Three Frontiers in Energy Modeling: Baselines, Technology and Uncertainty

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Three Frontiers in Energy Modeling

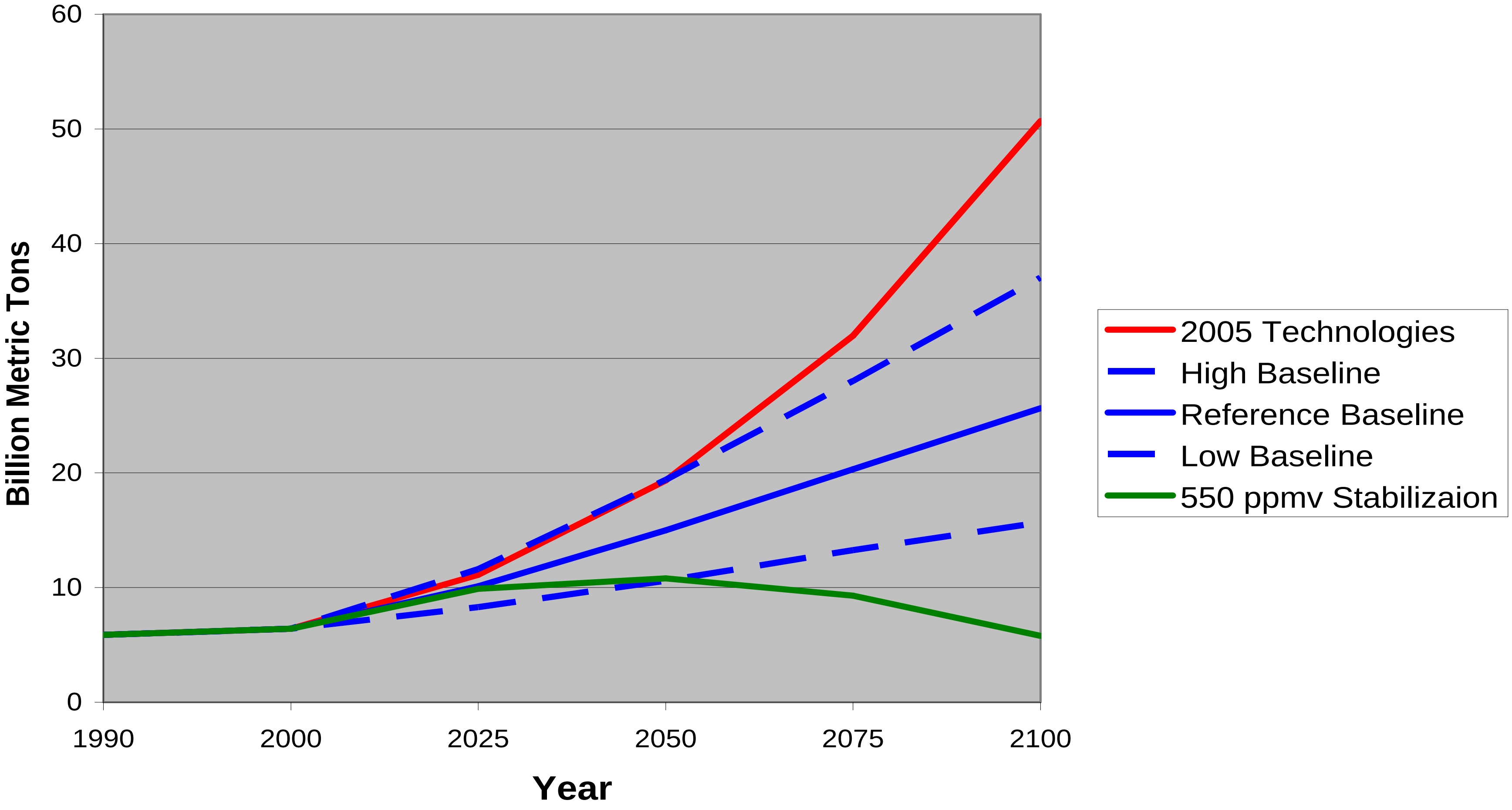
I. Developing Baselines

II. Representing Technology

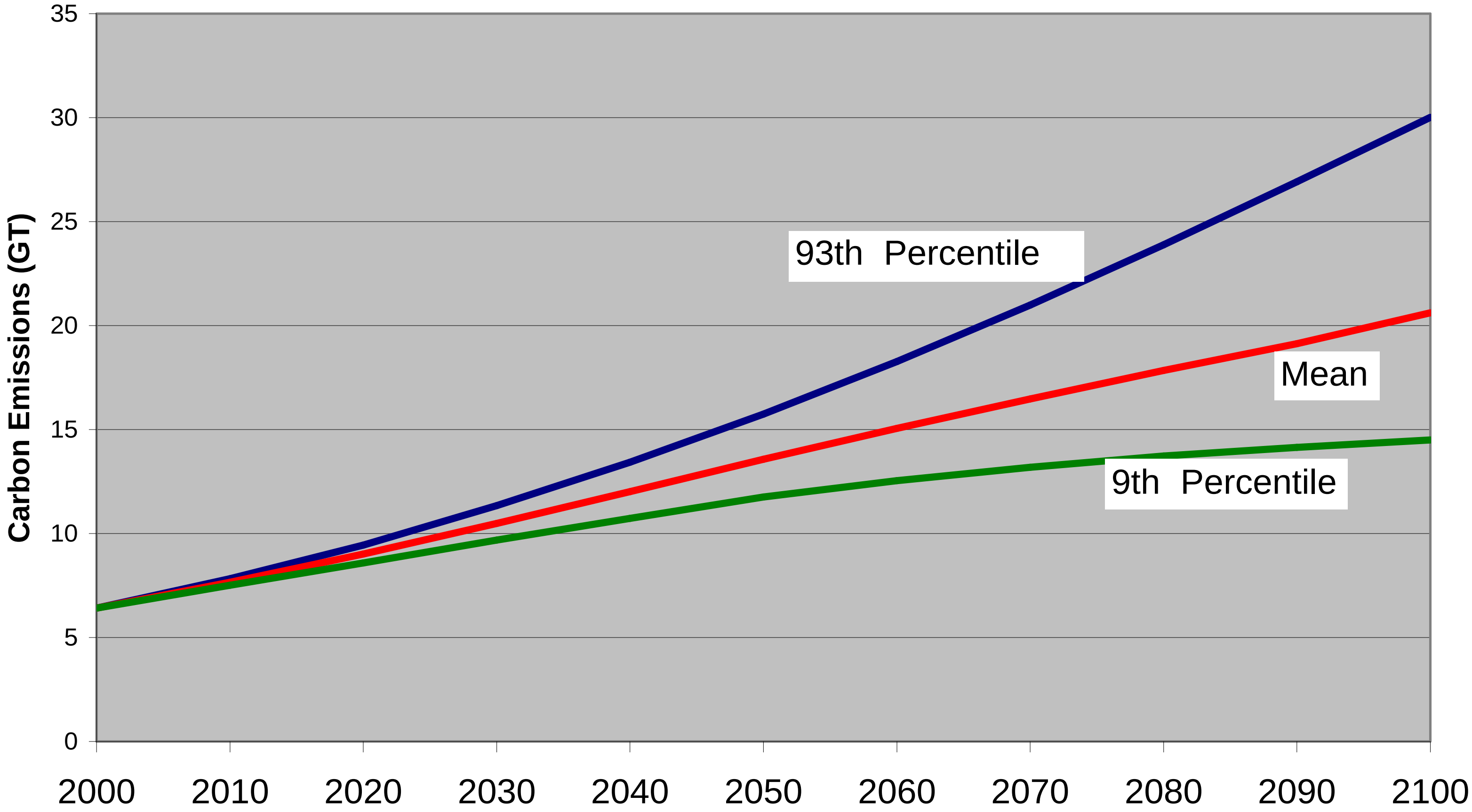
III. Incorporating Uncertainty

I. Developing Baselines:

Alternative Global Carbon Emission Projections



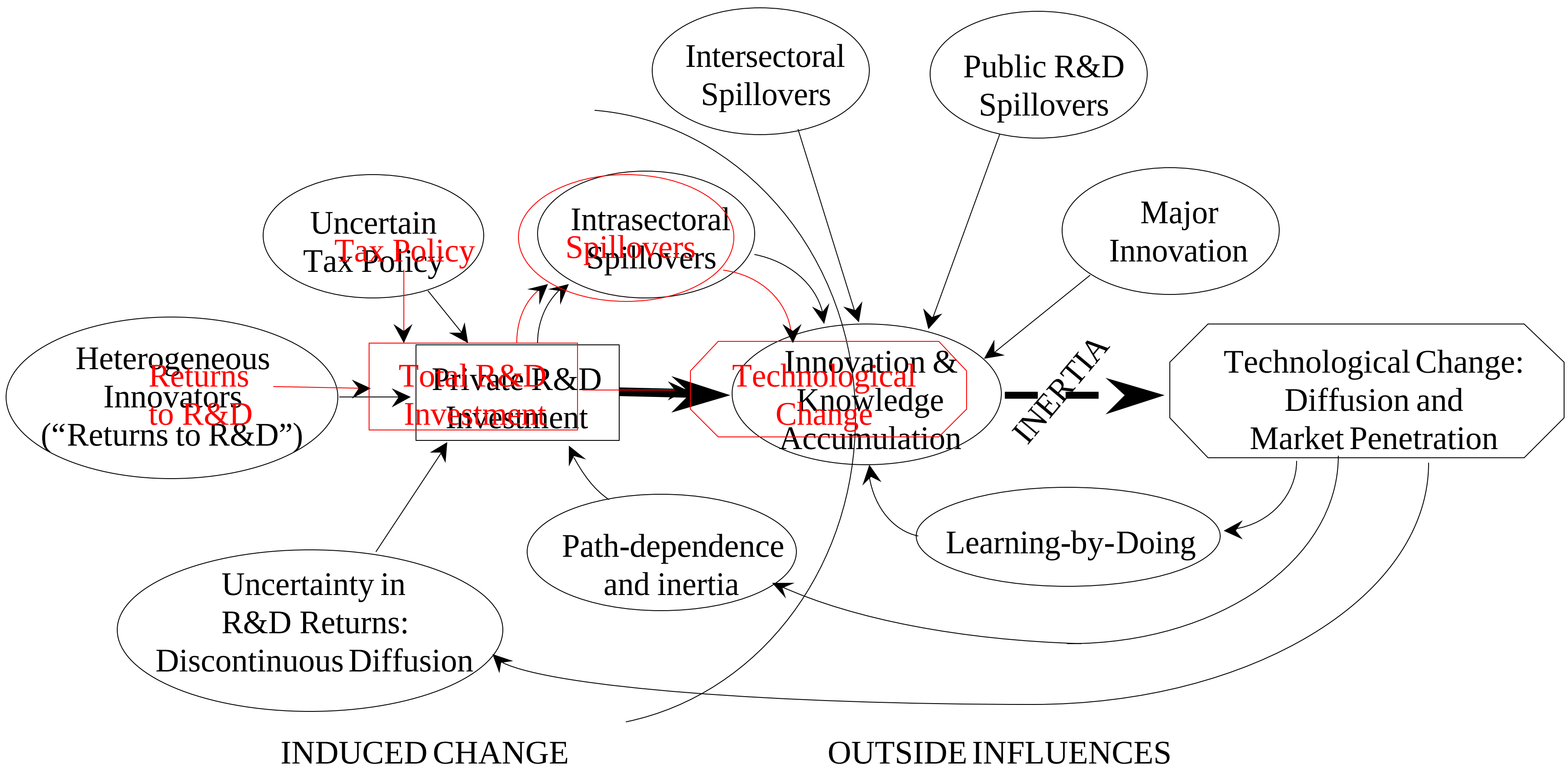
Projected Probabilistic Range of Global Carbon Emissions



II. Representing Technological Change

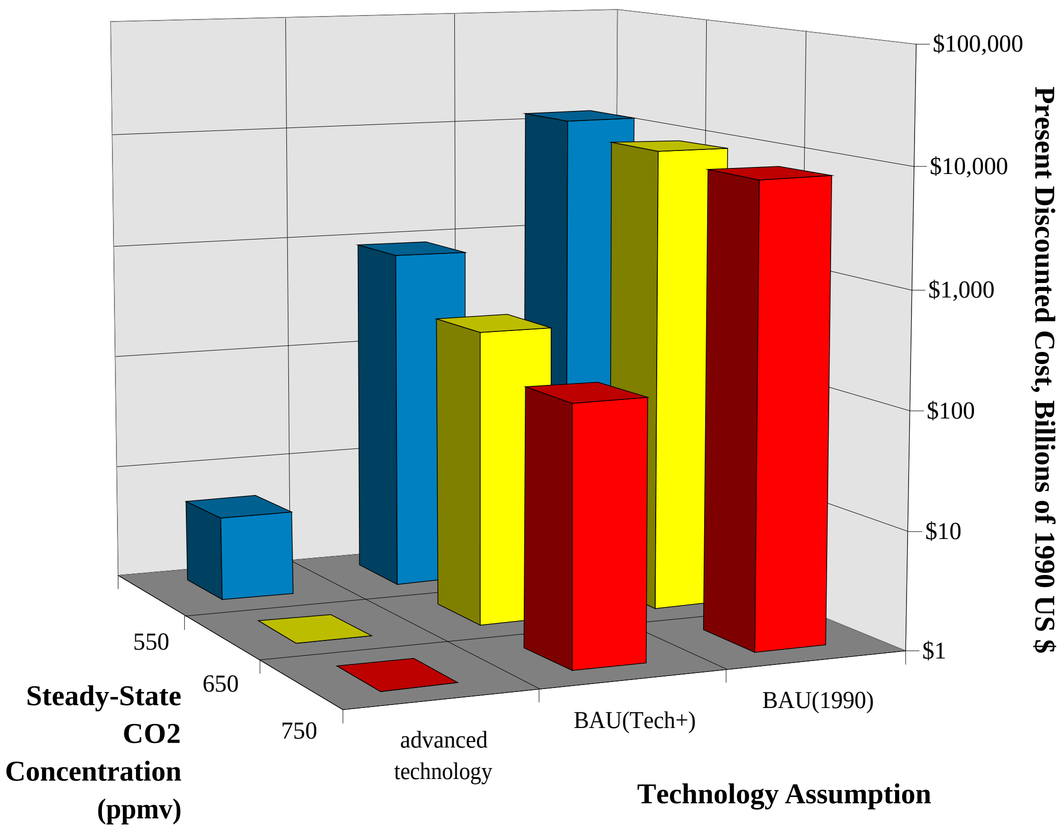
Limitations and Possible Extensions to Current Methods for Modeling TC

Current approaches omit important dynamics of technological change. A broader framework for analyzing TC is needed.



The VALUE OF DEVELOPING NEW ENERGY TECHNOLOGY

(Present Discounted Costs to Stabilize the Atmosphere)



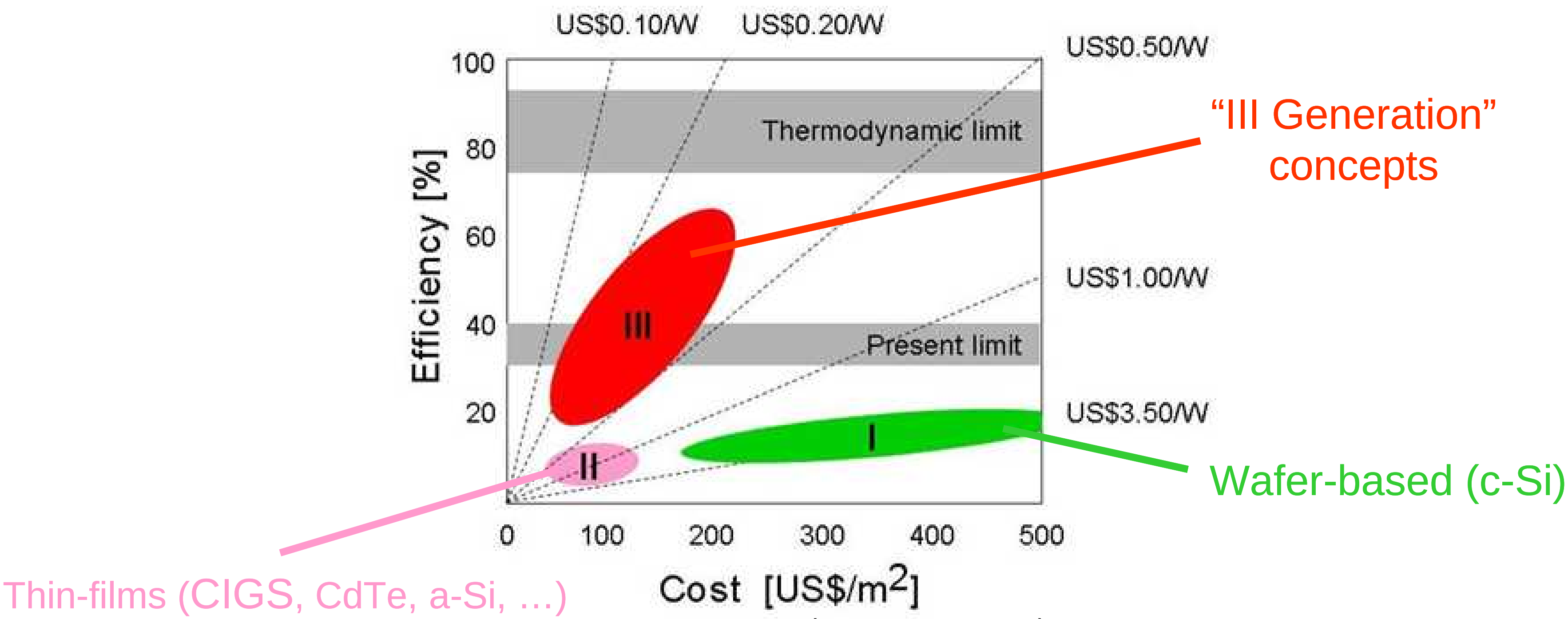
Minimum Cost Based on Perfect Where & When Flexibility Assumption. Actual Cost Could be An Order of Magnitude Larger.

Battelle Pacific
Northwest Laboratories

Table 1: Technology Assumptions

Technology	units	1990 Base	Year 2100 Mini-CAM B2	Year 2100 Mini-CAM B2 AT
US Automobiles	mpg	18	60	100
Land-based Solar Electricity	1990 c/kWh	61	5.0	5.0
Nuclear Power	1990 c/kWh	5.8	5.7	5.7
Biomass Energy	1990$/gj	$7.70	$6.30	$4.00
Hydrogen Production (CH_4 feedstock)	1990$/gj	$6.00	$6.00	$4.00
Fuel Cell	mpg (equiv)	43	60	98
Fossil Fuel Power Plant Efficiency (Coal/Gas)	%	33	42/52	60/70
Capture Efficiency	%	90	90	90
Carbon Capture Power Penalty (Coal)	%	25	15	5
Carbon Capture Power Penalty (Gas)	%	13	10	3
Carbon Capture Capital Cost (Coal)	%	88	63	5
Carbon Capture Capital Cost (Gas)	%	89	72	3
Geologic Disposal (CO_2)	$/tC	37.0	37.0	23.0

Reducing Cost and Increasing Efficiency of Photovoltaic Systems



(M. Green, UNSW)

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

Inorganic Thin-Film Photovoltaics

Materials

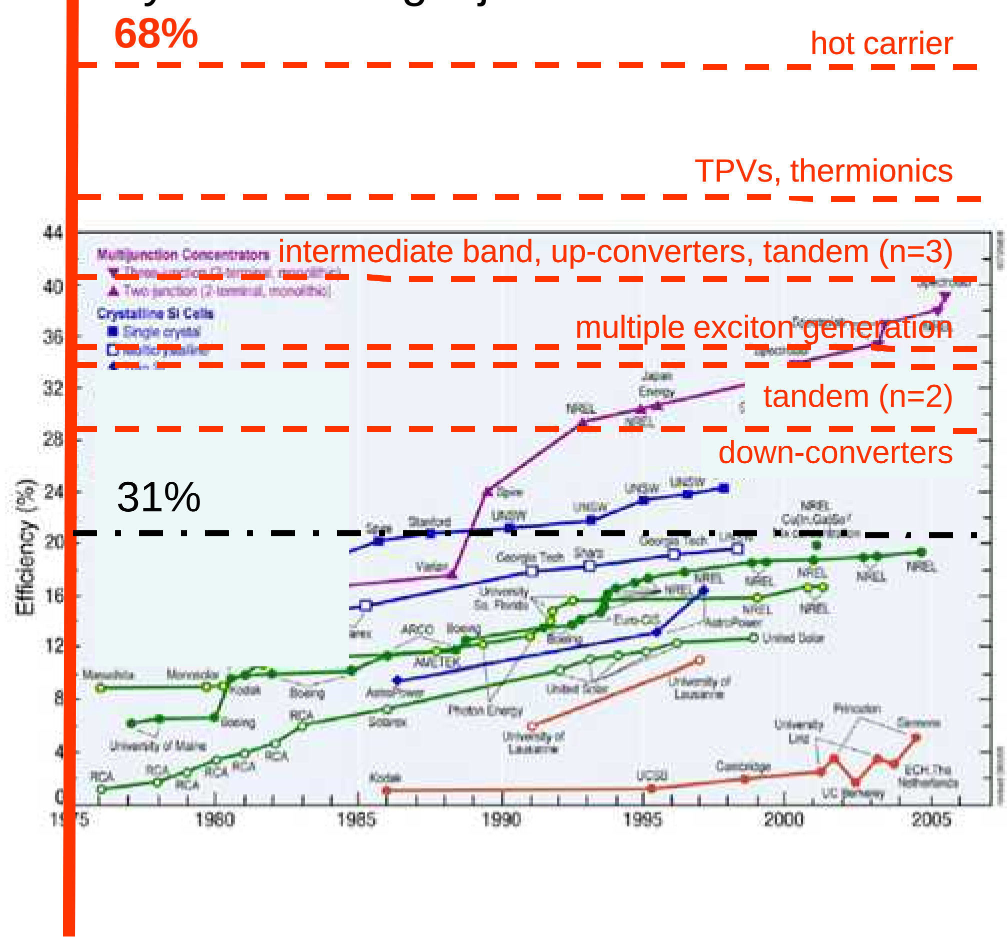
- (Novel) low-cost, abundant, non-toxic, and stable semiconductor materials
- Thin films: low volumes and lower requirements for charge transport
- Low-cost deposition processes

Nanoscale morphology

Performance enhancement through
- optimized geometry
- quantum effects

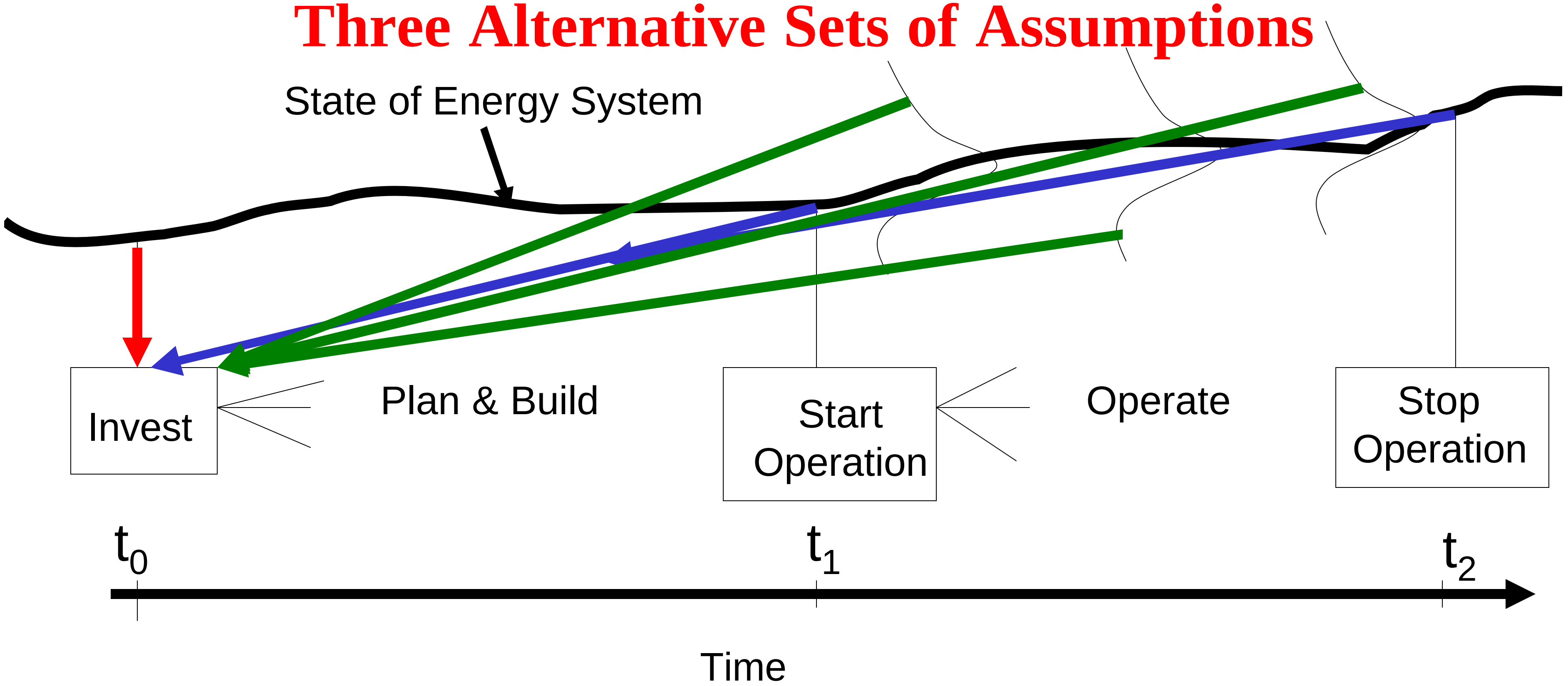
High efficiency

III generation concepts with efficiency limits beyond the single junction limit of 31%

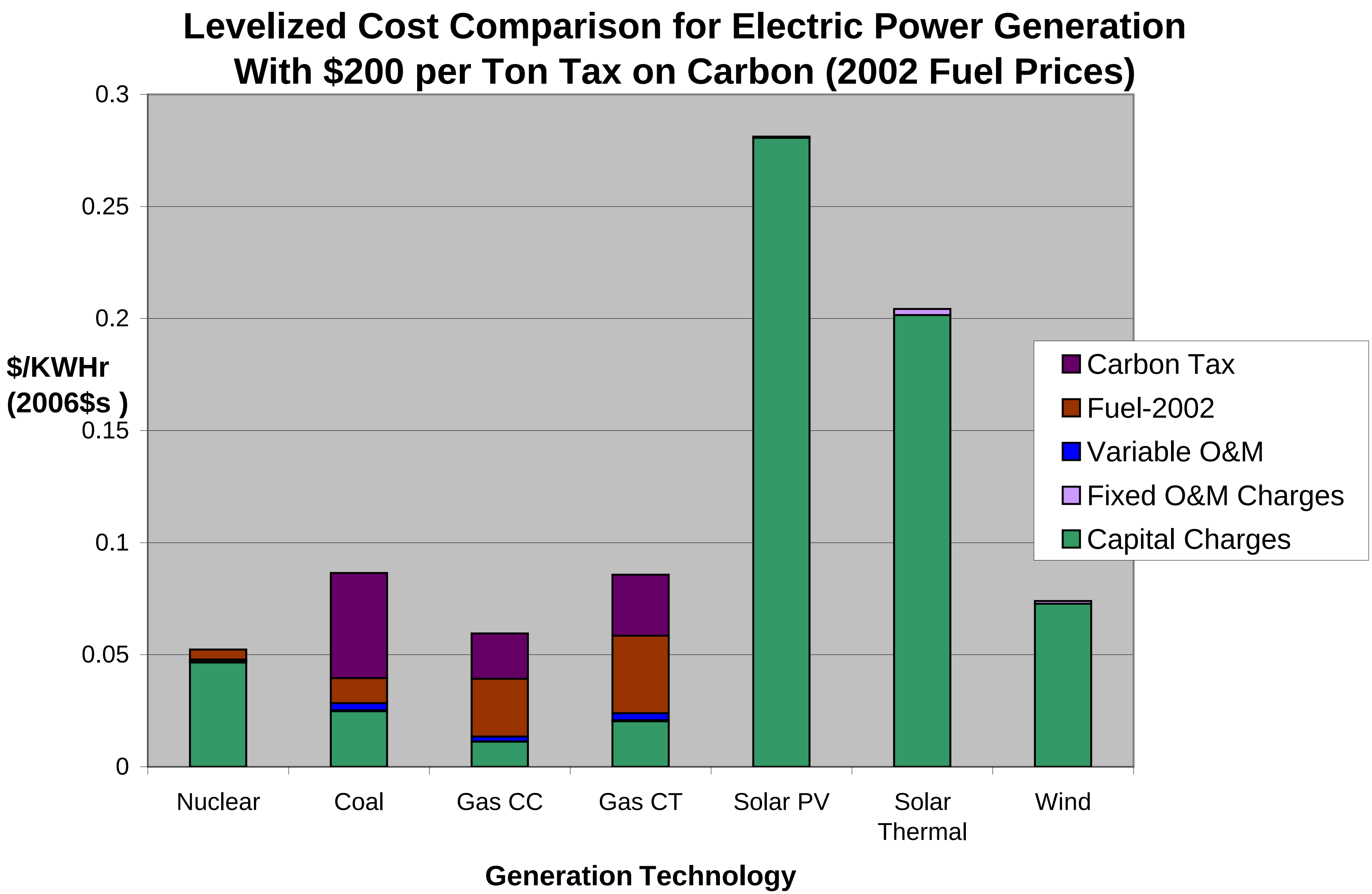


III. Incorporating Uncertainty

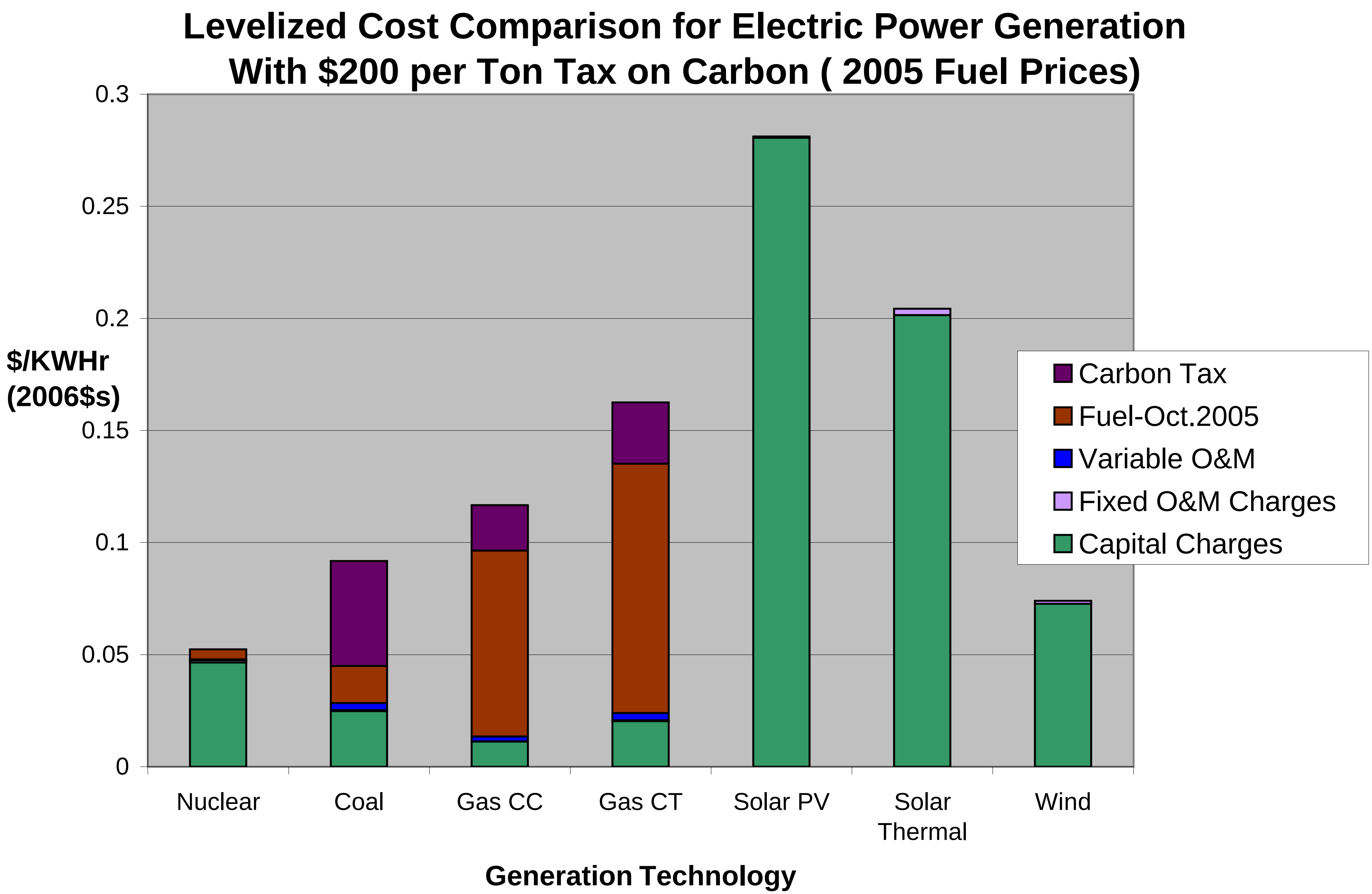
Information, Foresight & Uncertainty: Three Alternative Sets of Assumptions



(1) Static, Myopic, or Recursive Dynamic
(2) Perfect Foresight (Rationale Expectations)
(3) Decision Making Under Uncertainty



Levelized Cost Comparison for Electric Power Generation
With $200 per Ton Tax on Carbon (2002 Fuel Prices)
$/KWHr
(2006$s)
0.3
0.25
0.2
0.15
0.1
0.05
0
Nuclear
Coal
Gas CC
Gas CT
Solar PV
Solar Thermal
Wind
Generation Technology
Carbon Tax
Fuel-2002
Variable O&M
Fixed O&M Charges
Capital Charges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0.3
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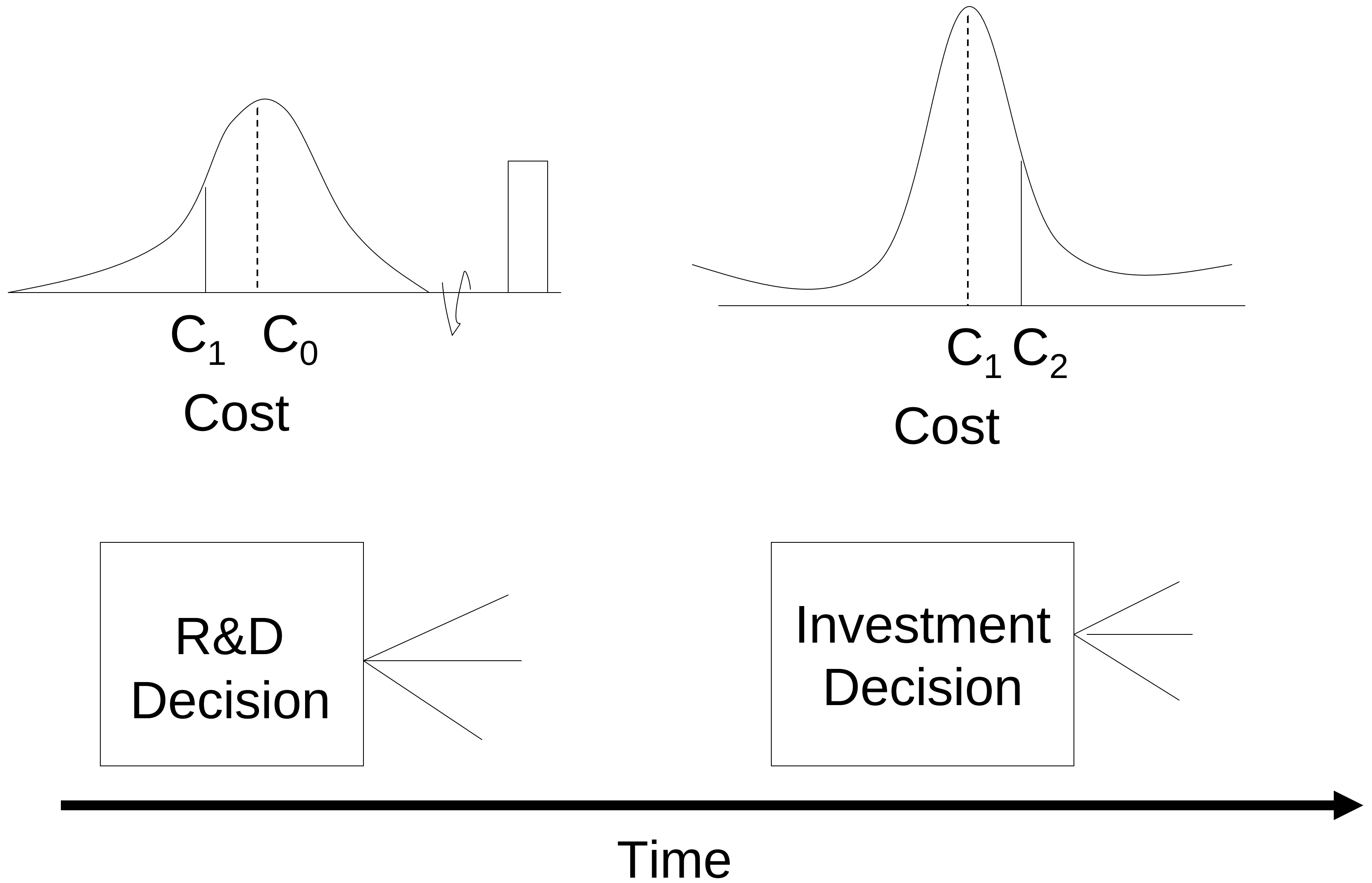
0.05
0
Carbon Tax
Fuel-Oct.2005
Variable O&M
Fixed O&M Charges
Capital Charges
Nuclear
Coal
Gas CC
Gas CT
Solar PV
Solar Thermal
Wind
Generation Technology

Interplay Between R&D and Investment Decisions

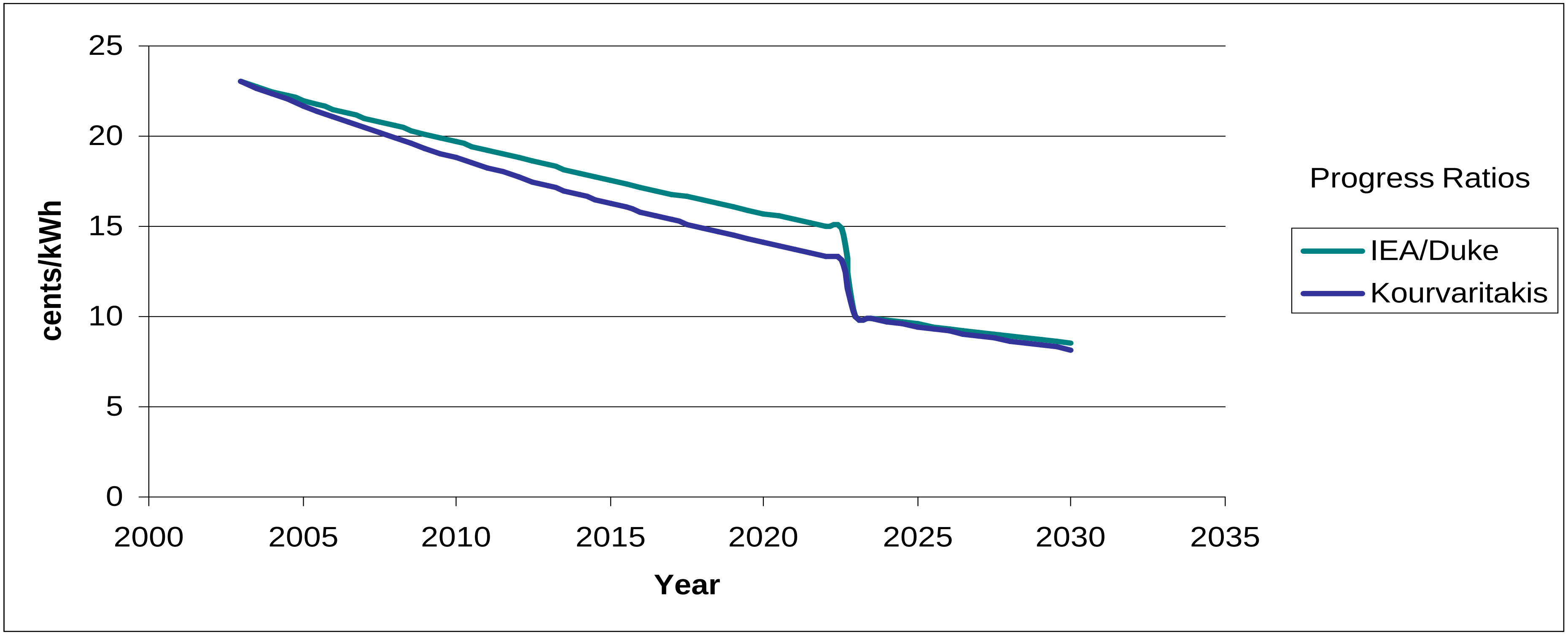


Assessments of R&D Projects
(Erin Baker, et al.)
Purely Organic Solar Cells

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.

Learning Curves Extrapolated for Solar PV Energy, with Thin-Film Technology Transfer in 2023



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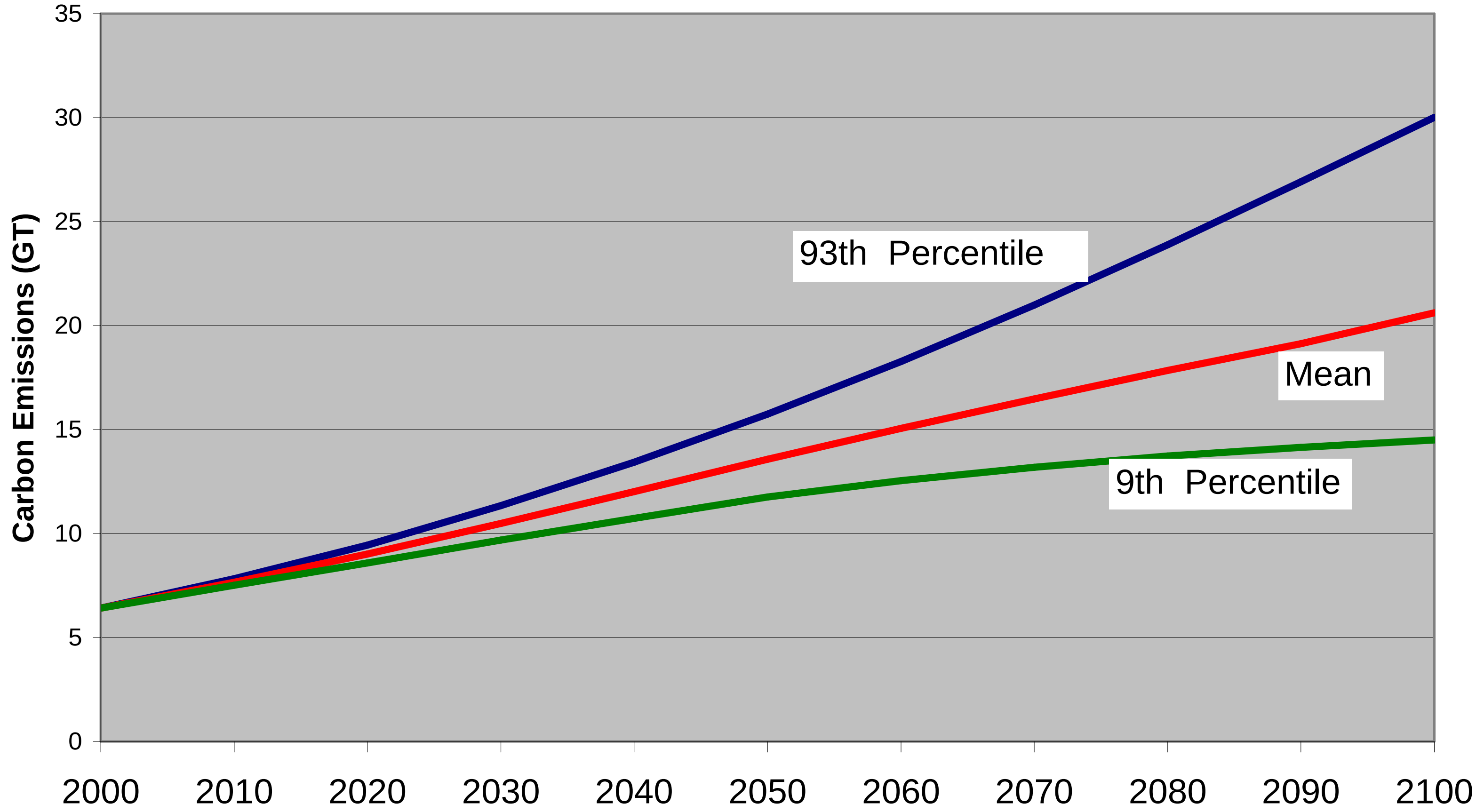
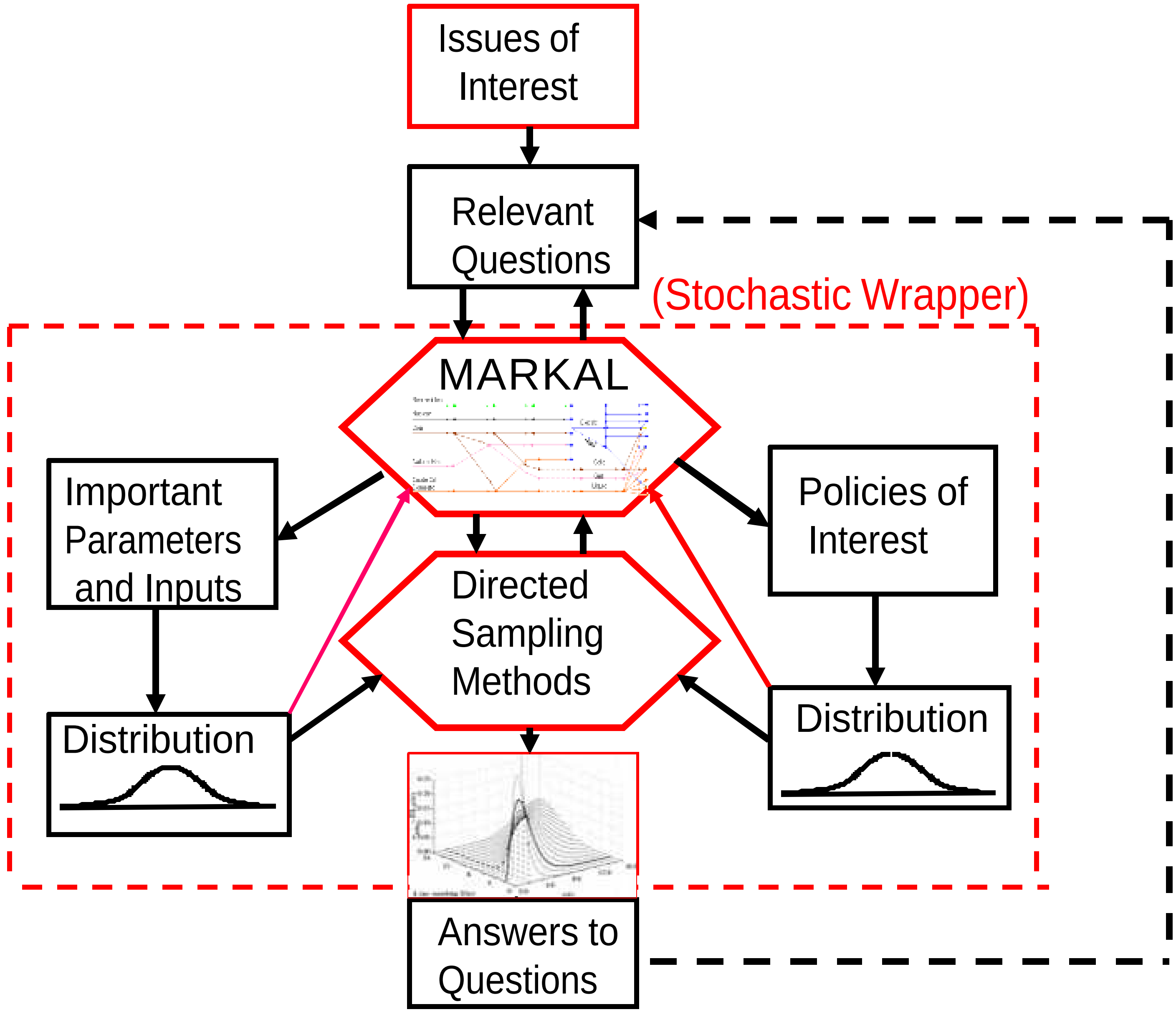


Approaches to Modeling Under Uncertainty

- Stochastic Dynamic Programming
- Stochastic Linear/Non-Linear Programming
- Stochastic Control
- Stochastic Simulation
- Intelligent Stochastic Simulation
- Bounding
- Sensitivity Analysis
- Multi-Dimensional Sensitivity Analysis
- Strategic Scenarios

CEMAC Approach to Modeling & Analysis



Recommendations for Energy Modelers

- Work Harder on Baselines
- Don’t Ignore Technological Change
- Don’t Ignore Uncertainty
- Don’t Let the Perfect Be the Enemy of the Good and Useful
  - i.e., Simple things are a lot better that no things.

Thank You!

Potential Areas of Model Refinement (I)

1. Technology/Technology Change
   - Invention
   - Innovation
   - Diffusion
2. Spatial/Temporal Disaggregation
3. Uncertainty
   - In the World, aka Scenario Uncertainty
   - How it Impacts Behavior of Modeled Agents
   - Related to Degree of Foresight Assumed
4. Data
   - Technology, Energy End Uses, Resources
   - Institutions
   - Economic Output, I/O, Fuel Markets, Trade

Potential Areas of Model Refinement (II)

5. Representation of Market Imperfections
6. Representation of "Non-Rational" Behavior
7. Ability to Analyze "Plausible" Policies
   - Standards
   - Sectoral Caps
   - Remedies for Market Imperfections
8. Macro/Microeconomic Integration
9. Public Finance/Financial Market Integration
10. Marrying Conceptual Structures With Data

Basic Strategies for Developing Models

- Identify All Potential Questions First, Then Design the Model to Help Address Them
- Develop a Flexible Modeling Architecture That Can Be Easily Adapted to New Problems
- Do Both!

Model Development/Assessment Issues: Common Pitfalls in Policy Modeling

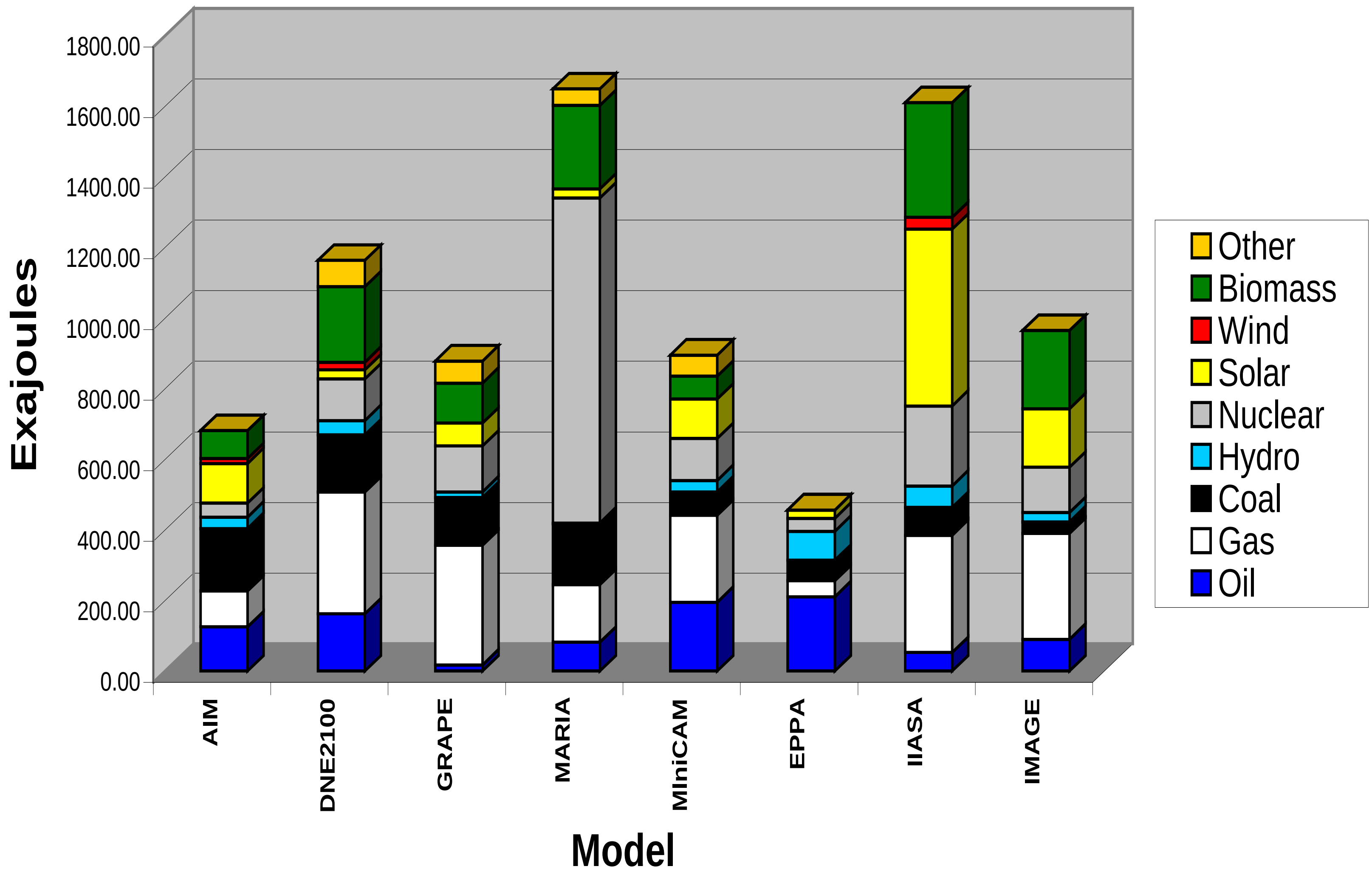
- Lack of Focus
  - Pick a basic model structure without a set of applications firmly in mind
  - Not modifying model in response to new problems
- Mistaking the Model for Reality
  - If its not in the model it probably doesn't exist
  - Test alternative assumptions only against the model
  - Methodological limitations imply real world restrictions
- Poor Communication of Results
  - Overstating strength of results
  - Omitting key relevant assumptions/qualifications

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 $\$50/m^2$;
  - 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.

The Energy Resource Mix

World Primary Energy in 550 ppm Case in 2100



Observations Regarding Current Approaches to Modeling Tech. Change

- Current approaches to TC provide a good foundation:
  - spillovers
  - innovation incentives and knowledge capital
  - heterogeneous firms and technologies
- Current approaches suggest weak or ambiguous effect of ITC, but underestimate importance:
  - Focus only on R&D-based technological change
    - learning-by-doing
    - diffusion or imitation by existing technology
  - Assume continuous, known returns to R&D function (no surprises or discontinuities)
    - No provision for major innovations
    - Model only one dimension of technological change (cost)
  - Neglect path-dependence and inertia in changing technology dynamics
- Modeling challenge will be to incorporate enough complexity to realistically capture technology dynamics in a meaningful way.
- Policy challenge will be to use insights from models, but qualify findings with a more complete understanding of technological evolution.