# Energy R&D Portfolio Analysis Based on Climate Change Mitigation

EMF Workshop on Critical Issues in Climate Change: The Economics of Technologies to Combat Global Warming

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# Overview

## Problem Statement

Given a limited budget, determine how to fund a portfolio of technology RD&D programs to achieve maximum climate change benefit.

## Assumptions

- Due to market imperfections, publicly-supported technology RD&D is necessary (see reservations in Nordhaus, this workshop).
- Funding a hedged portfolio of technology options is the optimal means of addressing uncertainty, in contrast to picking technology winners.

# Caveats

- This applied RD&D portfolio analysis addresses only a portion of total energy R&D spending; basic research and innovation is critically important as well (see Weyant and Vallario, this workshop).
- Some infrastructure investments critical to achieving multiple technology goals (e.g. advanced grid for improved efficiency and renewables integration) do not compete in the portfolio, but are simply inserted.

# Process

- As described last year:
  - **First task**: Estimate the potential benefits stream associated with improvement in a given technology.
  - **Second task**: Assign a likelihood of success to each technology based on level of investment and determine a discounted benefits stream.
  - **Third task**: Use the discounted benefits stream and the proposed budgets for each technology to determine the return on investment (ROI) and build the portfolio.

# Maximizing Technology Benefits

- **First task**: Estimate the potential benefits stream associated with improvement in a given technology
  - Can take the form of emission reduction or cost reduction
    - Need to determine how to assign benefits to individual technologies
  - Approach often used is to evaluate technical potential of technology
    - Bottom-up calculation based on best-case technology performance
    - No economics; considers individual technologies in isolation
    - EPRI Prism is well-done example
  - Approach used here includes economics through the use of integrated assessment modeling (IAM) with advanced technology scenarios

# Estimating Benefits using IAMs

- Last year, showed use of 2006 CCTP scenarios to inform FY09 budget process
  - Three scenarios available to explore benefits of technology clusters: CCS & hydrogen, advanced nuclear & renewables, breakthrough technology
    - Because technologies are clustered together, difficult to allocate benefits to individual technologies
  - Estimated *emission reduction* associated with individual technologies in each scenario
    - For each technology, chose scenario in which emissions reduction attributable to that technology is greatest

# FY09 Portfolio Analysis Approach

- Maximum emission reduction defined for each technology from three available scenarios
  - Similar to technical potential approach, but max technology contribution defined via an integrated scenario rather than bottom-up
    - Still, these benefits are NOT additive, since we are choosing the best from each scenario

| Technology Area | Most Challenging Scenario | U.S. Emission Reductions (MtCO2/yr) | | | | |
|---|---|---|---|---|---|---|
| | | 2020 | 2030 | 2040 | 2050 | 2100 |
| **Transportation** | BSS 450 | 371 | 530 | 687 | 858 | 1,247 |
| **Buildings** | BSS 450 | 157 | 275 | 388 | 501 | 543 |
| **Industry** | BSS 450 | 443 | 641 | 775 | 878 | 652 |
| **Coal & Natural Gas w/CCS** | CLC 450 | 130 | 340 | 711 | 1,230 | 2,162 |
| **Solar** | NEB 450 | 0 | 9 | 59 | 164 | 216 |
| **Wind** | NEB 450 | 11 | 89 | 237 | 421 | 476 |
| **Biomass** | BSS 450 | 0 | 8 | 56 | 168 | 214 |
| **Nuclear Fission** | NEB 450 | 33 | 197 | 548 | 1,071 | 1,895 |

# Assigning a Likelihood of Success

- **Second task**: Assign a likelihood of success to each technology and determine a discounted benefits stream
  - All technologies will not be successful simultaneously, so determine a probability of success, P, where $0 < P < 1$
  - Probability can be represented as product of market risk, largely outside of DOE control, and technical risk, more within DOE control:

    $$P = P_{market} \times P_{tech}$$

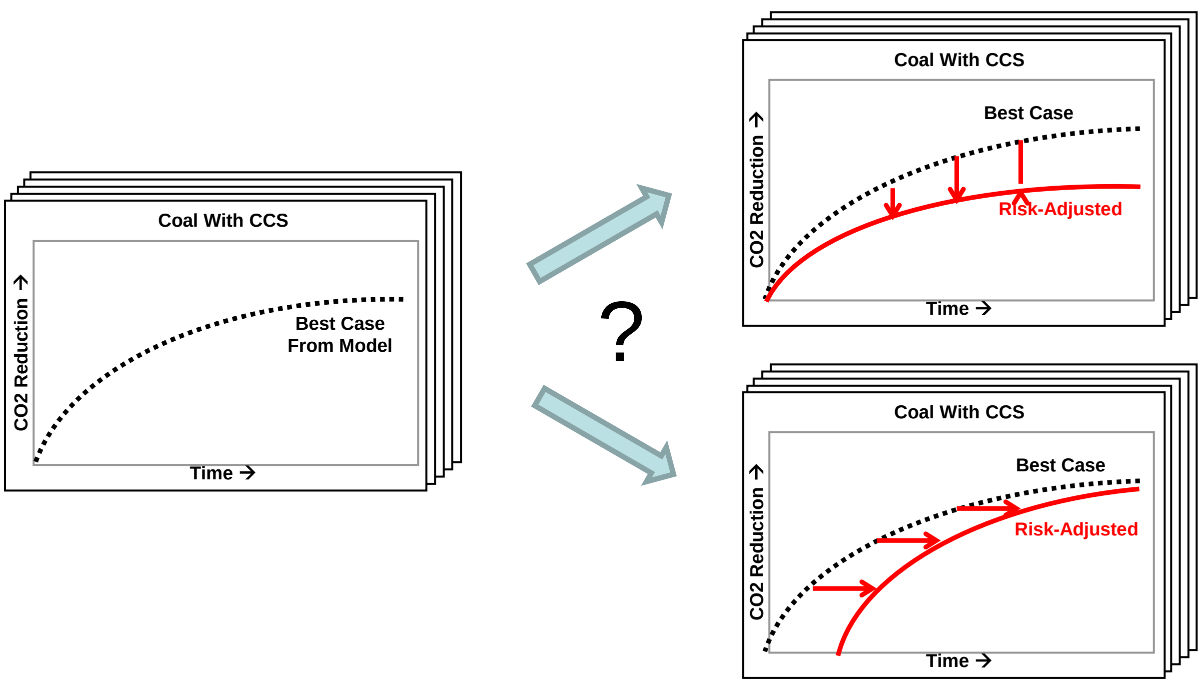
    - Thus, for some technologies (e.g. nuclear), P may be relatively low despite relatively high technical likelihood of success (low technical risk)
- Expert judgment required to determine both components of P
  - $P_{market}$ requires knowledge of market barriers and policy environment
    - Expert review panel external to DOE might be most appropriate
  - $P_{tech}$ requires knowledge of DOE program budgets and plans
    - Internal review panel required due to sensitivity of proposed budgets
  - Due to time constraints in FY09 process, both components of P estimated by internal panel

# Applying Likelihood of Success

What effect does a reduced likelihood of success have on technology deployment?

Discounted Benefits Stream = Maximum Benefit x function of Likelihood of Attainment: $e = e_{max} \cdot f(p)$

What is functional form of f(p)?




Simple scaling?

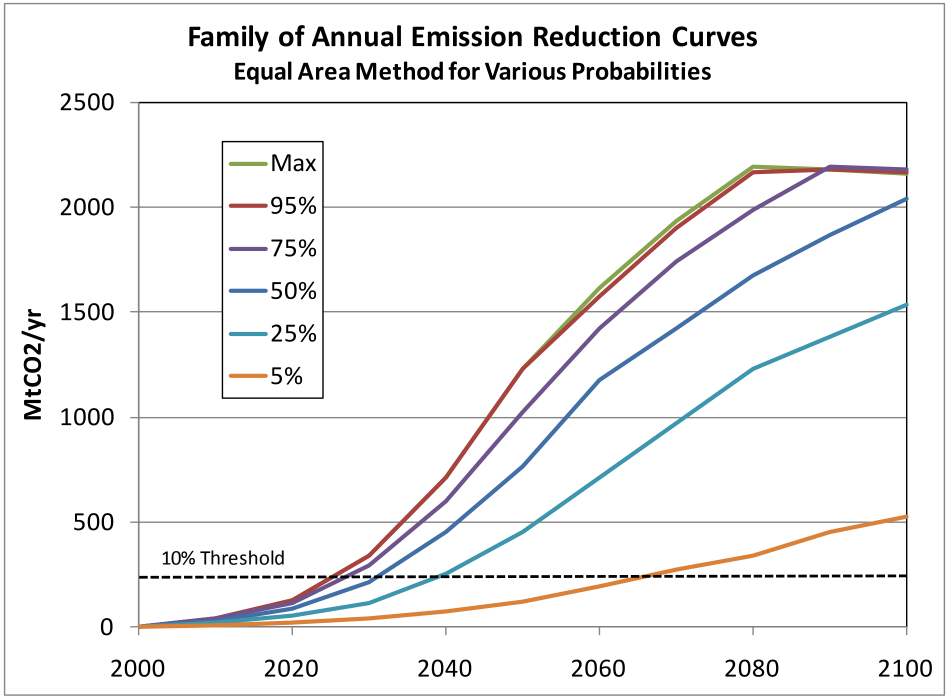
(crowding out, max deployment never achieved)

Delay?

(later deployment, but tends toward max)

# Applying Likelihood of Success

- Choice of decrease versus delay probably depends on technology
  - Mature technology with relatively small marginal cost improvement in the advanced case (e.g. wind) might be displaced and deploy at lower levels
  - New but potentially competitive technology (e.g. CCS) might be delayed, but still eventually deploy near maximum level
  - Chose a methodology that has features of both delay and simple scaling




Delay operator implemented using algorithm that scales delay inversely with P and allows cumulative abatement to catch up over time

# Determining Discounted Benefits

- Apply P to benefits stream for each technology using delay function, where P is defined by a range
  - Very likely (90 – 100%)
  - Likely (60 – 90%)
  - Maybe (40 – 60%)
  - Unlikely (10 – 40%)
  - Very unlikely (0 – 10%)

| Likelihood of CCTP Goal Attainment | | | | |
|---|---|---|---|---|
| Very Unlikely | Unlikely | Maybe | Likely | Very Likely |
| ✓ *A* | → | ✓ *B* → | ✓ *C* | |

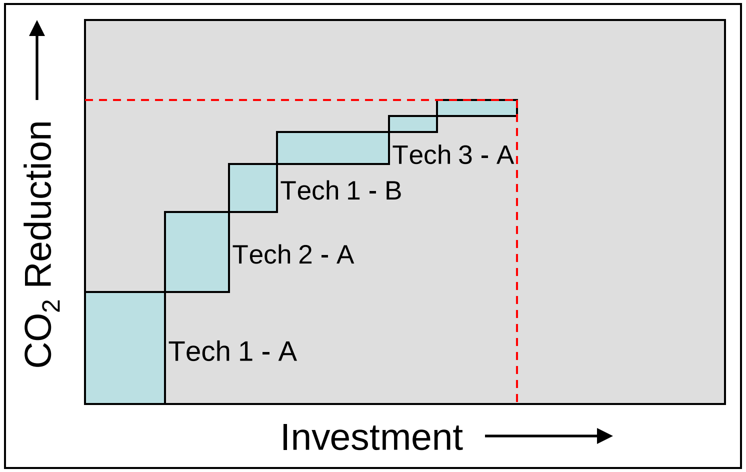
- Assume three levels of investment, I, proposed for each technology
  - A, B, and C could correspond, for example, to target, over target and goal-driven budgets

- For each level of investment in a technology, assign likelihoods of success: $P_A$, $P_B$, $P_C$

# Build the Portfolio

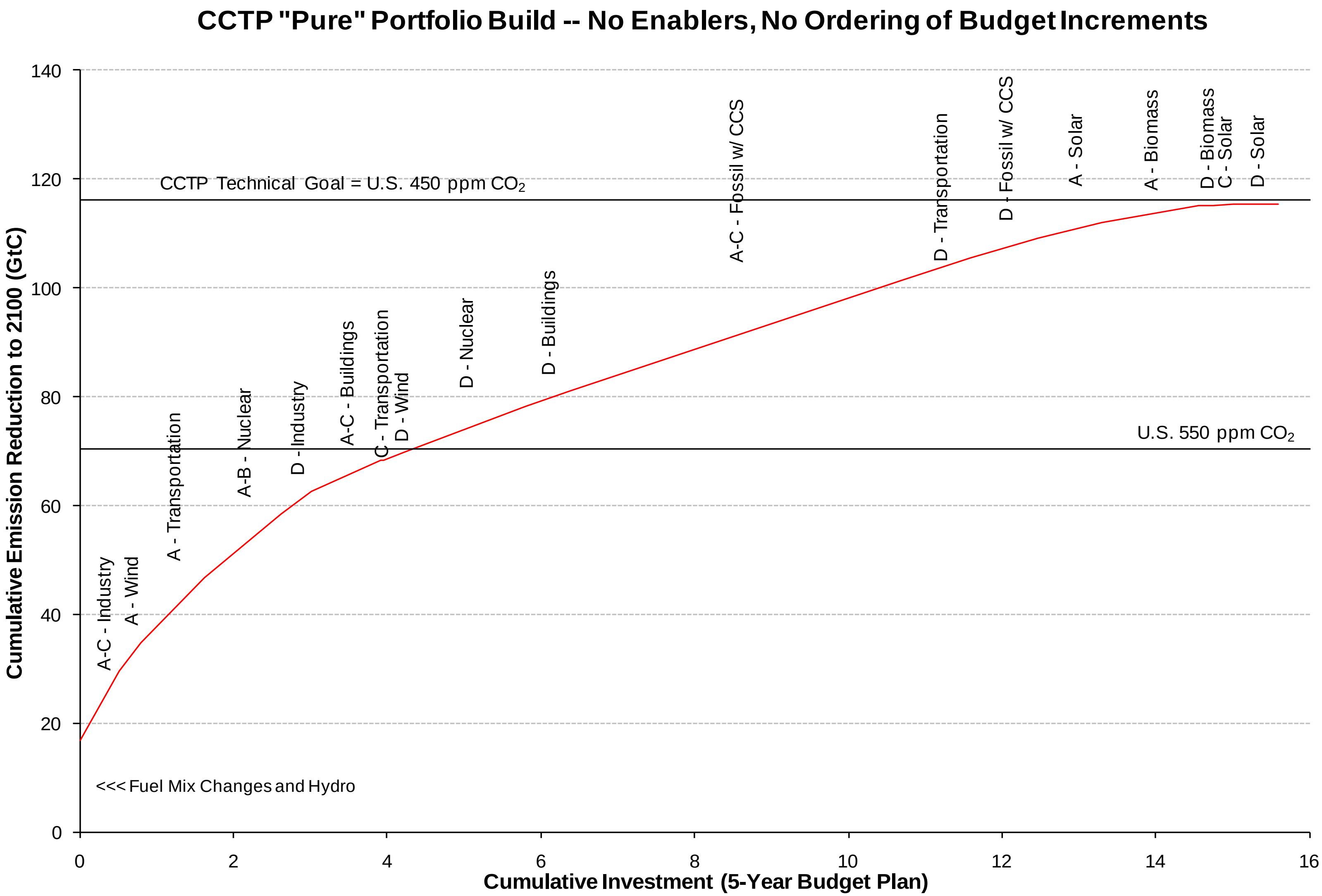
- **Third task**: Use the discounted benefits stream and the proposed budgets for each technology to determine the return on investment (ROI) and build the portfolio
  - Calculate discounted benefits (cumulative emissions reduction to 2100): $E_A$, $E_B$, $E_C$
  - Calculate ROI: $ROI_A = B_A / I_A$ , etc.
  - Build the portfolio by inserting the investments in diminishing order of ROI

Total benefit from portfolio investment

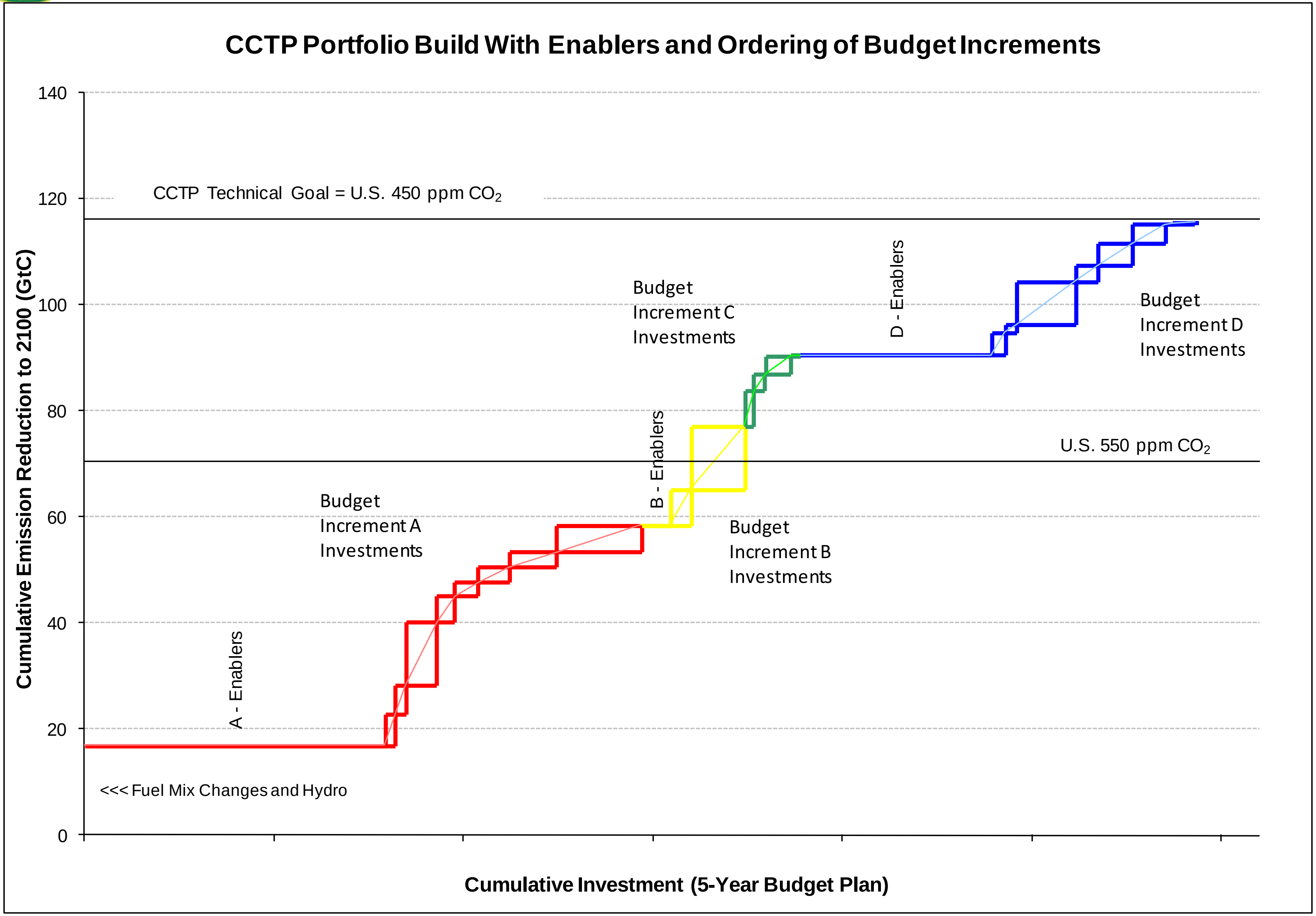



Total cost of portfolio investment

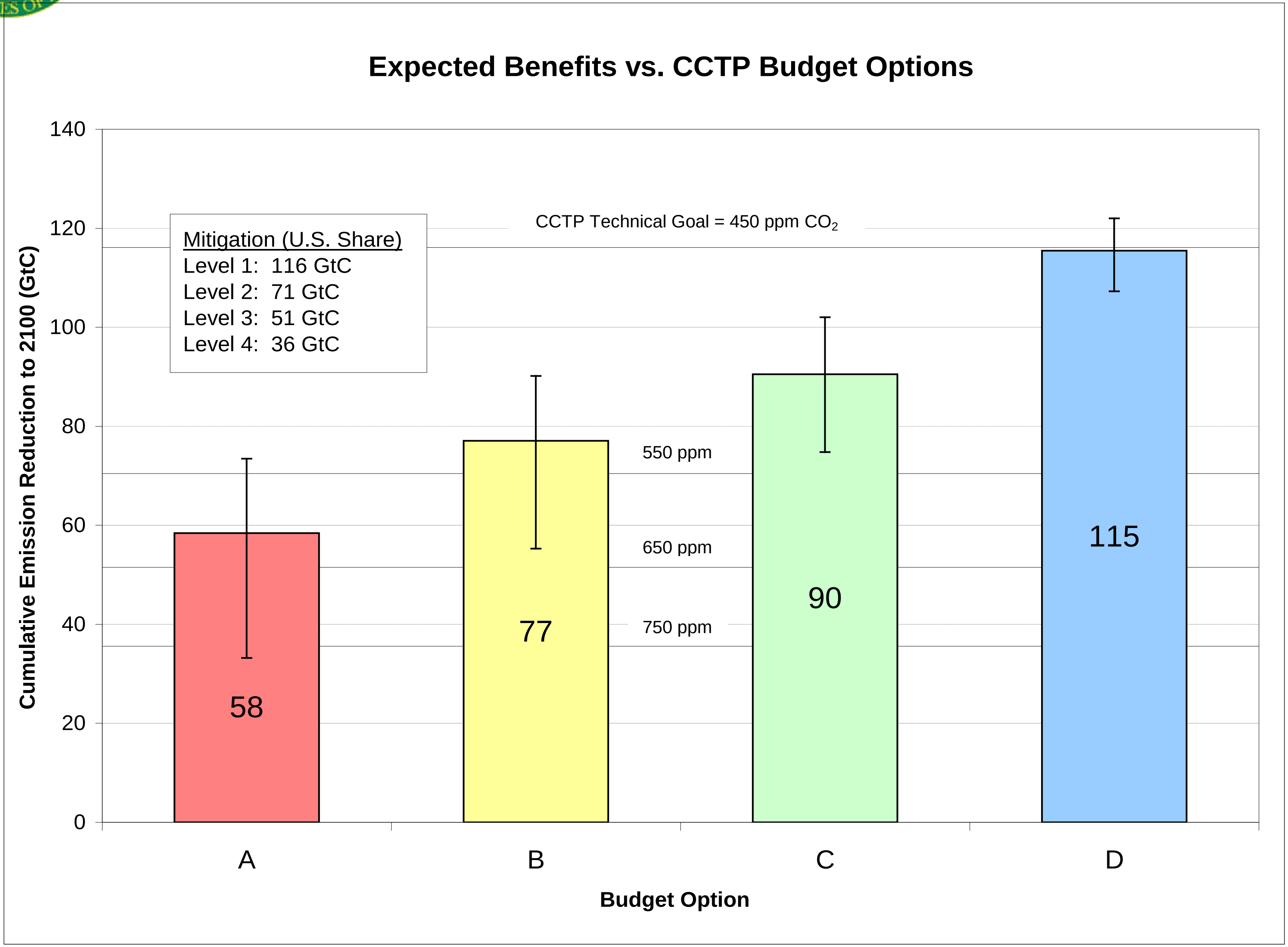
# “Pure” Portfolio



# “Realistic” Portfolio



# Total Mitigation in the Portfolio



# How to Improve the Approach

- Drawbacks related to this use of scenarios
  - The hedging process pushes and pulls deployment curves for single technologies in isolation, which destroys the integrated modeling approach
  - Attribution of carbon reduction to individual technologies is difficult, as it depends on the total energy mix
    - Also, technologists find it easier to focus on power generation/reduction and capacity
- How to isolate individual technology benefits while maintaining an integrated economic framework?

# One-Off Scenarios

- The 2008 CCTP Advanced Technology Scenarios with "One-offs"
  - MiniCAM used to model scenarios where contribution of advanced technologies to achieving climate objectives is evaluated in pairs
    - One scenario where an individual technology is advanced while all others are held in the reference state (the additive case)
    - One scenario where an individual technology is held in the reference state while all others are advanced (the subtractive case)
  - Enables estimate of maximum and minimum deployment and cost reduction for individual technologies for same level of emission reduction

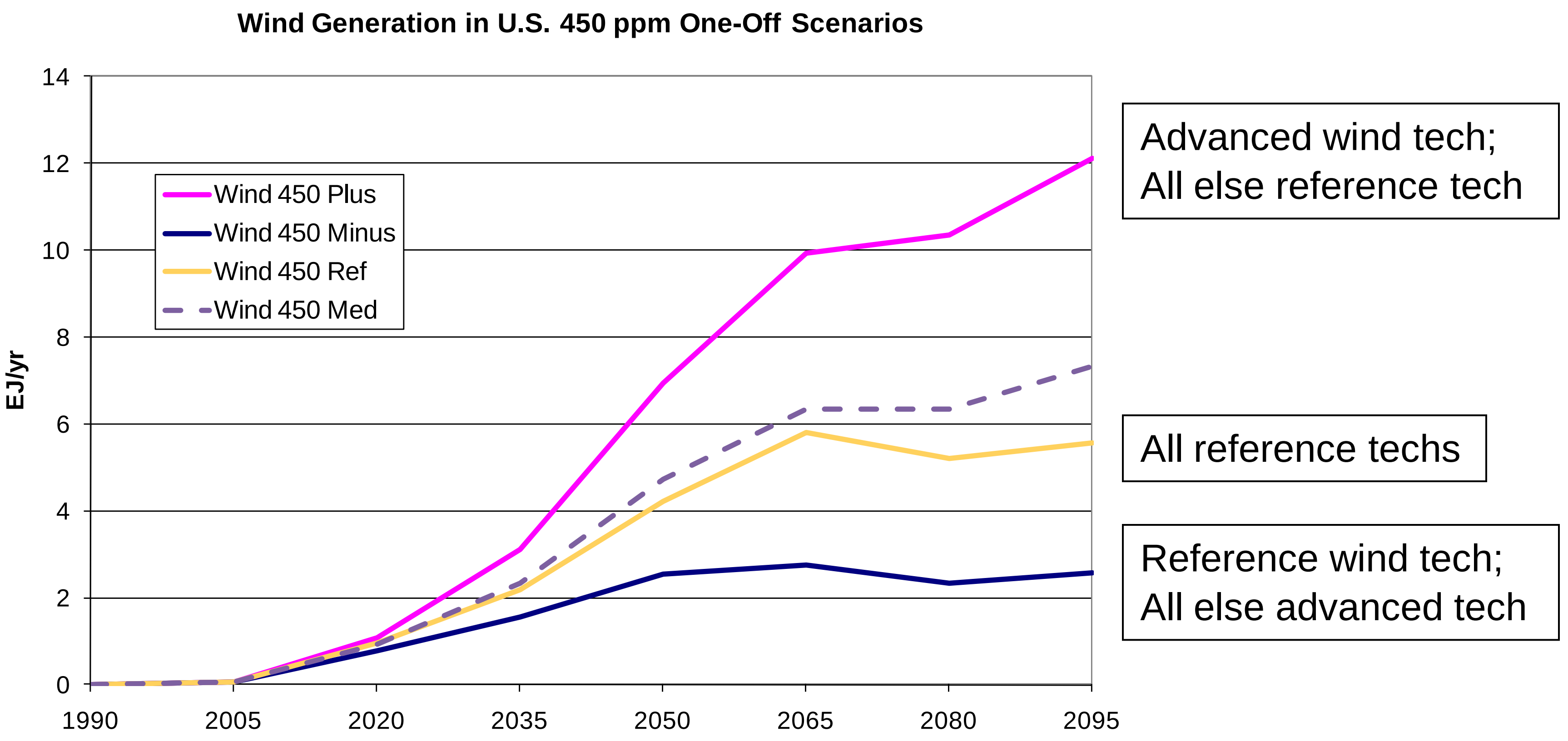
# One-Off Scenarios

| Technology Area | Low State | High State |
|---|---|---|
| Transportation: EV, FCV, other | Ref | Adv |
| Buildings | Ref | Adv |
| Industry | Ref | Adv |
| Electricity Production w/CCS | No CCS | Ref CCS |
| Solar: Central PV, CSP, Rooftop | Ref | Adv |
| Wind | Ref | Adv |
| Nuclear Fission | Fixed Nuc | Ref Nuc |
| Agricultural Productivity | | |
| Hydrogen Production | | |
| Geothermal Energy | | |

- Important caveat
  - Because there are significant policy/technology questions related to whether expanded nuclear power and CCS will be commercially viable, these technologies are represented in a binary fashion
    - They are not available in the reference state but are allowed to deploy economically in the advanced state
  - All other technologies deploy in either reference or advanced states

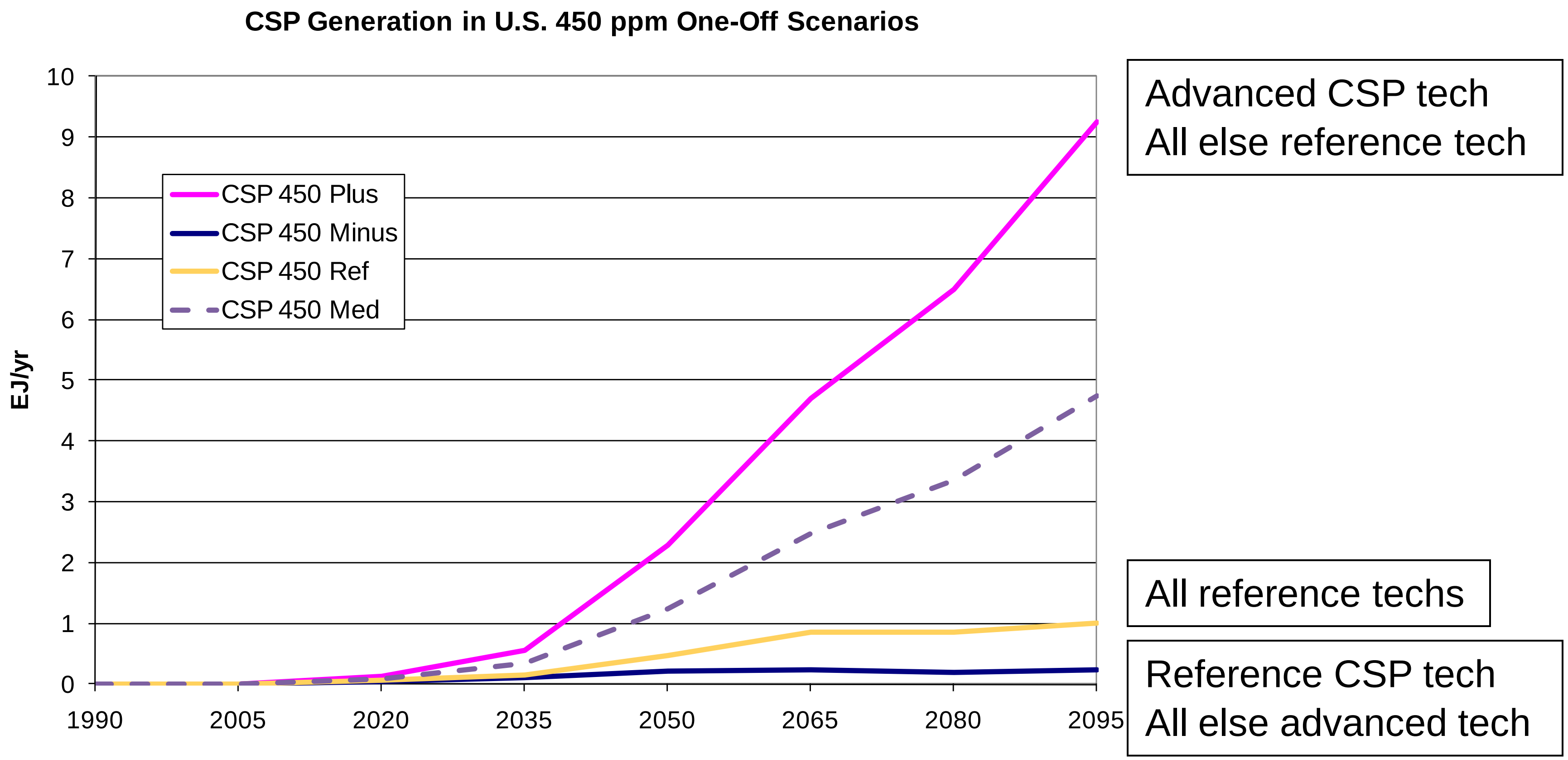
# Deployment in One-Off Scenarios

- U.S. wind example
  - Since wind deploys economically in its reference state with climate policy, the 450 Ref line lies near the middle of the two extremes
    - Median value of additive and subtractive case shown as dashed line



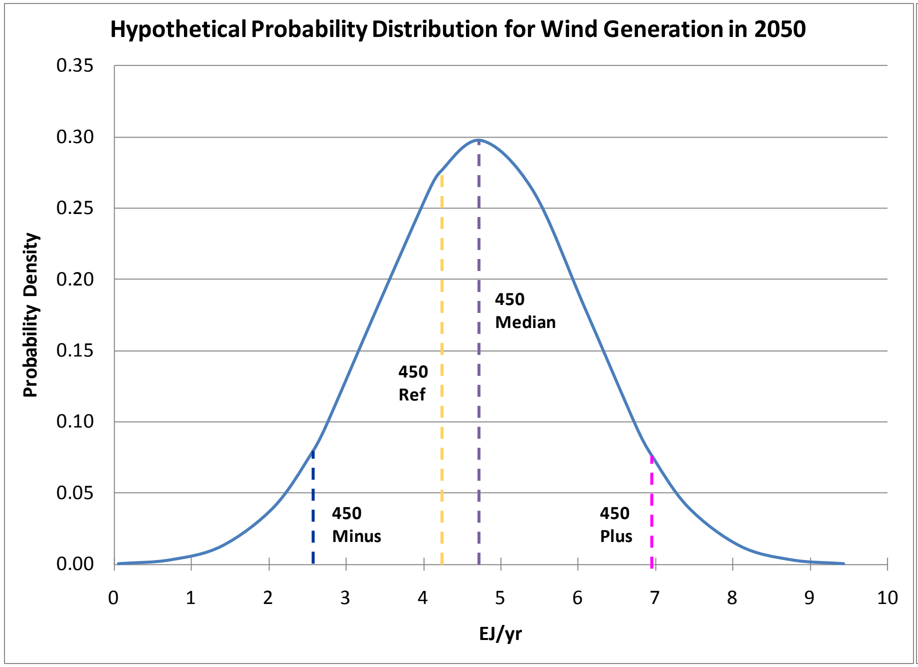
# Deployment in One-Off Scenarios

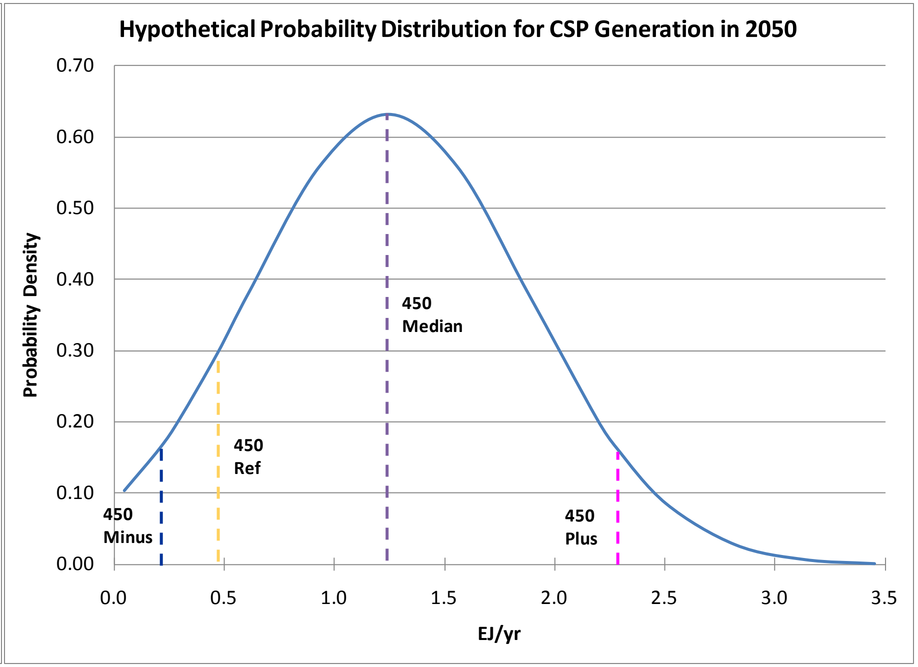
- Concentrating Solar Power Example
  - CSP doesn't deploy as economically in the reference state as wind
    - Result is that CSP 450 Ref deployment lies near lower extreme, well below median values



# Probabilistic Approach to One-Offs

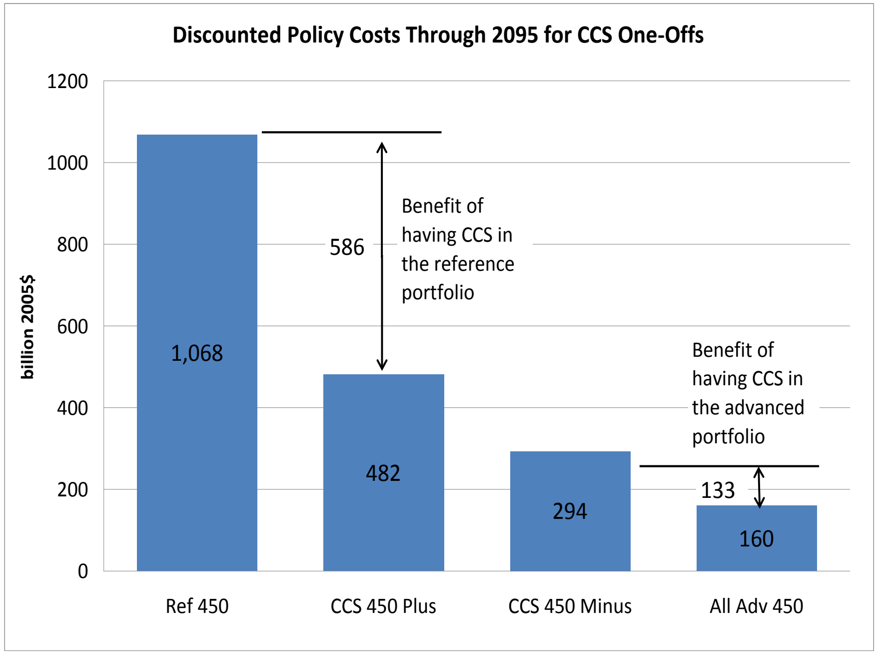
- Can view range of deployment in terms of probability distribution
  - It is unlikely that NO OTHER technology will advance, and perhaps equally unlikely that ALL technologies will advance
  - Therefore, the additive and subtractive cases define the low-probability extremes of the distribution
    - Shown below for arbitrary 5% likelihood

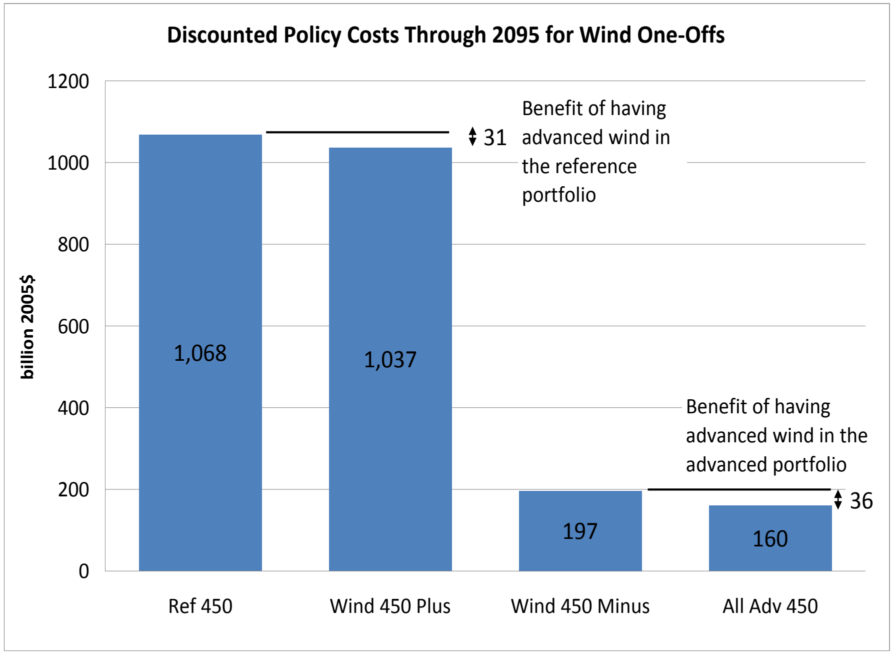


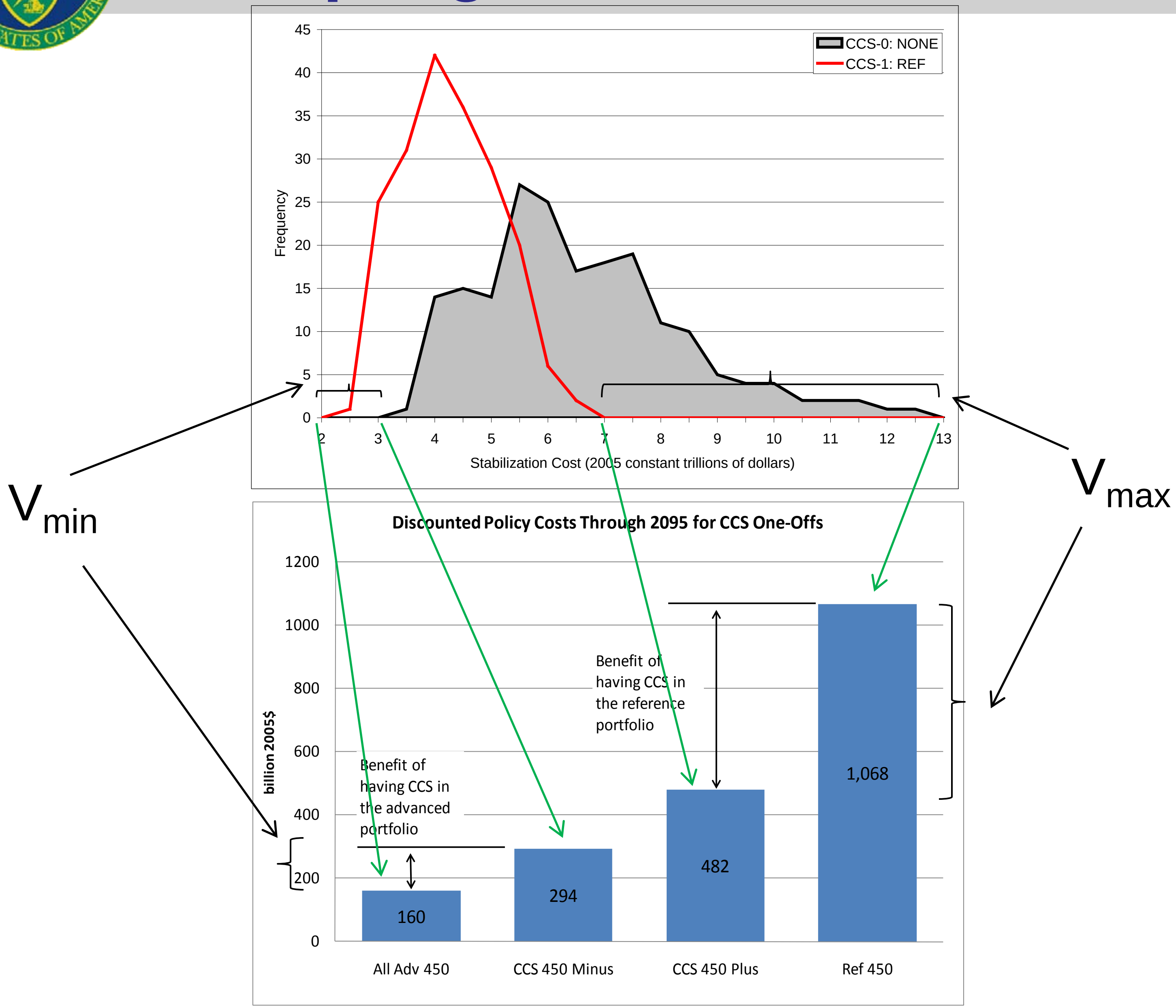
# Costs in One-Off Scenarios

- Defining a range for technology deployment is useful for setting program goals
  - Assessment of program plans relative to required deployment can be used to inform a judgment about the likelihood of success
  - However, the relative climate benefit of having, or not having, an advanced technology is not apparent
- What about impact of individual technologies on policy cost?



# Sampling from the Cost Distribution



# Using the Distribution in the Analysis

- The value of having an advanced technology in the portfolio lies somewhere between $V_{min}$ and $V_{max}$
  - The exact value depends on the status of the *rest* of the portfolio, but the distribution can be determined.
- We can use the likelihood of success estimate for each technology and use a Monte Carlo approach to sample from the probability-weighted distribution to determine V for each level of proposed investment.

# Revised Portfolio Methodology

- **First task**: Set deployment target range for chosen climate objective, based on one-off deployment distributions
- **Second task**: Use the proposed budgets for each technology to assign a likelihood of success and calculate the value V for each budget level.
- **Third task**: Use the value parameter and the proposed budgets for each technology to determine the return on investment (ROI) and build the portfolio
  - Calculate ROI: $ROI_A = V_A / I_A$ , etc.
  - Build the portfolio by inserting the investments in diminishing order of ROI

# BACKUP

# Mitigation and Readiness