

Thoughts on Modeling Technological Uncertainty in IAMs and Implications for a Coordinated Uncertainty Exercise

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Snowmass
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Folks that have worked on this research

▶ PNNL/JGCRI

- Haewon McJeon, Leon Clarke, Page Kyle, Ben Bond-Lamberty, Pralit Patel, Marshall Wise, Jae Edmonds

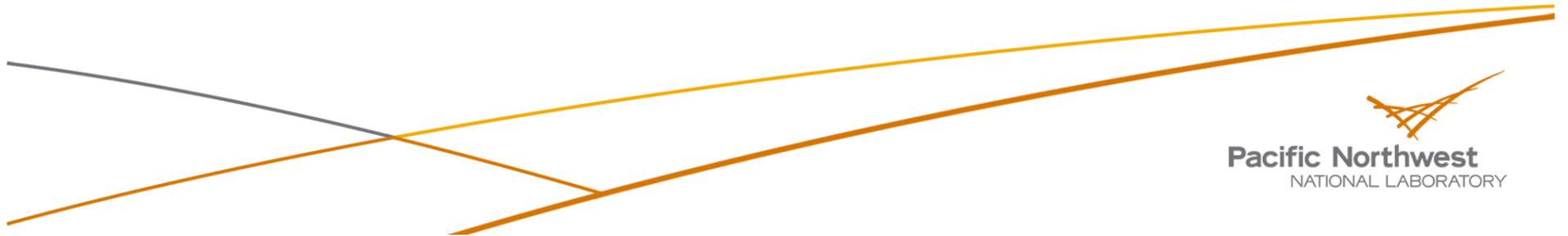
▶ RAND

- Robert Lempert, Andrew Hackbarth, Ben Bryant

▶ CCTP

- Bob Marlay, Graham Pugh, Bryan Mignone

“CLASSIC” TECHNOLOGY SCENARIOS



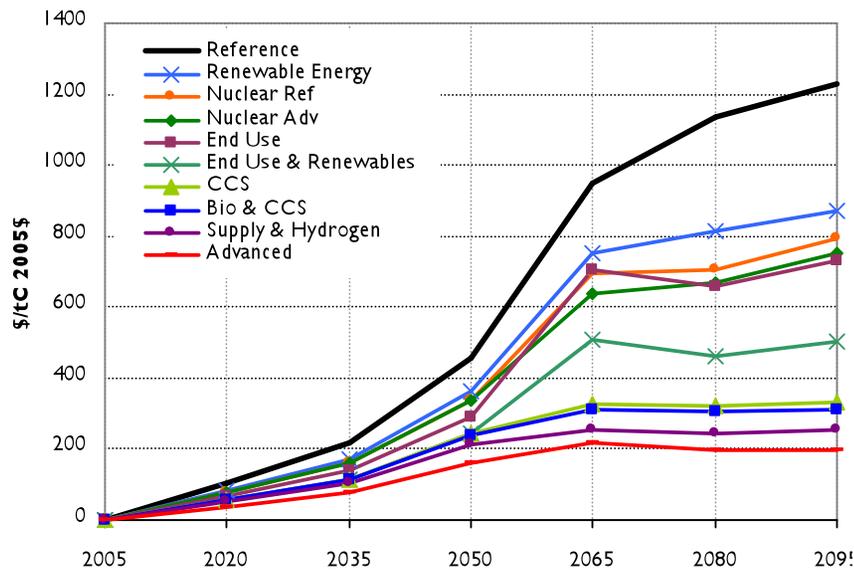
Like many IA groups, PNNL has been producing technology scenarios for some time.

A portion of this work has been technology scenario analysis for the Climate Change Technology Program (CCTP)

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

These scenarios explored the energy and economic implications of ten technology futures.

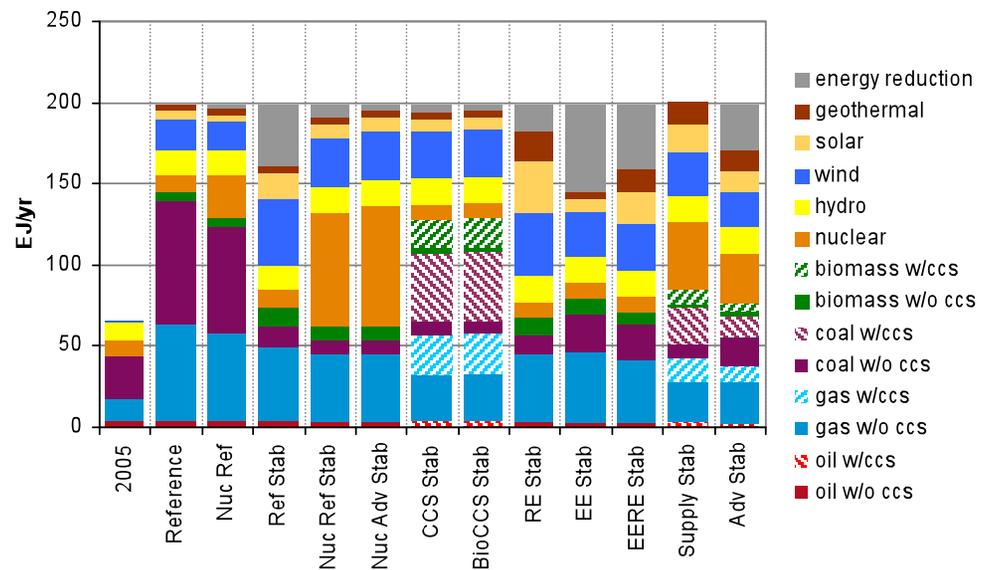
Carbon Prices across Scenarios



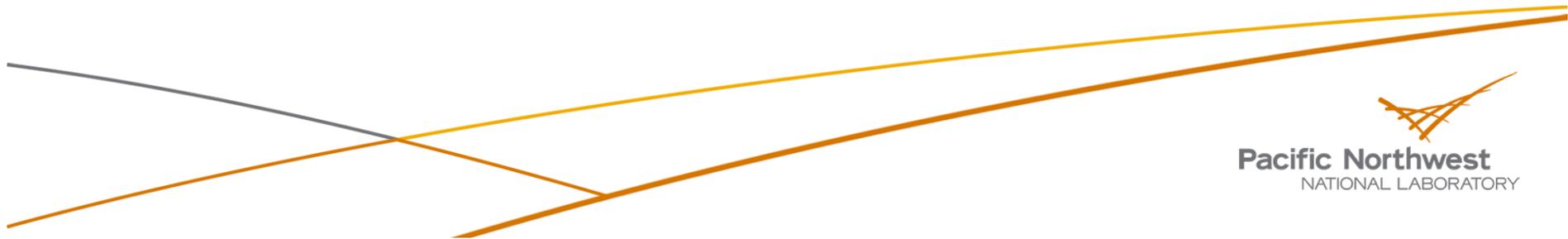
	450 ppmv	550 ppmv
Reference	11.6	2.5
Renewable Energy	8.5	1.6
Nuclear Ref	7.8	1.5
Nuclear Adv	7.4	1.4
End Use	5.6	0.6
End Use & Renewables	4.1	0.4
CCS	5.6	1.3
Bio & CCS	5.5	1.3
Supply & Hydrogen	3.9	0.6
Advanced	1.9	0.1

Mitigation Costs (Cumulative through 2095) across Scenarios

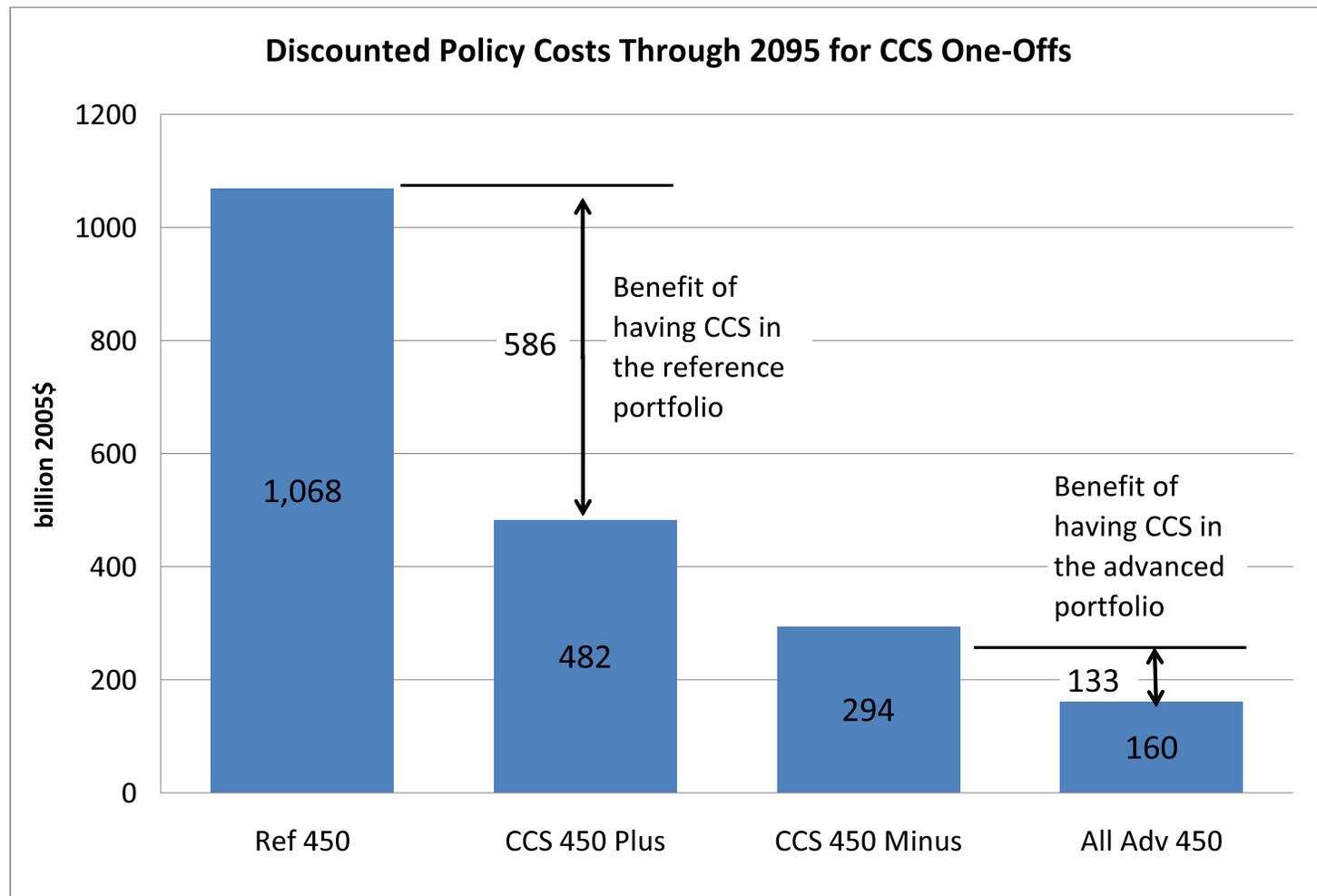
Primary Energy Production in 2050 across Scenarios (450 ppmv CO₂)



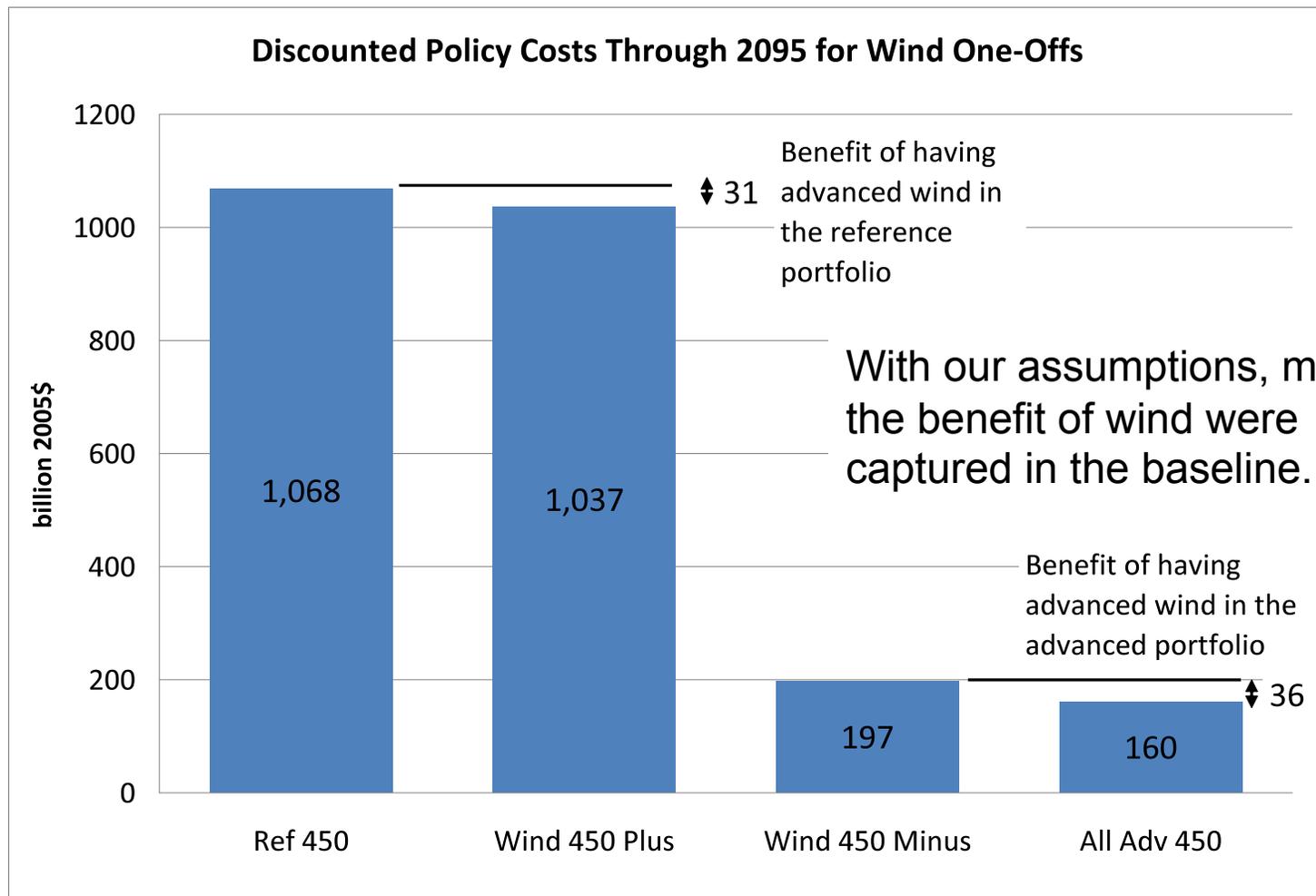
“ONE-OFFS”



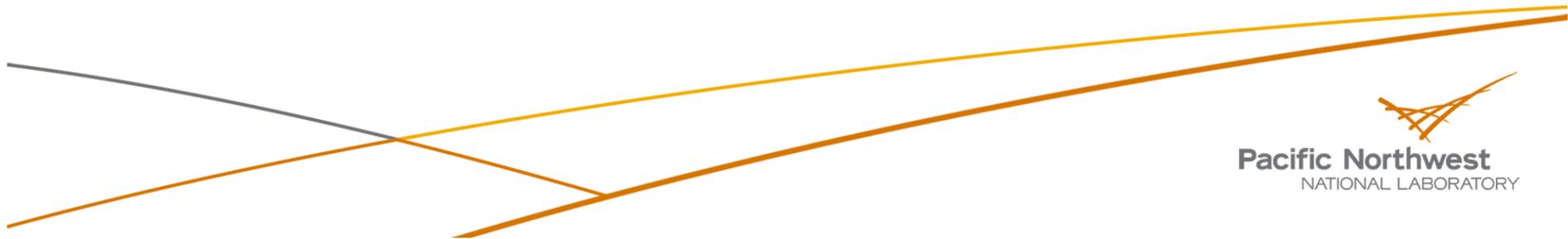
One-offs bound the value of advances in individual technologies by exploring value against an optimistic and a pessimistic background.



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LARGE ENSEMBLE RUNS



Exploring All Possible Combinations of CCTP Technology Modules for Deeper Insights of the Space

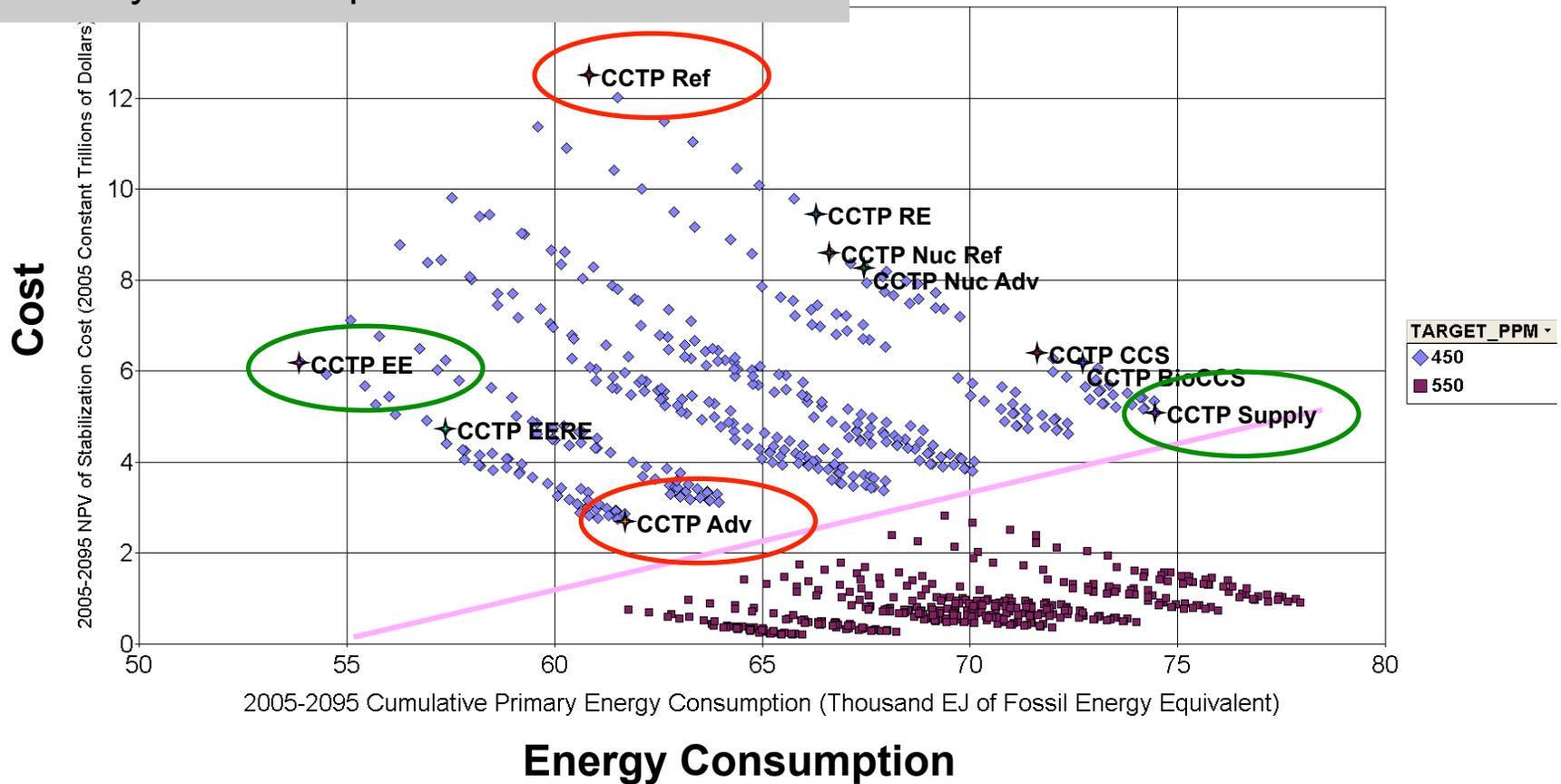
		0: FIXED	1: REF	2: ADV		
Supply Technology	Solar	N/A	Capital costs drop by 1%-2% per year 2005-2050	Capital costs drop by 2%-3.5% per year 2005-2050	2	3
	Wind	N/A	Capital costs drop by 0.25% per year 2005-2050	Capital costs drop by 0.5% per year 2005-2050	2	3
	CCS	No CCS in any applications	CCS available in electricity, hydrogen, and cement sectors (starting at about \$40 / t CO ₂)	N/A	2	7
	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	5
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	4
	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	4
	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	4
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	4

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

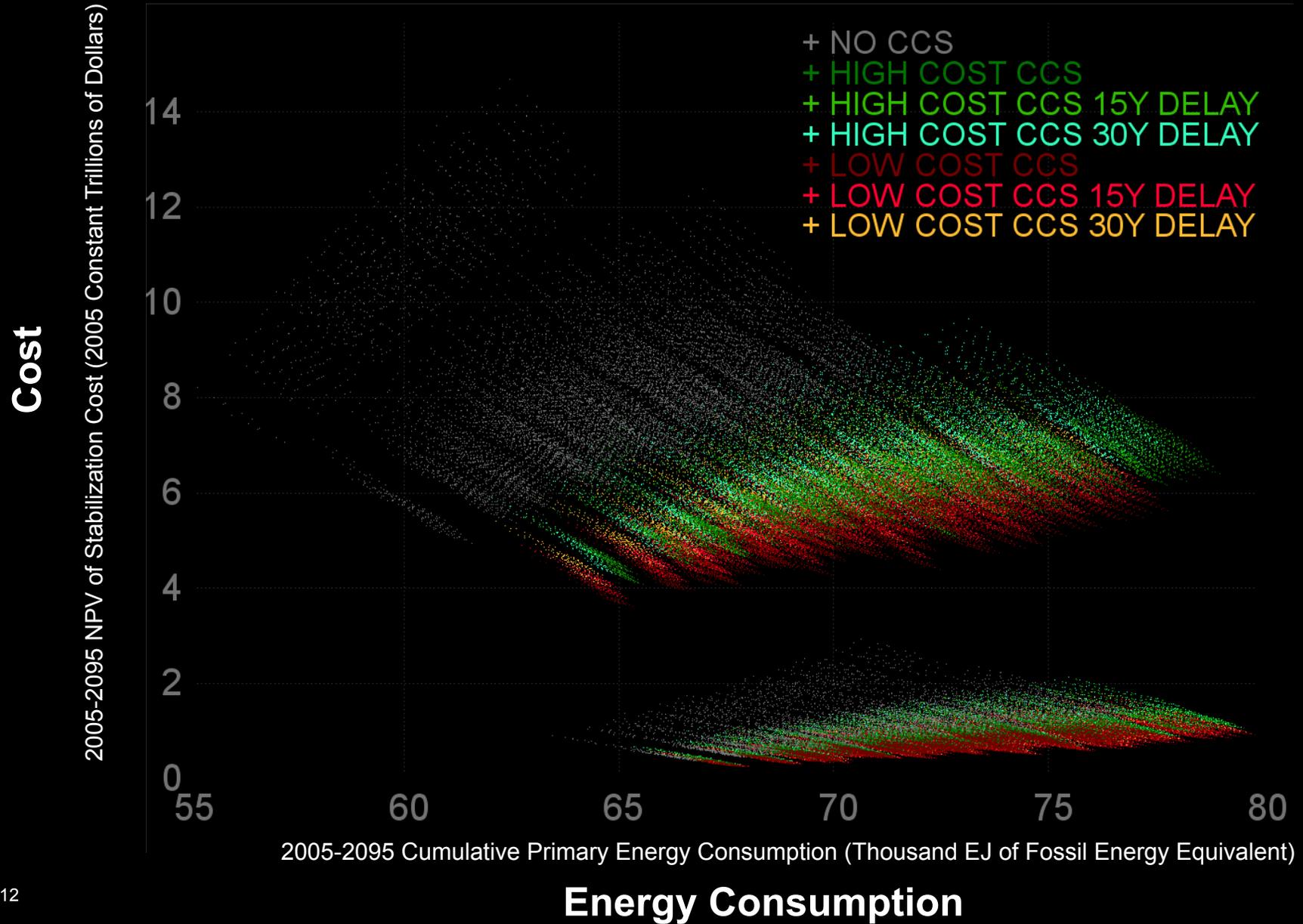
10 Total combinations with delays: $3^2 \cdot 4^4 \cdot 5 \cdot 7 = 80640$ combinations per level

Revealing the Interior of the Technology Space: a Plot of 768 Cases

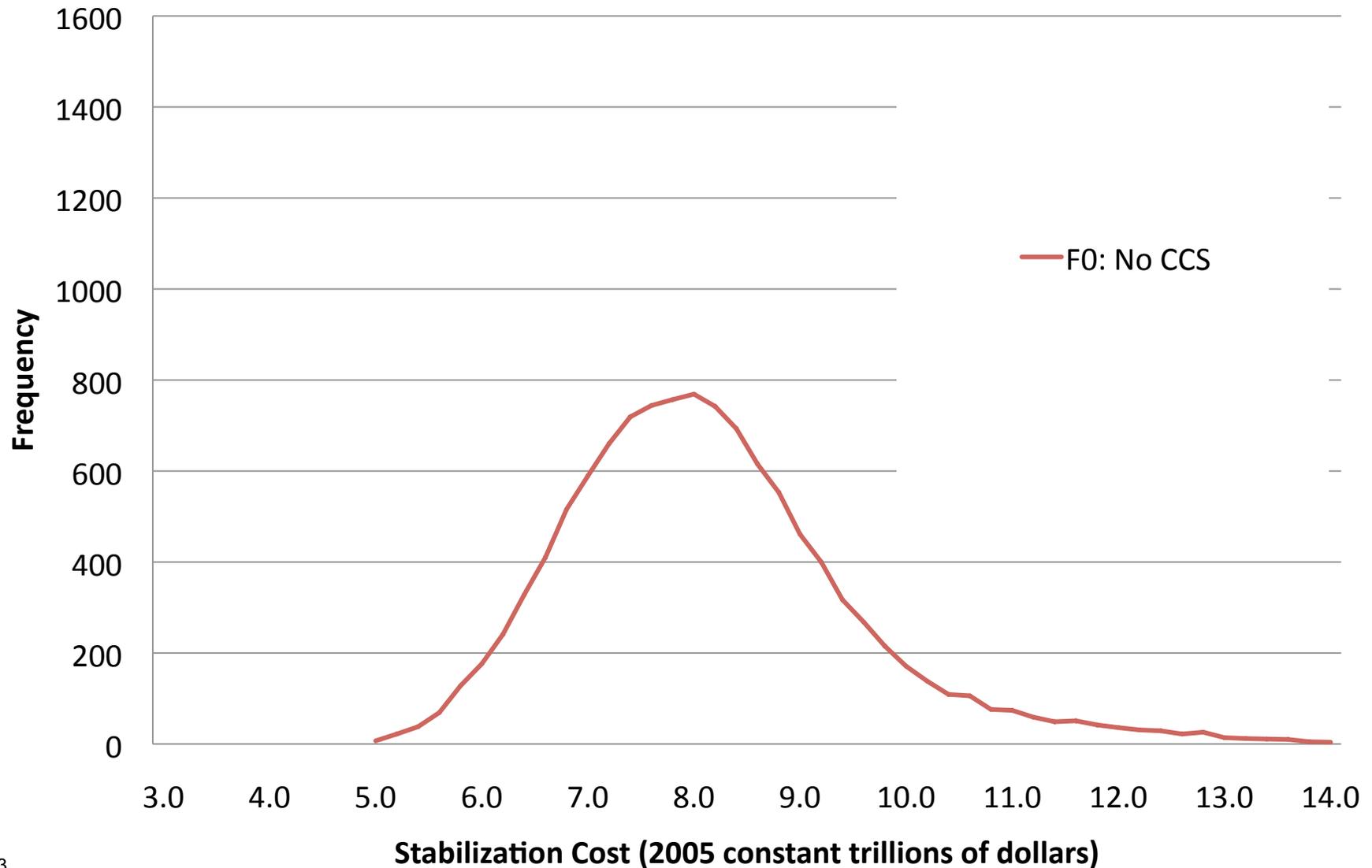
The CCTP scenarios spanned the space, but they did not explore the interior



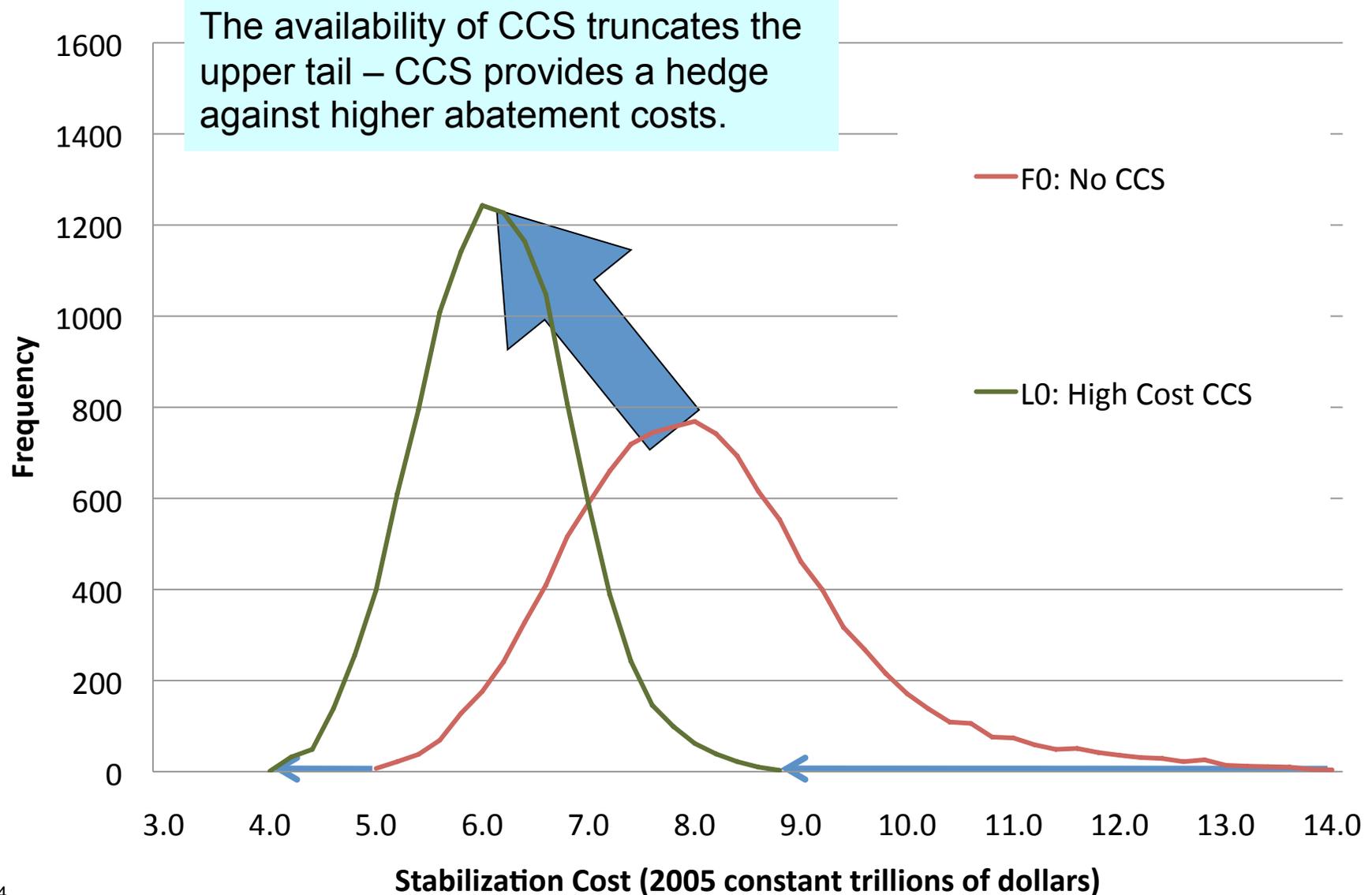
The Galaxy of 161k Technology Combinations



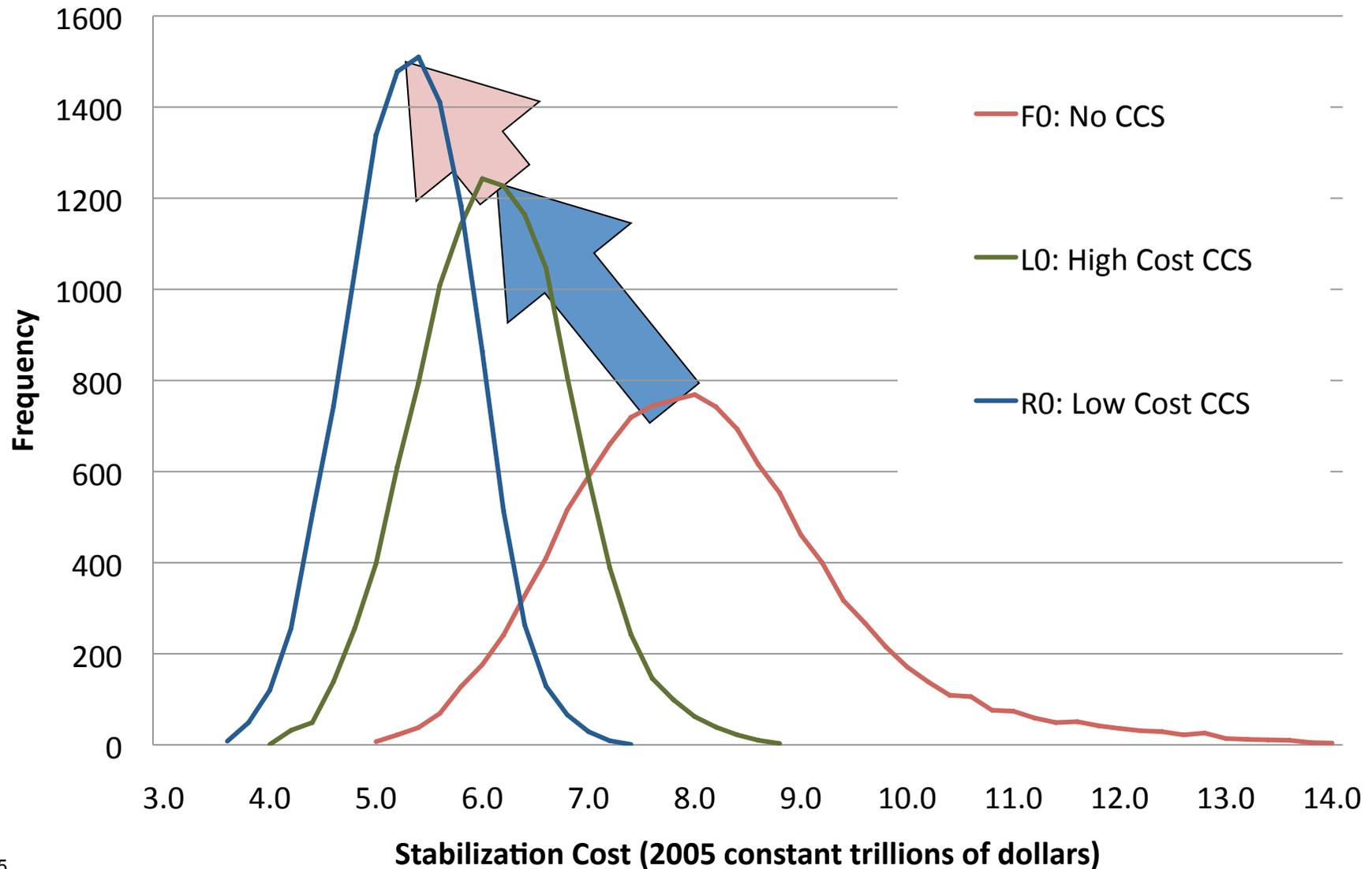
Carbon Capture and Storage (CCS)



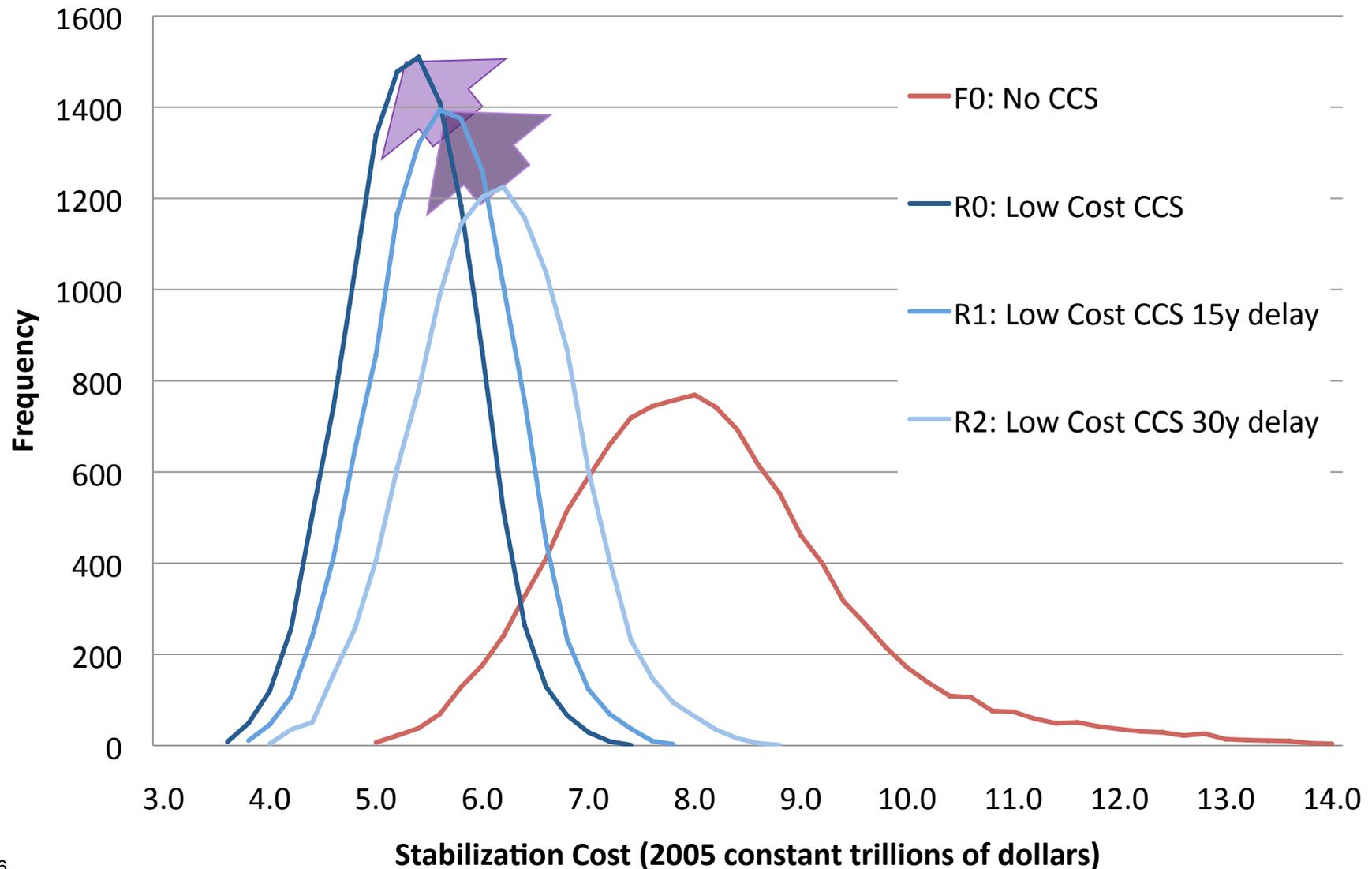
Having CCS Compresses the Distribution



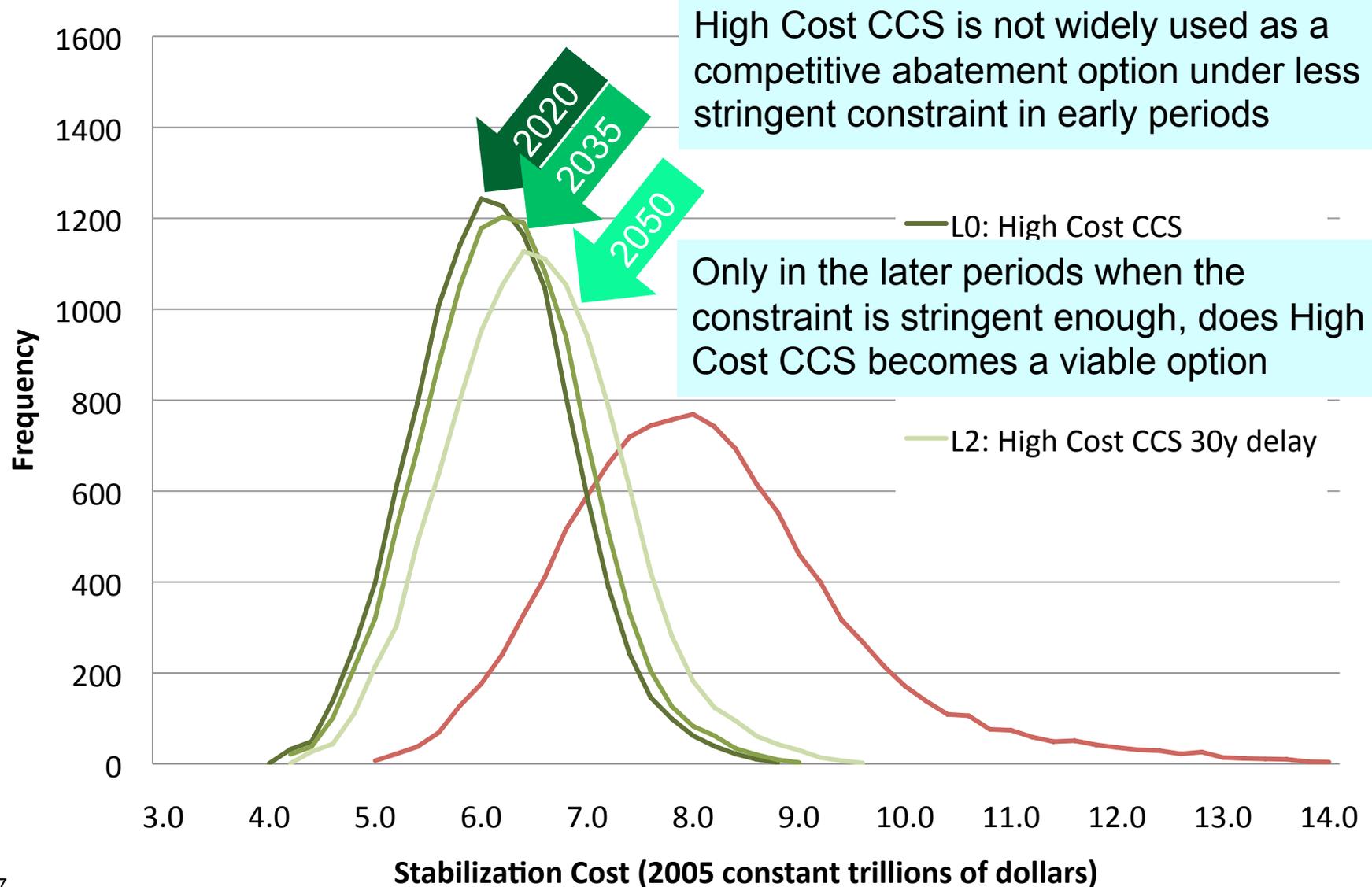
Smaller Additional Compression from Cost Reduction



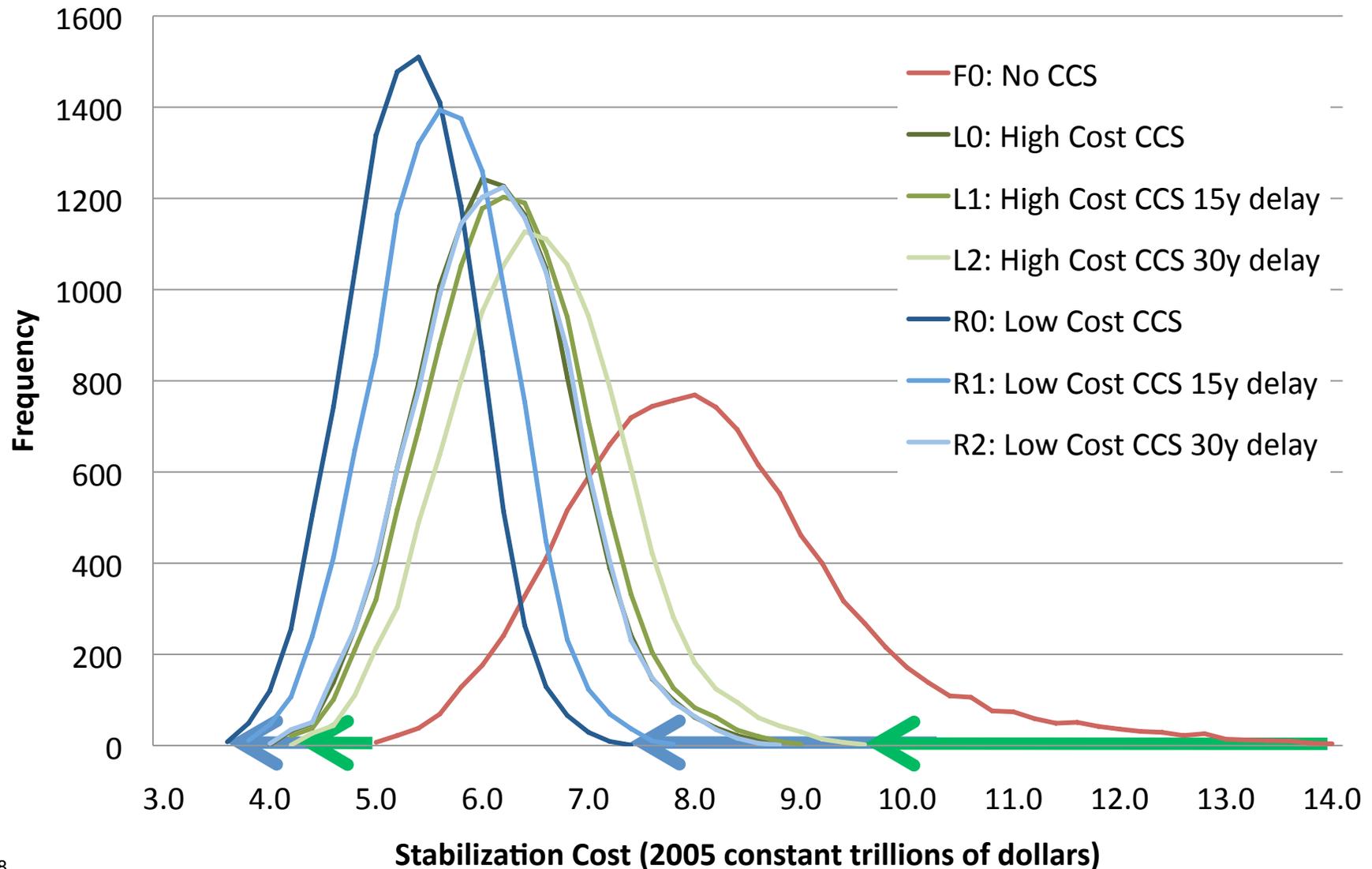
Early Availability of Low Cost CCS Induces Small but Noticeable Additional Compression



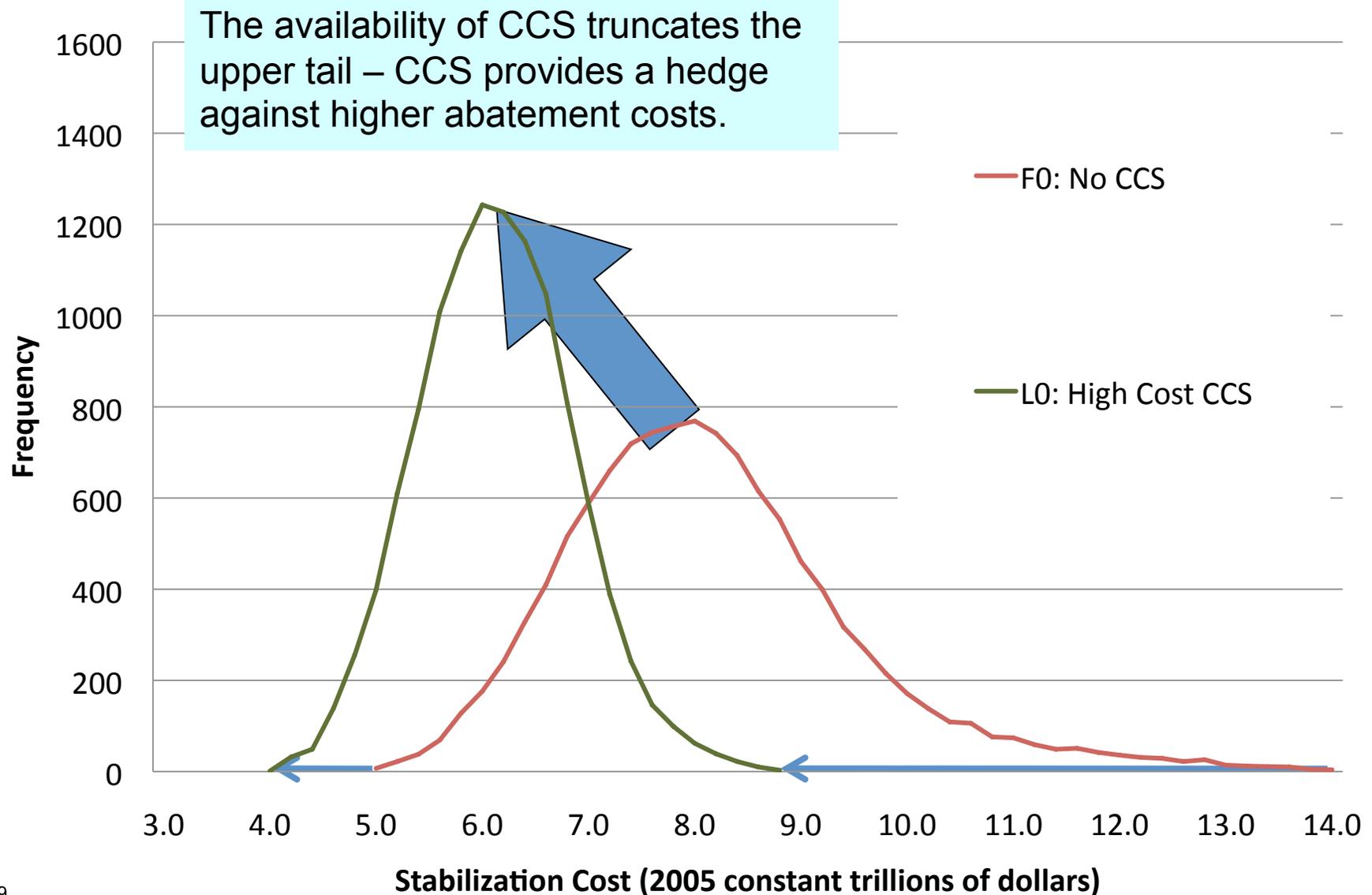
Early Availability of High Cost CCS Induces Much Smaller Additional Compression



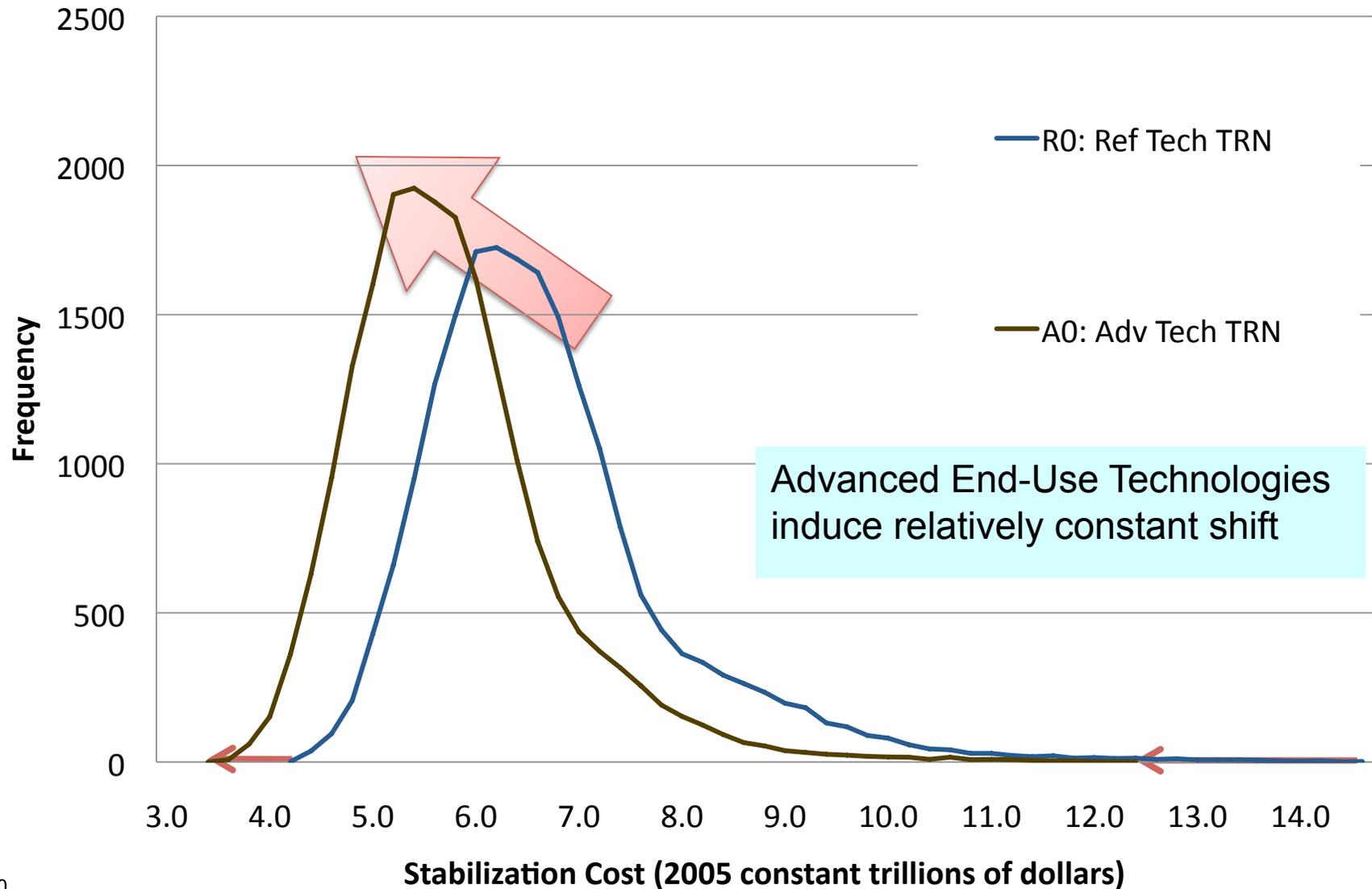
The Availability of CCS is More than Half the Story; Delays and Cost Reductions Explain the Remainder



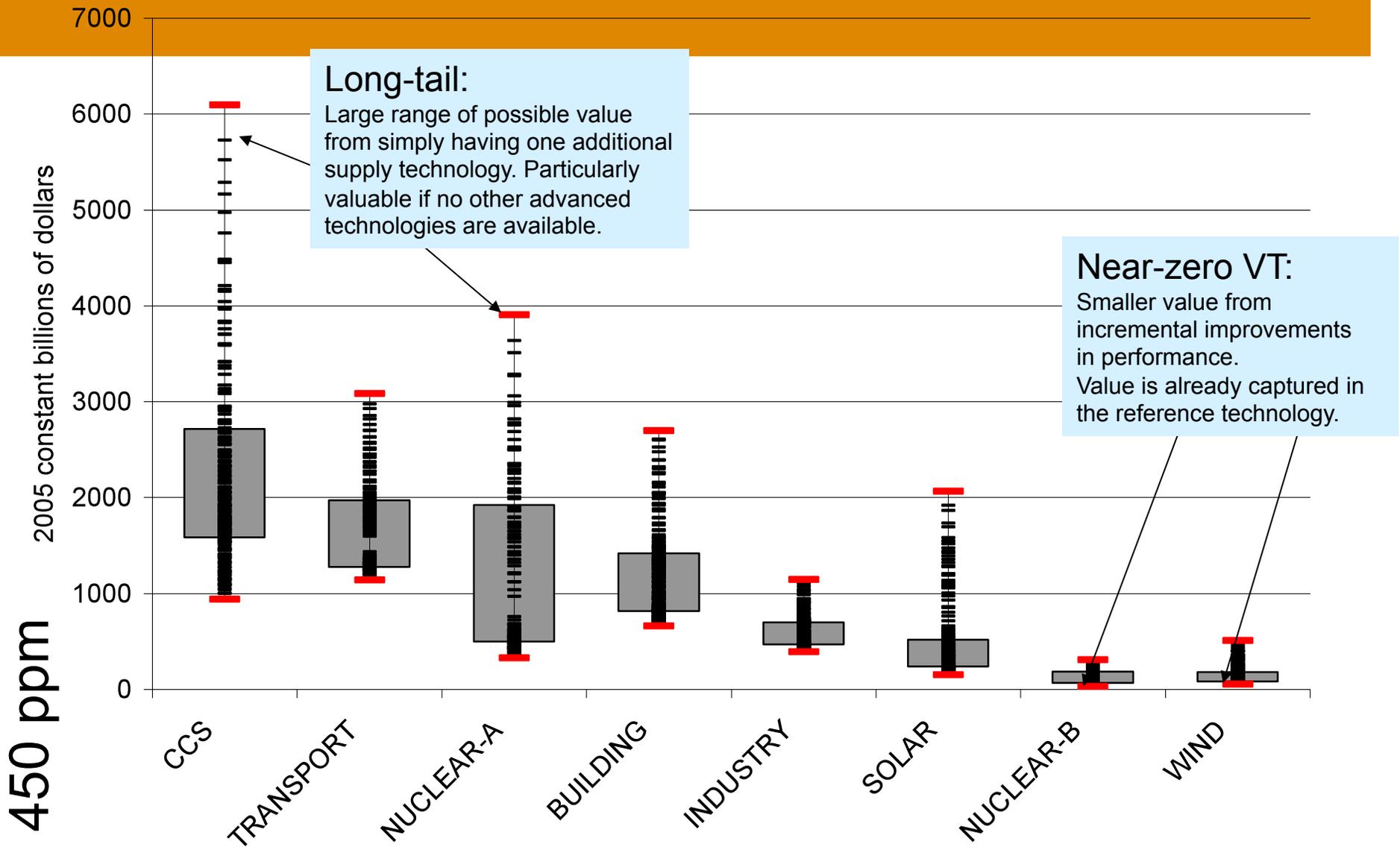
Having CCS Compresses the Distribution



How Technology Influences the Stabilization Cost: (B) Shifting of the Distribution



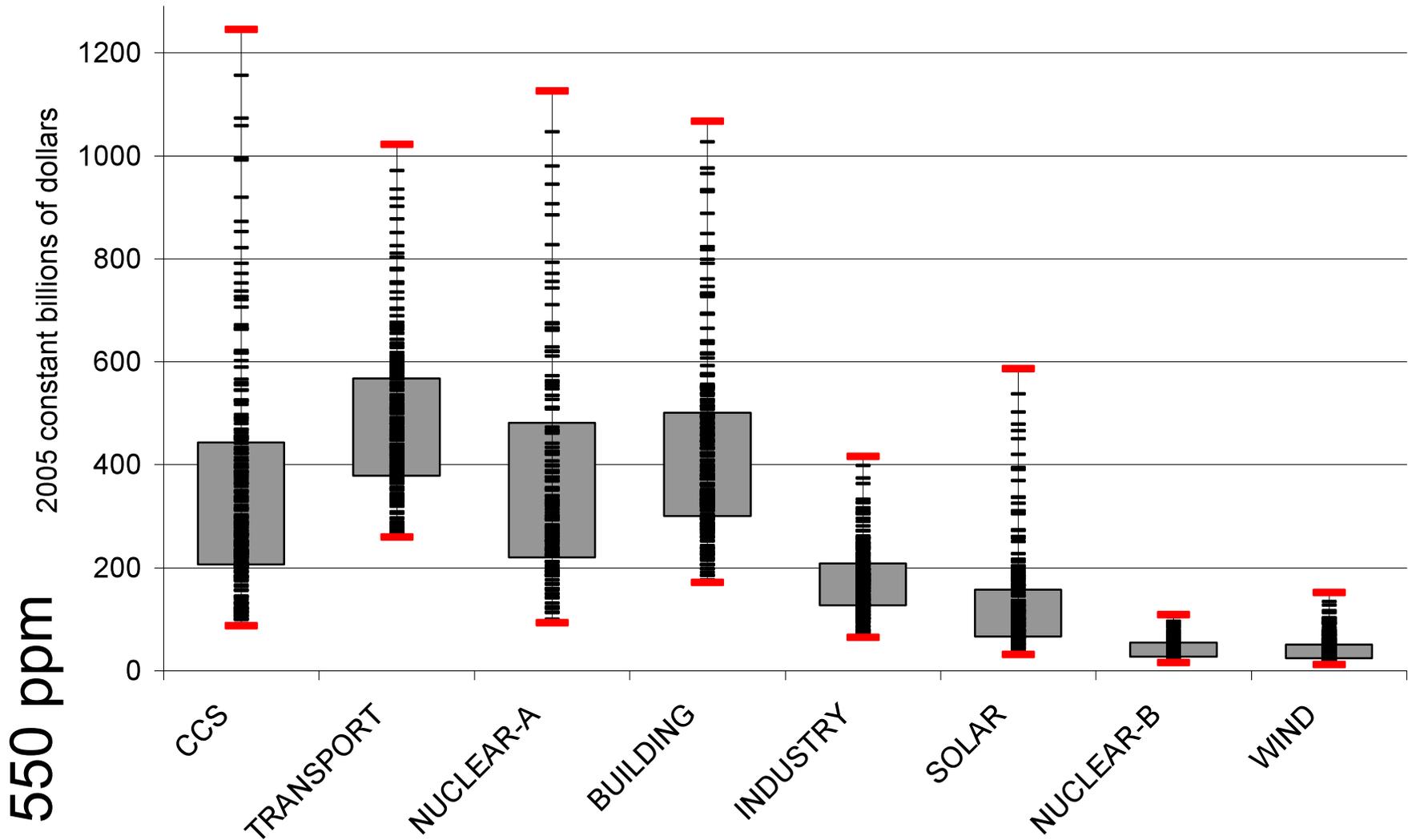
Value of Technological Advance



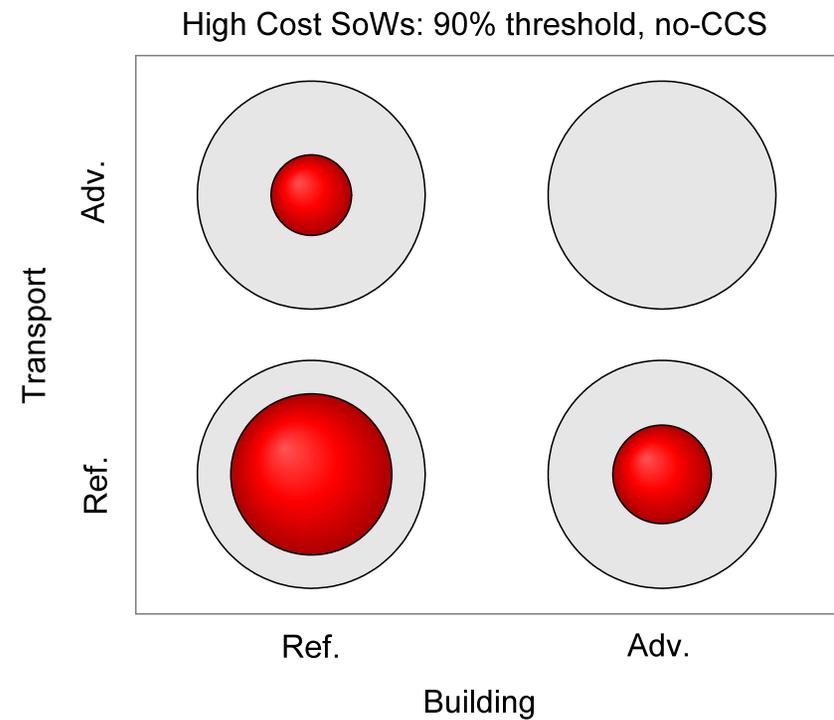
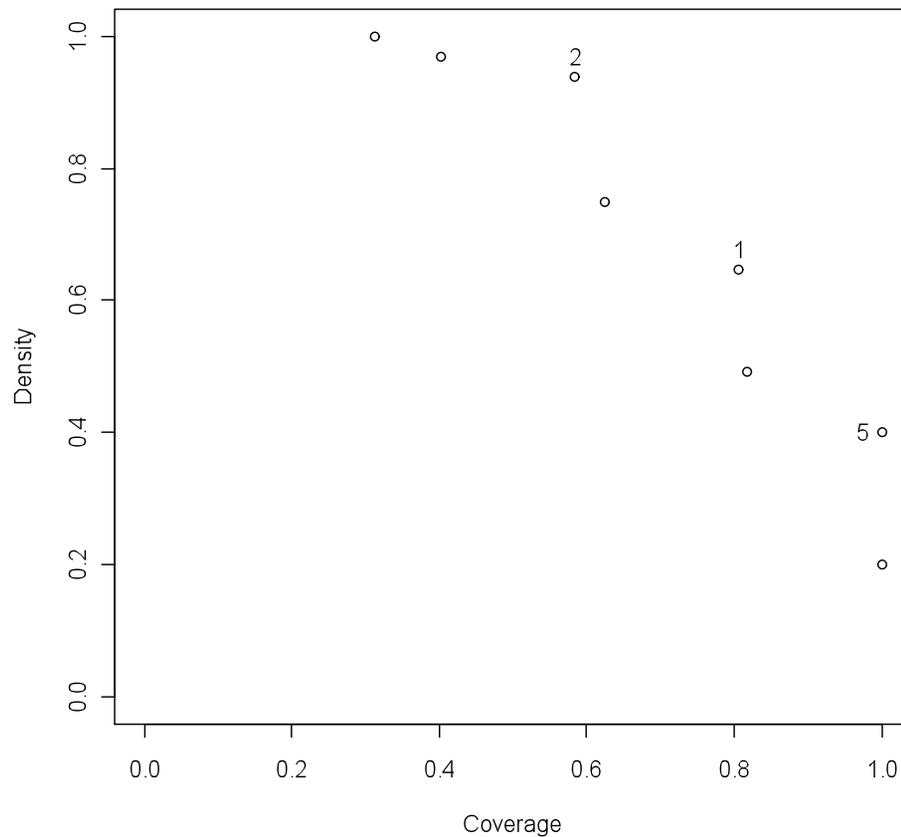
* From "No New Nuclear" to REF Nuclear

** From REF Nuclear to ADV Nuclear

Value of Technological Advance



Application: Scenario Discovery

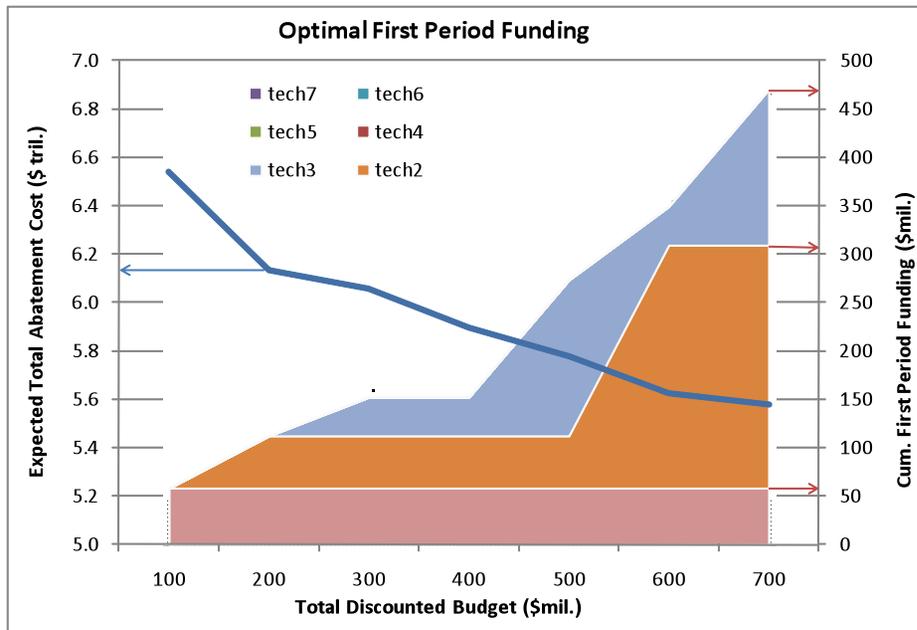
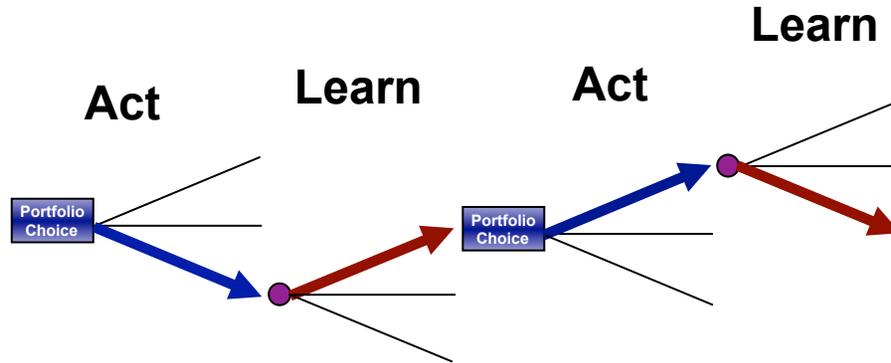


○ Total SoW
● High Cost

Box ID	PARAMETER RESTRICTIONS			Density	Coverage
	BUILDING	TRANSPORT	CCS		
1		Reference	Fixed	0.6458	0.8052
2	Reference	Reference	Fixed	0.9375	0.5844
5			Fixed	0.4010	1

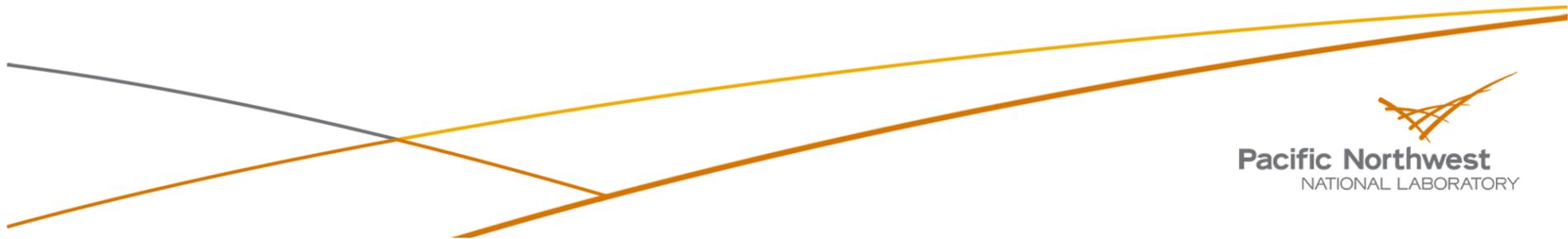


Current Research: Act-Then-Learn



- ▶ We implemented a prototype with a small number of technology choices.
- ▶ We are pushing harder now working with:
 - Probabilities from Baker & Keisler.
 - A larger space of outcomes (>1000).

SOME LESSONS FOR THIS EXERCISE



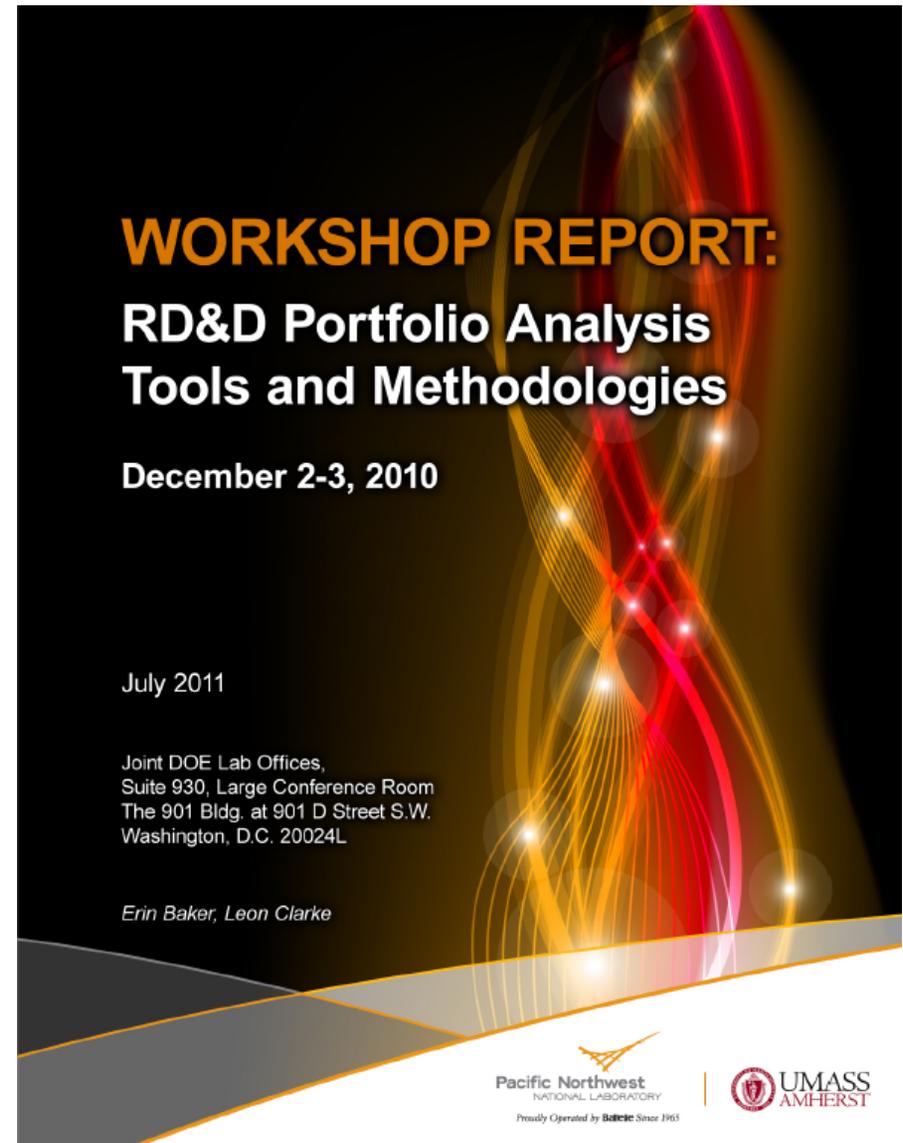
Some Reflections Based on this Research

- ▶ The IA community has extensive experience with sensitivities about technological change, but without explicit accounting for uncertainty.
- ▶ **PDFs FOR TECHNOLOGY:** Assigning probabilities is challenging.
 - There is ongoing research led by Valentina Bosetti and Erin Baker to better bring together expert elicitation and other uncertainty information for use in IA models and other consumers.
- ▶ **BEFORE OR AFTER:** If these are not dynamic exercises, then probabilities can often be applied after the fact.
- ▶ **ASSUMPTIONS IN GENERAL, PDFS AND OTHERWISE:** The IA community would benefit broadly from more coherent assessment of uncertainties surrounding technology.
 - Better information in this regard would also allow for interpretation of existing scenarios.
- ▶ **TECHNOLOGY RESOLUTION:** Higher-resolution IA models do not carry technologies in a continuous space.
 - The number of assumptions for representing technology can be enormous in the more technologically-detailed IAMs.
 - Representing continuous monte-carlo-type uncertainties is therefore challenging
- ▶ **TECHNOLOGY RESOLUTION:** Higher-resolution IA models represent a large range of technologies with a large number of parameters. This can make uncertain distribution development challenging. Differences in technology resolution are a big deal.
- ▶ **METRICS:** Much of the work to date has focused on macro-economic cost reductions from technological advances. But there may be other metrics that folks care about.



DOE's Office of Policy sponsored a meeting last year on R&D portfolio analysis

One of the key findings of the meeting is a need to better coordinate research on technology uncertainty with IA and energy-economy modeling for portfolio analysis



THE END

