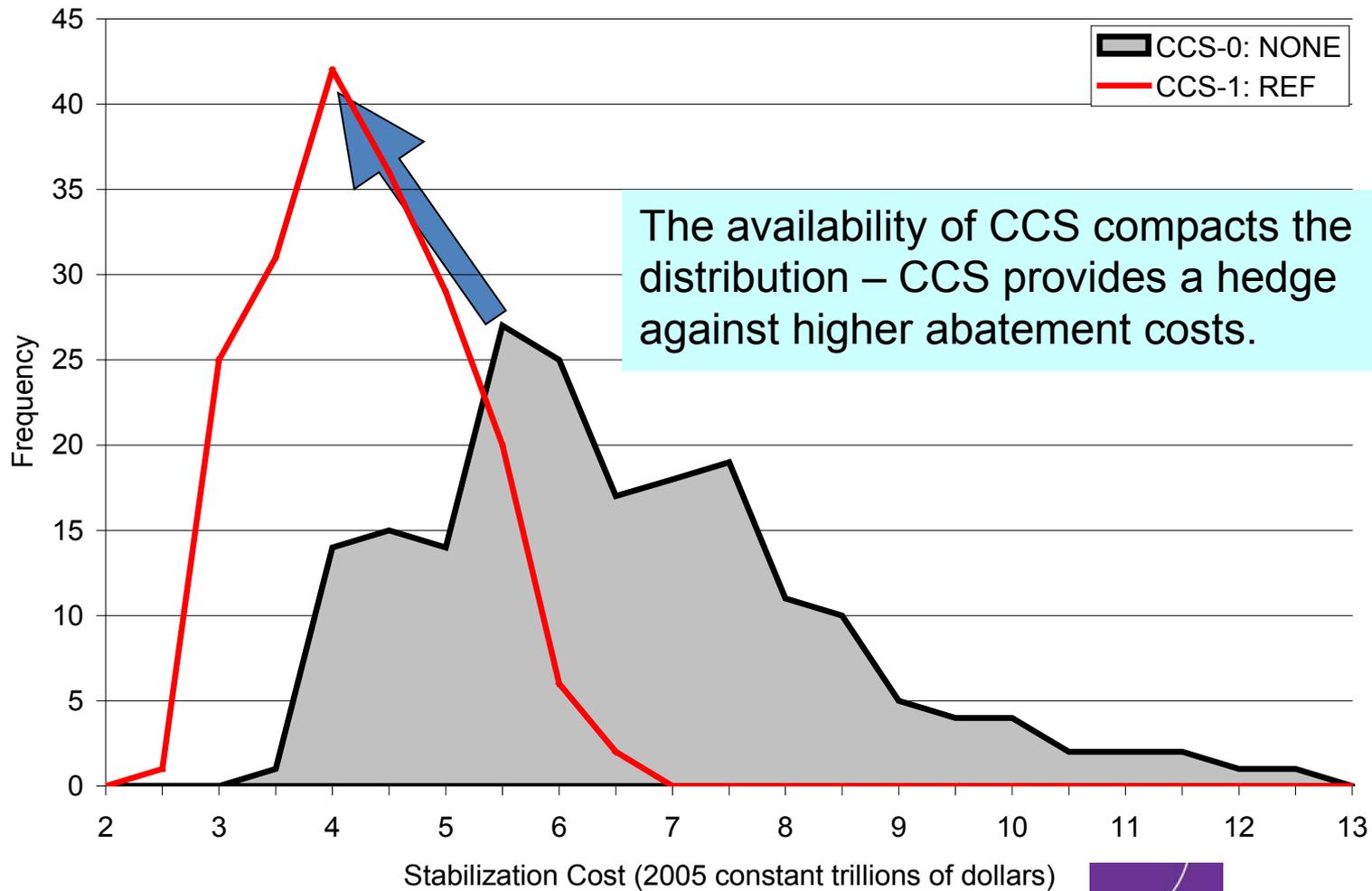
The scenarios *span* the space, but they don't *represent* the space.



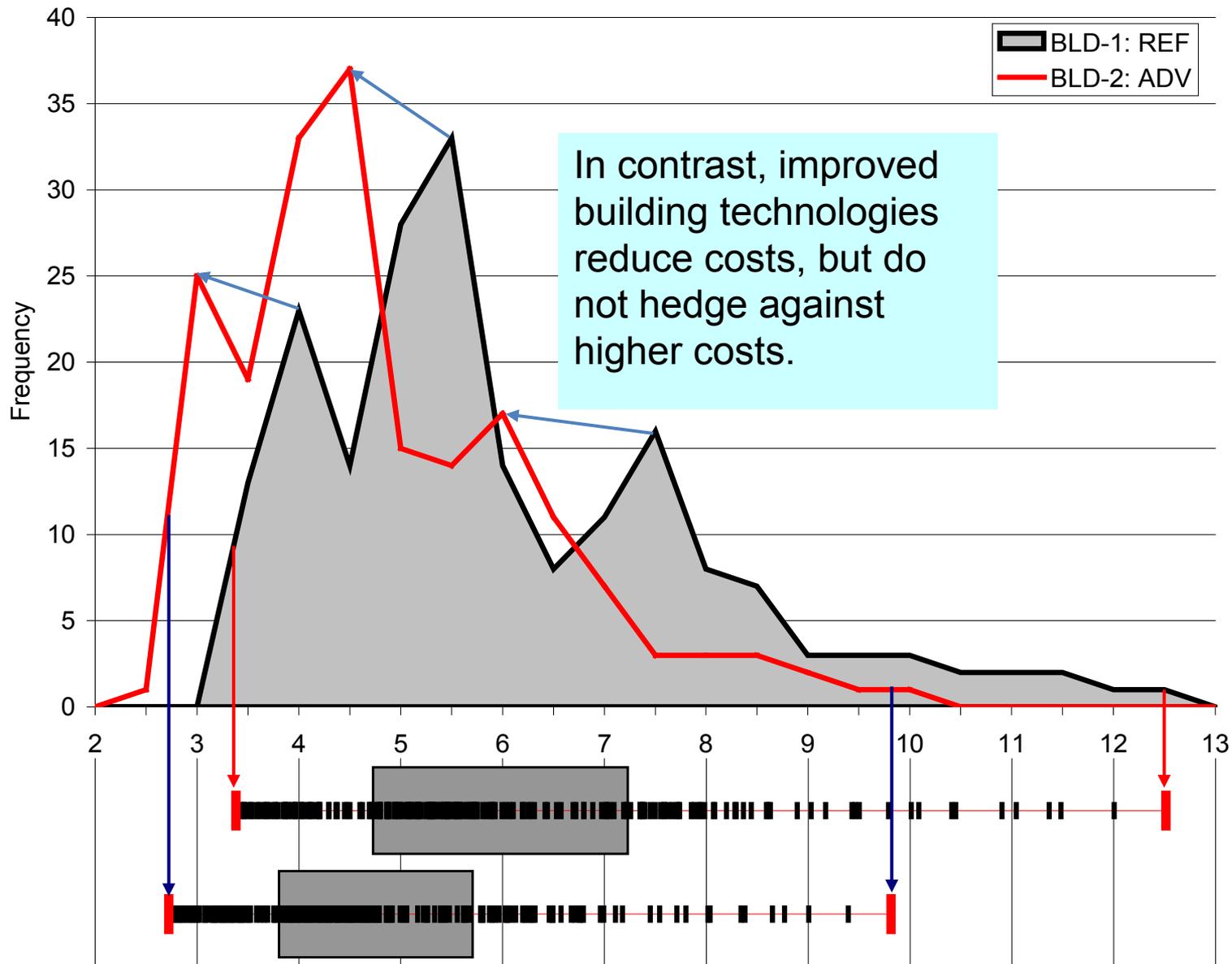
Focusing on Stabilization Cost Distribution



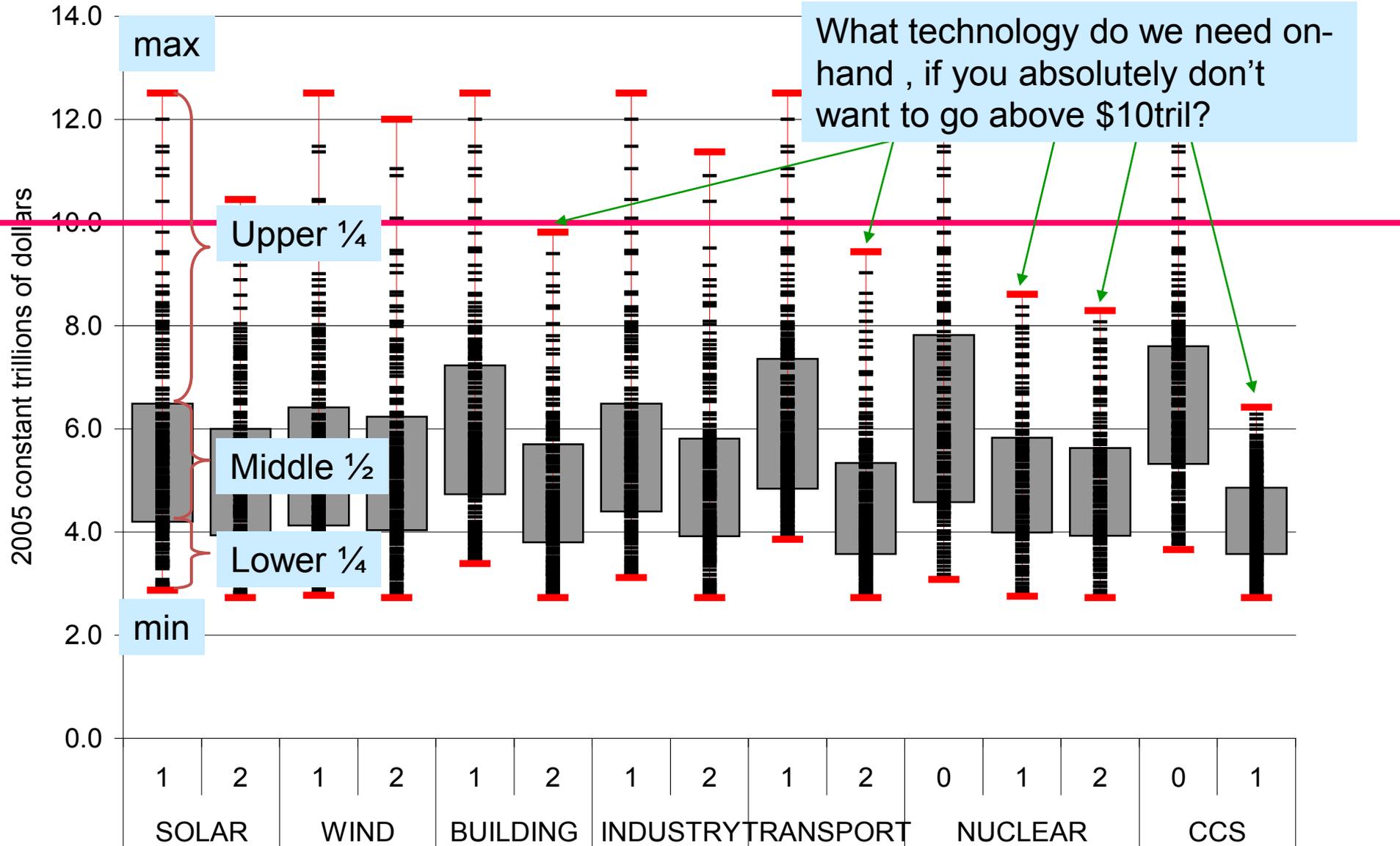
450 ppm Histogram – CCS focus



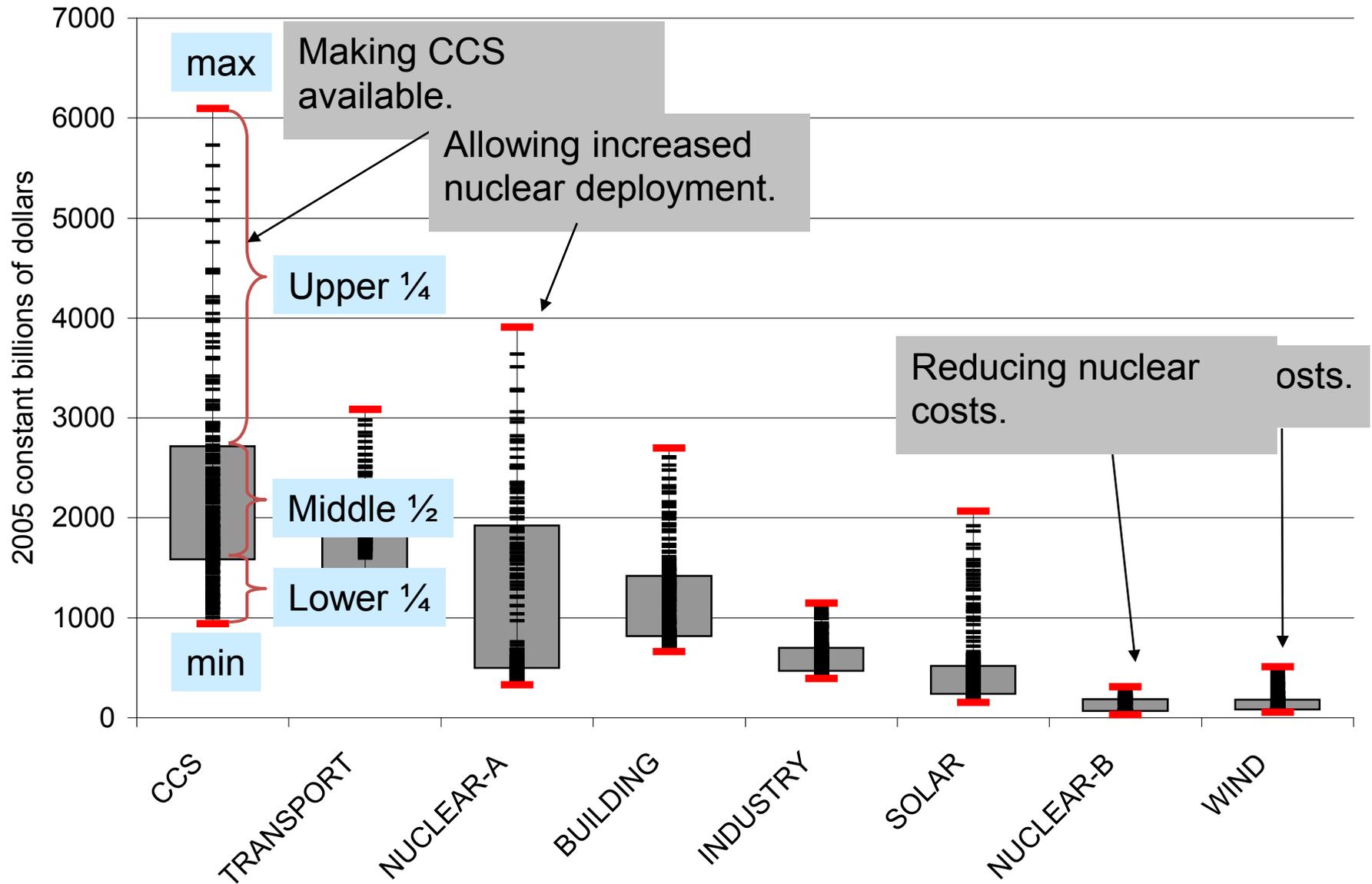
450 ppm Histogram – Buildings focus



Interpreting Abatement Cost Distributions



Interpreting Value of Technology Distributions



We Also Apply “Scenario Discovery” to GCAM Results

Scenario discovery uses statistical cluster-finding algorithms to identify easy-to-interpret, policy-relevant regions in the space of uncertain input parameters to computer simulation models.

Create database from many runs of simulation model

- Each case projects the performance of a proposed policy contingent on one set of assumptions about uncertain model input parameters

Index each record in the database, indicating whether the policy meets or does not meet its performance goals

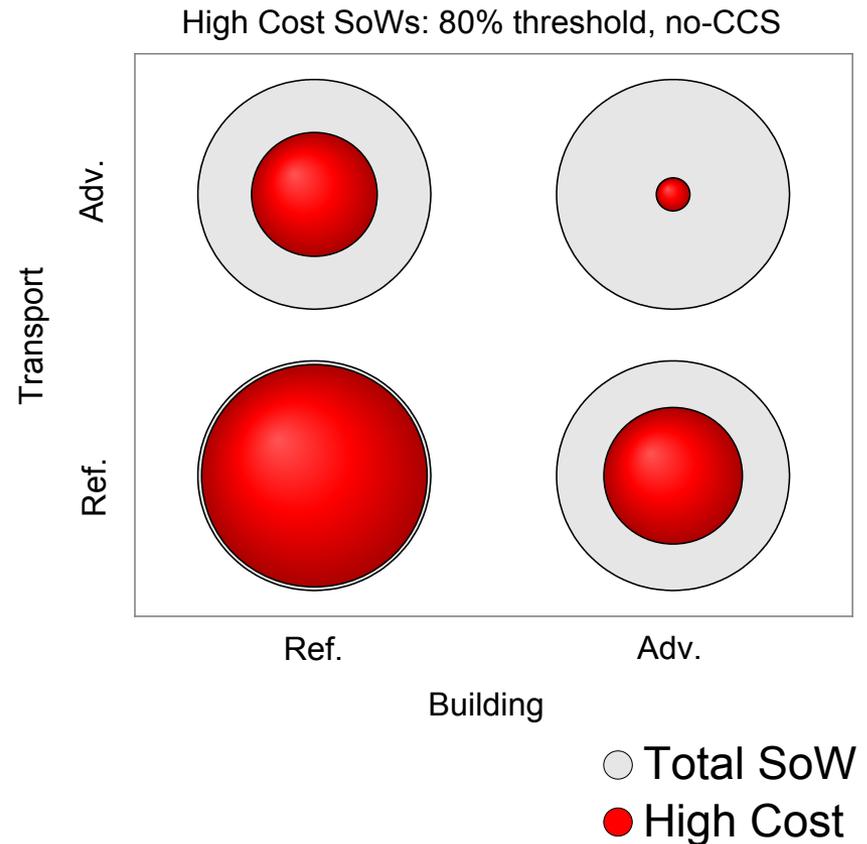
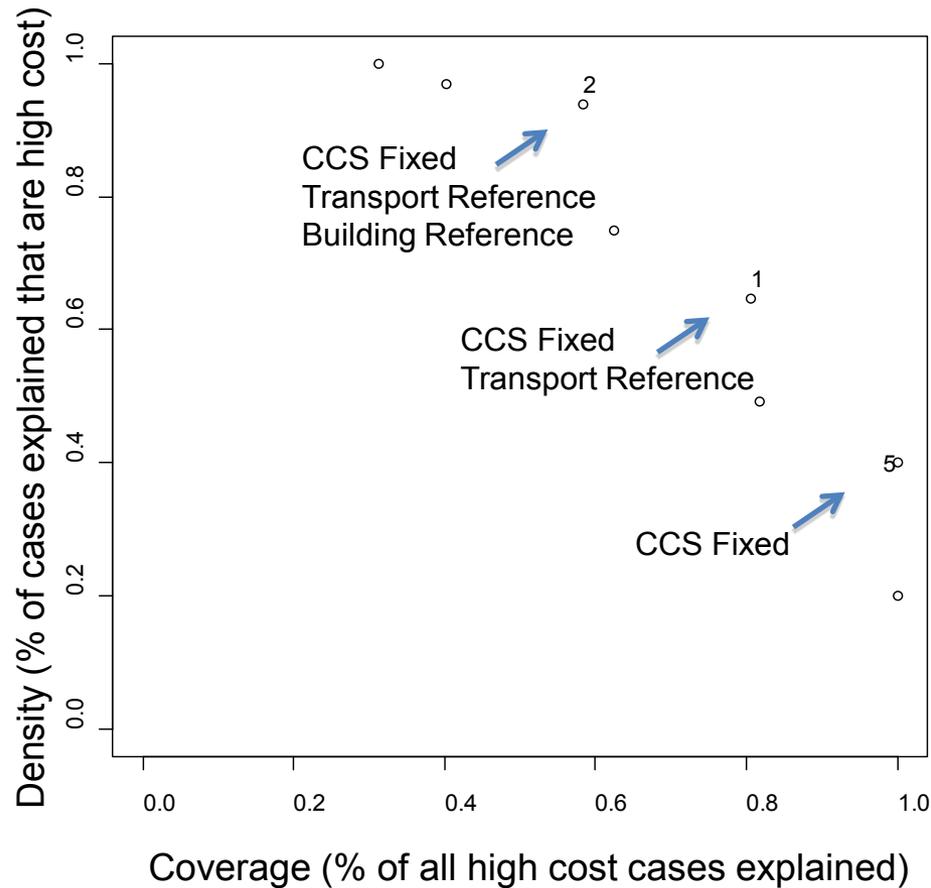
- Here we look for cases where meeting 450 ppm target costs more than \$6.8 trillion (80th percentile)

Run cluster-finding algorithms (we use PRIM – patient rule induction method) to find simple descriptions of combinations of input parameters that best predict the cases where 450 ppm policy has high costs





Analysis Suggests Assumptions About CCS, Transportation, and Buildings Most Important to Explaining High Cost Scenarios



Assumptions about Solar, Wind, Nuclear, Industry, and Other Technologies matter much less to explaining high cost scenarios



Possible Directions for Future Work

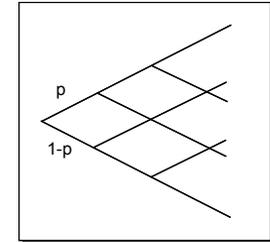
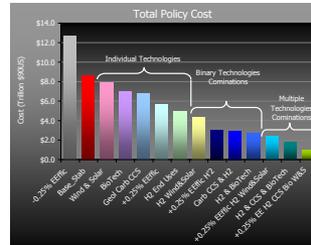
- ▶ Uncertainty analysis, of course
 - Incorporating into portfolio analysis and portfolio planning under uncertainty.
 - Monte Carlo analysis – dealing with covariance
- ▶ Different slices through the information – continue to explore the information we have
- ▶ More realistic policy contexts
- ▶ Depictions of technology states that are more tightly linked to real R&D decisions
- ▶ Better representations of technology in IAMs



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Thank You from 50,000 Permutations

