

**Balancing Environmental, Security, and
Economic Objectives
In the Design of Future Energy Systems**

**Presentation at Workshop on:
“Balancing Energy and The Environment”
Lehigh University
Bethlehem, PA
October 31 - November 1, 2007**

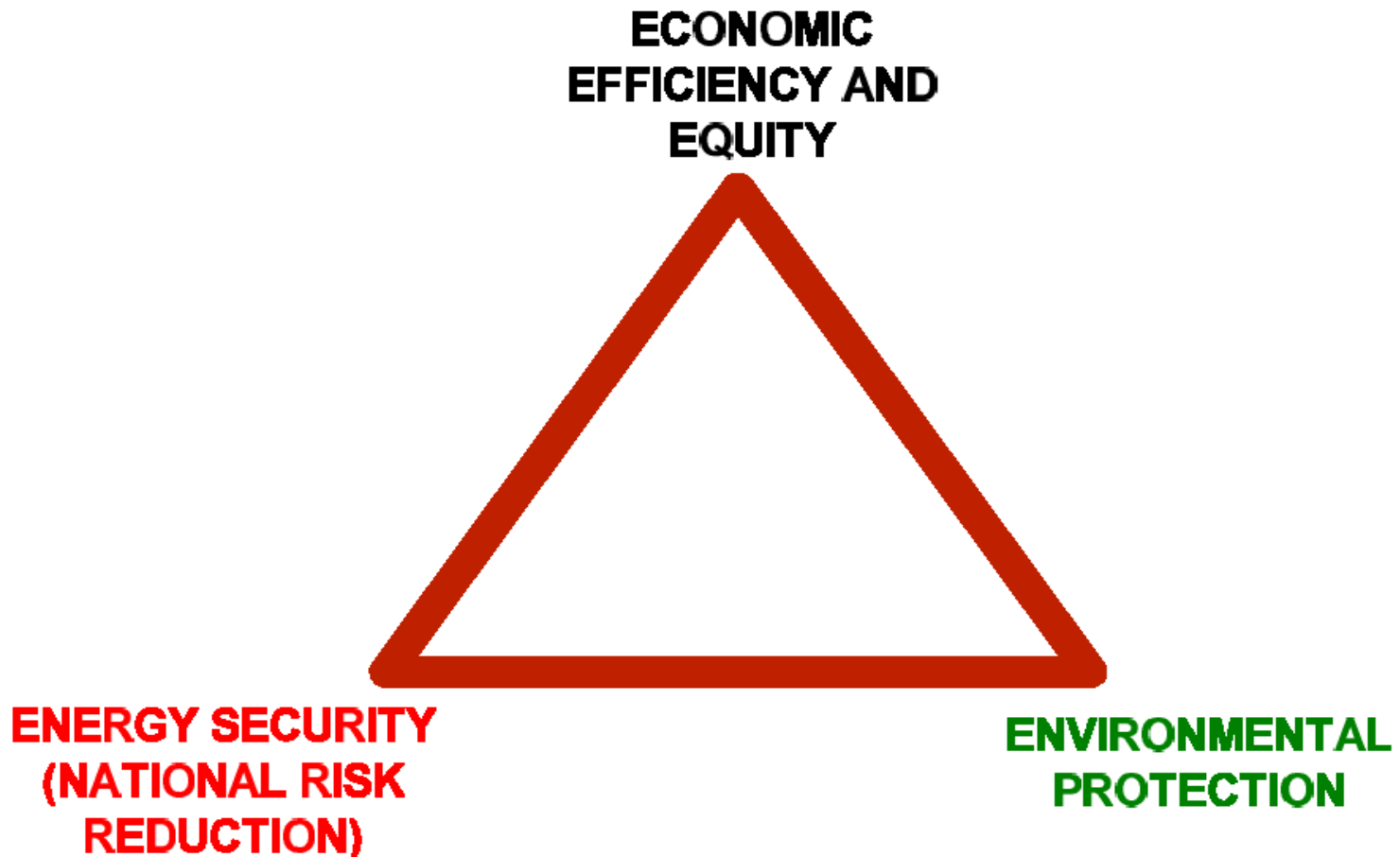
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Fundamental challenge

- Heightened concern about global warming has made **large reductions in greenhouse gas emissions** an urgent priority.
- **Oil import dependence** has again emerged as a critical national security problem.
- Climate and security concerns are together driving the need to make **significant changes in the energy system while avoiding large economic disruptions**.
- **Technological innovation** in the future is an inherent part of the solution.
- **Uncertainty** about many aspects of this problem abound and cloud our vision about what to do.

Metrics for Evaluating Energy System Tradeoffs

THE ENERGY POLICY TRIANGLE

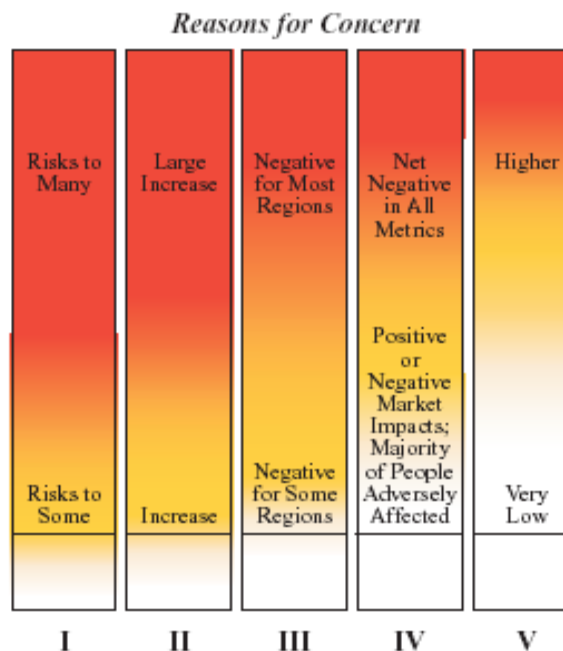
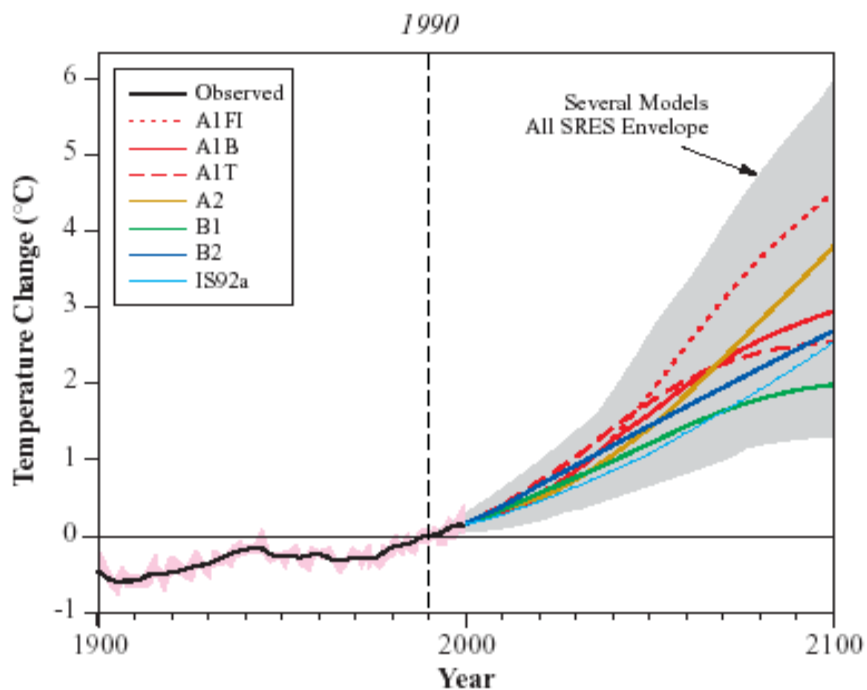


Energy security concerns

- Supply disruptions
 - Accidental or on purpose
 - Oil
 - Gas
 - Nuclear
- Use of revenue stream for aggression
 - Formal armed conflicts
 - Terrorism

Climate change concerns

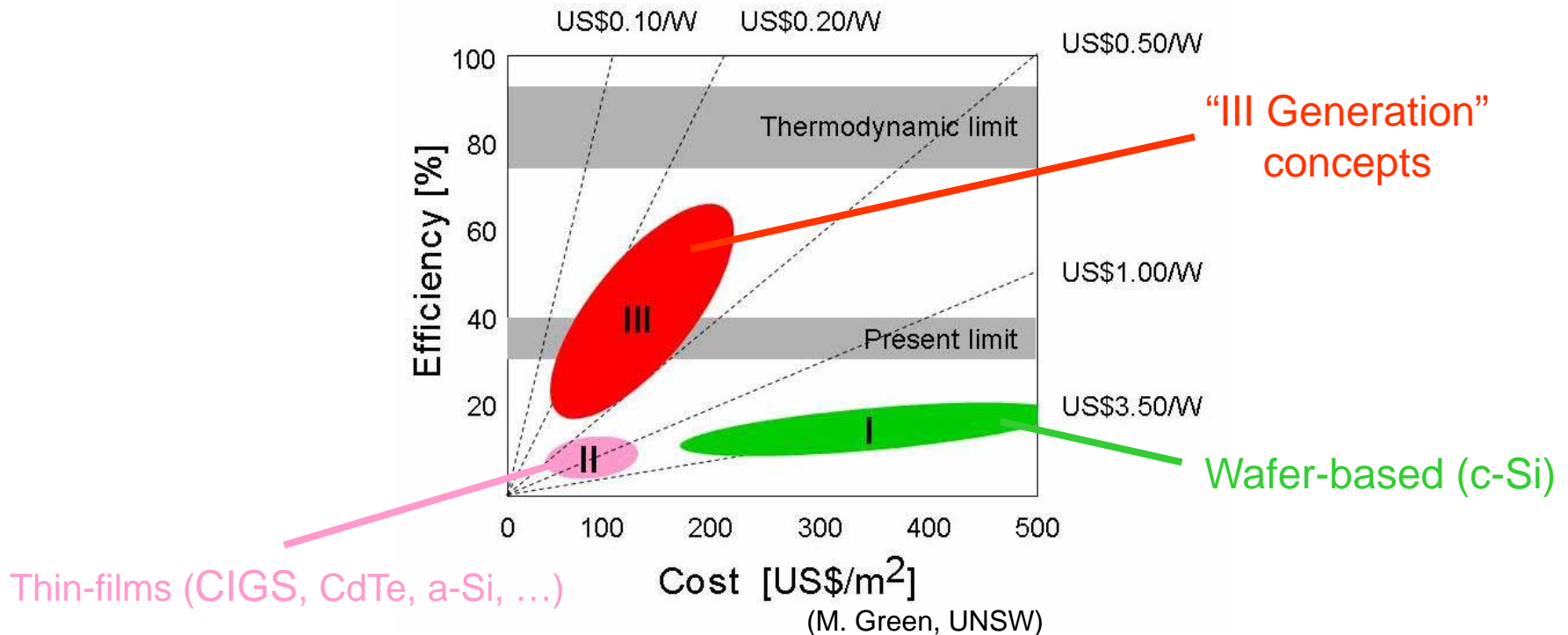
Reasons for Concern About Climate Change Impacts.



- | | |
|-----|---|
| I | Risks to Unique and Threatened Systems |
| II | Risks from Extreme Climate Events |
| III | Distribution of Impacts |
| IV | Aggregate Impacts |
| V | Risks from Future Large-Scale Discontinuities |

To understand why it's important
to deal with uncertainty
let's start with a couple of examples

The Global Climate and Energy Project (GCEP): Reducing Cost and Increasing Efficiency of Photovoltaic Systems



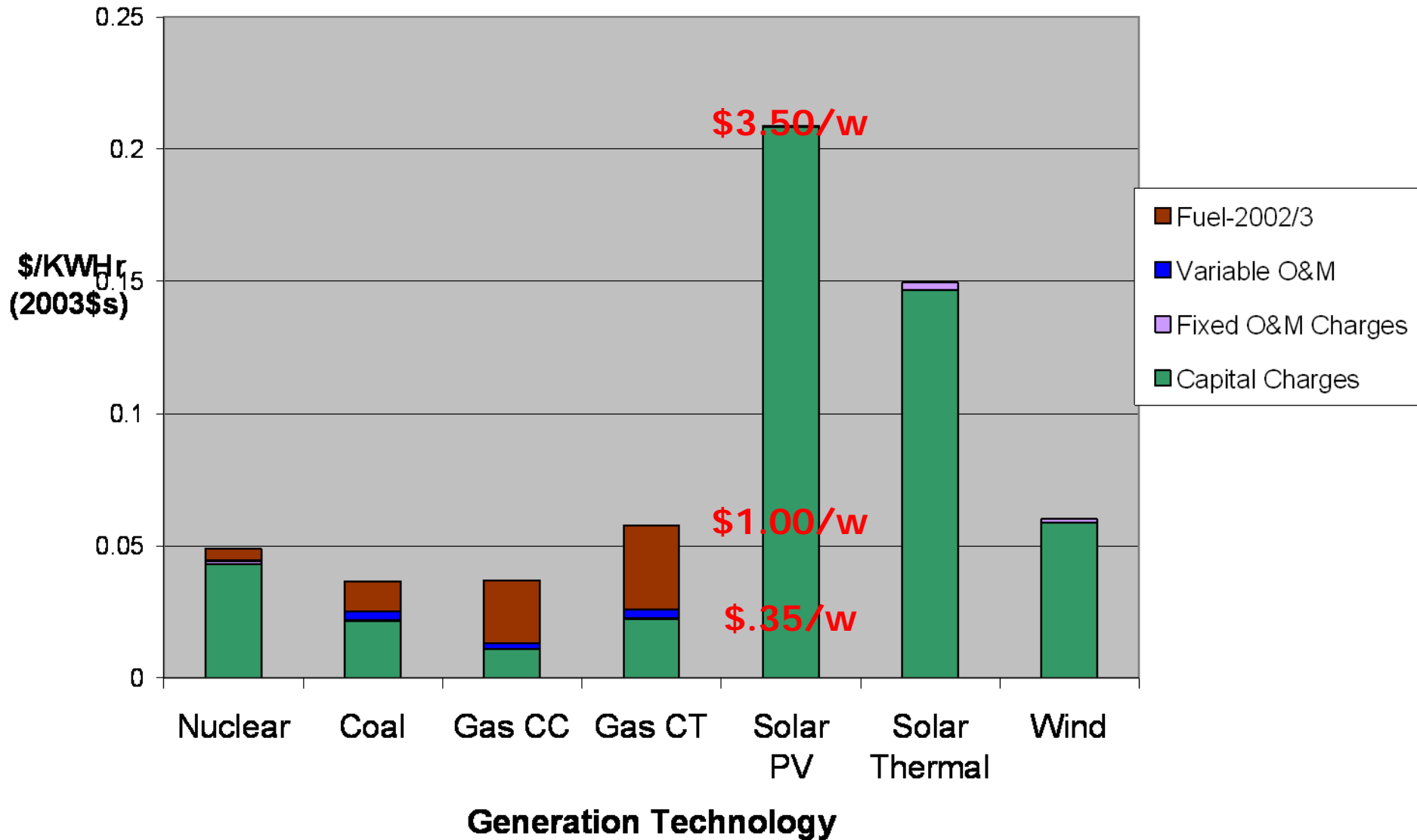
Cost ↓

- Cheaper Active **Materials**
(abundant inorganic or organic)
- Lower **Fabrication** Costs
(low-cost deposition / growth)
- Cheaper **BOS** Components
(substrates, encapsulation, ...)

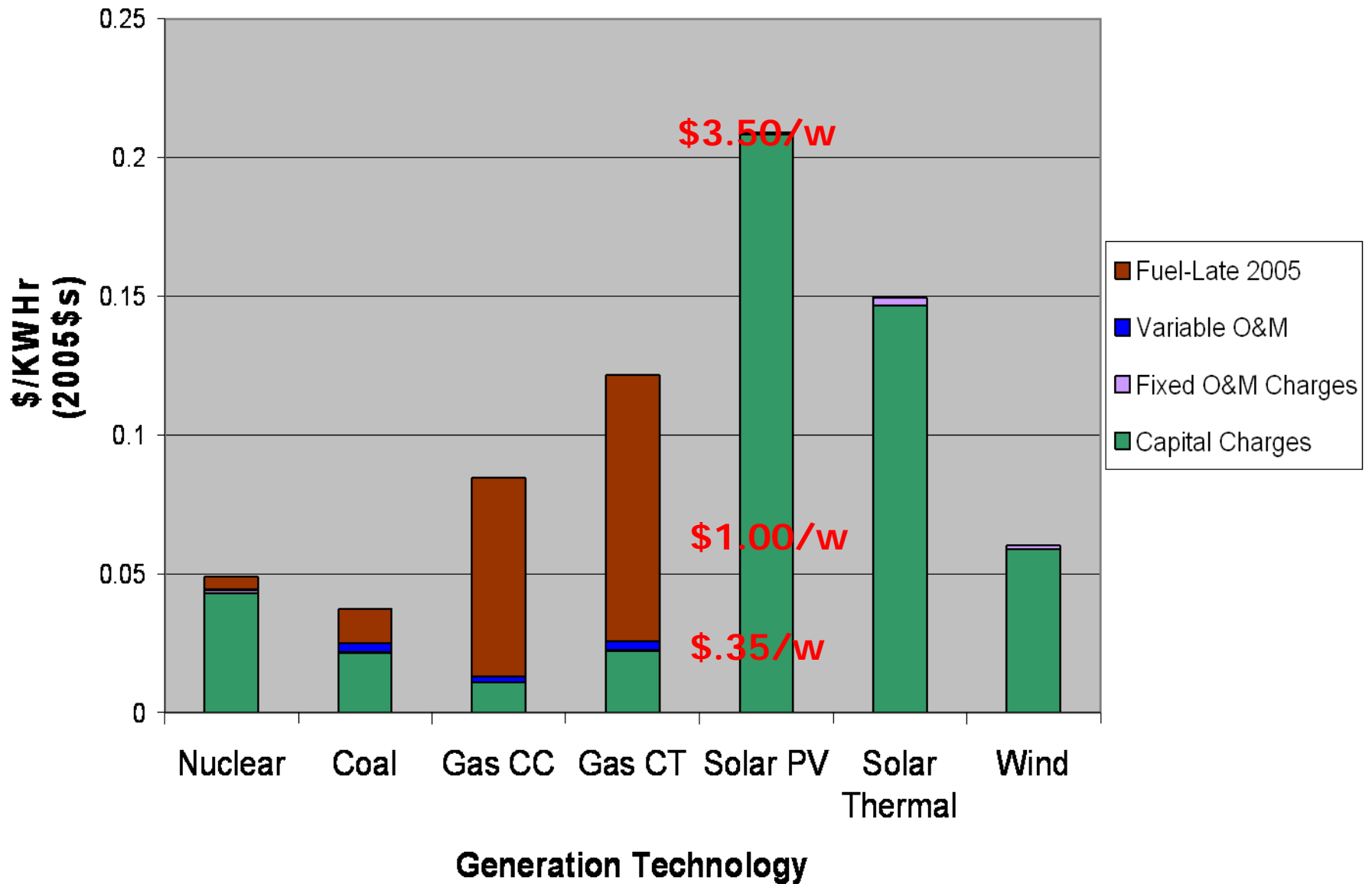
Efficiency ↑

- Reduce the **Thermodynamic Losses** at Each Step of the Photon-to-Electron Conversion Process
- Light Absorption
 - Carrier Generation
 - Carrier Transfer and Separation
 - Carrier Transport

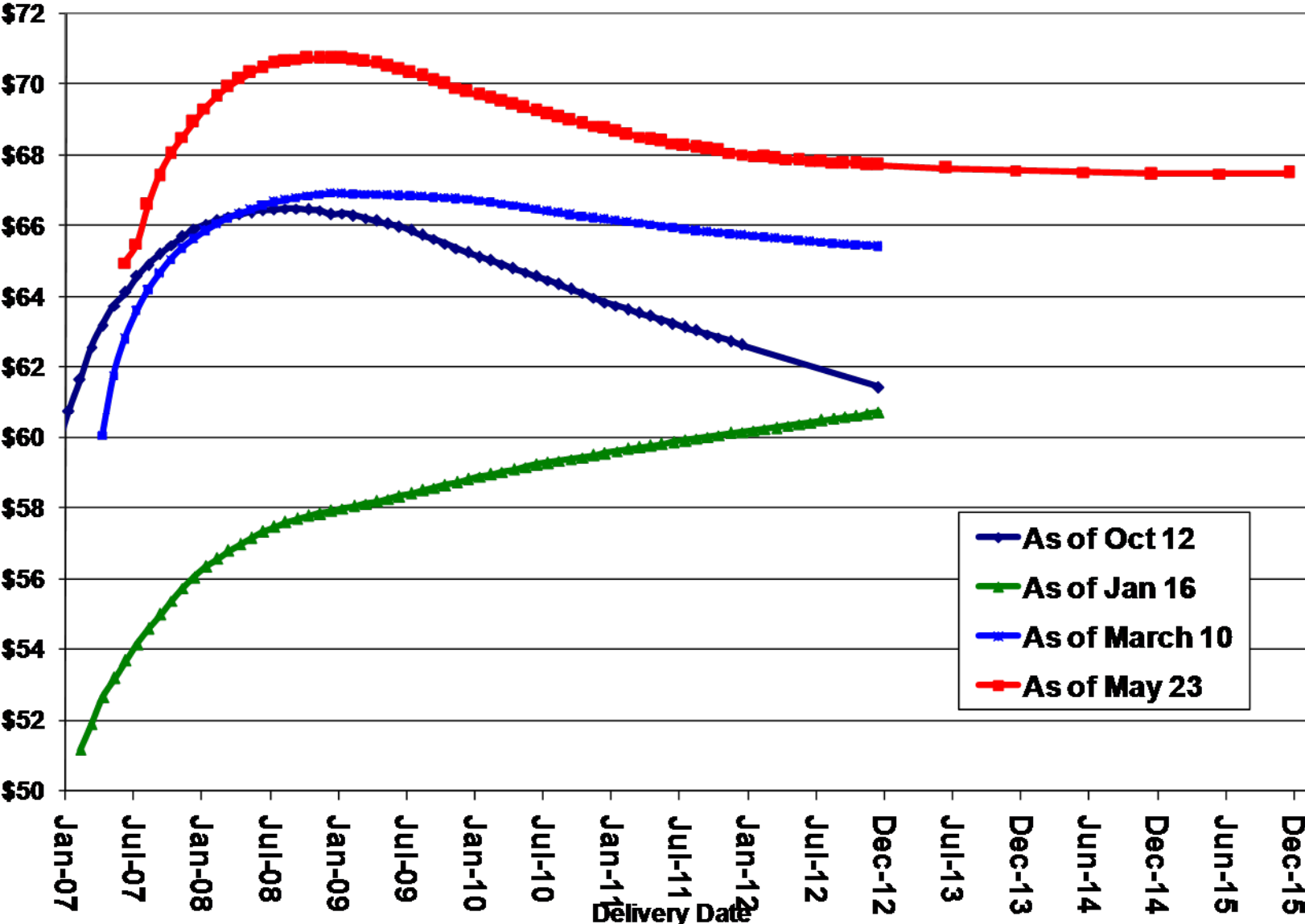
Electric Generation Cost Comparison (2002-03 Fuel Prices)



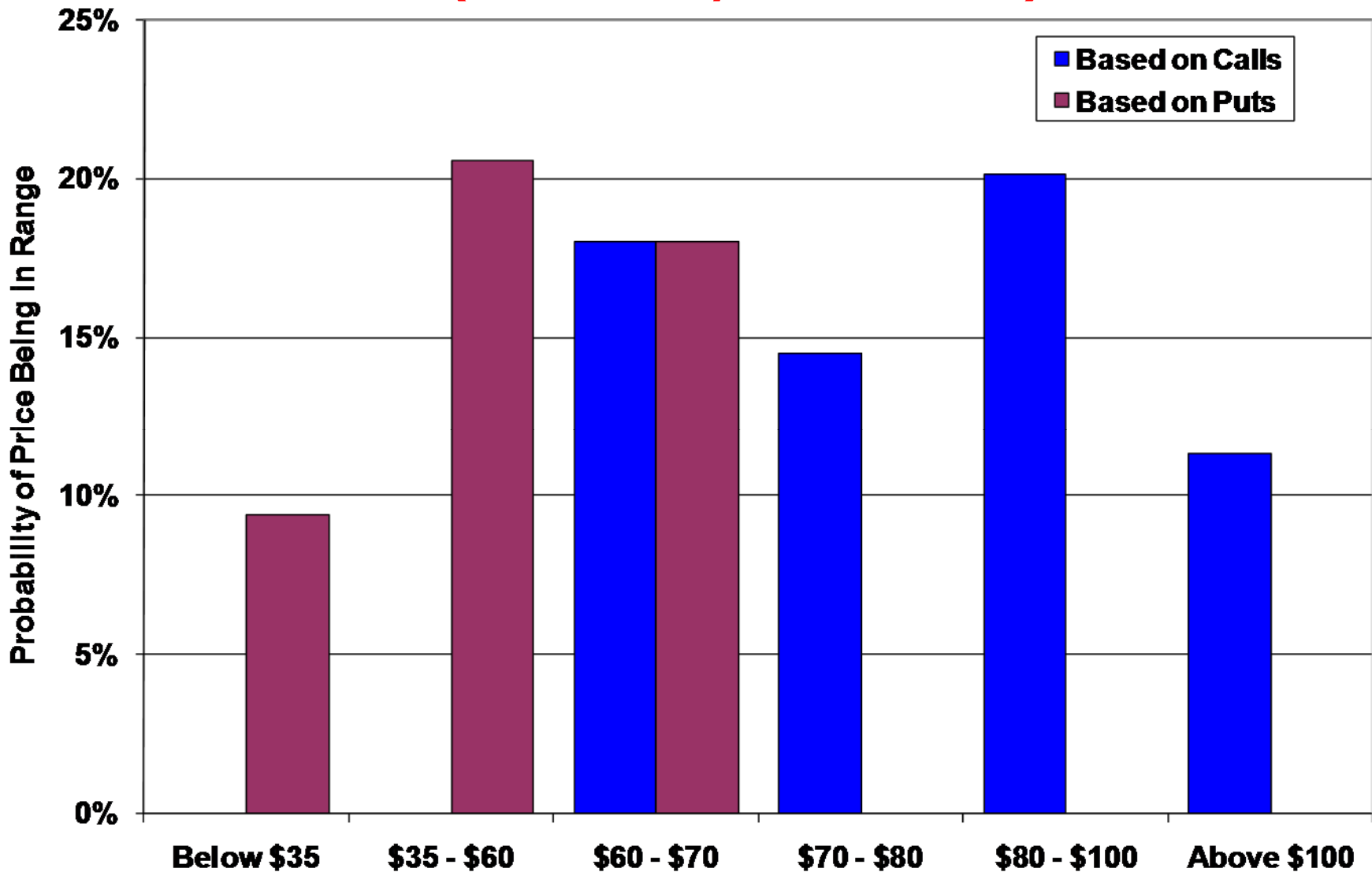
Electric Generation Cost Comparison (Late 2005 Fuel Prices)



Crude Oil Futures Prices: As of Four Dates



Oil price uncertainty - December 2009 delivery (data May 23, 2007)



Some approaches to uncertainty analysis

- Quantitative
 - Sensitivity Analysis
 - Scenario Analysis (Strategic Scenarios)
 - Stochastic Simulation
 - Decision Analysis
 - “Robust Planning”
- Qualitative
 - Story Lines
 - Strategic Planning Approaches
 - The Market Structure Approach
 - The Resource Based View
 - The Simple Rules Approach

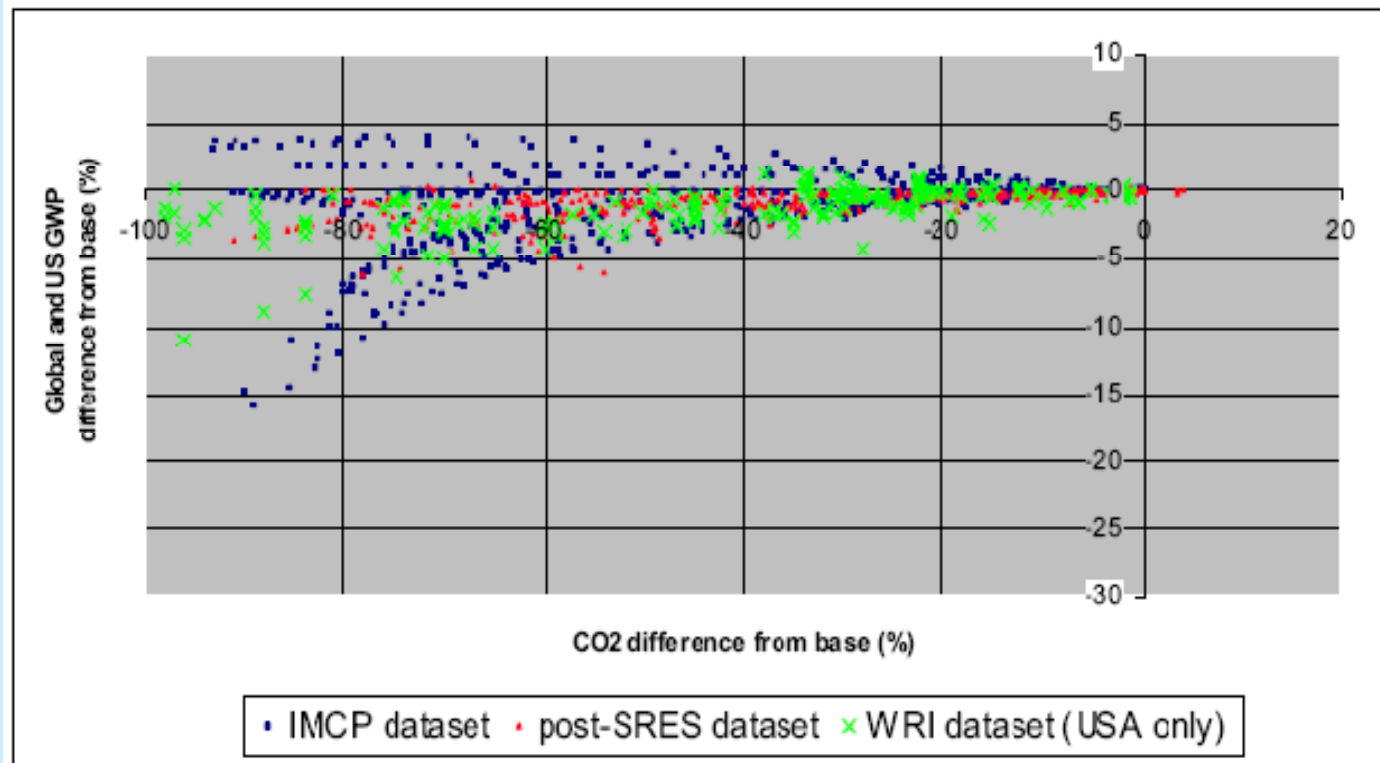
Two paradigms for problem-solving under uncertainty

	Conventional	Complex Adaptive
Defining ontology	Mechanistic	Complex
Social organization	Centralized/hierarchical	Decentralized/distributed
Competence/Knowledge	High, technocratic, explicit	Mixed, experiential, tacit
Scale of testing	Small number of large tests with high consequence of failure	Abundant small scale, safe-fail experimentation
Sources of legitimacy/power	Policy communities, management elites	Civil society, democratic action, markets
Social location	Top	Bottom and middle
Goal	Optimization of expected utility (according to explicit, well-defined preferences)	Satisficing of multiple, often conflicting, and sometimes incommensurable values

Example #1: the "Stern review" (2006): pick a number, any number

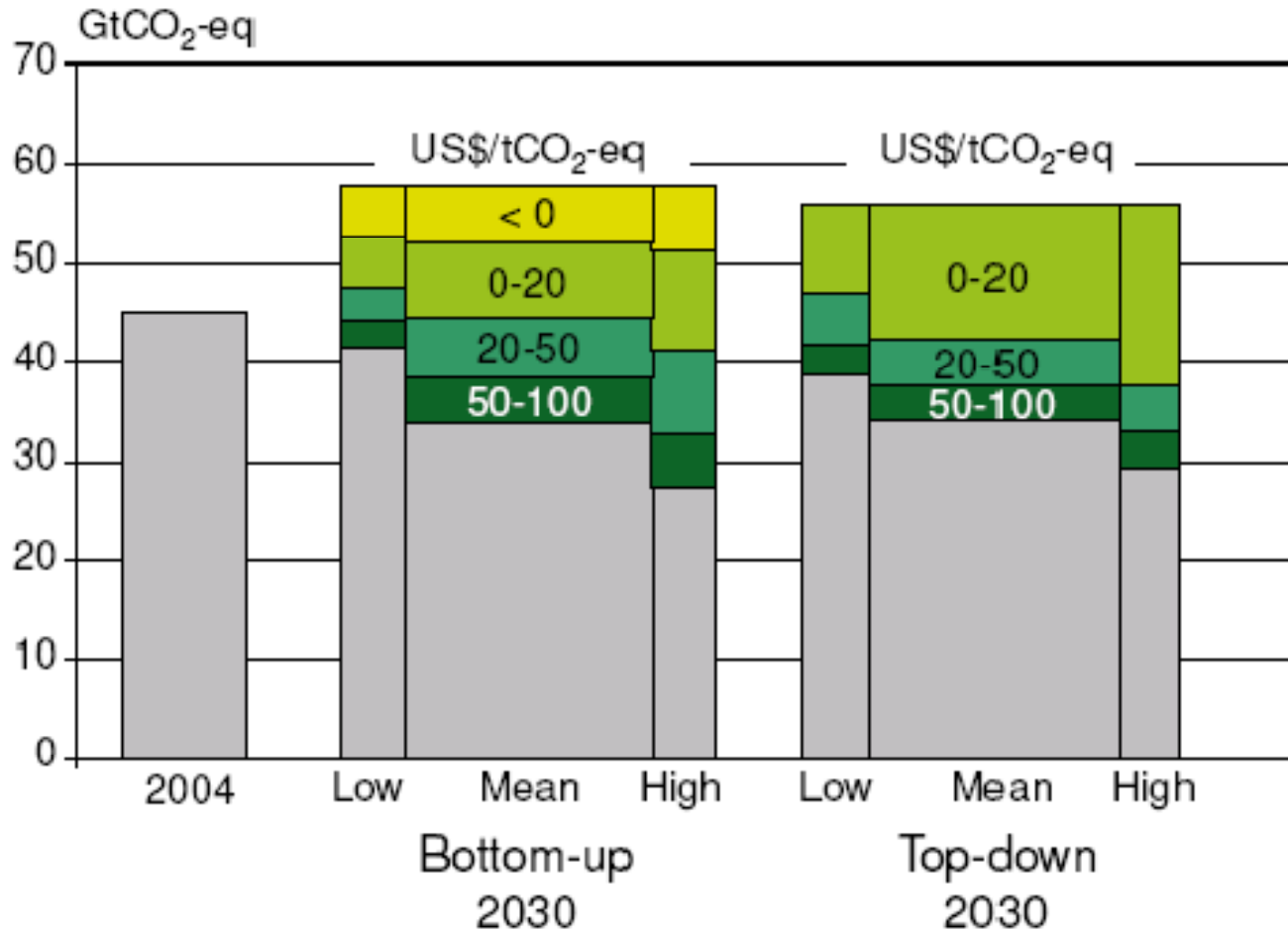
Figure 10.1 Scatter plot of model cost projections

Costs of CO₂ reductions as a fraction of world GDP against level of reduction



Source: Barker et al. (2006)

Example 2: The IPCC (2007) amazing agreement



The decision-maker's challenge

- Vast array of options
- Uncertainty about the future economic conditions and technological possibilities
- The effects of uncertainties on complex systems is hard to predict, and are non-linear
- Desire for simple solutions that please all constituents
- Existing analytical tools are poor for this problem
 - “Top-down” macro economic models have poor representation of technology
 - “Bottom-up” technology models (aka energy system models) are time-consuming to develop and can hide many details
 - No one model is good for evaluating many questions
 - Deterministic analysis
 - Poor effort to collect probabilistic data

What to do next?



California Energy Modeling and Analysis Consortium (CEMAC)

Jane Long, LLNL

Alex Farrell, UC Berkeley

Alan Sanstad, LBNL

John P. Weyant, Stanford



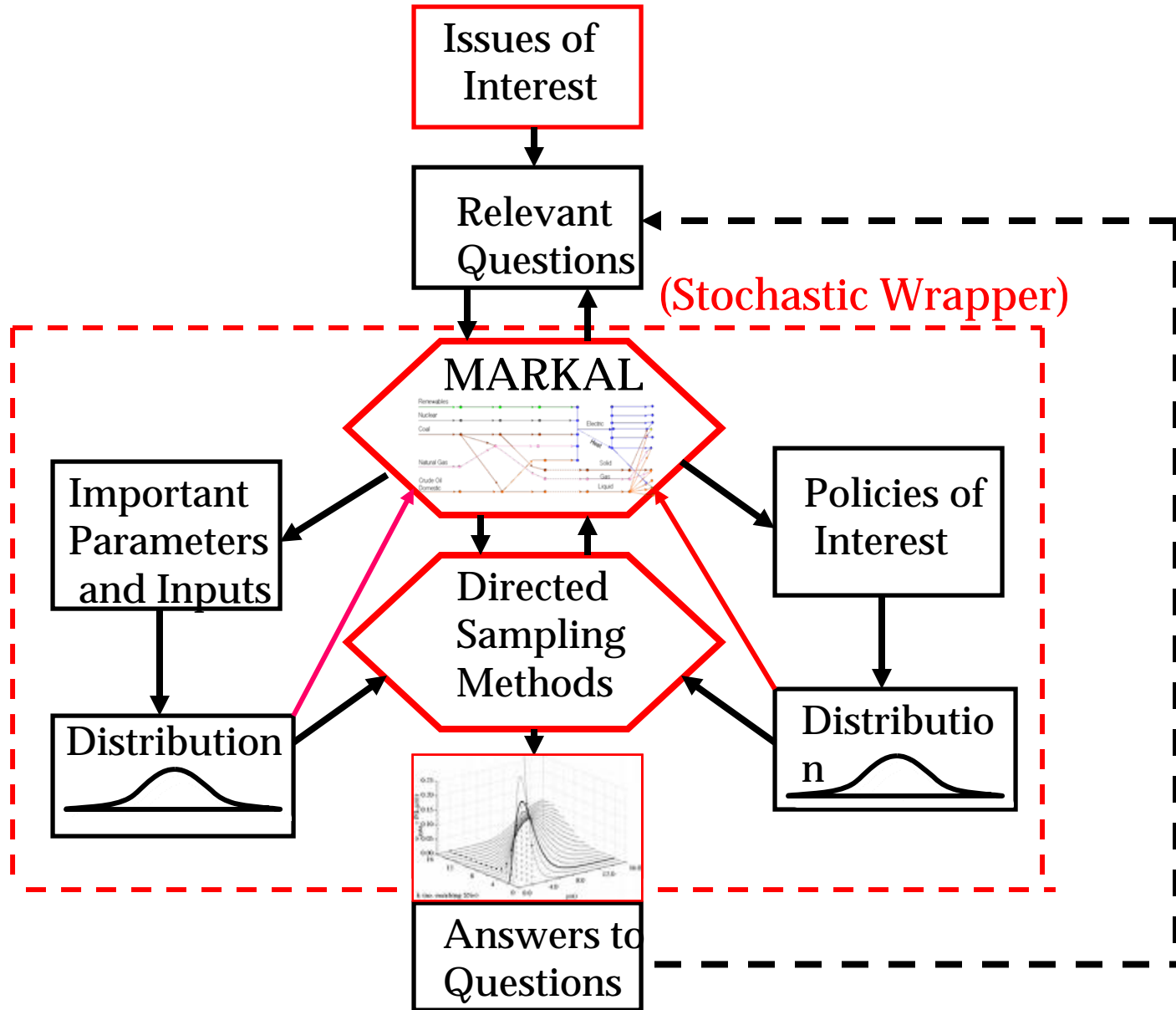
CEMAC was created to

- Address the economic impacts of energy system transformations driven by climate and energy security concerns
- Develop tools to systematically evaluate tradeoffs and compare policy options using complex models that can begin to replicate the behavior of real world systems under uncertainty.
- Combine the expertise of four major institutions to evaluate all aspects of the problem

CEMAC approach

- Identify relevant questions
- Use existing models as a “kernel”
- Identify key parameters and obtain probabilistic data
- Use existing model in a Monte Carlo simulation
- Analyze results using advanced statistical techniques
 - Results of this approach can be 300-1000 model runs, each of which produces 10,000 data points.
- Iterate on these steps to sharpen the analysis.
- Develop insights and recommendations that account for uncertainty, and forecasts that are probabilistic.

CEMAC approach to modeling & analysis



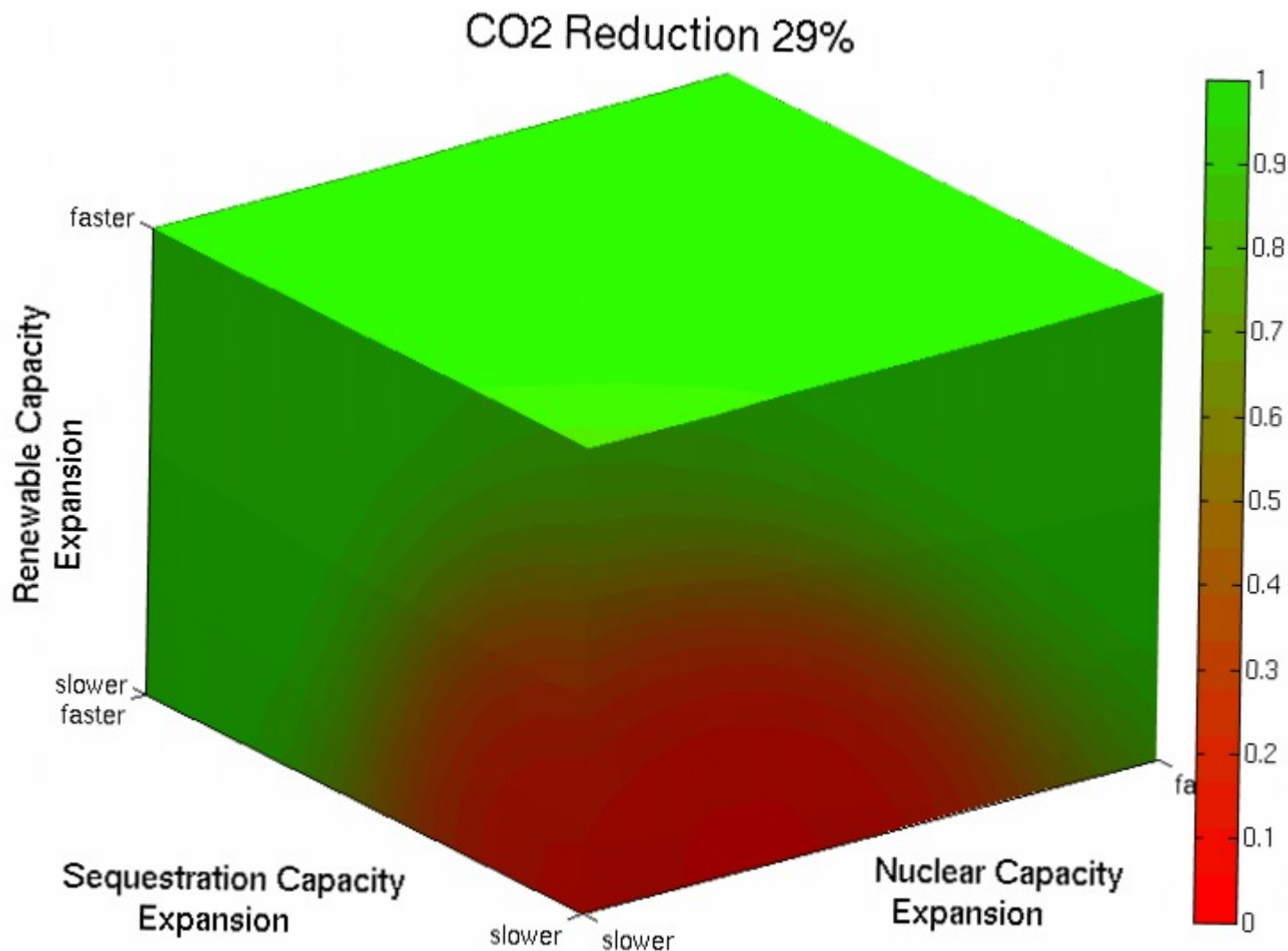
Demonstration application #1: electric power

- Exploring the Landscape of Electric Sector Policy Strategies for Aggressive CO₂ Mitigation
 - Policy Levers
 - Reduction of Cumulative Energy System CO₂ Emissions
 - Capacity Expansion Rates of Advanced Nuclear
 - Capacity Expansion Rates of CCS (Coal and Gas)
 - Capacity Expansion Rates of Renewables
 - Uncertainties
 - Technology Capital Costs
 - Oil and Natural Gas Prices

An example question of interest

What is the likelihood that expanded nuclear
And carbon capture and sequestration (CCS),
renewables pathways can reduce cumulative
CO₂ emissions by up to 20-30% at a cost
of $\leq 1\%$ of GDP?

Combinations of policies that have specified likelihood or greater of meeting cost target



Source of probability assessments (Erin Baker collaboration)

- We Are Working With A Researcher Who Conducts Expert Elicitations That Can Be Used As Probabilistic Input Data. We Are Not Just Making It Up.
- The Assessments Project Covers All Major Energy Technology Options
- Significant Effort Put Into Identifying the Right Experts and Structuring the Assessments

Assessments of R&D projects (Baker, cont.)

Define investment level and technical success

- Example: Advanced Solar; purely organic solar cells
- Investment: \$15 Million per year, for 10 years.
- Technical Success:
 - Cost of \$50/m²;
 - efficiency of 15%;
 - 30 year life time (defined as working at least 75% of original efficiency after 30 years)
- We will define intermediate hurdles:
 - Identifying molecules that can achieve efficiency.
 - Identifying molecules among that group that can achieve stability.
 - Hurdles related to the cost of depositing the material and identifying a low cost substrate.
- Then, assess probability of success.

Assessments of R&D projects (Baker, cont.) Purely organic solar cells

Need Estimates for	Funding Trajectory \$15M/yr 10 yrs	ex1	ex2	ex3
P1	Efficiency 15%	.85	.9	.8
P2	Stability 30 years	.50	.3	.5
P3	Low cost deposition (total < \$50/m ²)	.90	.5	.25
P4	Low cost substrate (total < \$50/m ²)	.90	.3	.1
Total		.34	.04	.01

We can reconcile divergent expert judgments through peer review; or run separate scenarios and see how overall policy changes under different expert judgments.

Some initial results

- Good probabilistic data are difficult to obtain, but extremely valuable.
- It takes a great deal of time debugging energy system models for use in Monte Carol simulations because they are often not written to allow for extreme events
- We appear to be partially successful in developing a method that propagates uncertainty through complex systems in a way that provides insightful answers
 - Statistical analysis is key to this process.

Questions?