Overview of Integrated Assessment

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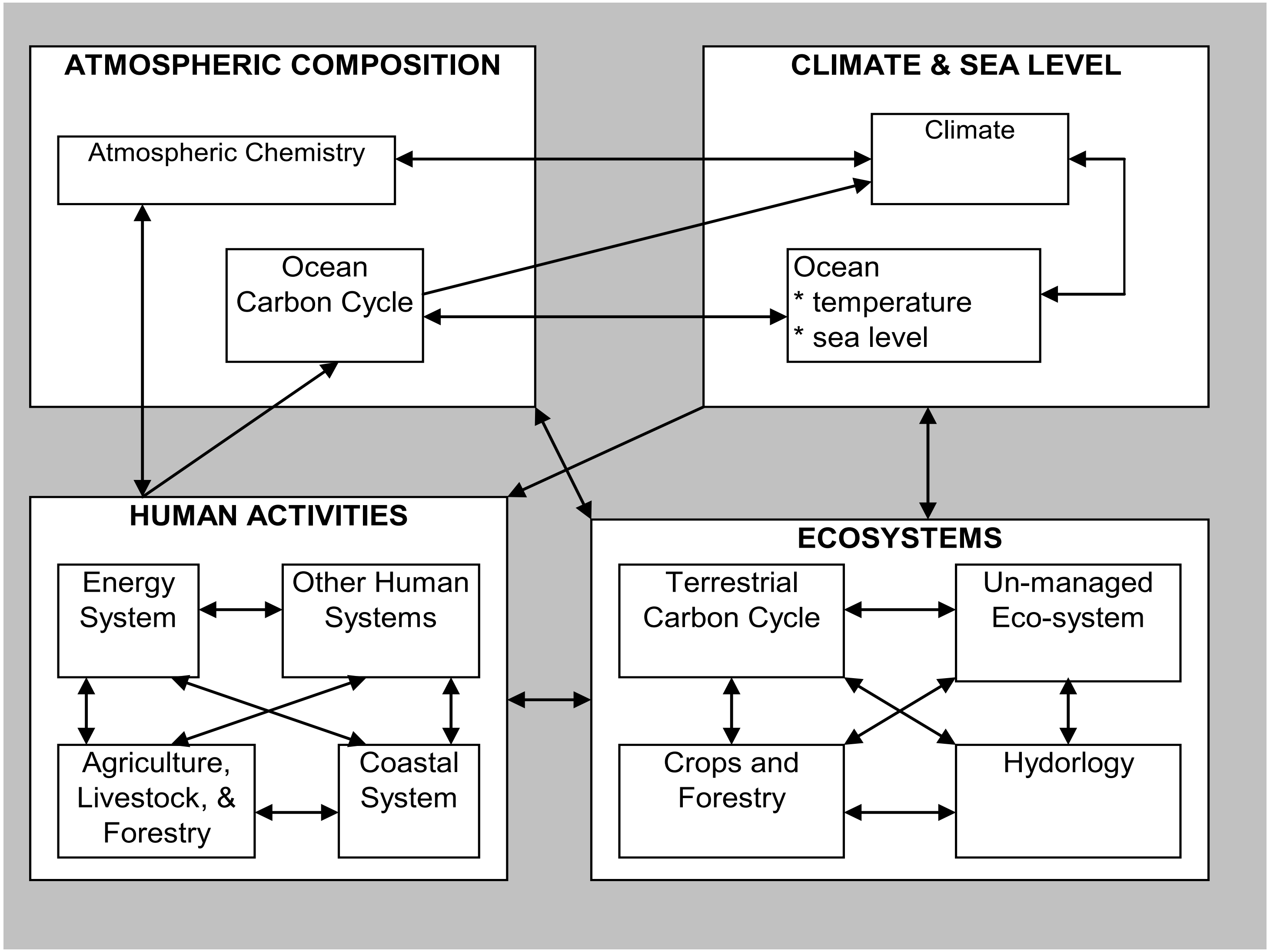
Outline

- What is Integrated Assessment?
- Contributions of Integrated Assessment
- Two Modes of Integrated Assessment
- Examples of Integrated Assessment
- Approaches to Uncertainty Analysis
- Approaches to Setting Policy Objectives
- Natural and Social Science Perspectives

What is Integrated Assessment? (USGCRP/ Edmonds, Early 1990s)



What is Integrated Assessment?

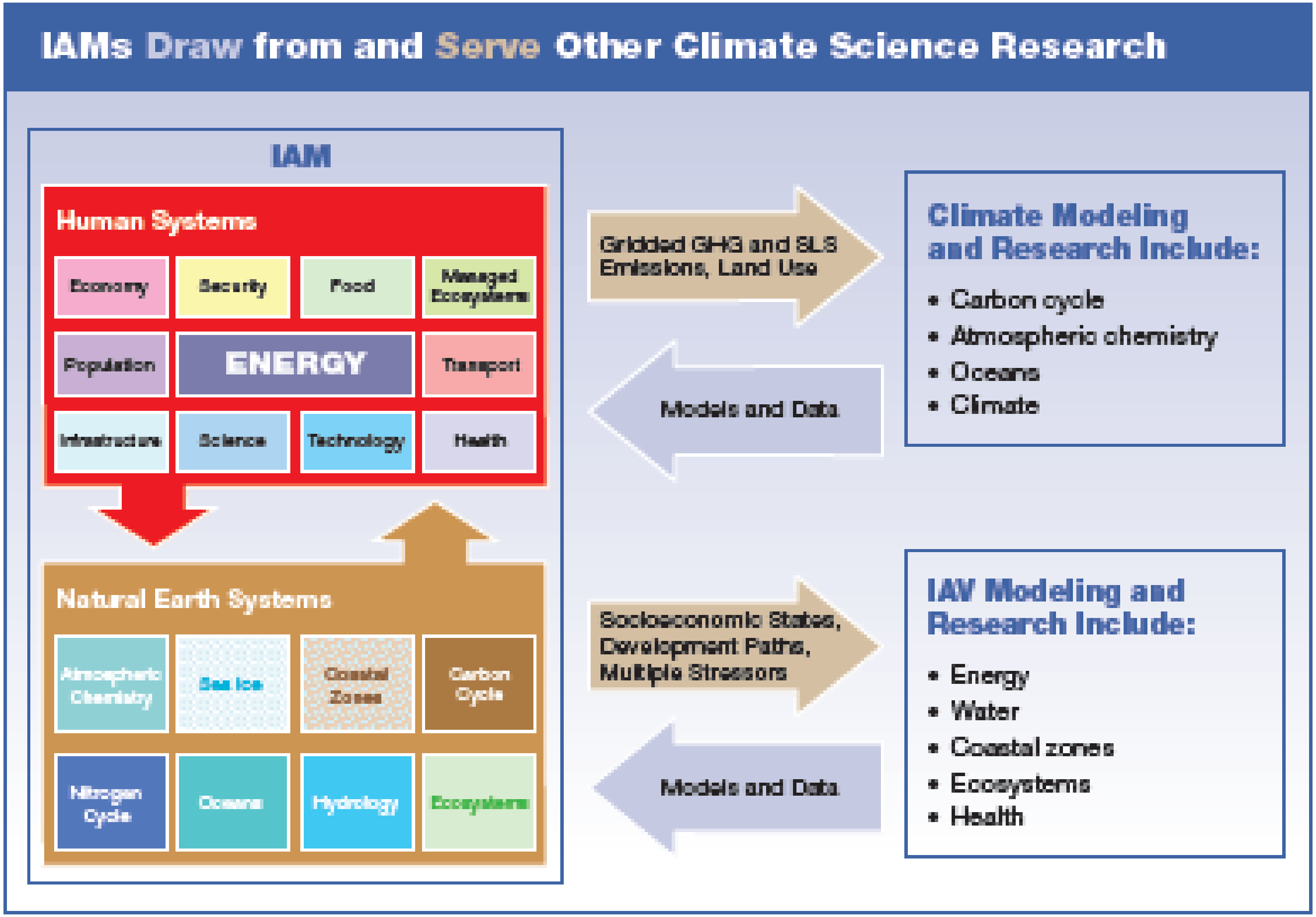
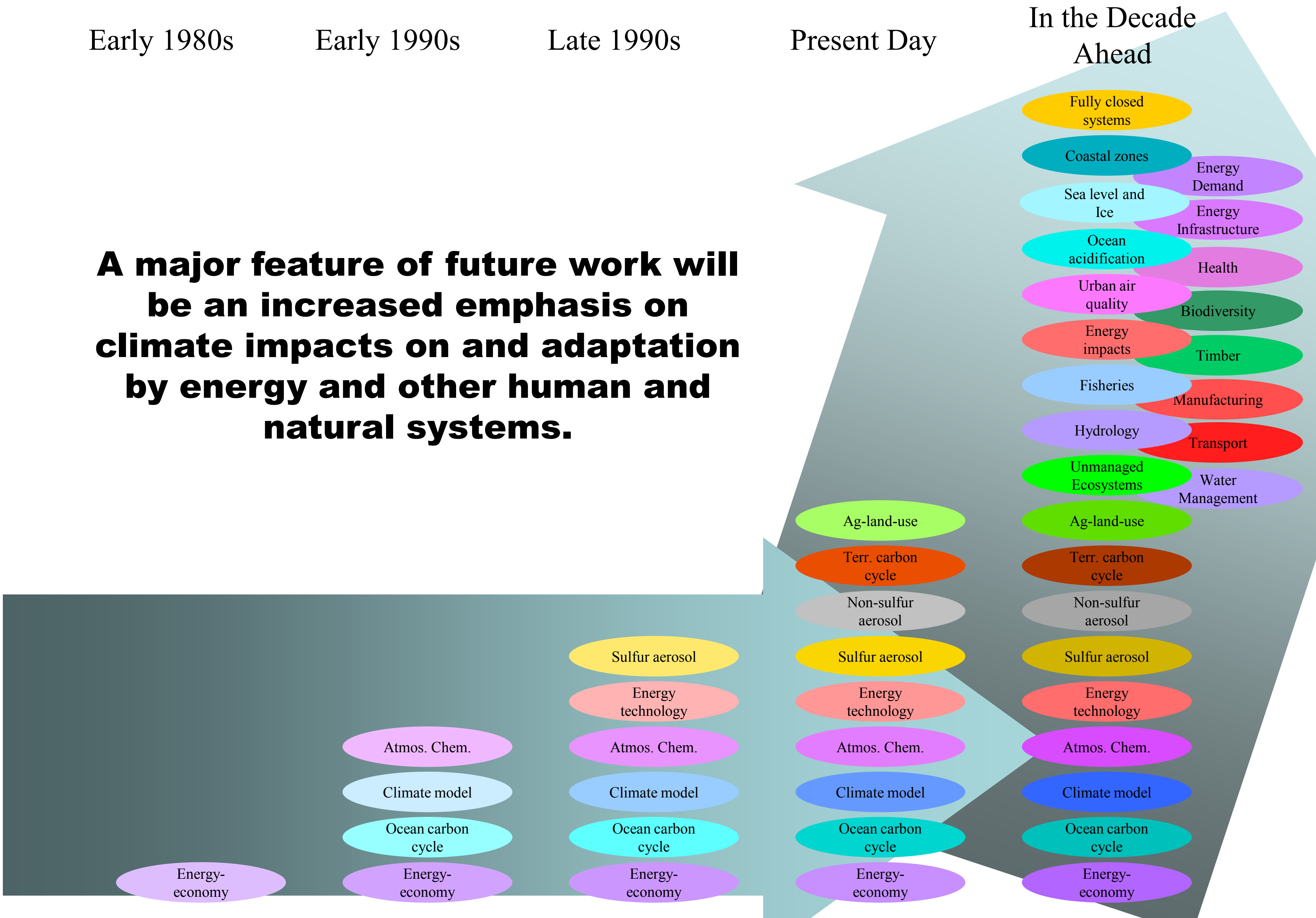


Fig. 1.1. Integrated Assessment Models (IAMs) Draw from and Serve Other Climate Science Research. IAMs include representations of climate, using models and data generated by the climate modeling and research community, and Earth systems, using models and data generated by the impacts, adaptation, and vulnerability (IAV) modeling and research community. In turn, IAMs provide to the climate modeling community emissions scenarios of greenhouse gases (GHGs) and short-lived species (SLS) and land-use projections. IAMs provide to the IAV modeling community projections of socioeconomic states, general development pathways, and the multiple stressors of climate change.

Evolution of IA (Edmonds)

A major feature of future work will be an increased emphasis on climate impacts on and adaptation by energy and other human and natural systems.



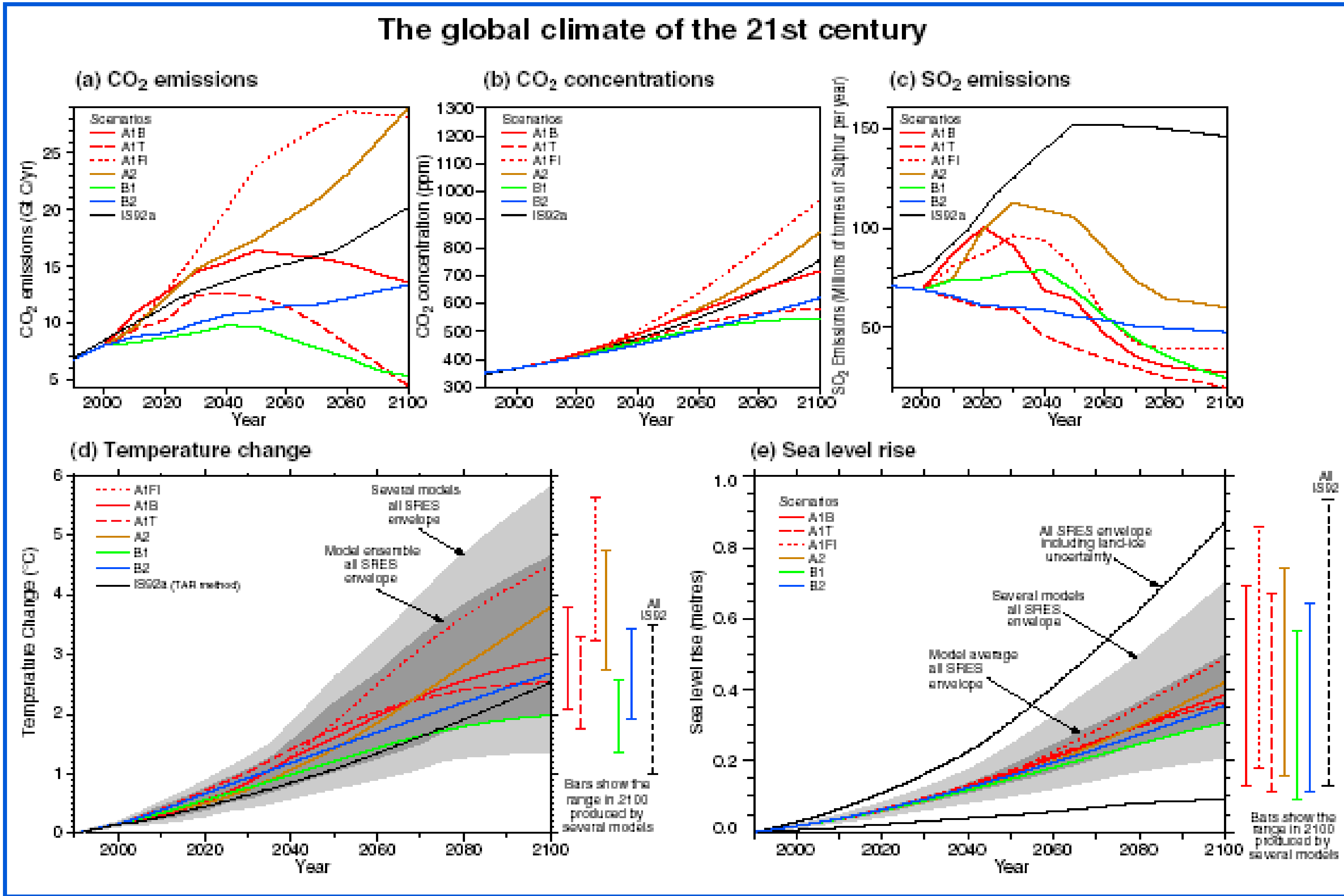
Contributions of Integrated Assessment

- Internal Consistency Checks
- Insights Like The Four Flexibilities
- Rough Numbers To Guide Policy Development
- Research Prioritization
- Put Probabilities on Future Climate Outcomes

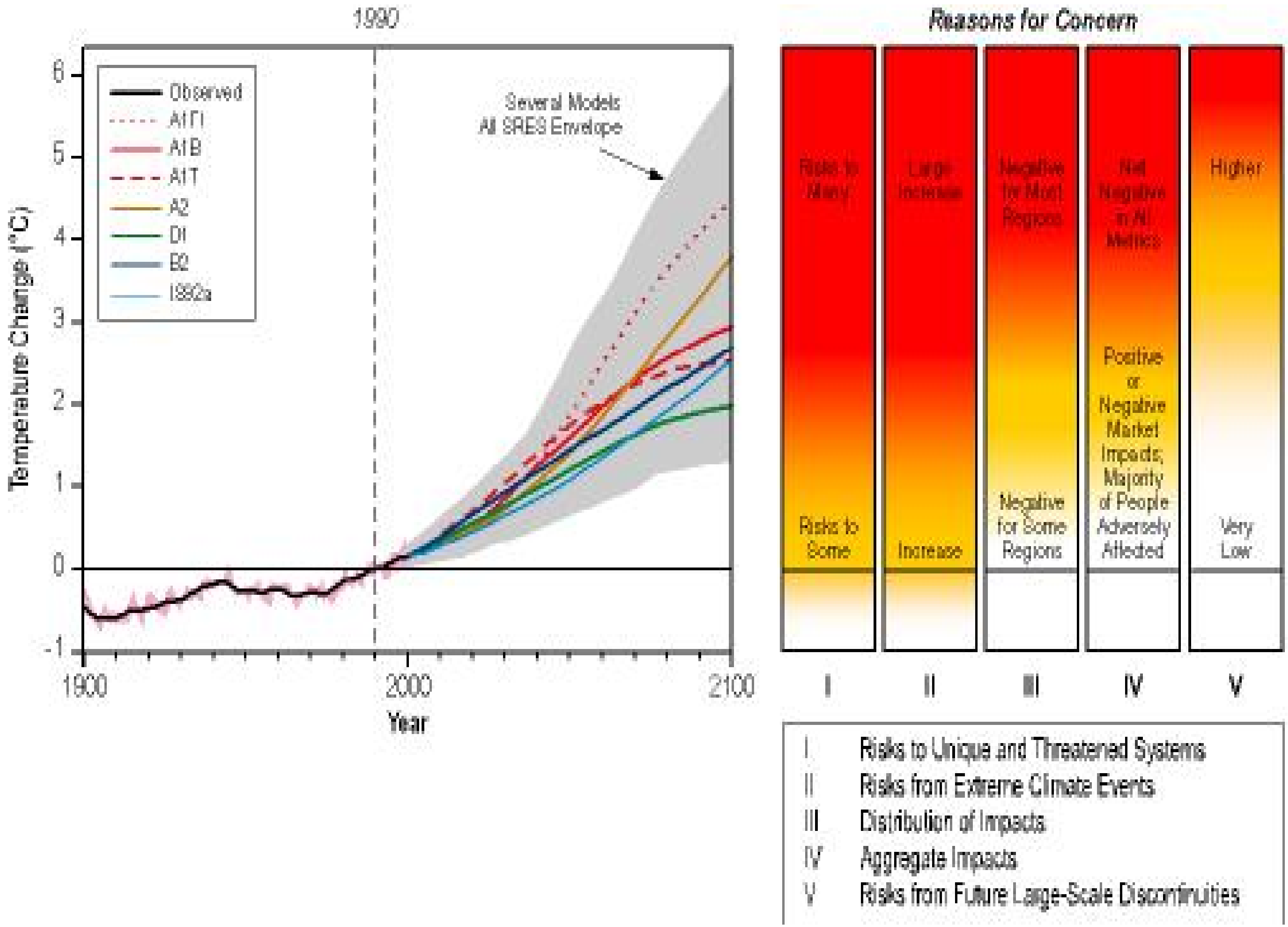
Two Modes of Integrated Assessment

- Policy-Oriented Simulations
  - Focused on Simulating Effects of Policies
  - Usually Much More Detailed Impacts
  - Can be Run Backwards - Tolerable Windows Approach
- Cost-Benefit Modeling
  - Focused on Finding "Optimal" Level of Emissions
  - Usually Include Impacts at the Aggregate Level
  - Can Be Run In Cost Effectiveness Mode

Example #1: IPCC "Meta Simulation"



Example #1: IPCC "Meta Simulation" Flaming Embers



Example #1: IPCC "Meta Simulation"

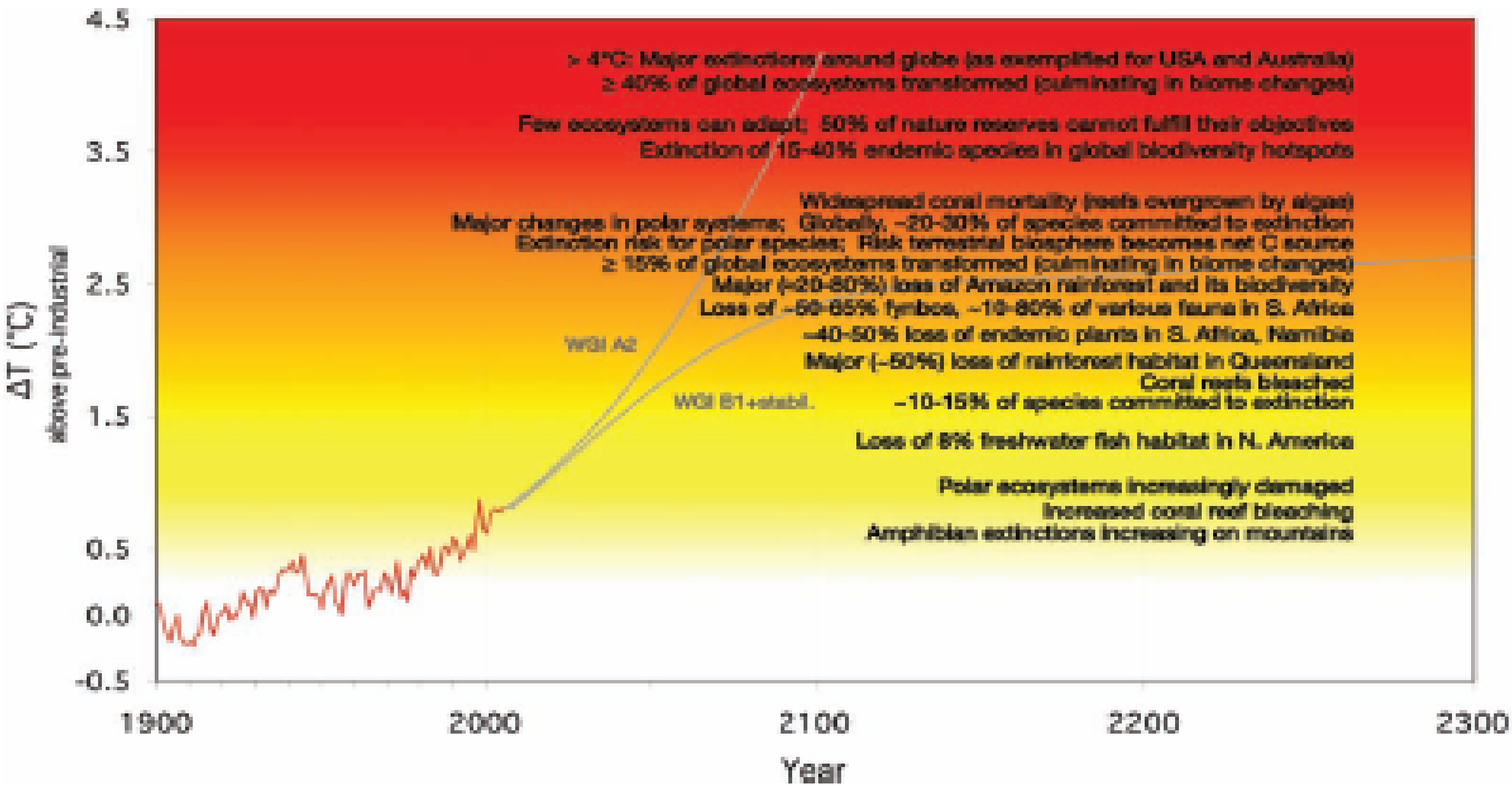
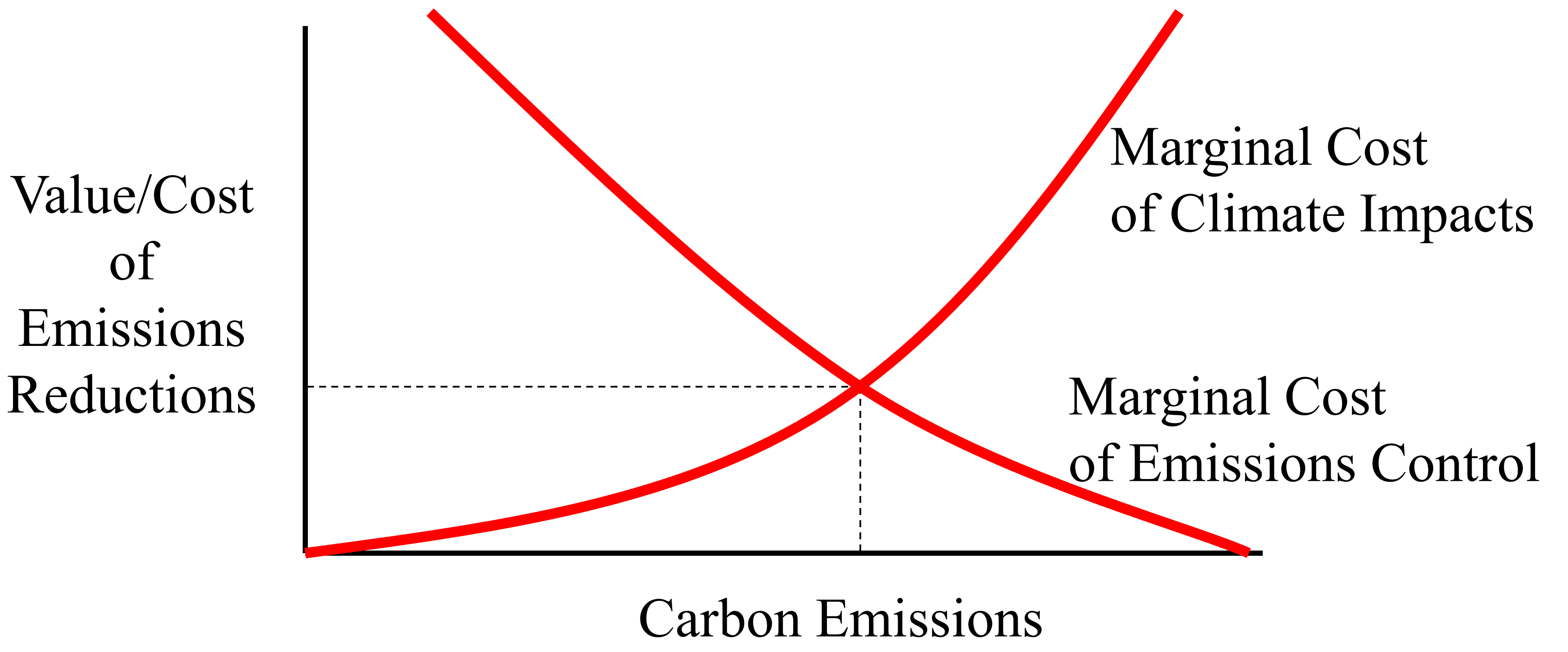


Figure TS.6. *Compendium of projected risks due to critical climate change impacts on ecosystems for different levels of global mean annual temperature rise, ΔT, relative to pre-industrial climate, used as a proxy for climate change. The red curve shows observed temperature anomalies for the period 1900-2005 [WGI AR4 F3.6]. The two grey curves provide examples of the possible future evolution of global average temperature change (ΔT) with time [WGI AR4 F10.4] exemplified by WGI simulated, multi-model mean responses to (i) the A2 radiative forcing scenario (WGI A2) and (ii) an extended B1 scenario (WGI B1+stabil.), where radiative forcing beyond 2100 was kept constant at the 2100 value [WGI AR4 F10.4, 10.7]. White shading indicates neutral, small negative, or positive impacts or risks; yellow indicates negative impacts for some systems or low risks; and red indicates negative impacts or risks that are more widespread and/or greater in magnitude. Illustrated impacts take into account climate change impacts only, and omit effects of land-use change or habitat fragmentation, over-harvesting or pollution (e.g., nitrogen deposition). A few, however, take into account fire regime changes, several account for likely productivity-enhancing effects of rising atmospheric CO_2, and some account for migration effects. [F4.4, T4.1]*

Cost/Benefit Modeling Approach:

Balancing the Costs of Controlling Carbon Emissions Against the Costs of the Climate Impacts They Cause



Example# 2: C/B Results From Nordhaus "A Question of Balance" Book 7/2008

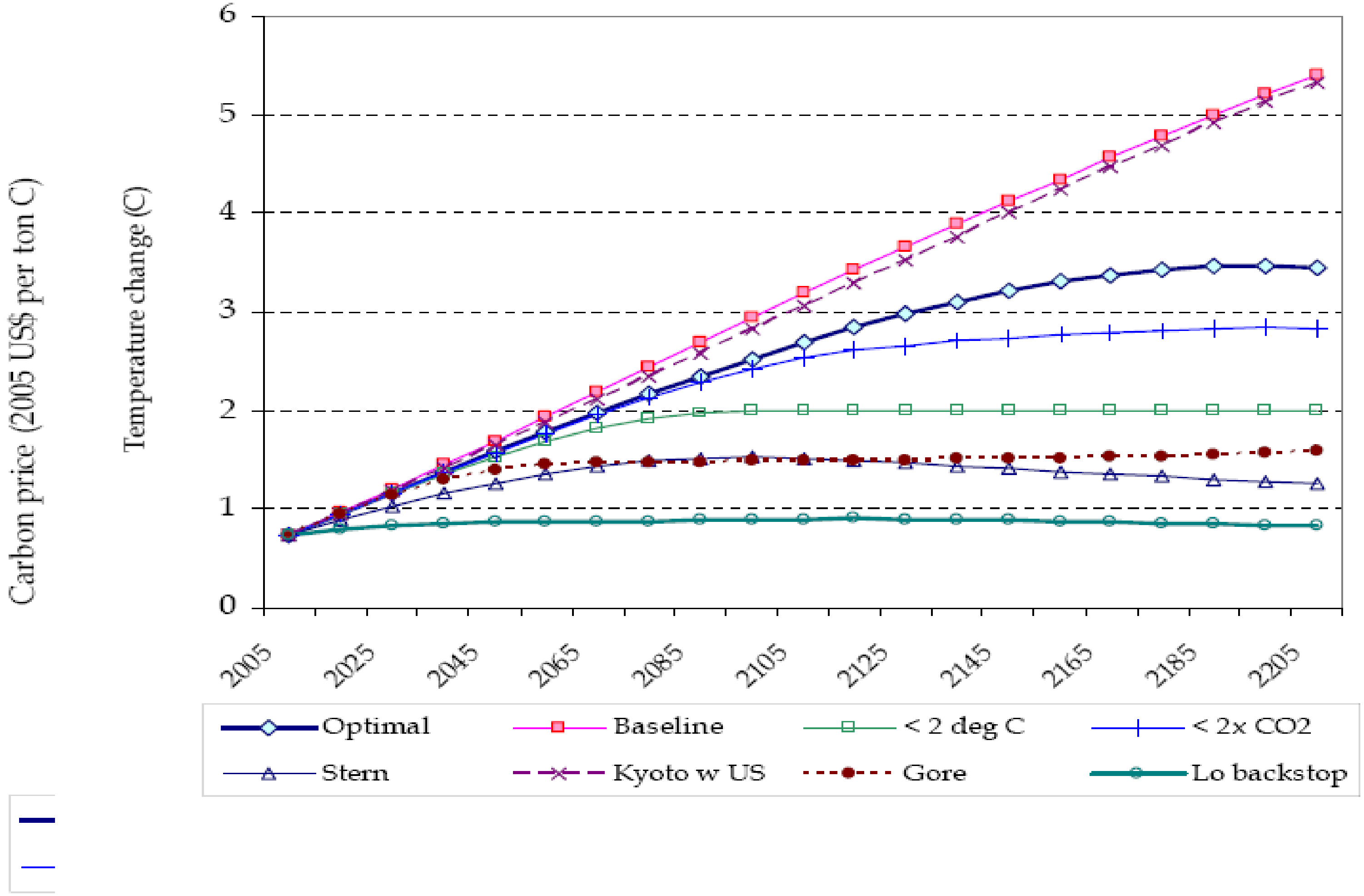


Figure V-8. Projected global mean temperature change by policy

Figure V-4. Carbon prices for different strategies

Example# 2: C/B Results From Nordhaus "A Question of Balance" Book 7/2008

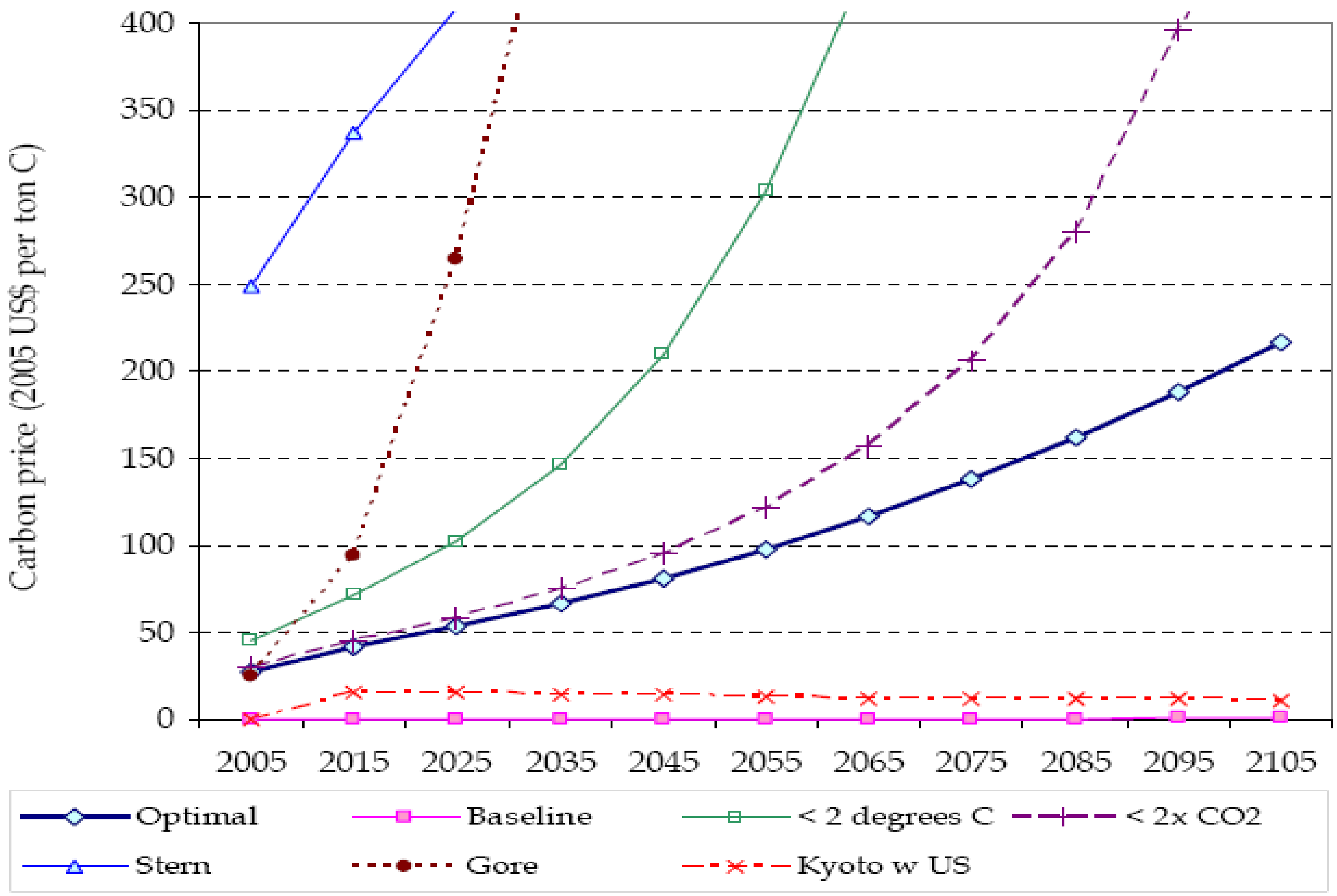


Figure V-4. Carbon prices for different strategies

Four Kinds of
Mitigation Policy Flexibilities

1. Where Flexibility
2. When Flexibility
3. How Flexibility
4. What Flexibility

Example #3: Merge-Flexibility Analysis

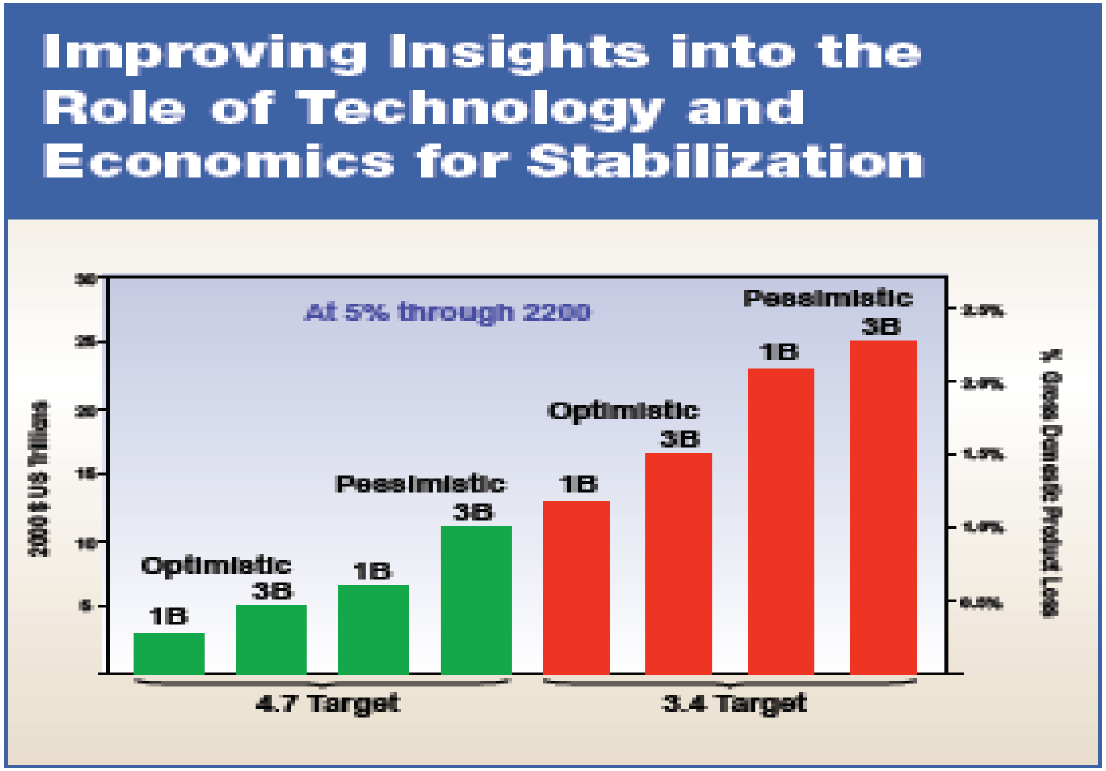


Fig. 3.6. Improving Insights into the Role of Technology and Economics for Stabilization. This figure, from analyses conducted using the MERGE model, shows the costs of mitigation for meeting different long-term climate goals with different assumptions about technology evolution and the degree of international participation in climate mitigation (first-best and third-best options). In this way, IA modeling provides insights into the consequences of approaches to climate mitigation and technology evolution. It demonstrates that improved technologies can have strong consequences for the economic costs of meeting climate goals. Source: Richels et al. 2007.

Example #4: PNNL MiniCAM Land/Biofuels

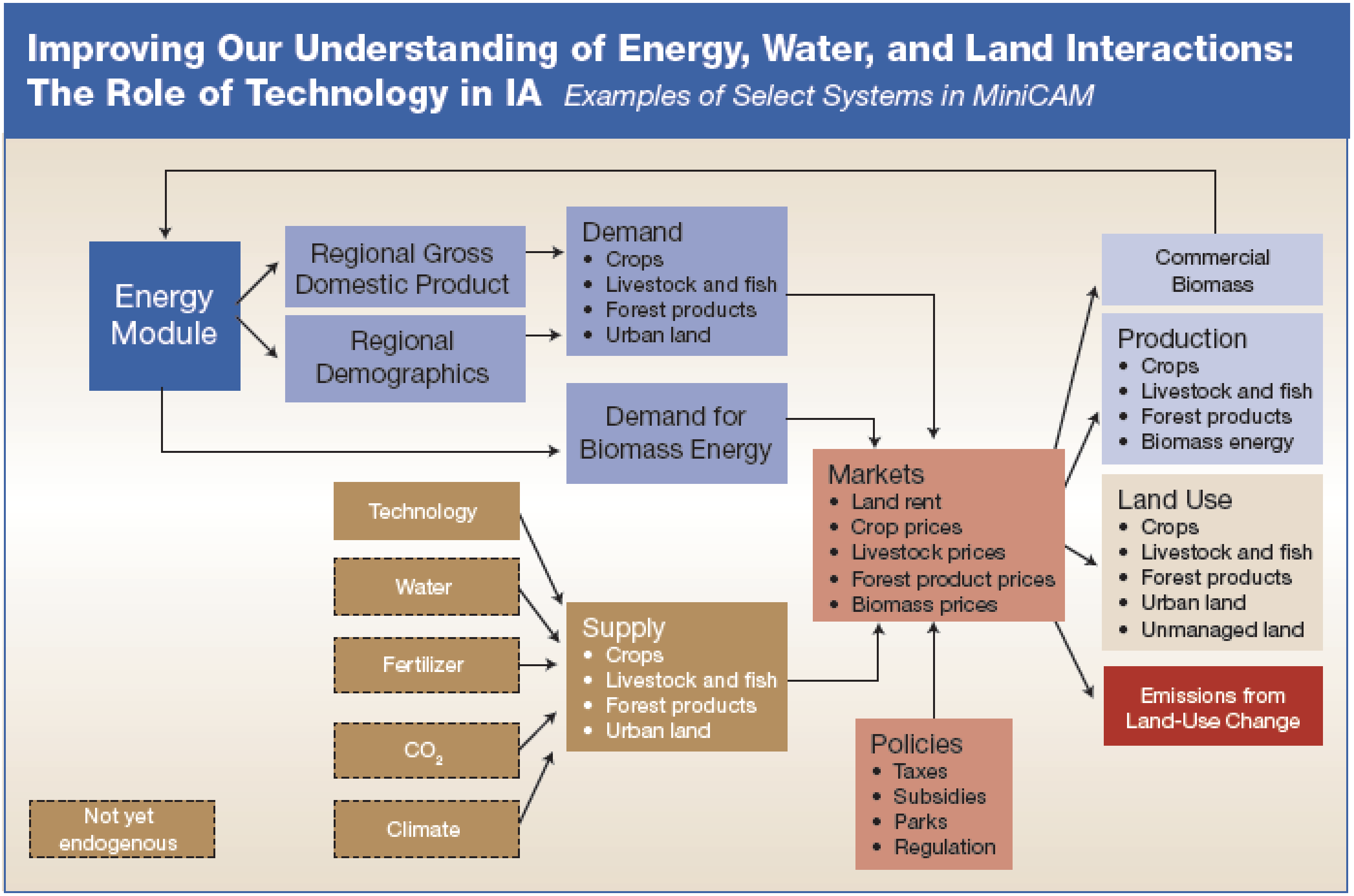
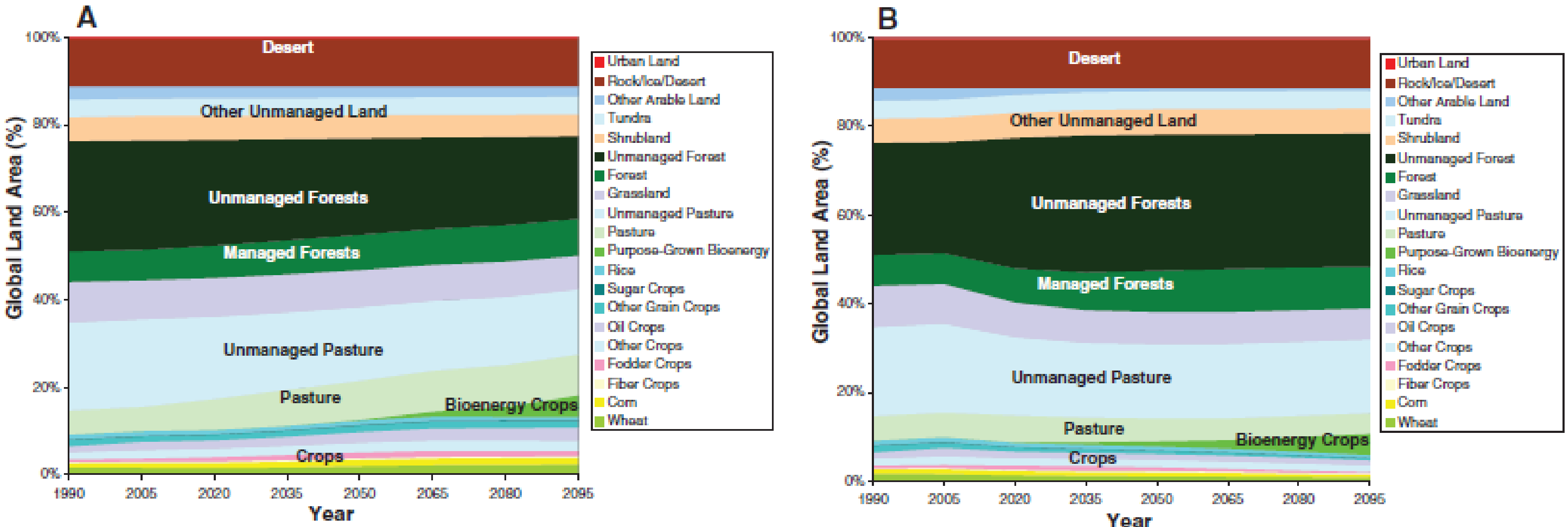


Fig. 3.2. Improving Our Understanding of Energy, Water, and Land Interactions: The Role of Technology in IA. The MiniCAM modeling system is built and maintained by the Joint Global Change Research Institute, a partnership of PNNL and the University of Maryland at College Park.

Example # 4: PNNL MiniCAM Land/Biofuels



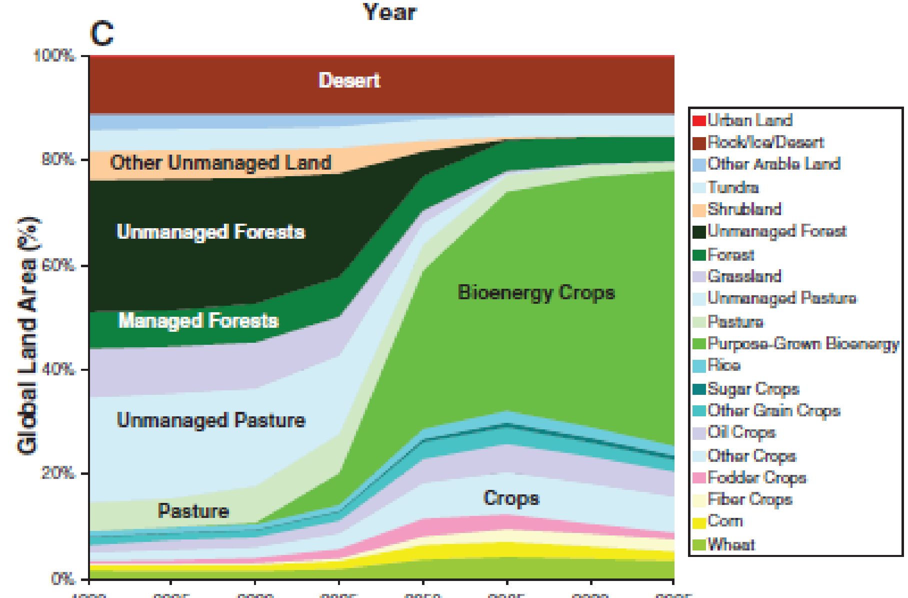


Fig. 2. A comparison of global land use under different scenarios. (**A**) Land use along the reference pathway. (**B**) Land use under a UCT pathway defined to achieve a CO_2 concentration target of 450 ppm, which limits fossil fuel, industrial, and terrestrial carbon emissions with a common carbon tax on emissions. (**C**) Land use along the corresponding FFICT scenario in which only fossil fuel and industrial emissions are controlled to achieve the same 450-ppm CO_2 concentration. In the FFICT scenario, the substantial increase in demand for purpose-grown biomass (four times as much as the reference scenario in Year 2095) intensifies its competition with food and fiber crops for the best cropland, pushing crops and biomass growth beyond traditional croplands and into lands that are inherently less productive. As a result, the relative increase in land required for biomass and other crops exceeds the relative increase in demand.

Example #5 - MIT IGSM

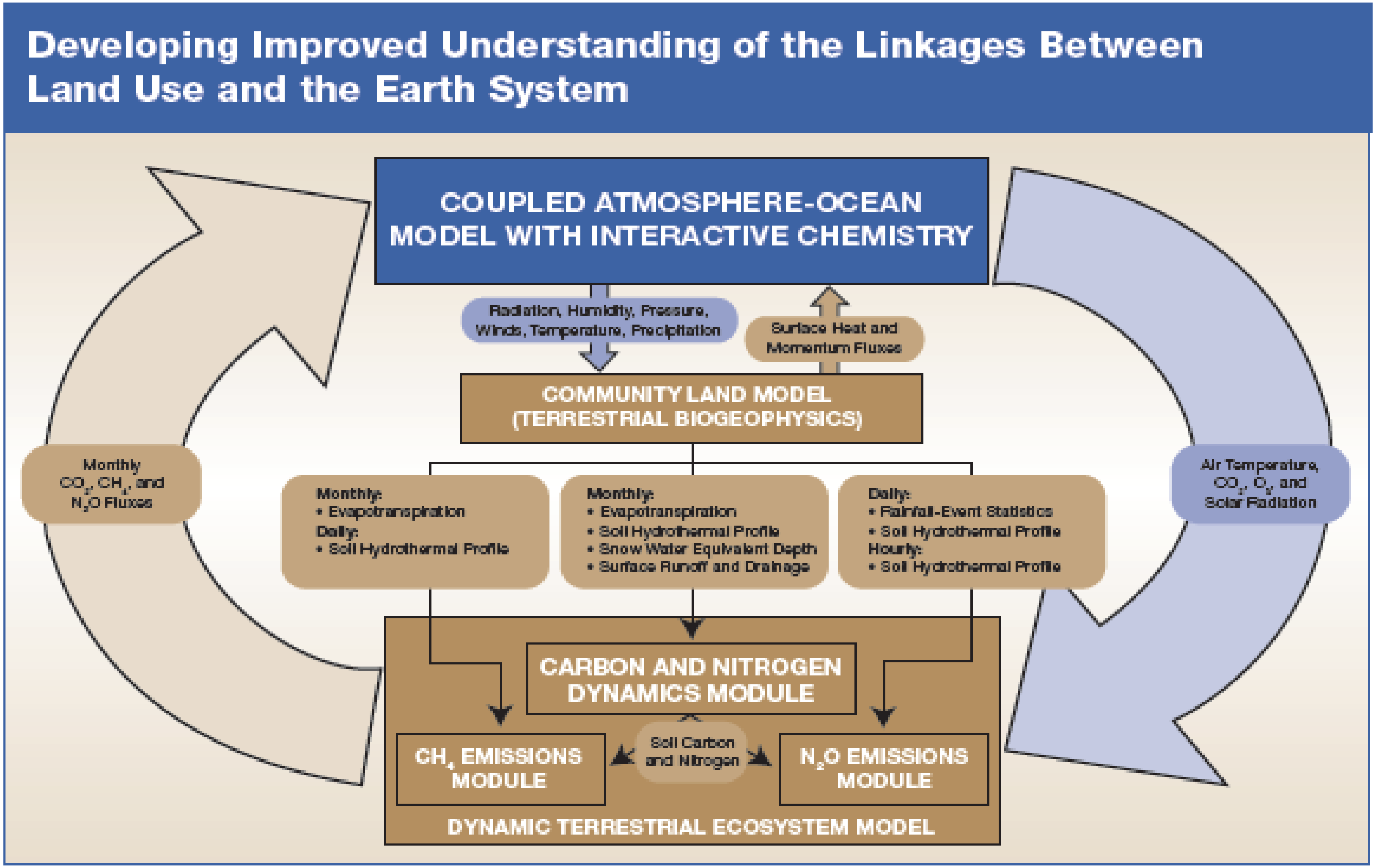


Fig. 3.7. Developing Improved Understanding of the Linkages Between Land Use and the Earth System. This figure shows the interactions and feedbacks between the atmosphere-ocean system and terrestrial biosphere, as represented in the Massachusetts Institute of Technology's (MIT's) IGSM. The atmospheric model provides climate variables to the community land model, adapted from a version developed by the National Center for Atmospheric Research, that feeds heat and moisture fluxes back to the atmosphere. A terrestrial ecosystem model receives data on soil conditions and other factors from the community land model and atmospheric submodels and computes CO_2 fluxes and the natural emissions of two non-CO_2 GHGs: CH_4 and N_2O. Fluxes of those gases then are fed back to the coupled atmosphere-ocean model. These interactions are computed on different time steps depending on the nature of the terrestrial processes.

Example #5 - MIT IGSM

Exploring the Regional Consequences of a Changing Climate on the Terrestrial Environment

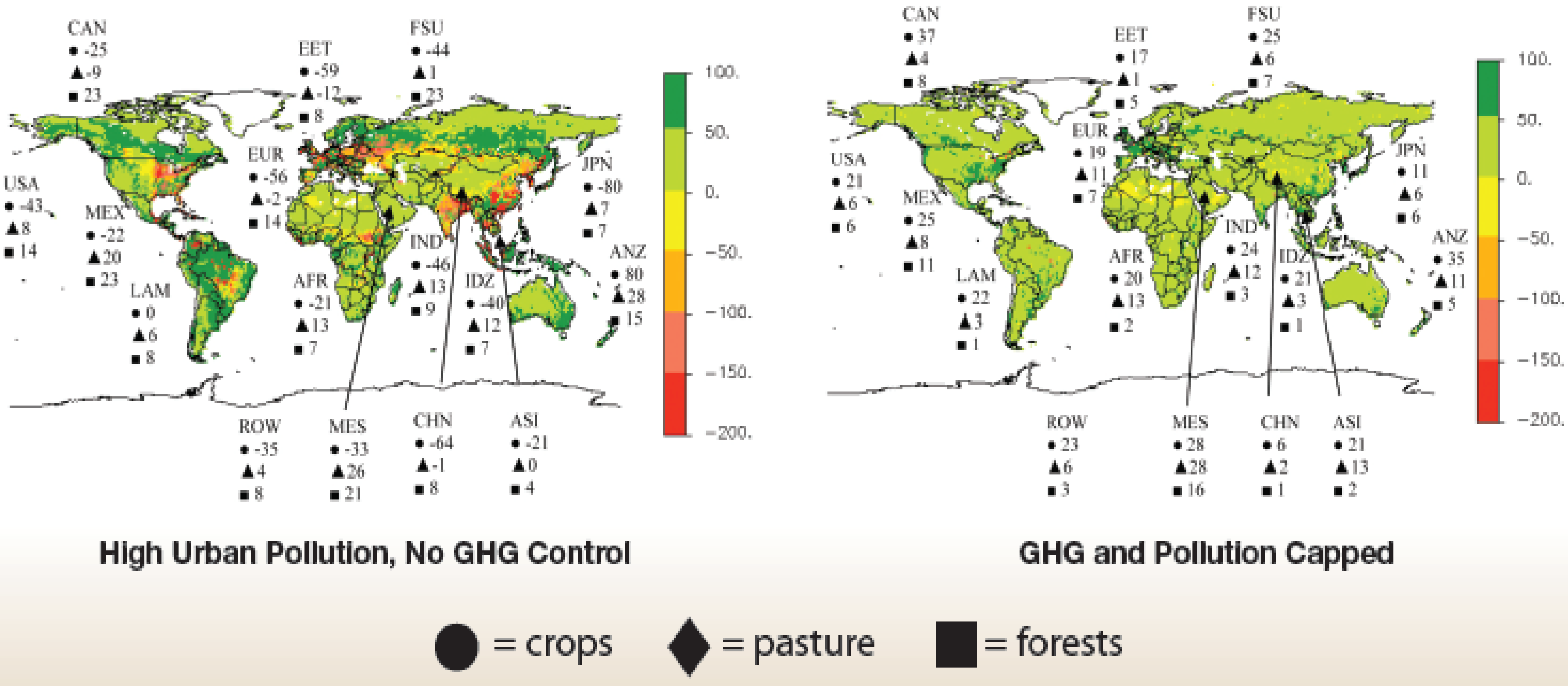


Fig. 3.9. Exploring the Regional Consequences of a Changing Climate on the Terrestrial Environment. Crop, pasture, and forest productivity are influenced significantly by climate change, CO_2 fertilization, and damage from ozone resulting from urban air pollution. For each of the economic regions in MIT's IGSM, the figures show the effects on yield (crops) and net primary productivity (pasture and forestry) between 2000 and 2100 (gC/m^2/yr).

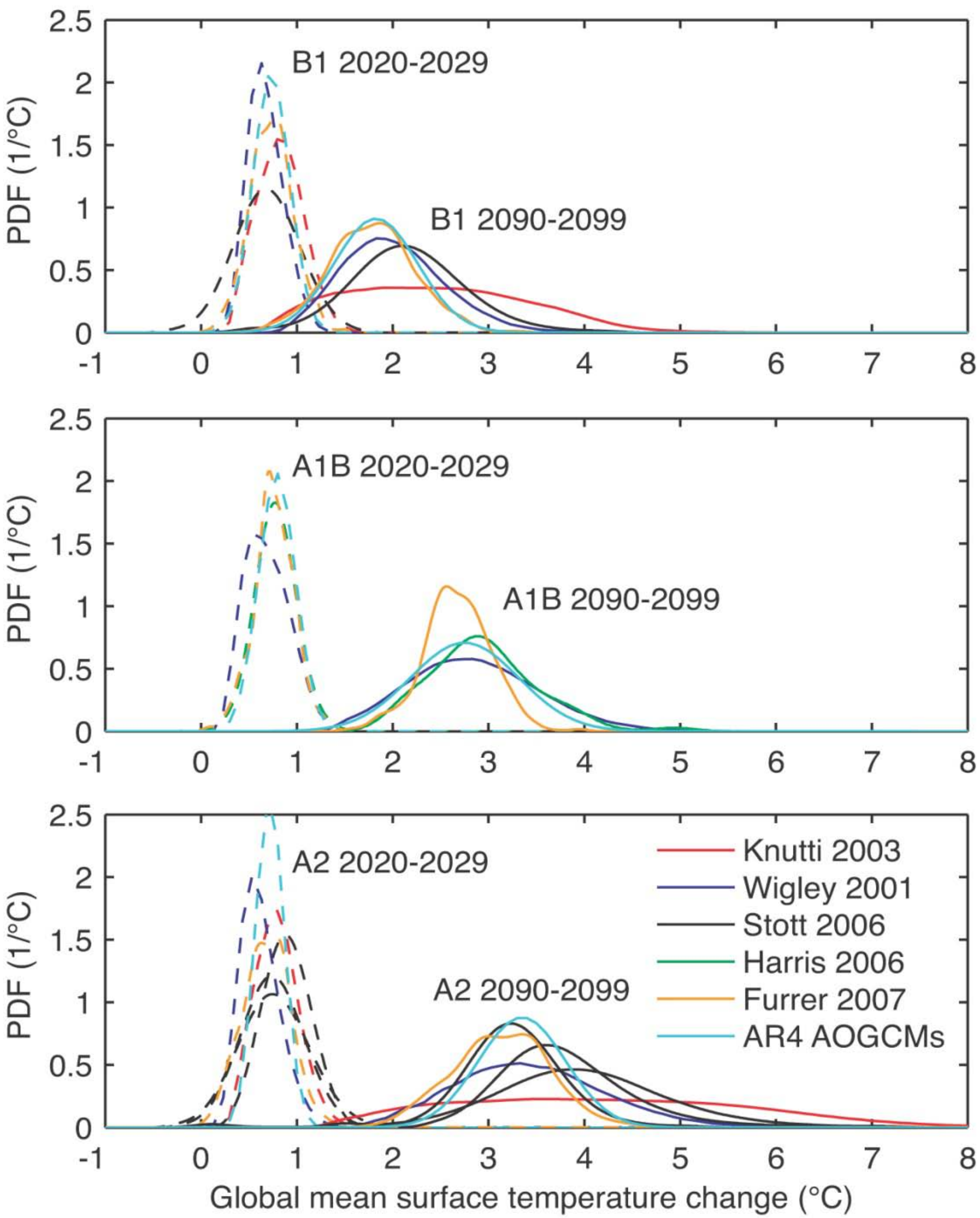
Approaches to Uncertainty Analysis

- Sensitivity Analysis
- Stochastic Simulation
- Decision Making Under Uncertainty
  - Sequential DMUU
  - Decision Analysis
  - Stochastic Control
  - Robust Planning

Four Interdependent Elements of Any Uncertainty Analysis

- Formulation
  - Who knows what, when, and what can they do with that info.
  - Information structure, dynamics, and stochastics
- Probability Assessment
  - Statistical
  - Subjective
  - Combinations
- Computation
  - Software and hardware
  - Simulation and optimization
- Interpretation and communication of results
  - Many dimensions for inputs, policies and outputs
  - Need for focusing on needs of decision makers grows exponentially
- These elements need to be designed and implemented together

IPCC AR4 PdFs Given Emissions



MIT Joint Emissions & Climate PdFs

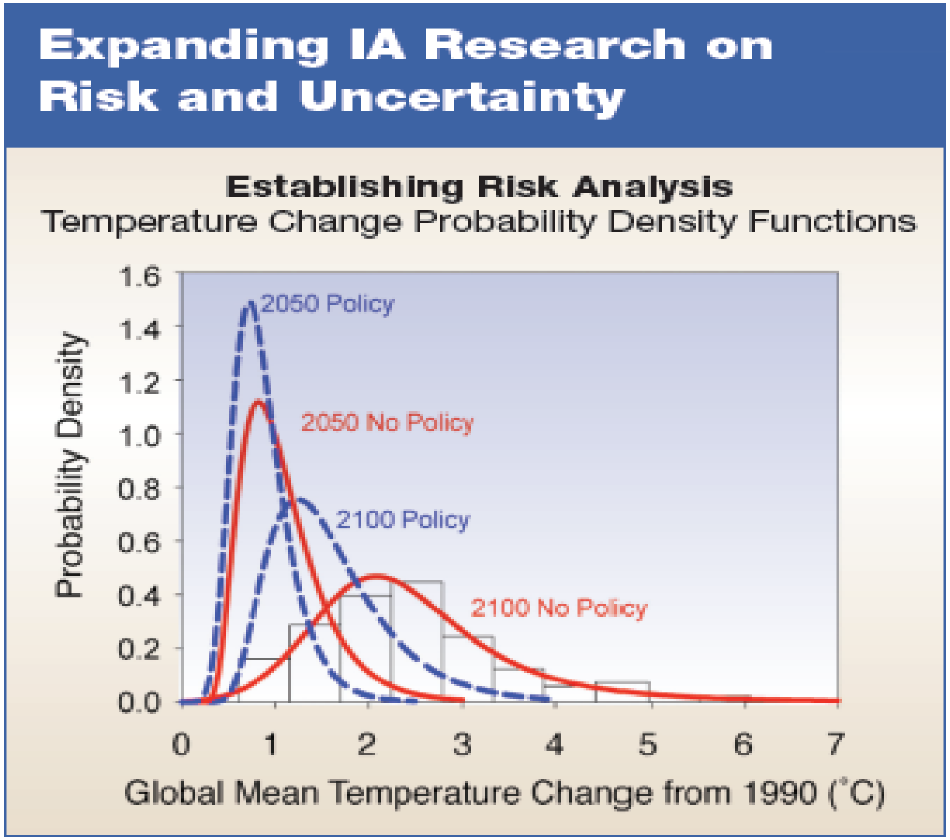
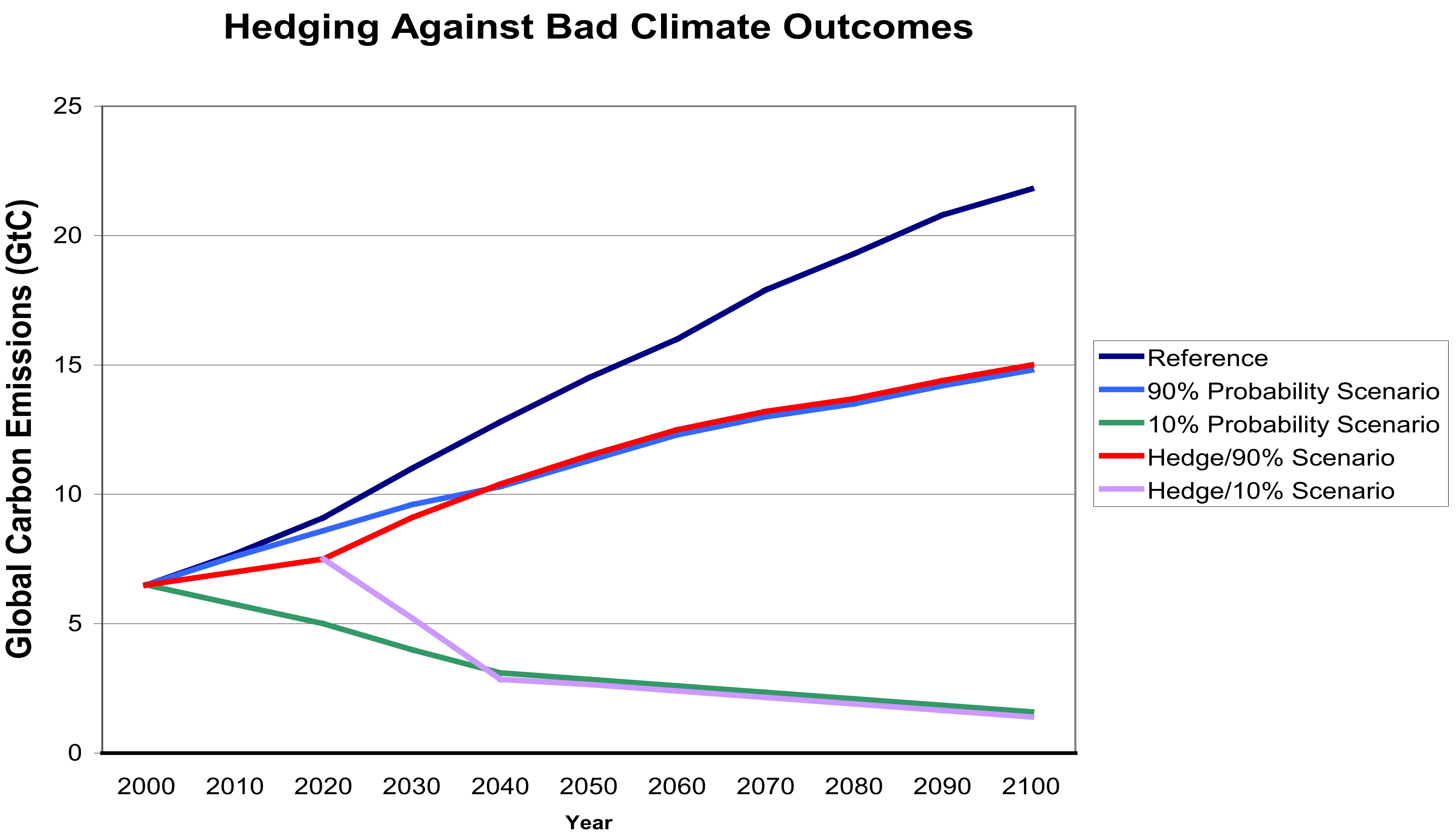


Fig. 4.4. Expanding IA Research on Risk and Uncertainty. Research at the MIT Joint Program on the Science and Policy of Global Change has explored the implication of uncertainty in human and natural systems. By applying methods to systematically sample potential combinations of IAM inputs, this research evaluates literally thousands of potential futures. One such exercise, illustrated in the figure, shows the results of these scenarios with a hypothetical "climate policy" imposed as a tax over varying time frames. The climate policy led to reduced GHG emissions, which in turn reduced the concentration of GHGs and Earth surface temperatures. These early efforts by this one modeling research team are paving the way for a new way to think about modeling risks within the IA community. Source: Webster et al. 2003

Decision Analysis Approach



Approaches to Setting Climate Policy Objectives

- Cost Effective Analysis- Careful Choice of Target(s) and Then Minimize Costs to Achieve It
- Formal Cost/Benefit Analysis
- Sequential Decision Making Under Uncertainty
  - Decision Theory Based
    - Hard to Implement
    - Get Value of Information About Key Uncertainties
  - Less Comprehensive Approaches
    - Tolerable Windows
    - Robust Planning Methods
    - Tolerable Windows With Cost Effectiveness Iteration
    - Evolutionary Theory Based Approaches-Simple Rules

Some Things We Find in Economics, But Not in Natural Sciences

- Preferences (possibly changing over time)
- Expectations (certainly changing over time)
- The ability to make contingent decisions
- These characteristics may lead to differences in:
  - Framing questions
  - Modeling systems
  - Integrating models
  - Assessing models

Two Different Objectives: Forecast Accuracy Versus Policy Insights

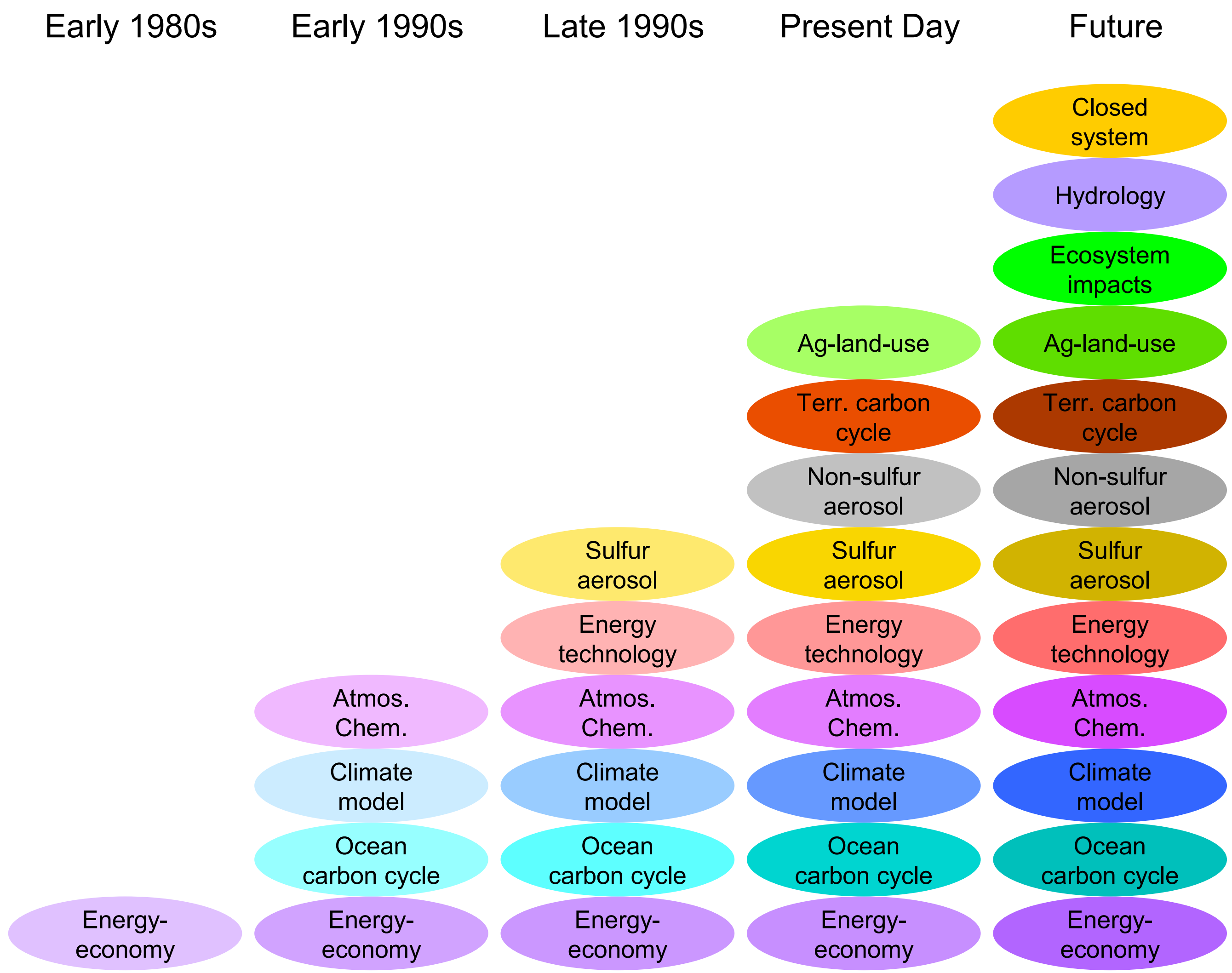
- “Science community” has focused more on forecast accuracy and uncertainty measurement.
- “IA community” has focused more on policy insights, and uncertainty characterization.
- These different perspectives have lead to very different ways of operating.
- The RCP approach may be a model for how to bridge the gap in a useful way.

Possible To IAM Do List

- Appreciate/use the insights we are already getting from IAMs.
  - To guide science priorities.
  - In a way that guides policy development.
- Apply appropriate science community validation & uncertainty measurement techniques to science modules of IAMs.
- Develop better ways to project and characterize uncertainty regarding socio-economic drivers and structural elements of IAMs.
- Develop a more integrated argument for employing a sequential decision making under uncertainty framework for deciding what to do about climate change.
- Develop strategies for integrating IAV concerns/ interests into the process.
  - Gridded socio-economic data from IAMs?
  - Further vulnerability analyses?
  - Develop strategic plan for where to focus first, second, etc.?
  - Uncertainty and validation methods.
  - Regional IAMs

Thank You!

Evolution of IA Modeling



Source: J. Edmonds - JGCRI

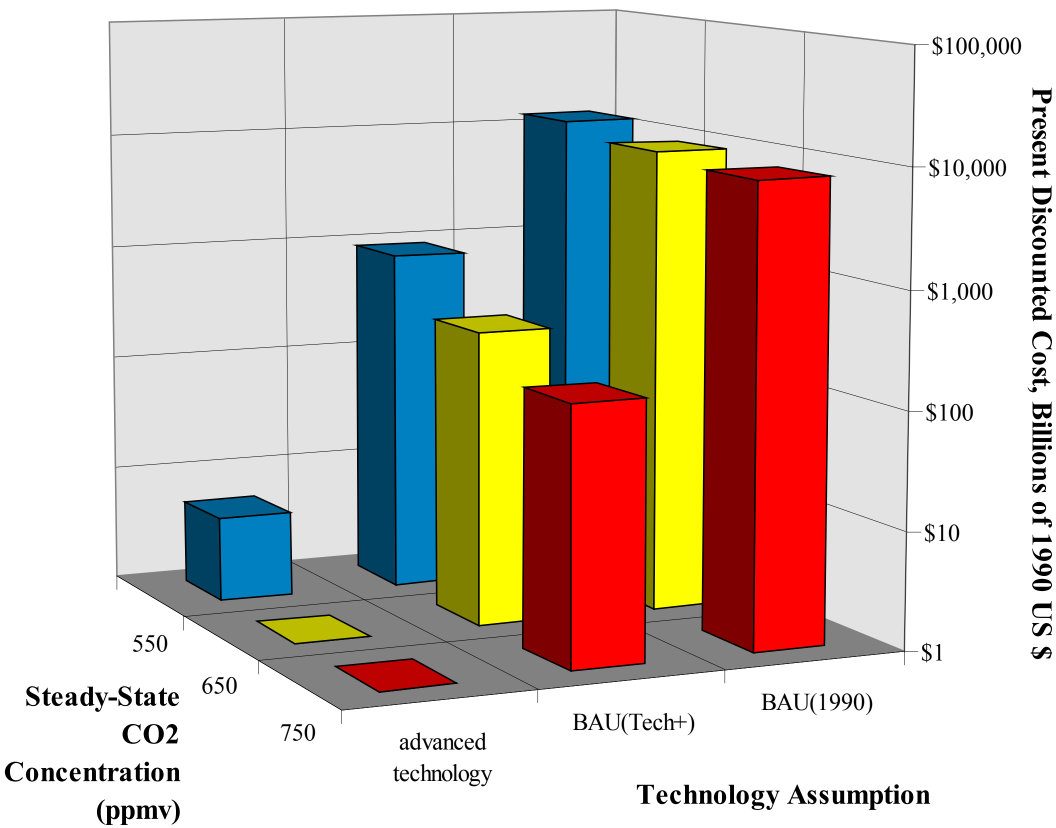
Some Areas Where Some Integration Has Proven Useful

- Biological Sinks
- CO_2 Fertilization
- Sulfate Aerosols
- Biofuels Assessments
- Health Impact Assessments

3. How Flexibility

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

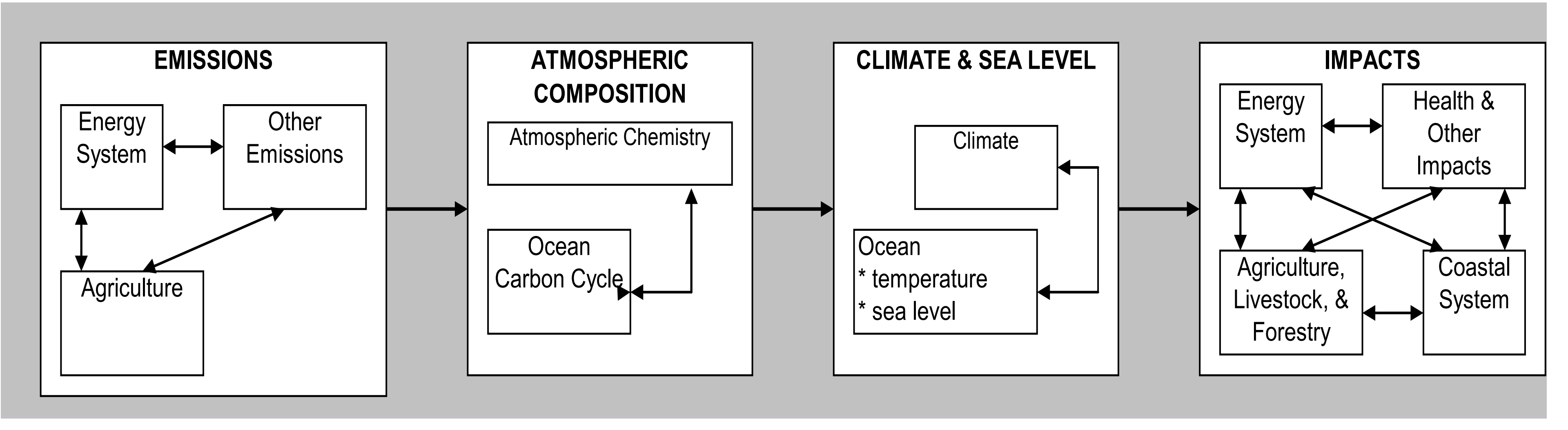
What is Integrated Assessment of Climate Change Policy?

- Many definitions of IA for many purposes
- Here we call integrated assessment of climate change policy any attempt to bring together the costs and benefits of climate change policies in a systematic manner

Background Questions

- Why assess?
  - Need insights and numbers for policy development
- Why model?
  - Consistency
  - Insights
  - Learning
  - Rough numbers +sensitivities
- What principles to use?
  - Disciplinary differences
  - What is empirical evidence?
- How should models be evaluated?
  - Backcasting
  - Model assessment
- Who decides these things?
  - Disciplines, national academies, lawyers, us

End to End Approach to Integrated Assessment



Types of
Integrated Assessment Models

Deterministic Models

Deterministic Policy Optimization Models	Deterministic Policy Evaluation Models

Decision Making Under Uncertainty Models

Stochastic Policy Optimization Models	Stochastic Policy Evaluation Models

Uses Of Integrated Assessment Models

Deterministic Models

Deterministic Policy Optimization Models

- Compute Optimal Carbon Taxes, Control Rates, etc.
- Calculate Costs of Meeting Emission/ Concentration/Climate/Impact Targets

Deterministic Policy Evaluation Models

- Insure Consistency in Assumptions
- Assess Interactions and Feedbacks
- Identify Critical Gaps in Research

Decision Making Under Uncertainty Models

Stochastic Policy Optimization Models

- Assess Optimal Policies Under Uncertainty
- Compute Value of Information/Research

Stochastic Policy Evaluation Models

- Compute Probabilities of Cost/Benefits of Climate Policies
- Compute Probabilities of Meeting Targets

Components of Mitigation Costs

- Direct resource costs
- Indirect opportunity costs
  - Less of one commodity, but perhaps more of another
  - Can include shifts in industry structure
  - Can include trade impacts
- Economic growth impacts
  - Tied into capital accumulation
  - Also depends heavily on technological change
- Dis-eqilibrium impacts

Areas Where Climate Change Impacts Are Anticipated

MARKET

- Agriculture
- Forestry
- Sea Level Rise
- Water Supply
- Energy Consumption
- Fisheries
- Extreme Events/Insurance

NON-MARKET

- Unmanaged Eco-Systems
  - Terrestrial
  - Marine
- Human Health*
- Bio-Diversity*
- Wildlife
- Recreation*
- Amenities

*Some Market Components

And Then We Have The Bottom-Up Engineering Models: IPCC AR4 Global Mitigation Cost Estimates

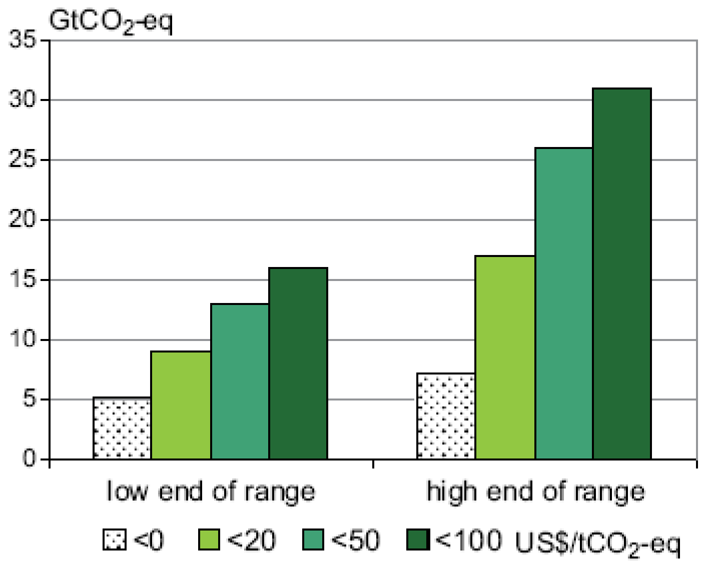


Figure SPM.5A: *Global economic mitigation potential in 2030 estimated from bottom-up studies (data from Table SPM.1)*

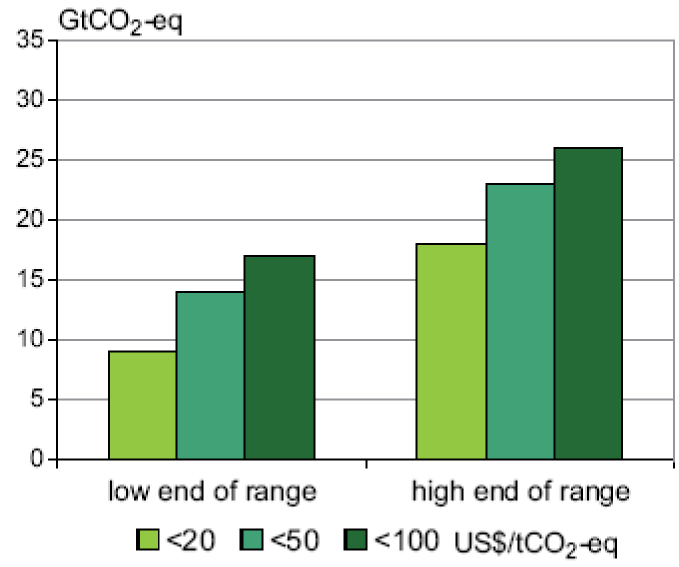


Figure SPM.5B: *Global economic mitigation potential in 2030 estimated from top-down studies (data from Table SPM.2)*

A Range of Approaches to Projecting Mitigation Costs

Table 3.12: *Top-down models assessed for mitigation opportunities in 2030*

Model	Model type	Solution concept	Time horizon	Modelling team and reference
AIM (Asian-Pacific Integrated Model)	Multi-Sector General Equilibrium	Recursive Dynamic	Beyond 2050	NIES/Kyoto Univ., Japan Fujino *et al*., 2006.
GRAPE (Global Relationship Assessment to Protect the Environment)	Aggregate General Equilibrium	Inter-temporal Optimization	Inter-temporal Optimization	Institute for Applied Energy, Japan Kurosawa, 2006.
IMAGE (Integrated Model to Assess The Global Environment)	Market Equilibrium	Recursive Dynamic	Beyond 2050	Netherlands Env. Assessment Agency Van Vuuren *et al*., Energy Journal, 2006a. (IMAGE 2.2) Van Vuuren *et al*., Climatic Change, 2007. (IMAGE 2.3)
IPAC (Integrated Projection Assessments for China)	Multi-Sector General Equilibrium	Recursive Dynamic	Beyond 2050	Energy Research Institute, China Jiang *et al*., 2006.
MERGE (Model for Evaluating Regional and Global Effects of GHG Reduction Policies)	Aggregate General Equilibrium	Inter-temporal Optimization	Beyond 2050	EPRI & PNNL/Univ. Maryland, U.S. USCCSP, 2006.
MESSAGE-MACRO (Model for Energy Supply Strategy Alternatives and Their General Environmental Impact)	Hybrid: Systems Engineering & Market Equilibrium	Inter-temporal Optimization	Beyond 2050	International Institute for Applied Systems Analysis, Austria Rao and Riahi, 2006.
MiniCam (Mini-Climate Assessment Model)	Market Equilibrium	Recursive Dynamic	Beyond 2050	PNNL/Univ. Maryland, U.S. Smith and Wigley, 2006.
SGM (Second Generation Model)	Multi-Sector General Equilibrium	Recursive Dynamic	Up to 2050	PNNL/Univ. Maryland and EPA, U.S. Fawcett and Sands, 2006.
POLES (Prospective Outlook on Long-Term Energy Systems)	Market Equilibrium	Recursive Dynamic	Up to 2050	LEPII-EPE & ENERDATA, France Criqui et al., 2006.
WIAGEM (World Integrated Applied General Equilibrium Model)	Multi-Sector General Equilibrium	Inter-temporal Optimization	Beyond 2050	Humboldt University and DIW Berlin, Germany Kemfert *et al*., 2006.

Source: Weyant et al., 2006.

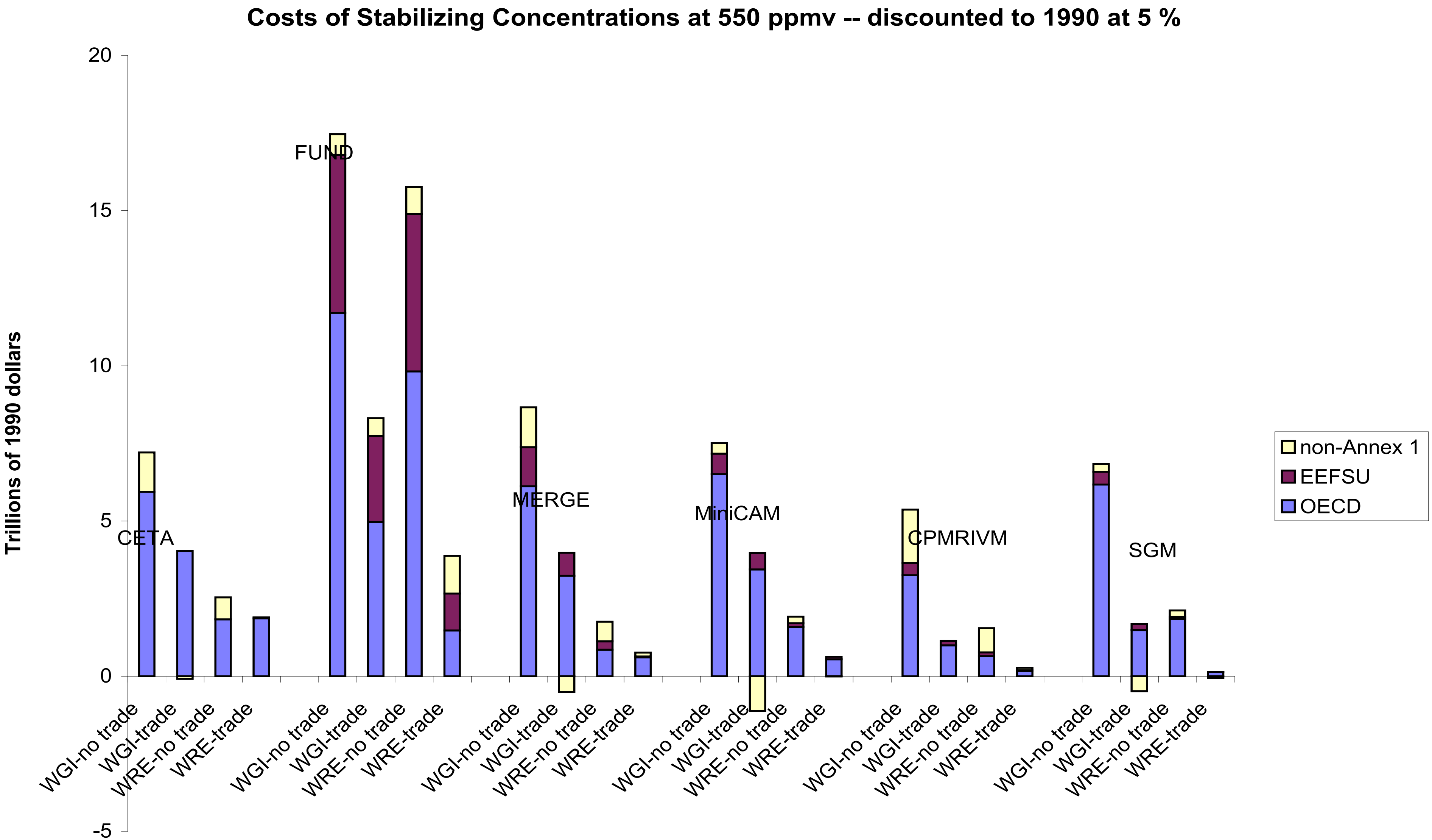
Frontiers in Integrated Assessment

- Coping with complexity
- Incorporating uncertainty
- Embracing technological change
- Integrating the sciences
- Synthesizing the impacts
- Promoting development

I. Coping With Complexity

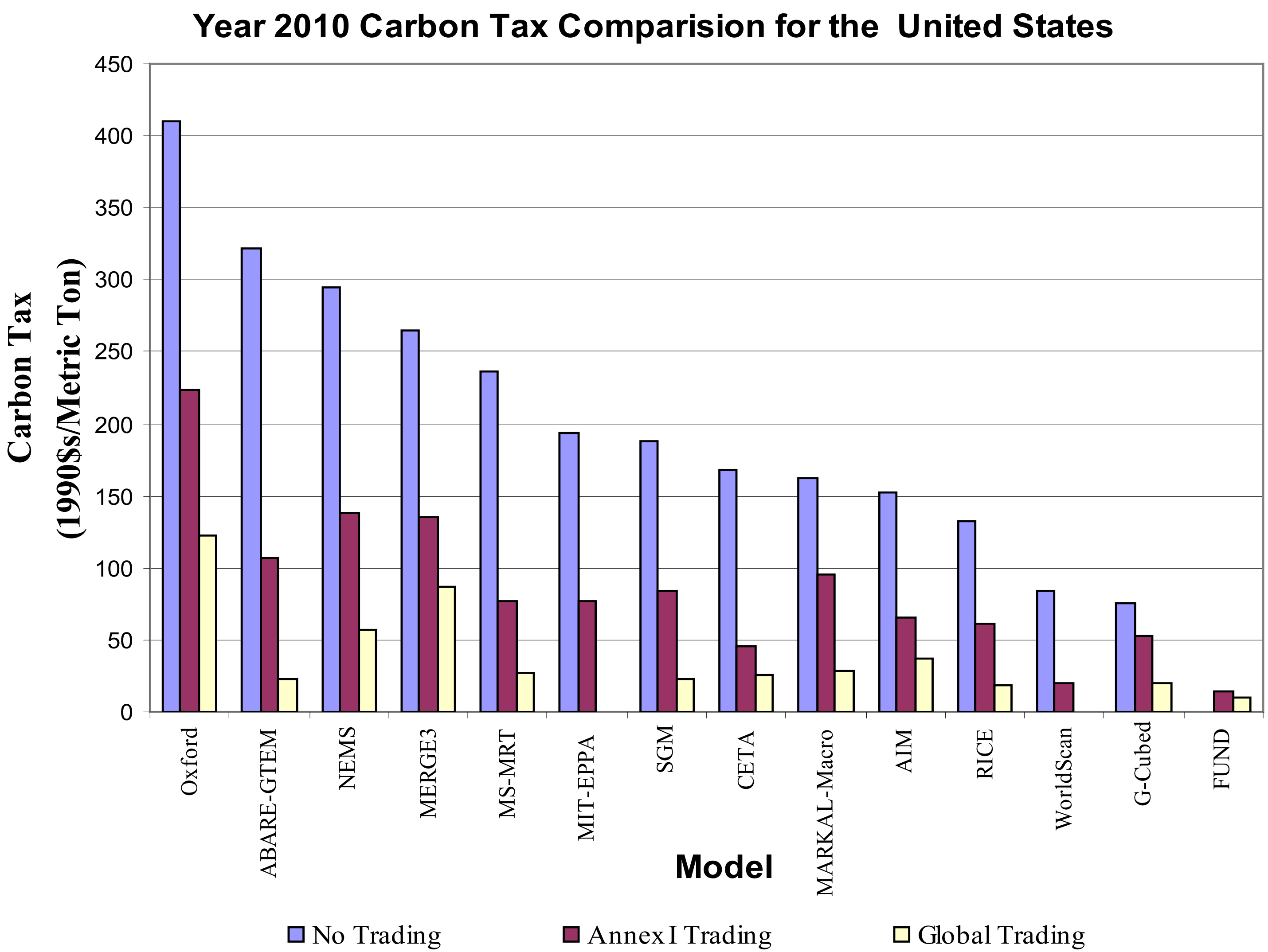
- Need to Maintain Problem Focus
- Proliferation of Data, Modules, Interactions
- Need Strategic Approach to Formulation/Implementation
- Lessons From Complexity Theory?
- Operationalize Multi-Level Cyclical Scaling?

2. Where and When Flexibility



1. Where Flexibility

The Cost of Kyoto



RCP Candidates: Published Scenarios With All Gases

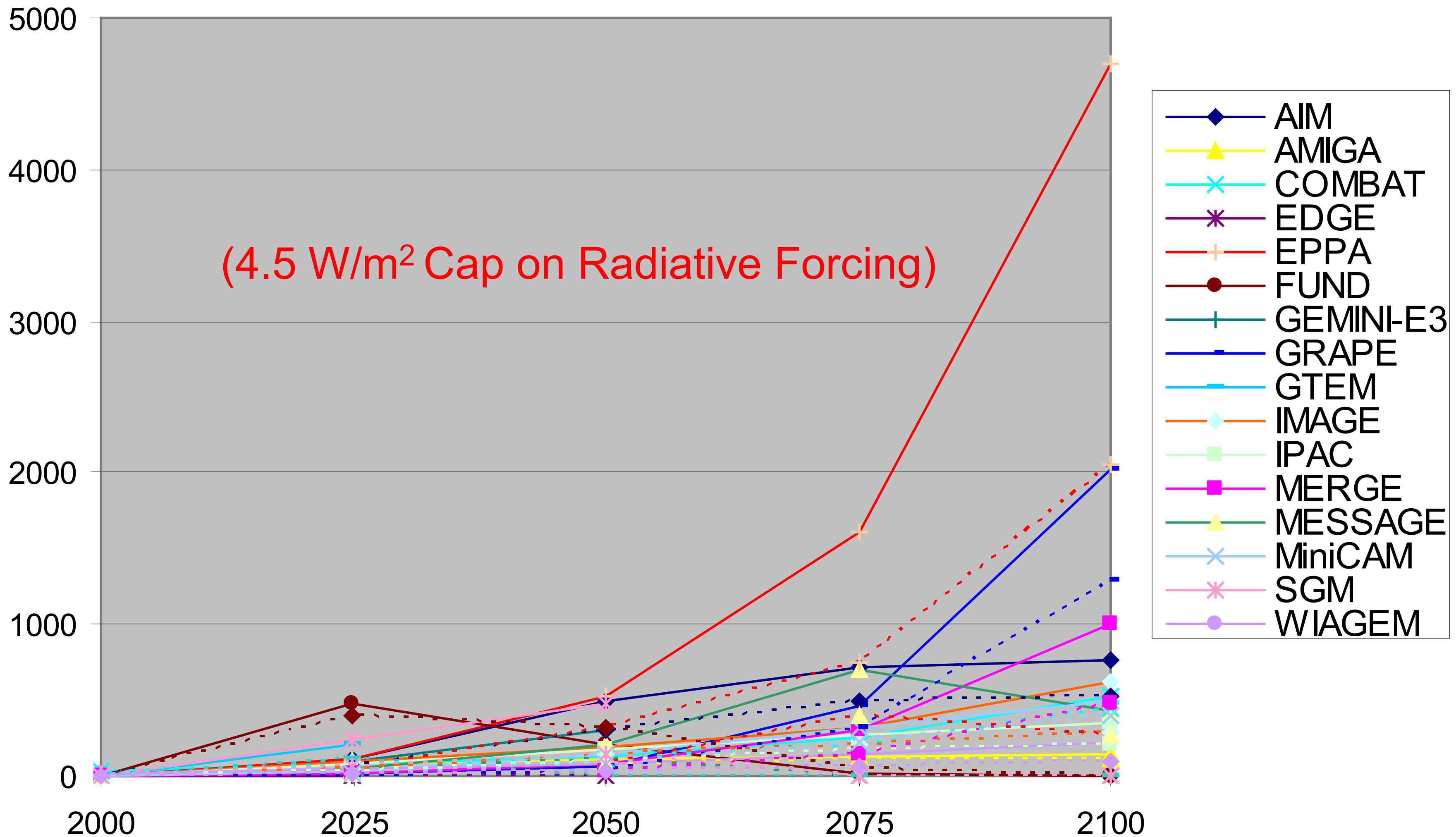
Table 2. RCP candidates. Asterisks indicate that at least one scenario is available, although there may be more than one.

IAM (affiliation)[1]	RCP8.5	RCP6	RCP4.5	RCP3-PD	Reference(s)
AIM (NIES)		*[2]	*	*[2]	Fujino et al. (2006)ć Hijioka et al. (2008)
GRAPE (IAE)			*		Kurosawa (2006)
IGSM (MIT)	*	*	*		Reilly et al. (2006)ć Clarke et al. (2007)
IMAGE (MNP)	*	*	*	*	van Vuuren et al. (2006ć2007)
IPAC (ERI)		*[2]	*		Jiang et al. (2006)
MESSAGE (IIASA)	*	*	*	*	Rao and Riahi (2006)ć Riahi et al. (2007)
MiniCAM (PNNL)		*	*		Smith and Wigley (2006)ć Clarke et al. (2007)

Notes:
[1] AIM = Asia-Pacific Integrated ModelćNIES = National Institute for Environmental StudiesćGRAPE = Global Relationship to Protect the EnvironmentćIAE = Institute of Applied EnergyćIGSM = Integrated Global System ModelćMIT = Massachusetts Institute of TechnologyćIMAGE = Integrated Model to Assess the Global EnvironmentćMNP = Netherlands Environmental Assessment AgencyćIPAC = Integrated Policy Assessment Model for ChinaćERI = Energy Resource InstitutećMESSAGE = Model for Energy Supply Strategy Alternatives and their General Environmental ImpactćMiniCAM = Mini-Climate Assessment ModelćPNNL = Pacific Northwest National Laboratory.
[2] These scenarios are availablećbut would require revisions to meet the RCP forcing criteria.

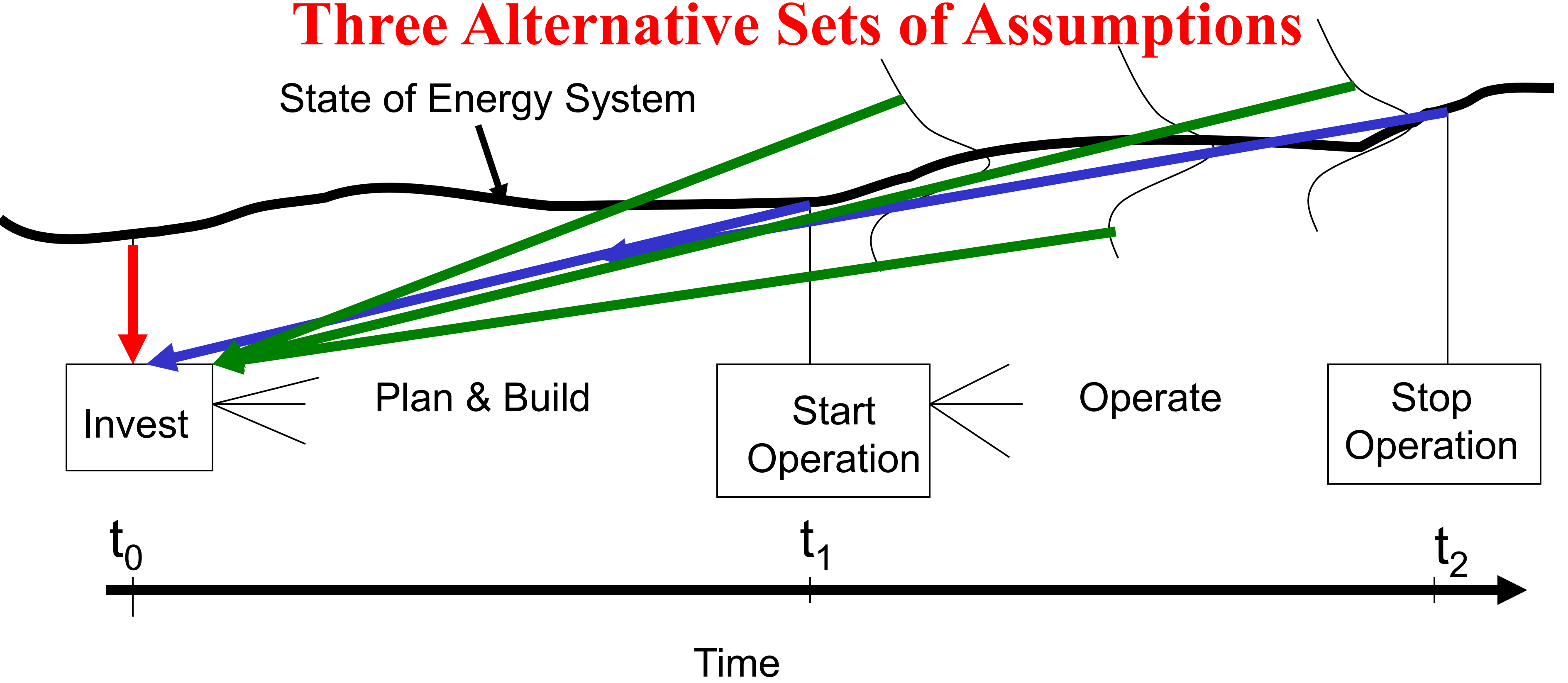
4. What Flexibility

Carbon Permit Price (2000 $USD / tC)
in CO2-Only (solid) and Multigas (dashed) Scenarios



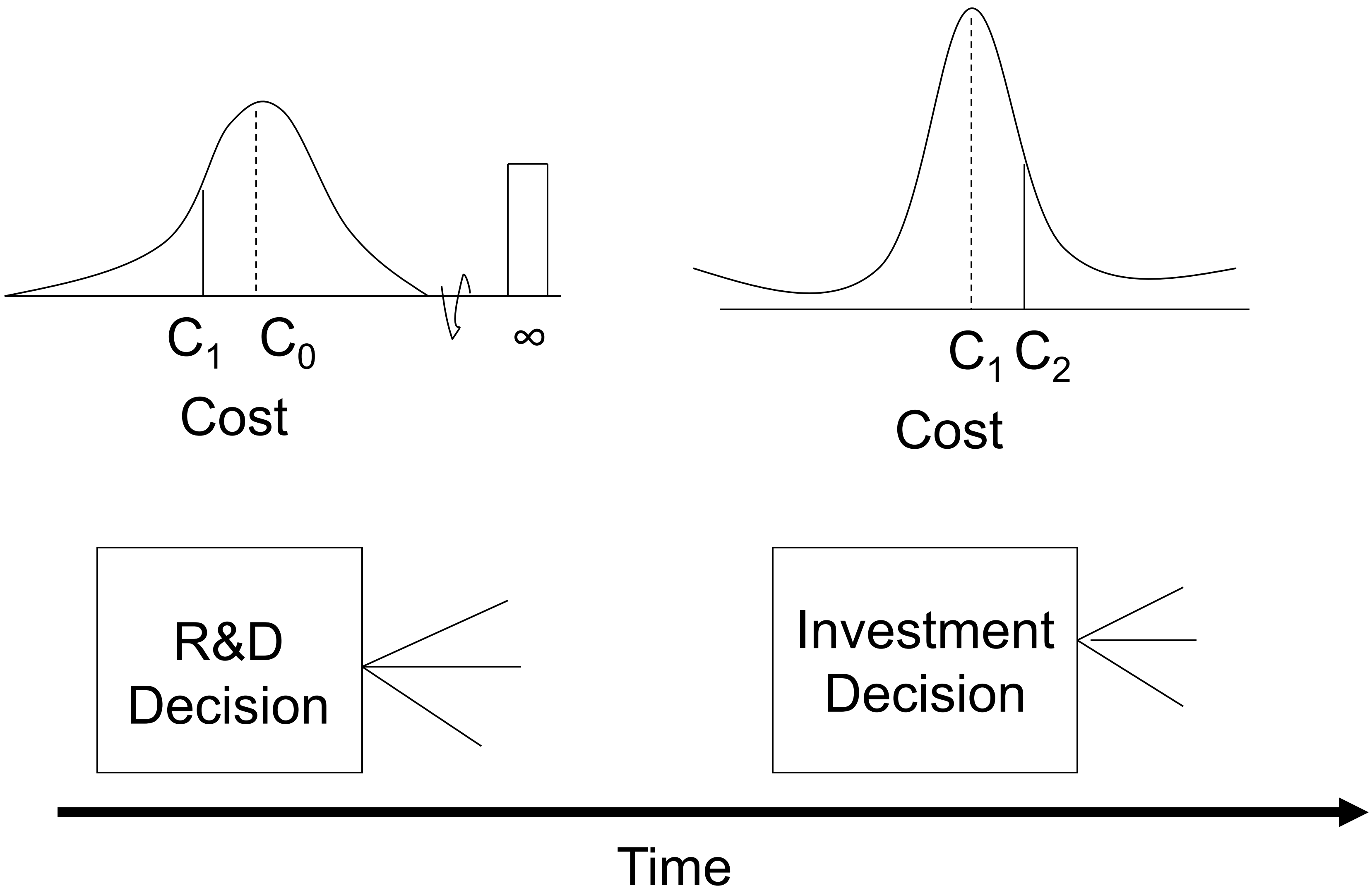
II. Incorporating Uncertainty

Information, Foresight & Uncertainty: Three Alternative Sets of Assumptions



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

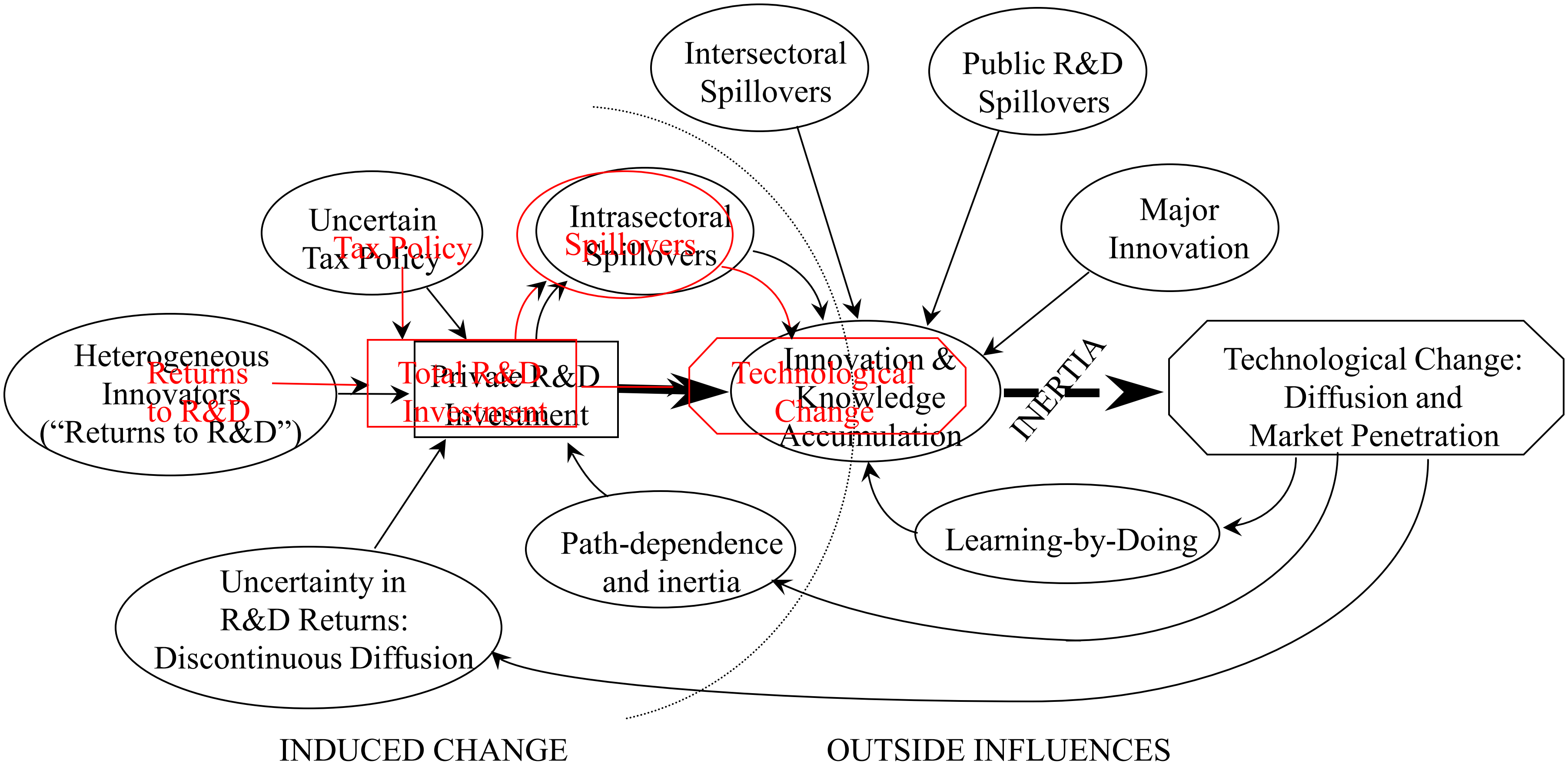
Interplay Between R&D and Investment Decisions



III. Embracing Technological Change

Limitations and Possible Extensions to Current Methods for Modeling ITS

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



What is Integrated Assessment?

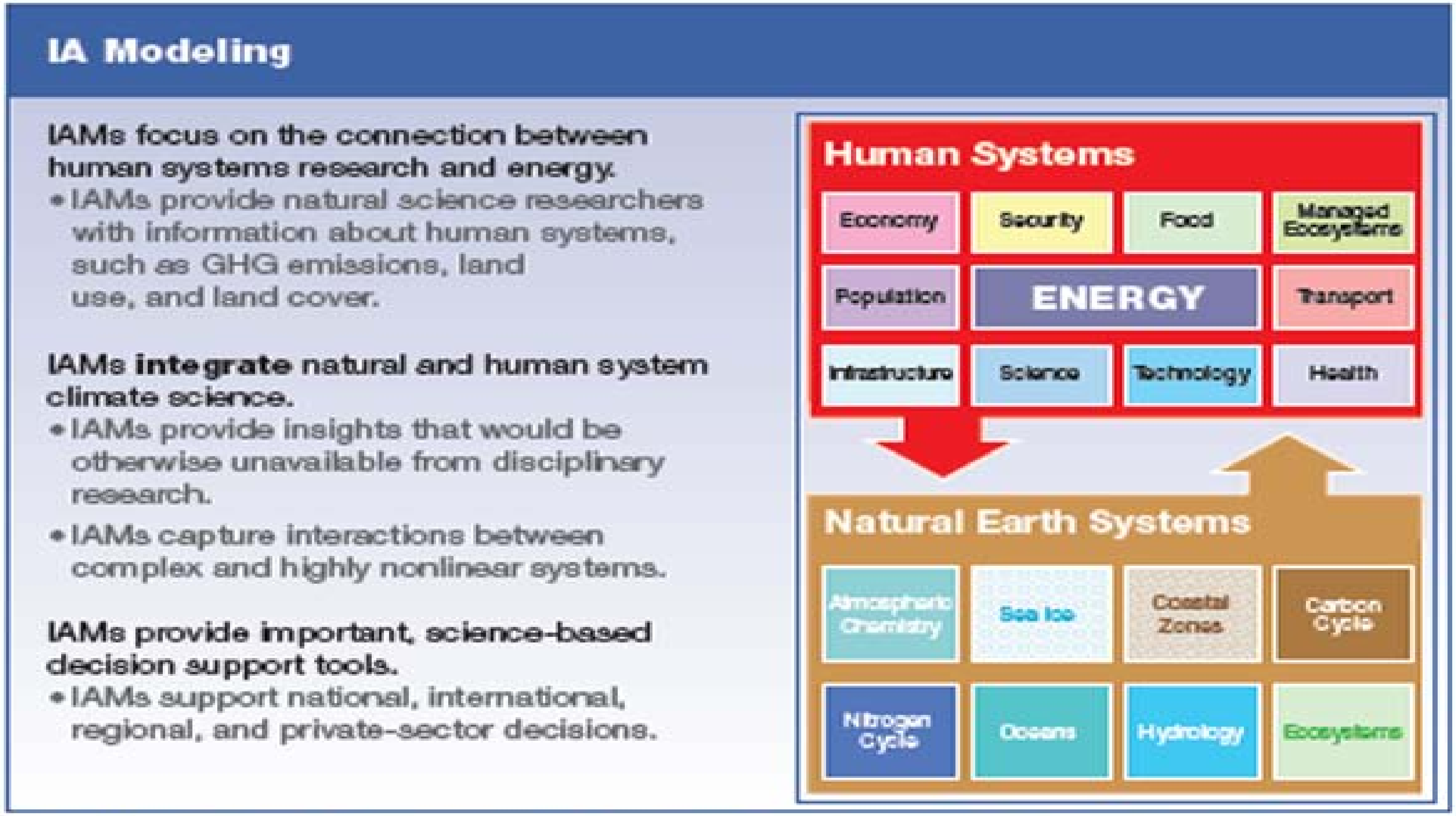
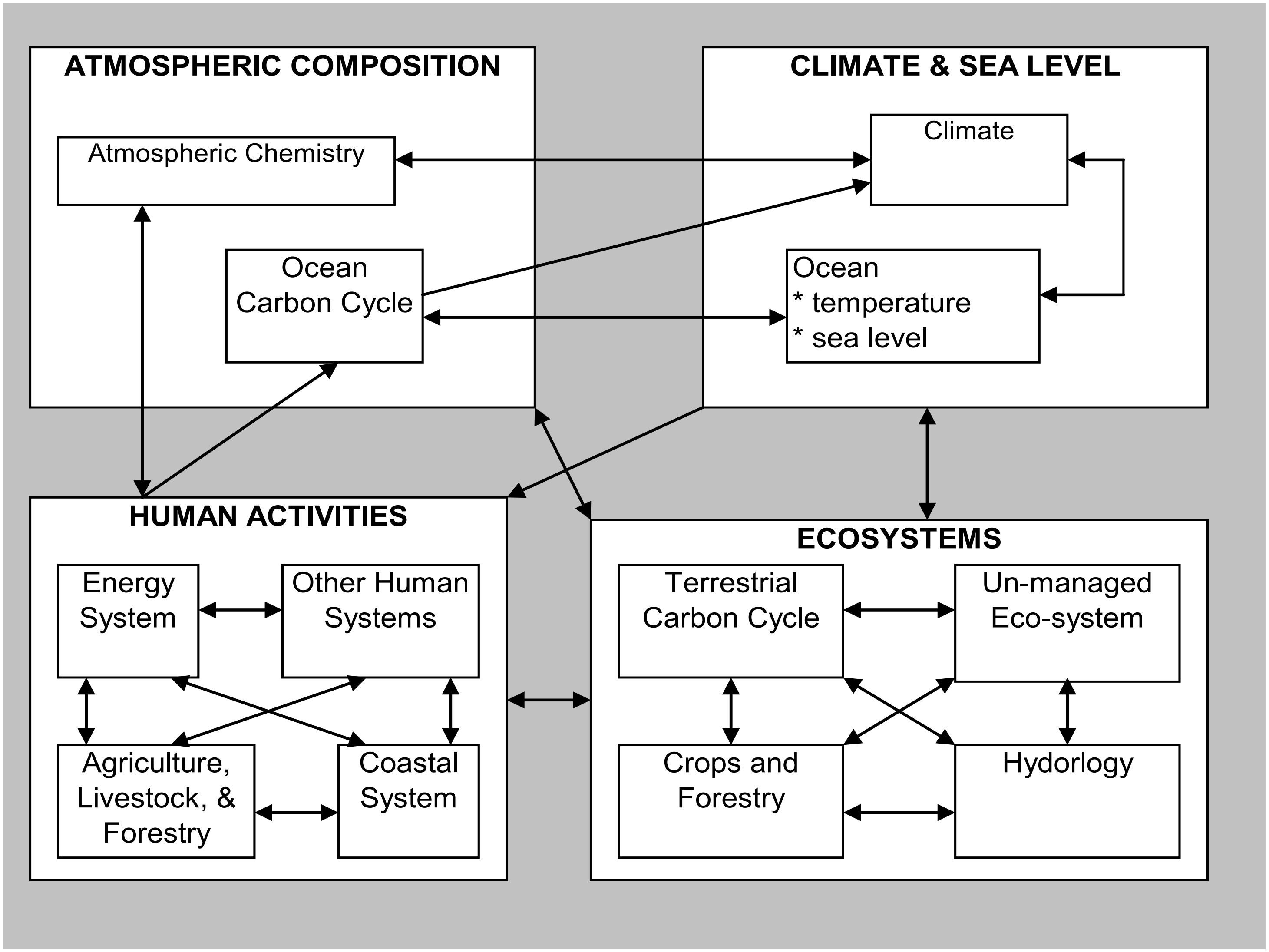


Fig. 2.1. IA Modeling. The focus of IAMs is on the interactions among human and Earth systems. Energy is the predominant human system represented in IAMs, but many systems—from the economy to managed ecosystems—are included. Earth systems that affect and are affected by humans encompass the atmosphere, oceans, fresh water, the carbon and nitrogen cycles, and ecosystems. Modeling the interactions among these systems yields insights that do not usually arise from disciplinary studies

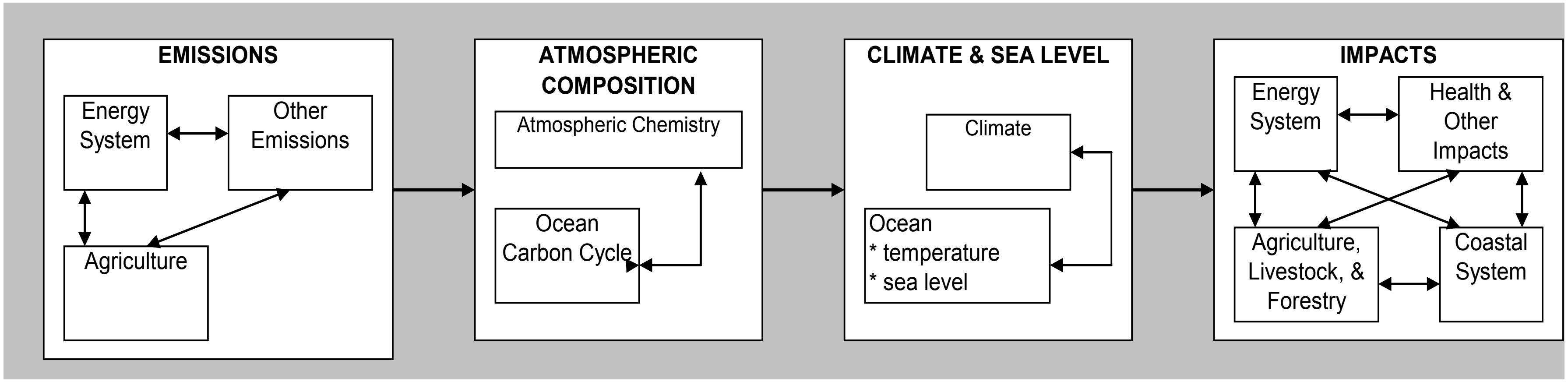
Observations Regarding Current Approaches to Modeling ITC

- Current approaches to ITC 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.

IV. Integrating The Sciences
Are We Integrated or…



…Still End-to-End ?



Do we need Integrated Earth Systems Models?

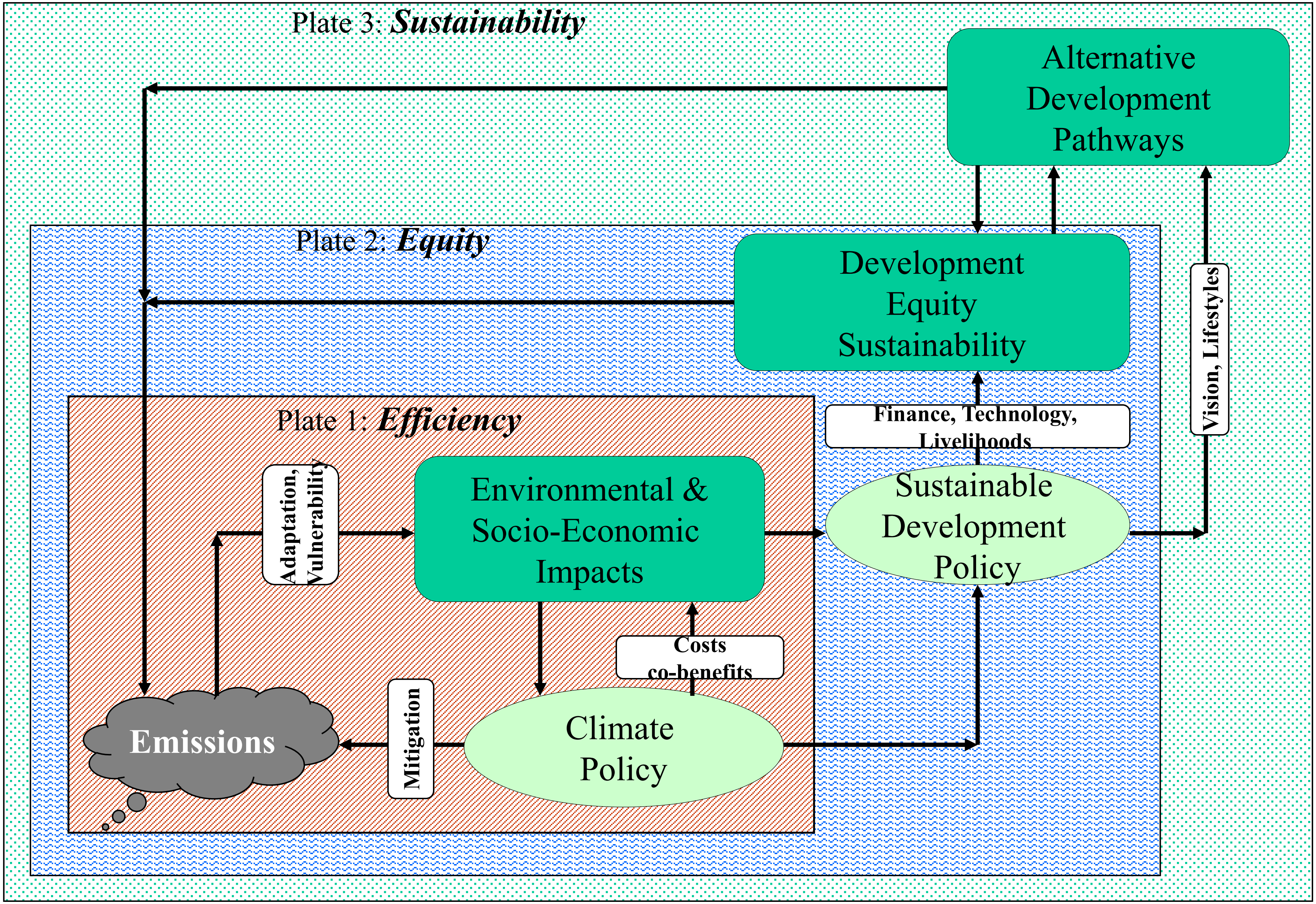
V. Synthesizing The Impacts:
Where We Are In Impacts/Adaptation Analyses

- Reasonable economics estimates in a few sectors
  - Agriculture
  - Forestry
  - Sea level rise
- Preliminary physical impacts representations in others
  - Health
  - Wildlife
  - Water supply
- First order causal mechanisms in others
  - Unmanaged eco-systems
  - Biodiversity
  - Extreme events – both changes in variability and abrupt changes
- How to weigh what we know and don't know and what we can measure or not measure and what we can value and not value is a big challenge

Key Challenges Faced in Projecting Impacts

- Projecting Regional Climate
  - Temperature
  - Precipitation
  - Variability
- Projecting Baseline Conditions
- Transient Versus Equilibrium Impacts
- Factoring In Adaptation
- Valuing Non-Market Impacts

VI. Promoting Development



Whither the Poor and Defenseless? A Revealed Preference Study of Climate Change Policy Analyses

<u>Class of World Citizen</u>	<u>Typical OECD (AEA Member?) Analysis</u>	<u>ROW Analysis</u>
2 Billion People Without Markets	What 2 Billion People?	High Priority: Reduce Their Vulnerability
2 Billion In or Near Poverty with Fragile Markets	They Don't Count for Much!	High Priority: Reduce Their Vulnerability
2 Billion Potential Decaf Latté Drinkers	Half Are Stuck In Transition, But the Rest We Can Help	They Can Take Care of Themselves

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

Integrated Assessment of Integrated Assessments?

– Peer Reviewed Proposals
– Peer Reviewed Literature
– Forum Analysis
– Model Assessment Projects
– PCMDI-Like Institution
– Other

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

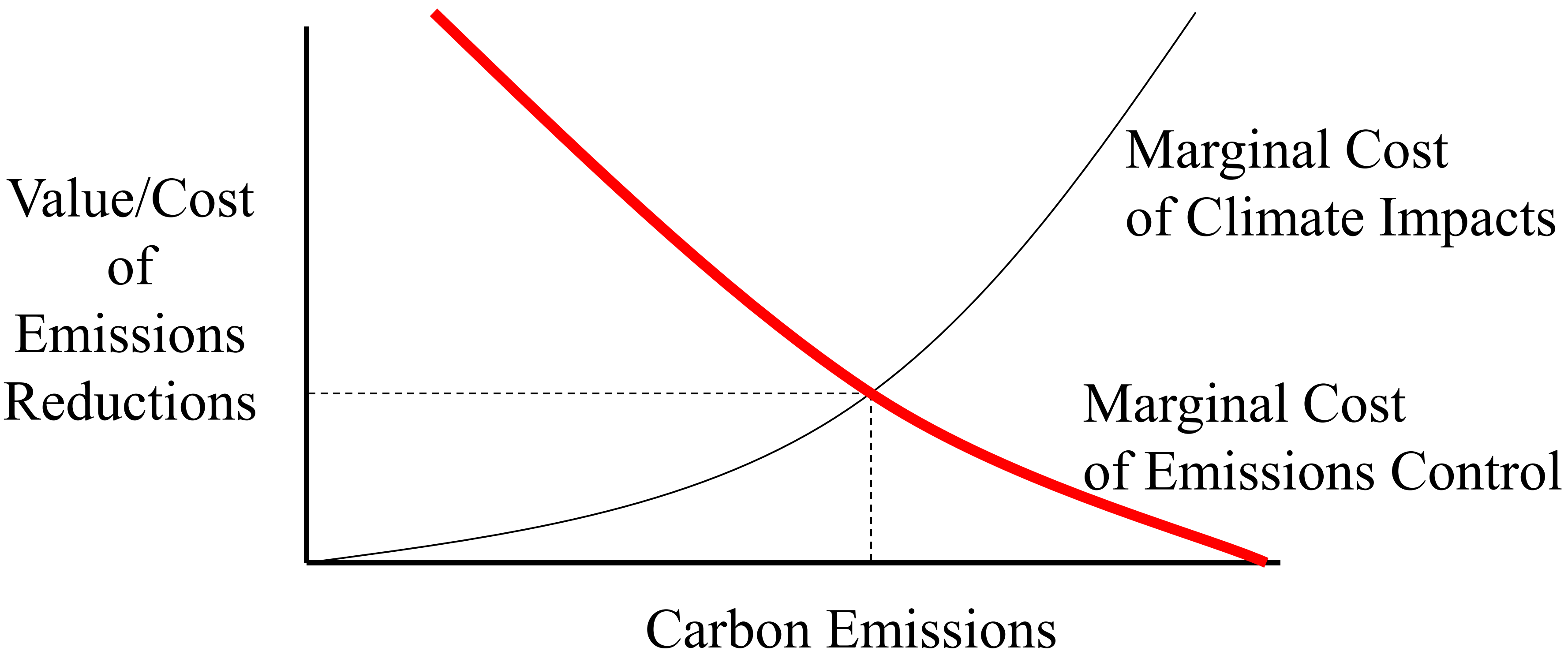
Technology is King

Table 1: Technology Assumptions

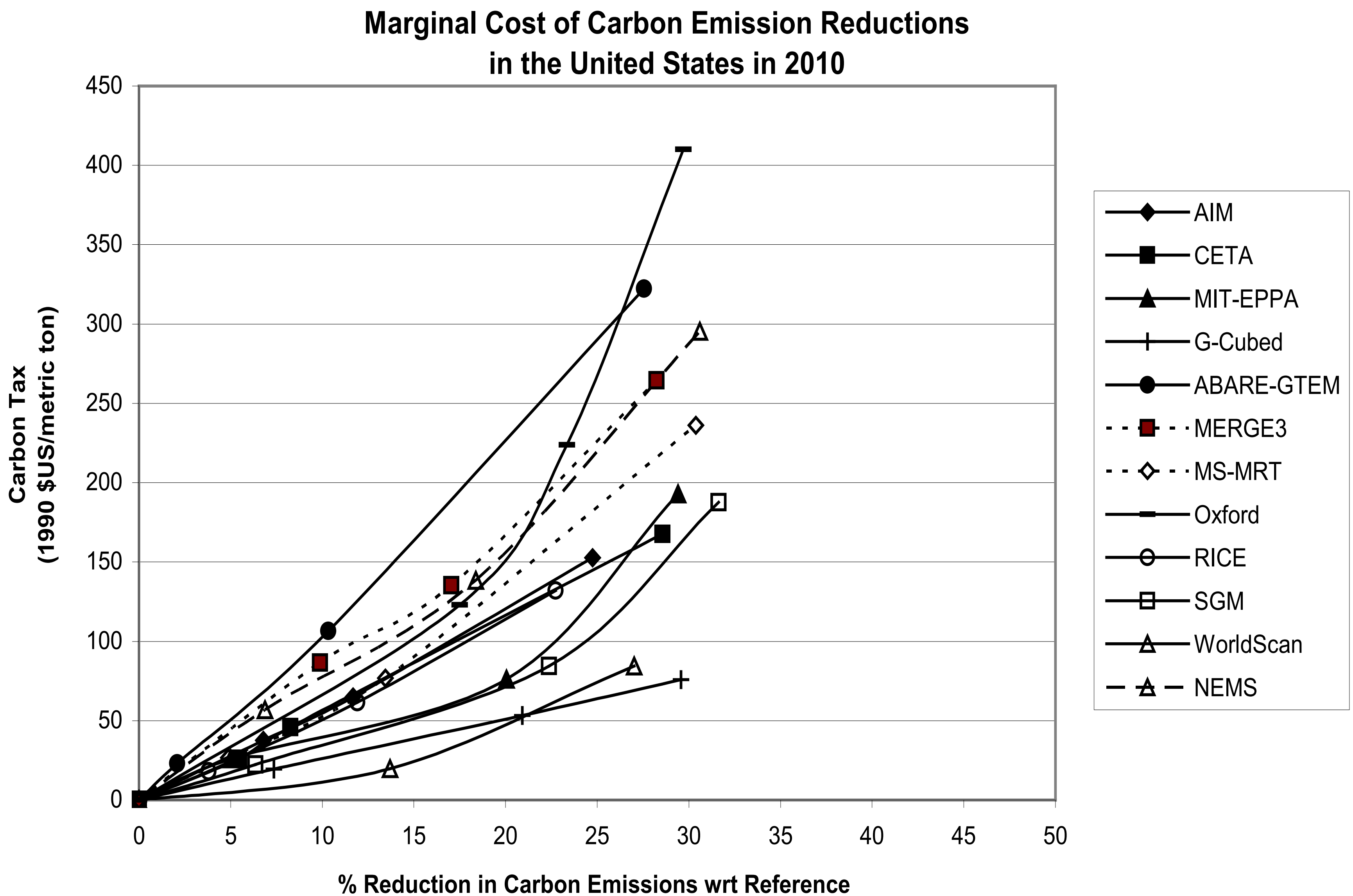
Technology	units	1990 Base	Year 2100 Mini-CAM B2	Year 2100 Mini-CAM B2 AT
US Automobiles	mpg	18	60	100
Land-based Solar Electricity	1990 c/kWh	61	5.0	5.0
Nuclear Power	1990 c/kWh	5.8	5.7	5.7
Biomass Energy	1990$/gj	$7.70	$6.30	$4.00
Hydrogen Production (CH_4 feedstock)	1990$/gj	$6.00	$6.00	$4.00
Fuel 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

Cost/Benefit Modeling Approach:

Balancing the Costs of Controlling Carbon Emissions Against the Costs of the Climate impacts They Cause



The Substitution in the Models



The Energy Resource Mix

World Primary Energy in 550 ppm Case in 2100