

**The Center for Integrated Study of
the Human Dimensions of Global Change:**

A History

By Diana Rhoten

INTRODUCTION

In 1995, the National Science Foundation awarded a competitive 5-year grant to a network of researchers committed to developing and applying methods for the integrated assessment of human dimensions of global change. Based at Carnegie Mellon University, the center included researchers at many institutions, in the United States and abroad, trained in diverse disciplines, but committed to this common goal. In 1999, an intensive review led to a three-year extension of the Center's life. Many other institutions have contributed additional support, for specific projects, conducted within the Center's general framework. This report describes major themes in that research. To provide narrative structure, it is organized into three roughly chronological sections, the periods before and after the NSF mid-course review, as well as projects emerging from its final period, to be completed afterward. This division, of course, oversimplifies. The early-stage projects have evolved into new ones; the late-stage projects had their roots in earlier work. Some major projects have continued throughout. Yet, the division does capture some of the ways in which earlier progress made later work possible. Not every project is described nor every investigator mentioned by name. A complete list of participating individuals and institutions appears at the end. We hope that this summary does justice to their collective efforts.

CIS-HDGC – THE FORMATIVE YEARS

Integrated Climate Assessment

Historically, integrated climate assessments have varied in priority and purpose. Some have emphasized characterizing optimal responses to climate change, in the context of specific assumptions regarding the dynamics of economic growth and abatement and atmospheric accumulation. Others have emphasized fine spatial detail in characterizing atmospheric change, impacts, and feedbacks. Carnegie Mellon University's Integrated Climate Assessment (ICAM), a primary focus of HDGC's early years, emphasized uncertainty and explored sequential and adaptive decision formulations.

The ICAM series was initiated in 1990 as part of the Global Change Integrated Assessment Program. In 1996, it became the foundation for the Carnegie Mellon University-based Center for Integrated Study of the Human Dimensions of Global Change (CIS-HDGC). For the overall global change community, the ICAM model series provided a shared mechanism by which academics, practitioners, and policymakers could collectively identify and address conceptual issues central to any integrated climate assessment. For the Carnegie Mellon-based HDGC more specifically, the models have been influential in terms of serving as a common platform around which many researchers and disciplines have come together. Thus, the Center's notion that diverse teams must work in integrated ways has served as a legacy and a lesson for researchers in as well as out of Carnegie CIS-HDGC.

There have been four successive versions of the model in the ICAM series, each focusing on how uncertainties can be addressed in climate policy making. Over the course of its evolution, the ICAM has treated hundreds to thousands of uncertain parameters, many in the form of subjective probability distributions elicited from experts, and has broken new ground in exploring uncertainties in model structure. The series has also included various detailed sectoral analyses as well as analyses of expert judgment of climate uncertainties, stochastic modeling of ecosystem change under climate change, coastal impacts, trace-gas indexes, geoengineering policy, and value-of-information calculations. A consistent result of many analyses with ICAM has been that socioeconomic uncertainties and preference variations are more important than biophysical uncertainties in evaluating impacts or policy responses.

*The interdisciplinary information needed to compose a coherent picture of climate change, its precursors and impacts could not be assembled from **existing knowledge**. To use a musical analogy, the instruments of the orchestra where neither in the same key nor being played to the same beat. Consequently, the **climate change symphony** was nothing more than **chaotic noise**.*

-- Hadi Dowlatabadi

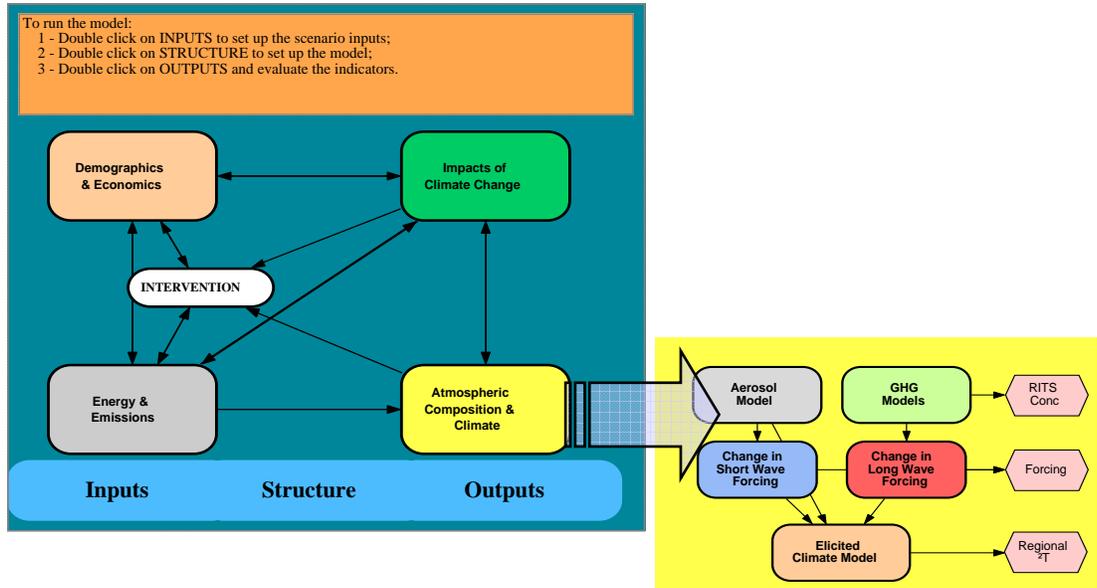
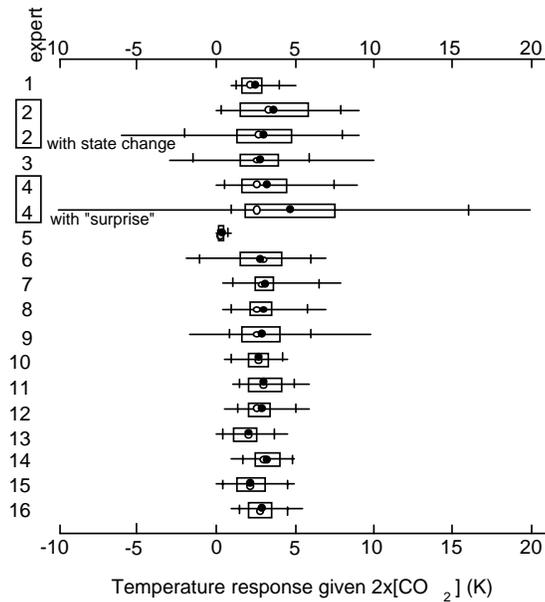


Illustration of the top two levels in the hierarchically organized ICAM model which was built in the Analytica® software environment.



Box-plot summaries of climate sensitivity estimates elicited by G. Morgan and D. Keith from sixteen leading U.S. climate scientists.

The first three versions of ICAM ran as predictive models designed to elucidate future climate and the consequences of alternative climate policies. Because of the high levels of uncertainty and because different socio-economic regions faced different circumstances it was found that no single policy would likely be optimal for the entire planet, and that substantially different conclusions were reached depending upon on which set of alternative model functional forms were employed.

<u>Components</u>	<u>Structure of the model</u>					
<i>Model:</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
Discounting: Schelling	r	l	l	l	l	
Technology: induced	r	r	l	l	l	l
Aerosols: included	r	r	r	l	l	l
Adaptation: included	r	r	r	r	l	l
Oil and gas: unlimited	r	r	r	r	r	l

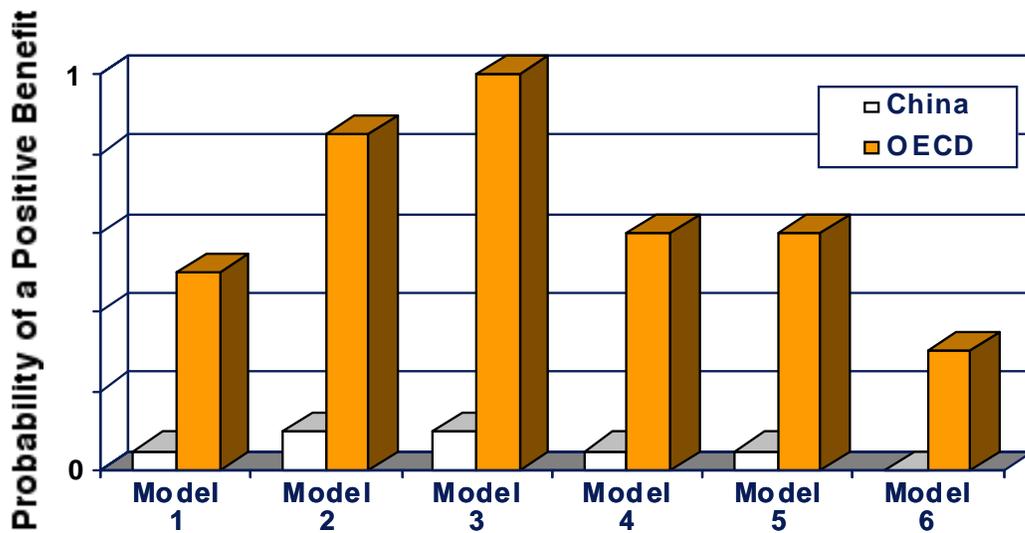
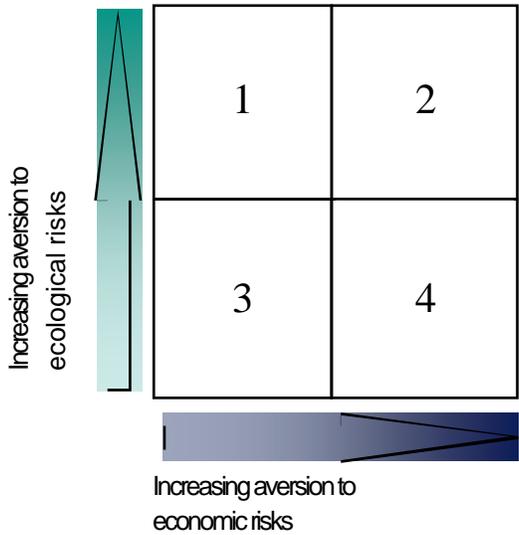
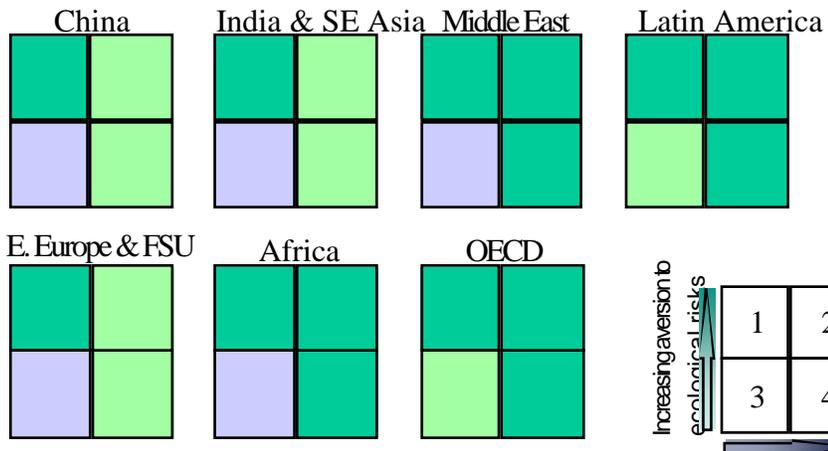


Illustration from ICAM of how different model structural forms change model conclusions across models used and in different parts of the world.

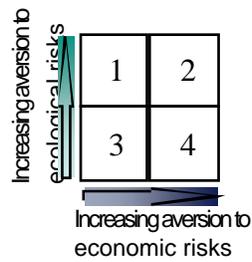


- Key to decision rules:
- 1. Minimize maximum ecological impacts.
- 2. Minimize maximum of total ecological and economic impacts.
- 3. Minimize expected ecological and economic impacts combined.
- 4. Minimize maximum economic impacts.



Key to strategies chosen:

- No abatement
- Fossil carbon emissions kept below 10 Gt/year.
- Atmospheric CO₂ concentrations kept below 500 ppm(v)



Example from ICAM how different decision roles lead to different policy choices in different parts of the world.

For these reasons, ICAM-4, adopted a very different strategy designed to determine the relative robustness of alternative policies, as opposed to the specific consequences of any particular policy. The model populated with autonomous agents representing each geographical region. These agents were given simple rules for assessing and responding to the changing environment in the model world. The model was then simulated repeatedly, allowing the investigators to determine which policies were robust in the face of a wide range of alternative futures, and which ones encountered serious difficulties. For example, it was that found that policies based on monitoring atmospheric CO₂ concentrations were much more robust than those that focused on emissions.

The ICAM series has sought four broad classes of contribution: (a) developing a systematic and coherent framework of key dynamic changes taking place simultaneously with climate change; (b) evaluating possible

policy responses to climate change; (c) contributing to broad comparative risk assessment; and, (d) characterizing uncertainties in our knowledge and prioritizing applied research on the basis of the sensitivity of various policy options to these uncertainties. Table 1 summarizes the contributions of the each ICAM model to these goals.

A number of the early PhD's supported though the Center involved refinements of specific elements needed in the ICAM models, for example, Anand Patwardhan worked on improving the characterization and treatment of sea-level rise. J. Jason West further developed the Center's thinking on sea-level rise focusing particularly on the role of storm damage. In addition West addressed the contributions of climate forcing made by fine particles. In his PhD, Milind Kanlikar, performed a systematic analysis of the limitations of "global warming potential" and conducted inverse studies to improve the global mass balance for methane. In subsequent work as a post-doc fellow in the Center, he collaborated with James Risbey on a study to develop and demonstrate probabilistic methods, incorporating expert judgment, for detection of climate change

Table 1. Summary of ICAM Contributions				
	Problem Framing	Policy Evaluation	Risk Assessment	Valuation of Impact
ICAM-0	Showed how subjective values dominate science uncertainties in policy determination	First to explore policy choice under different decision rules		Indicated the need to build a dynamic framework: ICAM-1
ICAM-1	First to frame the problem as a tropical-extra-tropical issue. For demographic, social, and climatic reasons	First to include geo-engineering along with mitigation and adaptation First to reject the notion of optimization given a diversity of stakeholder interests		First to quantify parameter uncertainties systematically and calculate the value of information. Indicated the need to consider aerosol effects – increase resolution of fuels and regions: ICAM-2
ICAM-2	First to include aerosols First to frame adaptation and adjustment as an event-driven process The first model to include explicit model uncertainties, endogenous technical change, endogenous demographics, endogenous regional environmental controls	First to note the short-term negative consequences of GHG controls related to aerosol forcing	First to include local air pollution and dynamics of local environmental controls	Indicated the models and model results too complicated to communicate effectively. Prompted a rethink how we evaluate policies: ICAM-3
ICAM-3	First to use adaptive artificial agents to search for robust policy strategies in an uncertain landscape	First to frame the issue of policy evaluation as one of socially detectable & politically important factors (as opposed to cost optimization)		Through including many complex interactions relating climate change and its impacts to more local processes it emphasized the challenges in balancing local and global environmental management and their potential for convoluted and unintended impacts on human welfare

As successful as the ICAM series has been in advancing research, practice, and policy around climate change toward new outcomes and outputs, it became clear with ICAM-3 that to effectively capture the full range of human dimensions of global change at the micro- and meso-levels, a different scale of models was needed. Such models would be able to include such issues as the effect of experience on individual preferences and decision making; the specifics of the policy implementation process; the heterogeneity of local conditions; and, the interaction between climate change events, impacts, and policies. Yet, even though ICAM-3 could not ultimately elucidate these anthropogenic factors, ICAM family of models presented a systematic "big picture" approach that gave rise to the widespread scientific acknowledgement that such forces play a central role not only in stimulating global change but also in modifying its ongoing processes.

One issue which is important in determining results in ICAM, as well as, all other integrated assessment models is the way in which time preferences are handled. ICAM allows for several alternative formulations to promote more systematic consideration of this issue within the integrated assessment community. The Center supported

the PhD thesis of Shane Frederick who worked under the supervision of George Loewenstein to perform both a systematic review of past research on time preferences and conduct a series of empirical studies. He found that many alternative elicitation formats indicate the public weighs the welfare of future generations and current generations about equally, and concluded “an adequate understating of intertemporal choice and the concept “discounting” requires conceptual separation of several distinct concepts, including the probability of future occurrence, objective changes in the consequence itself, changes in the utility function, utility from anticipation, utility from memory, opportunity costs, time preference, and, for distant consequences, intergenerational time preference.”

Text Box 1 lists some of the publications that have resulted from the work on ICAM.

Text Box 1

- Dowlatabadi, H. and M. G. Morgan 1993a. Integrated assessment of climate change. *Science* **259**(5103): 1813.
- Dowlatabadi, H. and M. G. Morgan 1993b. A model framework for integrated studies of the climate problem. *Energy Policy* **21**(3): 209-221.
- Lave, L. B. and H. Dowlatabadi 1993. Climate change policy: The effects of personal beliefs and scientific uncertainty. *Environmental Science and Technology* **27**(10): 1962-1972.
- Dowlatabadi, H. 1995. Integrated assessment models of climate change: An incomplete overview. *Energy Policy* **23**(4/5): 289-296.
- Tschang, F. T. and H. Dowlatabadi 1995. A Bayesian technique for refining the uncertainty in global energy model forecasts. *International Journal of Forecasting* **11**: 43-61.
- Morgan, M. G. and H. Dowlatabadi 1996. Learning from integrated assessment of climate change. *Climatic Change* **34**: 337-368.
- Dowlatabadi, H. 1998. Sensitivity of climate change mitigation estimates to assumptions about technical change. *Energy Economics* **20**: 473-493.
- Elizabeth A. Casman, M. Granger Morgan and Hadi Dowlatabadi: “Mixed Levels of Uncertainty in Complex Policy Models”, *Risk Analysis*, **19**(1),33-42, 1999.
- Rotmans, J. and H. Dowlatabadi 1998. *Integrated assessment modeling. Human choice and climate change, volume 3: The tools for policy analysis*. S. Rayner and E. L. Malone. Columbus Ohio, Battelle Press: 291-377.
- Dowlatabadi, H. 2000. Bumping against a gas ceiling. *Climatic Change* **46**(3): 391-407.
- Dowlatabadi, H. 2002. Scale and scope in integrated assessment: Lessons from ten years with integrated climate assessment model (ICAM). *Integrated Assessment* **3**(2-3): 122-34.

As early as 1999, driven by realization of ICAM’s strengths and limitations, the Center shifted its focus from trying to elaborate the anthropogenic aspects of ICAM to applying the general modeling approach more broadly to the human dimensions of global change.

With this shift, CIS-HDGC researchers began to organize themselves around: (1) methodologies for dealing with non-marginal change; (2) analyses of human values and decision making in large-scale environmental change processes; (3) social and technical strategies for adapting and abating global change, and (4) integrated assessment of health and equity issues with global implications.

By 2001, these four strategies crystallized into the following three primary domains of work for the Center, each of which has sought to bring together the physical and engineering sciences with the social and life sciences to look at both the natural and the human dimensions of global change:

- (1) Social and technical strategies for abating global change, with a particular focus on energy systems;
- (2) Integrated assessment of and global change impacts on health and equity; and,
- (3) Impacts of and adaptation to multiple stresses and extreme events.

In addition to extending the ICAM work, three other objectives cut across these domains: (a) capturing adaptive learning, (b) understanding and valuing non-marginal change, and (c) representing equity and its implications. In many cases, these issues have become topics unto themselves, performing fundamental research needed to execute topical applications.

Under the stimulus of the Center, then, sciences – from physical and biological to social and behavioral – which had been previously isolated by disciplinary boundaries or had languished in small interdisciplinary niches were integrated around new approaches to studying global change, for both climatic and non-climatic issues.

CIS-HDGC – THE LATER YEARS

*We have sought to make the **social sciences** into more equal “**players**” in the world of **integrated assessment**, complementing the role the **economics** has long had. That has meant finding **common language** for natural and social scientists, as well as projects in which both were motivated to learn it.*

- Baruch Fischhoff

the “integrated assessment” paradigm by other research groups like ARIDNET and LUCC have been to influenced by the Center’s work.

The Center’s initial research agenda propelled it to a great deal of coherent productivity during the formative years, facilitating the ICAM family of models. These drew on and informed the other research conducted at Carnegie Mellon and its partners. The next round of funding shifted the Center’s attention away from developing new models to examining uncertainties that were exposed, but not explained by these models. This included issues of central concern to the field of climate change – such as CO₂ emissions and climate change abatement – as well as themes that had received very little attention in the climate change research community – such as non-marginal change, learning, equity, and adaptation. Changes in the Intergovernmental Panel on Climate Change’s (IPCC) treatment of uncertainty, shifts in the Conference of the Parties (COP) (engaged in the design of global climate accords) conceptualization of impacts and adaptation, and adoptions of

Social and Technical Strategies for Abating Climate Change

Rather than operating from the assumption that “climate change is bad,” the ICAM series asked, “If there is climate change, what else has happened, what are the relative impacts and interactions of these and what can and should be done about it?” Work on ICAM-3, however, convinced researchers that irreducible uncertainties in such complex systems could not be fully captured in one model. Given the central role of CO₂ in climate change, it became a central focus in these subsequent studies. As one affiliate put it, “Being serious about climate change meant the Center getting serious about CO₂ emissions” in terms of understanding how to abate them effectively and efficiently as well as how to monitor their impacts and adapt to their effects.

Progress toward reducing CO₂ emissions requires a suite of changes in the energy system, including alternative fuel sources, new low – or no – carbon technologies, greater energy efficiency, and life style changes. In 2001, CIS-HDGC launched a suite of physical, social, and technical science research projects addressing and integrating these different strategies for reducing CO₂ and abating climate change, as well responding to its impacts. As these research activities have expanded over the years, some of the more technologically-focused projects have grown away from the Center’s focus on the human dimensions of global change. In order to cultivate these new directions, while preserving the CIS-HDGC core mission, a number of projects were used to form the core of a new Carnegie Mellon Electricity Industry Center (CEIC) in August 2001. CEIC is now one of 22 Alfred P. Sloan Industry Centers. CEIC has benefited from additional support from the Alfred P. Sloan Foundation, and the Electric Power Research Institute, as well as, the U.S. Department of Energy, The National Science Foundation, and industry. This spin-off (and others described below) supports the premise of NSF’s core investment in the Center, as a place where innovative research programs could be formulated and tested.

CEIC interprets the “electricity industry” to mean all the important stakeholders including private and public companies, cooperatives, labor, regulators, manufacturers and marketers of equipment and appliances, the service and consulting communities, the research communities, all classes of consumers, and state and national regulators. Co-Directors of CEIC are Professors Lester Lave and Granger Morgan. Alex Farrell was the founding Executive Director and once he left to join the faculty at UC Berkeley, he was replaced by Jay Apt. Farrell had previously been heavily involved in Center work, and original contact with Apt came from the series of joint seminars on global change that the Center ran with the Carnegie Museum, where Apt was Director. The problems of the electricity industry are inherently interdisciplinary, and CEIC has merged engineering, economics, risk analysis, and decision science to study problems such as these current areas of research:

- Electricity Markets and Investment
- Distributed Energy Resources
- Advanced Generation, Transmission, and Environmental Issues
- Reliability and Security of the Electricity Infrastructure
- Demand Estimation and Demand Response

Additional details on CEIC can be found at www.cmu.edu/electricity.

Transitions to Sustainable Energy Systems

In the past 60 years, the concentration of carbon dioxide in the atmosphere – primarily because of expanding use of fossil fuels for energy – has been raised from pre-industrial levels of 280 parts per million to present levels of over 365 parts per million. Predictions of global energy use in the next century suggest a continued increase in carbon emissions and rising concentrations of CO₂ in the atmosphere unless major changes are made in the way we produce and use energy. The newest, and perhaps most promising, way is to manage carbon through capture and deep geological sequestration. A critical, but more traditional way is to decrease the use of and thus need for carbon source fuels. And, a third approach is to increase the use of low-carbon and carbon-free fuels and technologies.

All three of these abatement strategies involve human as well as natural dimensions of global change. Research on each requires the study of social, economic, and technical aspects of energy use and production as well as the direct and indirect influences of such activities on environmental, physical, and ecological processes at various scales. Researchers at CIS-HDGC have conducted research on and across all three by pursuing integrative methodologies that pull together previously disparate and disciplinary pockets of research to (a) estimate industrial carbon management techniques, (b) assess renewable energy sources, and (c) examine consumer behavior patterns.

Industrial Carbon Management. Industrial Carbon Management (ICM) seeks to allow the continued use of fossil fuels, without contributing to climate change, by linking processes that capture the carbon content of fossil fuels while generating carbon-free energy products (e.g., electricity, hydrogen) with practices for sequestering the resulting carbon dioxide away from the atmosphere. Many ICM technologies already exist, making it possible to contemplate the use of fossil fuels with minimal atmospheric emissions of carbon dioxide. Nonetheless, ICM is still often seen as a radical break from current climate mitigation strategies, which tend to focus on eliminating or at least limiting rather than capturing and sequestering the carbon in fossil fuels. Our research has sought to reduce the uncertainty surrounding these options, while identifying designs that are more attractive from an economic, technological, legal, and political perspective.

Given our society's high rate of reliance on fossil energy – roughly 85% of commercial energy use domestically and globally – as well as the technical, social and economic difficulties associated with the large-scale use of other alternative energy sources (such as wind, nuclear, solar energy), the ability to use fossil fuels while avoiding greenhouse gas emissions must be evaluated as a potentially attractive option that could transform the economics and politics of the CO₂-climate problem. By lowering the cost of emissions mitigation, ICM may enable stabilization of atmospheric concentrations at an acceptable cost. By weakening the link between fossil fuel energy and atmospheric CO₂ emissions, ICM may make it feasible to consider a fossil fuel-based global economy through the next century. By reducing the severity of the threat that emission reduction poses to fossil fuel industries and fossil-fuel-rich nations, ICM may ease current deadlocks in both domestic and international abatement policy. However, at the same time that ICM holds great promise for the political economy of abatement and the design of abatement policies, ICM also carries novel environmental risks and raises certain inter-generational equity issues. Thus, a full understanding of ICM's implications and limitations is necessary if it is ever to play a central role in our energy future.

In this spirit, David Keith and Granger Morgan convened and co-chaired a weeklong CIS-HDGC workshop at the Aspen Global Change Institute in July 2000. The workshop was motivated by the concern that ICM technologies are well understood by the technologists who develop them but not by stakeholders affected by them. The lack of shared information, about both the implications and the limitations of ICM technologies, compared with those of other better-known means of CO₂ abatement, could jeopardize ICM's contribution. The principal goal of the workshop, then, was to forge links between the diverse interest groups who must come to share a basic understanding of three carbon capture and sequestration (CCS) techniques for improving ICM: (1) post-combustion separation after combustion in air, (2) pre-combustion separation, and (3) combustion in oxygen.

The workshop was attended by 32 representatives from the fossil fuel and chemical industries, the U.S. government, national laboratories, non-governmental organizations, and academia with expertise in capture technologies, geological and ocean sequestration, energy technology and policy, and risk assessment. Discussions and debates from the workshop



resulted in a 28-page conference report entitled *Elements of Change 2000: Industrial Carbon Management: Crosscutting Scientific, Technical, and Policy Implications* written by Keith and Morgan. This widely circulated report has affected the climate-change community at large by explicating the need for and more comprehensive analysis of all three ICM techniques, with all their complex designs and diverse impacts, so that both the technical community, asked to develop ICM technologies, and the public, asked to accept their implementation, avoid unexpected consequences.

As CCS strategies have become more prominent in ICM discussions and climate change debates over the last several years, the Center has also become increasingly engaged in direct research related to engineering, economic, risk, regulatory, and public perception aspects of the three different CCS techniques listed above. Because power plants are the largest stationary sources of CO₂, they have become the primary targets of such Center efforts.

An example of such work can be found in a recent project conducted by Edward Rubin and PhD students Anand Rao and Chao Chen. In the last few years, this team has created a general framework for evaluating a wide range of capture and storage options. They have applied and tested a detailed process simulation model of amine (MEA)-based CO₂ capture systems for a post-combustion flue gas stream. This model has been integrated with an existing power plant modeling framework that includes control technologies for other conventional pollutants, in order to produce integrated assessments of the feasibility and cost of carbon capture and sequestration at both new and existing coal-burning power plants. A similar model has also been developed for Integrated Gasification Combined-Cycle (IGCC) power plant designs and selexol scrubbing technology.

Improved energy efficiency, and fuel switching, are among the more promising strategies for reducing greenhouse gas emissions in the short run. In this context, small scale distributed generation which combines heat and electric power production (CHP) using natural gas fired internal combustion engines hold considerable potential for important short term improvements. In his PhD, Neil Strachan, examined why adoption such distributed energy systems was relatively unsuccessful in the UK and highly successful in the Netherlands. In his subsequent work as a post-doc in the Center he went on to perform an engineering-economic evaluation of distributed CHP in both northern and southern US settings. This work demonstrated that CHP technology holds significant potential for expanded US applications.

Working with Ed Rubin and David Hounshell, Margaret Taylor completed a PhD titled, “The Influence of Government Actions on Innovative Activities in the Development of Environmental Technologies to Control Sulfur Dioxide Emissions from Stationary Sources”. This thesis clearly demonstrated that environmental regulations were responsible for driving technological innovation in the case of sulphur air pollution. Since then Rubin and Hounshell have supervised two additional studies along similar lines. While not supported through the Center, Jaegul Lee, has explored similar issues in automotive emissions control technology and with Center support post-doctoral fellow, Sonia Yeh, has explored historical rates of environmental technology innovation with an eye to making predictive judgments about likely future trends for CCS technologies.

In related work, David Keith and Timothy Johnson have used a capacity planning and dispatch model to examine CCS in a regional electricity market (the MAAC NERC region as well as Texas). The stabilization of atmospheric greenhouse gas concentrations will require significant cuts in electric sector carbon dioxide emissions, and the ability to capture and sequester CO₂ in a manner compatible with today’s fossil-fuel based power generation infrastructure. Yet, the extent to which CCS technologies will actually lower the cost of electric sector CO₂ control is still unknown and will ultimately depend on how they diffuse into existing systems, with their mix of capital equipment of different ages and real-world dispatch needs. Thus, in contrast to typical macro-economic or single plant-level analyses, Keith and Johnson developed an intermediate-level approach to these questions. By focusing on electric system dispatch, they examined how natural gas prices, sunk capital, and the availability of coal plant retrofit options affect CCS economics. Despite conservative assumptions about cost, CCS units are seen to provide significant reductions in base-load CO₂ emissions at a carbon price above 100 \$/tC.

In parallel with this work, Claire Palmgren, Granger Morgan, David Keith, and Wändi Bruine de Bruin have conducted a series of studies pertaining to public perceptions of the risks and benefits of CCS options. Using a modified version of the Center’s signature mental-model method, this team conducted interviews and focus groups. Their results suggested that most of the public is at best unsure about the notion of CCS in general and is concerned about the unknown problem and unintended consequences that might arise from CCS strategies.

In all these examples, investigators reported that without CIS-HDGC as the incubator, they might not have been able to attract the resources they needed, accomplish the results they produced, nor advance the field as they did.

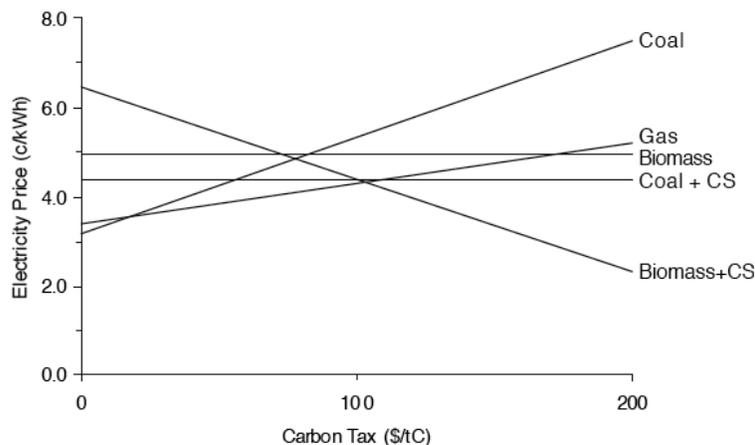
The outcomes and outputs of this work have had a significant impact on the way researchers and other stakeholders – from utility companies and state agencies to environmental NGOs and individual consumers – view current CCS technologies, which can only be seen as a critical step in the broader efforts to mitigate climate change.

Renewable Energy Sources. In many parts of the world, there is increasing interest in renewable energy sources, such as solar energy, hydro energy, wind power, and biomass fuels. In this area, CIS-HDGC research has focused on coupling biomass fuels with Industrial Carbon Management techniques, on large-scale use of wind generation, and on building integrated photovoltaics. These topics have required input from various corners of the Center’s distributed expertise, including physical sciences for atmospheric effects, biological sciences for ecosystem impacts, engineering sciences for facilities analyses, and social sciences for valuation assessment.

Of course, the surest way to address the problems of carbon fuels is to avoid them. Biomass has long been investigated both as a (nearly) CO₂-neutral substitute for fossil fuels and as a means of offsetting industrial emissions by sequestering carbon in terrestrial ecosystems. Because of its compatibility with the existing energy infrastructure, biomass energy provides not only one of the most viable substitutes for fossil fuels, but also one of the most feasible strategies by which to decouple the energy sector from atmospheric CO₂ emissions. Center affiliate investigators performed engineering-economic analyses of a variety of biomass applications. For example, Lester Lave and his students have explored the use of bio-ethanol as a motor fuel. Alan Robinson and his students have explored bio-mass co-firing of coal plants. David Keith and his students have examined bio-mass electricity production combined with CCS – effectively, a “carbon pump” – to remove CO₂ from the atmosphere.

As described above, the possibility of using fossil fuels without carbon emissions by CO₂ capture and sequestration (CCS) technologies has emerged as an important alternative for mitigating atmospheric emissions. And, while it has remained largely unexplored, the combination of biomass energy products and CCS technologies may hold the key to the largest potential impact on atmospheric CO₂ concentrations per unit of land due to its double benefit of being able to reduce emissions from energy production and effectively remove carbon from the carbon cycle via sequestration in geological formations. Other factors also make this biomass-CCS combination an attractive option within a portfolio of carbon mitigation strategies: (i) The net reduction in atmospheric CO₂ from biomass-CCS systems provides a mechanism to offset emissions anywhere in the economy; (ii) the system would efficiently utilize limited land and water resources relative to other biomass strategies; and, (iii) all of the components necessary for biomass-CCS either currently exist at large scales or are in the late stages of development for such applications.

In order to examine this potential of the biomass-CCS combination, David Keith and Jamie Rhodes developed a crude bottom-up engineering-economic model of one feasible, though non-optimal, biomass integrated gasification combined cycle system with CCS (BIGCC-CCS). The model was based on pre-existing component cost estimates and ASPEN simulation results. In addition, they modeled capture and sequestration of CO₂



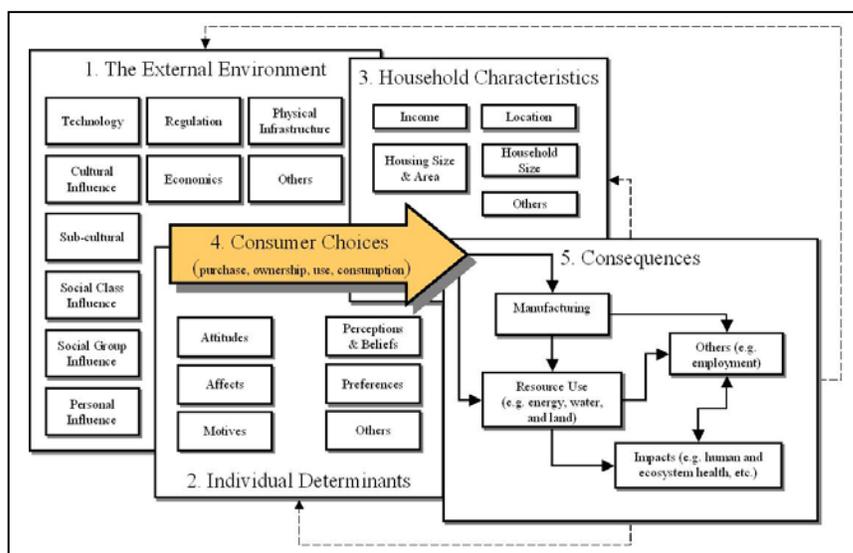
fermentation off-gases (Ethanol-CCS) in a pre-existing engineering-economic model of bio-ethanol production. Then, to compare the economics of these systems with other mitigation options, Rhodes and Keith also developed a top-down energy cost model for electricity and liquid fuels as a function of carbon price. Rhodes and Keith’s initial conservative estimates suggest that biomass energy with sequestration would have mitigation costs below 200 \$/tC. If the atmospheric reductions from this system were credited to sources with only high-cost mitigation options, then the cost of mitigation would essentially be capped at 200 \$/tC. Alternatively, if a carbon tax or shadow price system were established, biomass energy from a facility with sequestration would become the lowest cost option at shadow prices below 200 \$/tC.

In terms of other alternative energy sources, wind – with generation costs that can be less than 4c/kWh – provides a competitive option to fossil fuel electricity generation. Yet, the Center has found, through the work of David Keith and Joe DeCarolis, that the intermittent character and geographic distribution of wind resources can add significantly to the real cost of electricity from wind. Where wind turbines represent a significant fraction of the generation capacity, the spatial correlation of intermittent wind resources forces a choice. System designers can either install dispatchable (non-wind) storage/backup capacity or distribute wind turbines over a larger geographical area in order to reduce the variance of power output and meet reliability standards. Whereas previous work has focused on the economics of wind generation in isolation or with storage or backup generation for small turbine arrays, Keith and DeCarolis, have explored the role of long-distance transmission and dispatchable backup capacity in determining the economic viability of large wind systems (tens to hundreds of gigawatts). They have shown the extent to which transmission can mitigate the problem of intermittent supply. This analysis can be extended to the general problem of meeting demand variation by aggregating imperfectly correlated demands.

Wind power extracts its energy from the boundary layer of the atmosphere. In collaboration with GCM modelers at the National Center for Atmospheric Research and Princeton University, Keith and DeCarolis have explored whether large scale use of wind could extract enough energy to produce local and regional climate impacts. Their preliminary conclusion is that on a per kw basis, wind may have climate impacts comparable to those of coal-fired electric power, although of course it would only rearrange climate patterns, not produce net warming.

Consumer Behavior. Obviously, the negative impacts of energy on climate change would be less of a problem if people used less of it, particularly carbon-based fuels. Historically, a sectoral approach (based on the industrial, transportation, commercial, and residential sectors) has shaped the calculation of anthropogenic emissions of CO₂ and analysis of energy conservation and CO₂ mitigation. This sectoral categorization, however, has limited capacity to reveal the total impacts of consumer activities on energy use and the related environmental impacts. In order to address more encompassing questions like “How do consumer activities influence energy consumption and CO₂ emissions?”, Shui Bin, Hadi Dowlatabadi and Baruch Fischhoff collaborated in developing the Consumer Lifestyle Approach (CLA). With it, they have been able to categorize consumer consumption activities according to their direct and indirect influences on energy use by power and by prepared goods and services. With it, they have thus been able to estimate direct and indirect CO₂ emissions attributable to consumer preferences and demands.

Estimates based on this methodology reveal that more than 80% of the energy used and CO₂ emitted in the U.S. is a consequence of individual consumer demands and the economic activities to support these demands. Direct individual energy consumption (home energy use and personal travel) represent only 4% of the U.S. GDP, but they account for 28% and 41% of U.S. energy use and CO₂ emissions, respectively. Indirect economic activities supporting individual energy consumption (e.g., housing operations, transportation operations, food, and apparel) represent a larger share of U.S. GDP, energy use, and CO₂ emissions. In fact, indirect activities represent 1.5 times the energy use that direct consumption does and two times the CO₂ emissions of direct consumption.



If direct and indirect activities surrounding individual energy consumption are the primary sources of energy use and CO₂ emissions, then understanding the structure and distribution of these activities is critical to contemplating strategies of energy conservation and CO₂ abatement. To this end, Shui, Dowlatabadi, and Fischhoff developed a cluster analysis procedure that exploits the wealth of information available in the Residential Energy

Consumption Survey's audit of some 5000 US households. Their analysis shows patterns confounding the natural assumption that energy consumption rises with income and general consumption. They have been able to trace these anomalies to structural factors, such as homeowner incentives to use electric rather than gas hot water heaters. Their research suggests that changes in housing regulations and some education should be able to effect a cost-effective reduction in energy consumption and emissions that is largely invisible to consumers yet highly significant in terms of its positive impacts on the environment.

Thus, not only has the CIS-HDGC, through the CLA, provided a method for more accurately portraying aggregate national energy use and CO₂ emissions patterns, but, in so doing, it has revealed counter-intuitive results that could reduce the stereotypical "us versus them" (individual consumers versus industrial polluters) framing of energy issues. These findings and the results of the accompanying cluster analyses have important implications for how energy conservation strategies are designed as well as toward what CO₂ abatement strategies are directed.

Integrated Assessment and Global Change Impacts on Health and Equity

At the same time that technical, physical, and social scientists from CIS-HDGC have been collaborating on strategies to reduce CO₂ and mitigate climate change, they have also been working to assess the immediate and long-term impacts on both the health and welfare of individuals and society. This is a difficult task. Because it is not clear what physical effects global environmental processes taking place today will have in 100 (or even 20) years, it is even less clear what the human consequences of such change will be. Moreover, the cumulative interaction of these factors with the growth of the population over the course of a century is still more uncertain. Because of such uncertainties, many individuals and organizations working the field of climate change science have historically failed to address these issues. By the very nature of the Center's integrated approach, however, CIS-HDGC has actively included, rather than passively ignored the social, economic, and political determinations and ramifications of global change in the Center's analyses.

To date, the Center's work in this area has focused primarily on discerning health and socioeconomic impacts of global change and clarifying the dimensions of the uncertainties that remain. Grounded in social theory and empirical observation, this work has advanced policies at the national and international levels for mitigation as well as adaptation.

Climate Change and Human Health

Although the impacts of environmental changes on human health have long been recognized, it was not until the early 1990s that scientific awareness gradually turned from local level impacts to large-scale and long-distance effects of climate change. And, it was also not until this time that the scientific community began to identify the physical, biological, and human determinants of such processes. In the late 1990s, CIS-HDGC began responding to these developments by initiating what became a series of projects focusing on the direct and indirect health impacts of climate change and climate change policy, with the objective of developing an integrated understanding of the socio-economic as well as environmental factors that both complicate and mitigate public health outcomes in this interaction. The portfolio of projects that evolved under this initiative covered three domains: (a) air pollution, (b) water-borne pathogens, and (c) vector-borne diseases.

Air Pollution. The core methodology of integrated assessment was from the beginning motivated, at least in part, by the need to obtain a comprehensive picture of the mix of emissions, at different time and geographic scales. In order to model specifically the interactions between the outcomes of actions that create or control criteria air pollutants (e.g., PM, SO₂, NO_x), hazardous air pollutants (e.g., Hg, HCl, H₂SO₂), and greenhouse gas emissions (CO₂, CH₄), CIS-HDGC researchers created integrative models of coal combustion systems and gasification combined cycle systems, and applied them to evaluating alternative technologies. These models have increased users' ability to optimize system performance, and have reduced the risk that interventions focused on a single pollutant may unwittingly increase others.

Because accurately estimating air pollution risks requires not only knowing what pollutants are interacting but also how people are exposed to them, CIS-HDGC expanded these original models to include exposure studies that integrate behavioral data with engineering and dispersion analyses in unique ways. These novel models have been applied to both developed and developing country contexts in an effort to characterize exposure patterns over time and identify more cost-effective as well as cleaner technological responses. Examples of this work appear below.

Because of its heavy use of coal, the Center initiated an aggressive set of research activities targeting the economic and public health aspects of China's air pollution problems in 1997. Under the leadership of Keith

Florig, the Center's studies in this region have been undertaken with Chinese collaborators to focus on: air pollution exposures, impacts, and management; public awareness and attitudes regarding the environment; domestic solar, wind-turbine, and nuclear energy industries; links between pollution concentrations and levels of economic development; and, lay ranking of environmental risks. The most oft-cited China-related work completed with Center support was an analysis of the nationwide health impacts of air pollution in China. This research concluded that air pollution claims roughly 1 million lives annually in China, with the bulk of those deaths occurring among rural residents who use solid fuels for household cooking and heating. In the spirit of integrated assessment, this project sparked collaboration with Kirk Smith (University of California at Berkeley) to model China's air pollution risks from household solid fuels, which became part of a larger World Health Organization (WHO) sponsored study of environmental health worldwide. Without the Center, the type of sustained support needed to develop viable projects, attract suitable collaborators, and generate the type of interdisciplinary research needed for this work would have otherwise been impossible.

In parallel with this work in China, Lave and Cifuentes developed epidemiological models estimating the effects of air pollution and climate extremes on mortality rates in two U.S. cities and Santiago, Chile. They found greater effects from pollution than from climate, but strong indication that premature deaths are related to temperature: at high temperatures (during summer) an increase in temperature has an immediate effect on mortality, as shown in the next figure, while at lower temperatures (during the cold season), the effect is negative, with effects lasting as long as five days.

In other related work, Dowlatabadi worked on estimating the response of urban pollution to CO₂ control. Together with Sonnenblich they adopted the health impacts module from ADAM (an integrated assessment model for acid rain control in North America) for ICAM. This permitted assessment of the health impacts of ambient air pollution in ICAM. Ambient air pollution is a function of fuel choice and local pollution controls. In more industrial countries SO₂ and NO_x emissions, major determinants of ambient air quality and public health have come under increasingly stringent controls since the 1950s. Further emission reductions under these initial conditions are very costly and may be more economically achieved through fuel switching that also reduces CO₂ emissions. In less industrialized countries, SO₂ and NO_x emissions are not being controlled. They can be reduced at a fraction of the cost of CO₂ reductions. Devoting scarce resources to CO₂ controls in such circumstances retards economic development and has a deleterious impact on public health. This finding counters assertions by the IPCC and is attributable to the discipline that an integrated assessment framework such as ICAM imposes on the impact assessment process.

Particulate Controls in China

Most of the literature on air pollution policy and implementation focuses on the industrialized world. Theories explaining air pollution behavior have been espoused and examined within a limited range of political, economic, and cultural systems. To contribute to a broader understanding of the forces that drive air pollution policy, Guodong Sun and Keith Florig investigated the factors that have influenced air pollution management in urban China since the early 1980s. Data were drawn from Chinese official documents and a series of interviews conducted by Sun with local government officials in five Chinese cities spanning a wide range of population, per capita income, heating demand, and fuel availability.

Coal burning is the main source of ambient particulates in urban China, where it has long been used for residential heating and cooking, as well as for industrial processes. When China first started publishing ambient measurements of total suspended particulates (TSP) in the early 1980s, TSP concentrations in urban areas far exceeded Chinese air quality standards. Throughout the late 1980s and 1990s, however, TSP levels remained stable or declined in many Chinese cities, despite steady economic growth and urbanization.

Interviews with local officials revealed that these gains against TSP were the consequence of several air pollution control programs, the earliest of which were the addition of particulate removal devices to boilers and the provision of processed coal briquettes for household stoves. Sun and Florig found these measures to be surprisingly cost-effective. Models of exposure reduction and health benefit applied to the case-study cities yield typical values of \$3 and \$20 (1990 USD) per disability-adjusted life-year saved for boiler and household-stove measures, respectively.

Implementation of these particulate control measures was faster in some cities than in others. Data suggest that wealthier cities performed better than poorer cities. More-polluted cities drew greater attention from the central government and received larger subsidies for pollution control than less-polluted cities. In the case of coal briquettes, cities where the ratio of prices of processed and raw coal was high (i.e., cities with the cheapest raw coal) made slower progress than other cities.

The authoritative nature of China's political system both hindered and helped China's progress against particulate pollution. Although in most industrialized countries, citizen groups played a significant role in motivating air pollution laws and regulation, China had no non-government organizations to educate government officials on air pollution issues. On the other hand, once central-government officials decided to clean the air, the top-down structure of China's government provided for fairly swift action at the local level. In one city, for instance, boiler operators were told that their coal supply would be cut off unless they installed the required particulate control devices.

As China continues its transition to a market economy, new forces for particulate control are coming into play. These include cost-minimizing behavior by industry, pollution levies, and a transition to gaseous and liquid household fuels made possible by increasing wealth.

Source: Keith Florig

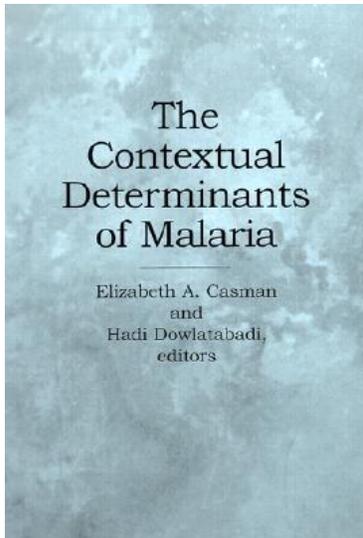
Water-borne Pathogens. Early in the Center's life, Baruch Fischhoff, Mitchell Small, and Elizabeth Casman developed a strategy for communicating risk information about waterborne cryptosporidiosis¹ outbreaks. In order to calculate the contributions of various individual risk factors associated with cryptosporidiosis outbreaks, the team incorporated both the mental model-expert model method developed by Fischhoff and his collaborators (substantially supported by earlier NSF center funding) an assessment model that integrated processes involving engineering (water treatment), ecology (land-use), biology (proliferation, testing), public health (surveillance, notification), and psychology (public response). When applying this model to typical U.S. conditions, the team's analysis showed that traditional boil-water notices are ineffective as a response to *Cryptosporidium* because vulnerable populations will have been exposed before the problem is detected. Soon thereafter, at Hadi Dowlatbadi's suggestion, the research group adapted this model in order to project future risks of cryptosporidiosis under a range of possible future climates. Results of this analysis suggested that under the conditions of these scenarios, cryptosporidiosis risks should be manageable, as long as public health infrastructures remain intact. In this light, the risks of climate change may be primarily indirect, if it leads to environmental deterioration, causing, in turn, economic and civil dislocations that imperil public health services.

¹ *Cryptosporidium* is a water-borne parasite best known in the United States for a massive outbreak in Milwaukee in the early 1990s, which sickened over 400,000 pple and caused many deaths, mainly among immunocompromised individuals.

This work meshed techniques unique to CIS-HDGC in a manner that pushed climate and health research to new and different places. Initially, the express purpose of this work was to design risk communication materials. However, the Center's interdisciplinary style and integrated modeling strategy made it a more interesting problem. Not only did Casman et al. discover that a traditional boil-water notices would come too late to be useful, but they also identified opportunities to correct this design and make recommendations for future research priorities (rapid detection methods and real time monitoring of treated water). Second, having built an integrated assessment model of factors contributing to present risk, Center members could approach the problem of future factors, using Center expertise in climate change and its human impacts. As with the Center's research on global change and air pollution health impacts, the Center's research on water borne pathogens revealed the importance of representing social institutions in predictive models.

In 2002, Ken Strzepek and Gary Yohe also began exploring the impacts of climate change on water-related health problems by adapting the Center's existing integrated river basin models (previously applied to Egypt and elsewhere) to the management of water in the arid, semi-arid and humid regions of southern Africa, with a particular focus on its implications for HIV-AIDS. Because the South African context presents the challenge of achieving productive, equitable and sustainable water management in an area with deep historical inequities, it was particularly important that the model consider institutional as well as technological measures. Thus, in this application, the model integrated demography (population), economics (development), and engineering (water resource management) in order to evaluate the impacts of climate and climate variability on the population as

well as assess the costs and benefits of strategies, such as investing in water supply and sanitation. The model then also explicitly addressed the linkage of water quality and water-borne disease to human health and especially HIV and AIDS progression.



Vector-borne Diseases. In a 1997 editorial essay published in *Climatic Change*, Hadi Dowlatabadi lamented the poor state of research addressing human health impacts of climate change. Pointing specifically to IPCC and WHO studies on vector-borne diseases as an example, Dowlatabadi claimed that research was uninformed about historic and current ranges of disease vectors and, thus, often misattributed the absence of disease vectors in temperate regions to climactic factors rather than to development patterns and public health measures. By way of contrast, Dowlatabadi argued that land-use, disease surveillance, and well-developed public health networks were primarily responsible for the current dearth of vector-borne diseases in temperate regions. He further noted that, because of this miscalculation in IPCC and WHO studies, the 50- and 100-year projections of health impacts of climate change in Africa had precluded any role for economic, social, and public health development in that region, even

though such developments could lead to a successful control of diseases such as malaria (or further deterioration).

Dowlatabadi, along with Elizabeth Casman, began looking at the effect of climate change on the spread of malaria. Their integrated assessment went beyond examining simple correlations of temperature and malaria to including possible risk factors such as public health infrastructure failures and socioeconomic inequities. In order to scope these issues, CIS-HDGC raised supplementary funding from ExxonMobil, NSF, and EPRI to support an International Workshop on Contextual Determinants of Malaria, held in Switzerland in May of 2000. The papers commissioned for the workshop and the syntheses developed from the workshop resulted in an edited volume entitled *The Contextual Determinants of Malaria* (Casman and Dowlatabadi (eds.), 2001). The volume not only reviews the relevant research from an unusually broad perspective but also offers general approaches to managing and integrating knowledge from these various sources.

The workshop and volume have introduced new implications for analysis into climate change science and policy as well as influenced a general change of rhetoric in scholarly works about climate change and malaria. Whereas before the workshop it was common to predict dire scenarios of malaria re-emergence based on climate change, today the discussion routinely considers other determinants of malaria and their dominant influence. For example, Richard Tol and Hadi Dowlatabadi explored this issue further by combining insights from the MIASMA model (regarding climate and malaria vector prevalence), FUND (demographics, economics and climate change), and BMR (economics, trade, and climate policy). In so doing, they found that socioeconomic factors tend to be more important than climate as a determinant of malaria. If true, then unilateral mitigation efforts by Annex 1 countries, designed to reduce commodity imports from poorer countries,

might lead to a cooler (or at least less warm) world, with a higher disease burden. While non-climate determinants are increasingly “common knowledge” and studies of this sort are more widespread today, the idea was novel and controversial five years ago and its emergence would have been much delayed without Center funding, leadership, and intellectual foresight from its interdisciplinary base.

Climate Change and Social Equity

The impact of climate change is projected to have different effects within and between countries, where the poor are generally thought to be more vulnerable than the rich. At the same time, the rich emit most greenhouse gas emissions. This raises important issues related to equity. Standard project and policy appraisal methods cannot handle this type of problem. In principle, these methods search for policy interventions that leave nobody worse off and at least one person better off. In (the common) case where such policy interventions do not exist or are insufficient, these methods prefer policies that could, with appropriate compensation, leave nobody worse off – even if that compensation is not actually paid. With climate change, even theoretical possibility of such a transfer is inappropriate: It grants special status to the case without policy intervention, in the sense that an eligible policy must be better than no policy at all. However, with the global-scale issues addressed by climate-change policies, the fundamental inequity may reside in the case without policy.

In a series of papers, Richard Tol – with non-CIS-HDGC co-authors Claudia Kemfert and Roda Verheyen – explored methodological alternatives and applied them to the question of long-term targets for international climate policy. Simplistic solutions, such as increasing the weight given to the poor in decision making or the weight given to future events, have as drawbacks that climate policy would seek to solve all the world’s woes, and would be inconsistent with other long-term policies. Letting emitters of greenhouse gases compensate victims of climate change would restore equity and provide a strong incentive to emission abatement only if liability for emissions goes back to at least 1896 (Arrhenius). If liability starts at the point when climate change was recognized as a serious problem (say with the formation of the IPCC in 1988), then the larger part of climate change is the liability of developing countries, and China may even have to compensate the U.S. A policy that sought to restore the inequities of the world as they would have been without further climate change, would require such drastic emission reduction that political feasibility is questionable. However, a policy in which every country acts as if it is the worst affected, would avoid the worst inequities and would call for substantial but not infeasible emission reduction. This, however, would require substantial acts of altruism and compassion.

In the final two years of the Center, James Tansey began to examine the linkages between research on population health and the concept of resilience as it pertains to health outcomes. The premise for this research is that populations with a higher state of positive health are more resilient to external stressors including those resulting from climate change. Population health research suggests that a number of social structural factors can have significant impacts both on the incidence of chronic conditions and on immune system function. These factors include employment security, agency, social stress, inequality and social networks. Recent work on social networks suggests that they have health effects that are comparable in magnitude to the effects of smoking.

In this study, Tansey has focused on resource dependent communities in British Columbia and has focused on the role of social networks in mediating health outcomes. To date, the findings from research suggest that access to educational opportunities is important in determining the extent and density of social networks. Social trust variables appear to be strongly correlated with health outcomes for reasons that are not entirely understood at this stage. NSF support has provided an invaluable foundation for this work and for the preparation of a number of applications for ongoing research support.

Impacts of and Adaptation to Multiple Stresses and Extreme Events

Even if atmospheric greenhouse-gas concentrations were stabilized, let alone reduced, over the next decades, global temperatures would likely increase for another few decades and sea levels would continue to rise for a number of centuries. These lagged effects, attributable to past CO₂ emissions, are often referred to as the “commitment to climate change” that nature and society have to manage. As a result of this expanding commitment and the increasing recognition that current patterns of greenhouse gas emissions are not likely to be curbed significantly in the near future, there has been growing awareness that strategies of adaptation to global change can complement strategies of CO₂ abatement and climate change mitigation in order to reduce climate change risks.

Just as with abatement and mitigation, sound strategies of adaptation require sound science. Despite this need, however, scientists and policymakers paid little attention to adaptation until only recently. It was only after the Intergovernmental Panel on Climate Change Workshop on Adaptation to Climate Variability and Change (1998) and the IPCC Third Assessment Report (2001) that scientific attention began to shift in this direction. Researchers from CIS-HDGC and other institutions initiated serious scientific inquiry into the processes and mechanisms along which adaptation occurs. It is only since the 8th meeting of the Conference of the Parties (2002) that adaptation research has begun to receive the widespread attention and increased funding that it requires.

In addition to limited resources, scientists and policymakers have avoided research in this area because of the inherent difficulties and uncertainties associated with trying to monitor and measure adaptation. Not only must adaptation be understood as an adjustment in both biophysical and socioeconomic systems, in response to climatic stimuli and (actual or anticipated) their impacts, but adaptive strategies must be evaluated in terms of economic efficiency, technical feasibility, environmental safety, cultural compatibility, and social equity. Thus, the processes and mechanisms of adapting to global change are linked with non-climatic as well as climatic developments, and are hence situated in a dynamic societal as well as natural context. As a result, designing, implementing or assessing adaptation requires consultation from various disciplines in the social, technical, physical, and biological sciences.

By virtue of its integrated orientation and systems-level approach, CIS-HDGC was uniquely positioned as one of few institutions with the interdisciplinary partners and perspectives to approach the study of adaptation in a way that respected its complexity. Consequently, CIS-HDGC has been an early adopter of and leader in this kind of research. In fact, insights generated through the Center's work helped forge the bi-directional link between adaptation and societal context: Socio-political-economic factors can enhance or impede a system's ability to adapt, while stresses of climate change influence the development future socio-political-economic processes.

The Center's portfolio of research in this area has looked at both adaptation and adaptive capacities, for both biophysical and human systems, in the face of long-term shifts in average climate and sudden, extreme of climatic events. Whereas much research into adaptation strategies tends to emphasize the origins and impact of some climate change or event, adaptive capacity research focuses on the vulnerabilities and responses of that system to such changes. CIS-HDGC researchers have considered both aspects of the process, in the context of how both biophysical and socio-economic systems manage global change. Center work conformed early to the emerging view from the IPCC Third Assessment Report that vulnerability is a function of both exposure and sensitivity and that these two factors can be influenced by adaptive capacity. People who begin their work with climate change origins and impacts tend to worry most about exposure; but more recent work focuses attention on sensitivity to external stress of which climate change is but one source.

Adaptation Strategies

There are various ways to classify or distinguish between adaptation strategies. First, depending on the timing, goal and motive of its implementation, adaptation can be either reactive or anticipatory. Reactive adaptation occurs after the initial impacts of climate change have become manifest, while anticipatory (or proactive) adaptation takes place before impacts are apparent. Second, adaptation may be considered to be autonomous or planned. Whereas autonomous adaptation occurs without intervention of an informed decision maker, planned adaptation requires informed and strategic actions. Most biophysical and socio-economic systems will undergo autonomous adjustments in response to changing climatic conditions. These adjustments are likely to occur both with gradual climate changes and more drastic events. In this area, CIS-HDGC has looked at cases of both reactive and anticipatory adaptation to acute and chronic change in the context of desertification and degradation, land use change and urbanization, and sea level rises and storm surges.

CIS-HDGC has focused some its work on this area on the issue of uncertainty. Autonomous or reactive adaptation strategies can handle varying conditions and unknown futures only if conditions usually stay within a coping range. Planned or anticipatory adaptation strategies struggle with uncertainty almost by definition. Thus, stakeholders who try to implement planned or anticipatory strategies are in the same situations as Center researchers who have tried to include adaptation into their models across a range of not-implausible climate and socio-political-economic futures. It is precisely in these contexts, that the value of information can be examined so that we can better understand what sort of information would be more valuable across various types of adaptation under what circumstances.

Desertification. The United Nations Convention to Combat Desertification (UNCCD) defines desertification as "land degradation in arid, semi-arid, and dry subhumid areas resulting from various factors, including climatic variations and human activities." Furthermore, UNCCD defines land degradation as a "reduction or loss ... of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands" While there is general consensus that desertification is *linked* to CO₂-induced climate change by virtue of the feedbacks between land degradation and precipitation, there is substantial disagreement over whether desertification is *driven* more by climatic or anthropogenic factors. In many areas, activities such as cultivation, overgrazing, and fuel gathering have eliminated or reduced natural vegetation and thus accelerated soil erosion rates. Many claim that, consequently, the capacity of these lands to support human populations, livestock, and wild herbivores has been substantially reduced (i.e., desertified). However, others vigorously contest this notion, arguing that not only is desertification triggered or exacerbated by climate variability (mainly drought), rather than by anthropogenic factors (at least locally), but most observed changes do not directly affect human welfare.

Over the past 30 years, international efforts to address desertification have been stalled, if not stopped, by the tangle of uncertainties surrounding the causes, processes, and effects of land degradation. The cycle of endless debates leading to negligible agendas or actions has pointed to the need for new thinking beyond existing regional and disciplinary frames. In response to this need, CIS-HDGC – led by James Reynolds and in conjunction with the Collaborative Research Network for Assessment, Research, and Integration on Desertification (CRN – ARID) – has been developing a synthetic assessment framework for addressing the varied dimensions of global desertification, ranging from basic ecological to human dimensions. The ultimate goal of this initiative is to deploy this framework in a way that is useful to scientists, land-managers, and policy-makers, especially in the context of the UNCCD.

The first cut at this synthetic framework is the “Dahlem Desertification Paradigm” (DDP), developed at the 2001 Dahlem Conference on “The Meteorological, Ecological, and Human Dimensions of Global Desertification” (<http://www.fu-berlin.de/dahlem/>). Drawing heavily from the chapters in the Dahlem Conference book, *Global Desertification. Do Humans Cause Deserts?* (2002), the DDP embraces a range of elements within coupled human-environment systems, including: non-linear processes, resilience, vulnerability, traditional range ecology, human perceptions, panarchy theory, social structures, economic factors, etc. At the core of the DDP, then, is the recognition that desertification cannot be framed in terms of single measures alone, but must simultaneously involve both biophysical and socio-economic factors. These factors, together with their implications for action, are determinable, with some precision, because a limited number of ‘slow’ variables determine the dynamics of linked biophysical/socio-economic systems at different scales. The DDP recognizes how important it is to keep the evolution of each subsystem in balance with each other through the development of appropriate local environmental knowledge and offers a well-structured approach to relating defined types of land ‘degradation’ at finer scales to the emergent concept of ‘desertification’ at broader scales, e.g., the CCD.

The DDP framework has implications for research, monitoring, community development programs and policy. In particular, Reynolds played a leading role in establishing ARIDnet, an international consortium of researchers from global change programs on natural and human-influenced systems. ARIDnet serves as a mechanism for providing the intellectual leadership for critical thinking about the causal factors (and their interactions) of land degradation in aridlands, spanning a wide range of temporal and spatial scales, from small geographical units to larger regions. This will be accomplished by a critical evaluation and refinement of the DDP. General objectives of ARIDnet are to (i) foster international cooperation and exchange of ideas about desertification, as summarized in the DDP; (ii) open communication channels to foster more practical, field-level interactions with stakeholders in sustainable land management; and (iii) use the concepts, experiences, and applications developed by group members to support on-going international discussions on principles, criteria, and policies related to global desertification.

In addition to ARIDnet, the DDP initiative has yielded several seminal publications and presentations that could ultimately change the face of the debate and, eventually, turn the corner toward new policies and programs. These initiatives have benefited from external participation and funding, building on the essential initial support provided CIS-HDGC’s financial and intellectual resources. This progression is a tale of how interdisciplinary collaborations can change the minds of scientists and the faces of their science.

Land-Use and Land-Cover Change. The expansion of problems entertained by global change science has vaulted the study of “land-change” science to the forefront of international and national agendas, be it the newly minted Global Land Project of the IGBP-IHDP or the NRC’s *Grand Challenges in the Environmental Sciences* (2001). This science seeks to understand land change in its own right—to explain, model, and project—the

improvements of which provide profound insights to carbon, ecosystem services, hydrology, biodiversity, and human well being. Land-Change Science seeks to advance this understanding by integrating natural, human and remote sensing/GIS sciences. Two projects led by Clark University have been leaders in development of the practice of this science. The SYPR or Southern Yucatán Peninsular Region project, and the HERO-CM or Human-Environment Regional Observatory-Central Massachusetts project.

CIS-HDGC has been one of two pillars through which the SYPR project has been built and come to be recognized as a premier example of the emerging subfield of “integrated land change science” as illustrated in *Integrated Land-Change Science and Tropical Deforestation in the Southern Yucatán* (2004). The Center’s contributions and impacts go well beyond its direct funding. They have been central to at least three facets of the SYPR project. One of its goals is developing a spatially explicit integrated assessment models informed and parameterized by the findings of the project at large. Center members helped to formulate the SYPR integrated assessment model and launch the career of Dr. Steven Manson (now at U. Minnesota); his genetic, agent-based models are considered to be a cutting edge in the field, and were strongly influenced in their initial development by close contacts within the Center. Their architecture involves interactive agents, environment, and institutions and deliver land-change outcomes at the pixel level (30 x 30 m).

A Tale of Two Sciences and The Rise of the of the Dahlem Desertification Paradigm

Soon after accepting an invitation to participate as a co-PI, I experienced something akin to ‘buyers remorse’. Upon reading a draft of the Center proposal, I became apprehensive about committing myself to a project that appeared so foreign. The term ‘human dimension’ sounded alien – after all, I was an ecologist studying ‘natural’ desert ecosystems and as far as I could tell, none of the ‘dimensions’ of my work had anything to do with ‘human beings’!

After the first annual meeting, my concerns were somewhat (but not completely) alleviated. The goal of this meeting was to refine the overall strategy and future directions of the Center. I recall listening to a wide range of presentations covering a variety of research topics. To my surprise (now I can admit this), I found many of these quite interesting and stimulating in spite of the jargon and difficulty associated with listening to disciplinary-based research. Based on my cryptic notes, topics discussed included issues such as integrated assessment, equity (I wrote: “everyone thinks it’s important but can’t seem to agree on exactly what it is”), social capital, institutional structures, cross-cultural dynamics, uncertainty and so forth. A foreign language to me.

At the same time, Granger Morgan made a series of statements that resonated with me. Among these, he discussed the need for better impact assessment in the context of global change, both in qualitative and quantitative terms (the latter being one of the existing strengths of the Center, e.g., the ICAM model). As a modeler of basic processes in arid ecosystems, such as decomposition, nutrient cycling, plant growth and mortality, hydrologic run-on and runoff, and soil water redistribution, I was particularly interested in developing process-based models but hadn’t really given any prior thought to the idea of including human dimensions vis-à-vis impact assessment. This was important considering that my work dealt with the topic of desertification, which is land degradation in arid and semiarid regions and is caused by (or triggered by) either natural drivers, e.g., drought, or anthropogenic drivers, e.g., overgrazing by domestic animals or poor agricultural practices, or a combination of both. To this point, I had concentrated solely on the roles of meteorological and ecological dimensions (the biophysical variables) of desertification with only limited recognition of the human dimension side of things.

In fact, it wasn’t until the second annual meeting—when I gave an oral presentation on my desertification work in southern New Mexico—that I better appreciated that I was going to take my Center research in the direction of human dimensions. Billie Turner contested some of the global figures that I presented on land degradation (which I had taken directly from the UN bible on The Convention to Combat Desertification), rightly pointing out that many of these figures were unsubstantiated and/or exaggerated for a variety of reasons, ranging from political (to attract foreign aid) to scientific (lack of a generic definition of ‘degradation’). At the time, it hadn’t occurred to me that land degradation was really in the ‘eye of the beholder’: so what if a rangeland has some soil erosion if the manager is still able to make a living? As an ecologist, I might argue that erosion gulleys are indicative of ‘land degradation’ but the problem is that humans are often concerned only with that subset of this broad definition of desertification that impacts on human activity—whether at the local land-use level or through feedbacks at a wider scale.

Over the next several years, I wrote several major reviews on the topic of desertification with this fundamental idea in mind. I learned a lot! Then, teaming up with Hadi Dowlatabadi and Billie Turner, we put on an international Dahlem Conference, which was entitled “The Meteorological, Ecological, and Human Dimensions of Global Desertification.” The key product of the meeting was a new synthetic framework for global desertification, which we now call the Dahlem Desertification Paradigm (DDP). In terms of Granger Morgan’s plea for better impact assessment in the context of global change, both in qualitative and quantitative terms, I consider the DDP a powerful contribution to strengthening the qualitative issues involved in global desertification. The next step is to initiate a quantitative integrated assessment. As a follow-up to the Dahlem Conference, we have established ARIDnet, which is, like and thanks to CMU HDGC, an intentionally very interdisciplinary group of collaborators.

I have benefited from the Center in a variety of ways. First and foremost, the opportunity to interact with a stellar group of colleagues has been intellectually stimulating and rewarding. Second, the Center stimulated me to think ‘out of the box’ (while perhaps a cliché, it certainly is apropos in my case). My research interests have broadened substantially during the life of the Center as a direct result of my participation. I no longer consider myself solely an ecosystem ecologist per se but instead a generalist interested in integrated modeling of the causes and consequences of desertification.

I believe that the insight on and collection of desertification research stemming from the Center has the potential to be highly influential in global change research and policy on this topic. This insight will be the springboard to the next level of research on desertification for myself, my future students, and perhaps other interested researchers.

Source: *James Reynolds*

Making these models operative down to the pixel level required new, experimental techniques, able to derive Landsat TM-based classifications suited to both the natural and social science facets of the problem. This required, especially, the need to identify subtle difference in forest types, agricultural practices, and fallow-successional growth. This effort was aided by detailed training sites for which the land-use histories were reconstructed. The cutting edge work by Dr. Rinku Roy Chowdhury (U. Miami) and Dr. Laura Schneider (Brown U.) was enhanced by annual Center critiques of the statistical processes used to derive such fine-tuned classifications. Subsequent work by Dr. Ron Eastman (Clark U.) has added yet more detail with an accuracy assessment of 90%.

Finally, the SYPR has refined its “vulnerability” concepts through interactions (especially at the annual meetings) with the overall Center membership, leading to SYPR’s important role in the Sustainability Science Project of NOAA-NSF and the development of the SYPR vulnerability model (conceptual), recently highlighted in a special feature section of the *Proceedings of the National Academy of Sciences* (2003). One participant, Alexander Pulsipher, translated his Center experience into an NSF Graduate Student Fellowship. The SYPR model links regional perturbations and stresses (e.g., hurricanes and thin markets) in the coupled human-environment system to the macro-environmental and political economic conditions from which they emanate, addresses their impacts on interactions of the human and natural subsystems and their copying capacities, and illustrates how the outcomes feedback on the extra-regional conditions. The SYPR project currently awaits the outcomes of various grant proposals to launch a multi-year vulnerability study.

In contrast to the tropical forest frontier problems of the SYPR, the HERO-CM addresses the highly developed conditions of Central Massachusetts. The HERO study areas encompass the frontier of an emerging megalopolis, i.e. the increasingly connected cities of Boston and Providence, which extend to New York and Washington. The HERO program has four nested study extents, the smallest of which is the town of Worcester and its nine surrounding towns, the largest of which is all of Massachusetts. HERO research examines the manner in which humans transform landscapes and the environmental consequences of those transformations. A major purpose is to have undergraduates involved in high-level research, so every year HERO selects a half-dozen students in a competitive process to carry out a 12-month research project.

The Center has supplied resources for HERO to hire a doctoral research assistant to facilitate HERO-related work. Over the last several years, Center funds have been invested in using the HERO infrastructure to create and illustrate new concepts in quantitative analysis of land change. Each year, the funded research assistant has produced a major research product. For example, Pontius and Pacheco (in press) created a multiple-resolution version of the Relative Operating Characteristic (ROC) that allows land change scientists to quantify how the measurement of a land-change model is sensitive to the resolution of the underlying data. This ROC idea originated from interaction with Center faculty, and we have been able to extend this idea in order to customize it for land-change science. Pontius et al. (2004) derived methods to detect important transitions of land change; their work provides as the intellectual basis of several more papers in production.

The creation of new methods is essential, but not sufficient for scientific progress. In order to capitalize on the creation of new methods, those methods must be made accessible to scientists via user-friendly software. Therefore, during the last two-years, the Center has also funded a programmer at ClarkLabs, the part of Clark University that produces the GIS-software *Idrisi*. This support has allowed these newly developed methods to reach an audience of 35,000 scientists. *Idrisi* now has four modules that can be traced directly to the Center’s support: Geomod, ROC, Validate, and Multiple-Resolution Crosstab. Taken as a whole, these modules allow scientists to calibrate a model of land change, to assess the performance of the model with validation statistics, and to extrapolate the pattern of land change with a measured estimate of certainty. The existence of these software products has lead directly to many publications including: Pontius and Schneider (2001), Pontius and Batchu (2003), Pontius et al. (2003), Pontius and Malanson (in press). Without the investment in the development of concepts and software, this work would have been impossible. These methods are being adopted increasingly by researchers outside the Clark and Carnegie Mellon communities.

Coastal Zone Developments. As mentioned, climate change impacts create two classes of problems: (a) acute problems due to extreme events, which happen for current climates, usually over a geographically limited area, and require rapid, massive relief; and (b) chronic problems due to subtle shifts in conditions – such as sea level rise – which happen under current conditions but are expected to become more widespread and significant. Whereas the long-term impacts of chronic problems are often much larger than those of acute problems, they are often less widely noticed and alleviated with relief efforts. Furthermore, because humans detect and respond to acute events, their occurrences can help reduce chronic problems by signaling the need to abandon vulnerable locations. The impacts of sea level rise or coastal storms can be very different for individuals for society as a

whole. Large personal losses and gains may mean little change for society, just as small individual changes may have unappreciated cumulative effects.

Thus, extreme events may inflict less damage and result in lower private and social costs than subtle shifts. Such is the case with the long-term subtle coastal processes vis-à-vis infrequent extreme coastal events. While it is true that extreme coastal events (when they happen) can do damage in orders of magnitude higher than expected, chronic problems are often far more damaging. To test this hypothesis, Gary Yohe, Hadi Dowlatabadi, and Jason West developed, at CIS-HDGC, a simulation model of households living in a hypothetical community on the east coast of the United States. Building on Yohe's earlier work, estimating the economic cost of sea-level rise along the actual developed coastline of the U.S., the new model simulated potential future storms, long-shore drift, and sea level rise. It estimated both inundation and storm damages (which were calibrated with insurance claims data) in a hypothetical coastline community, making assumptions about the critical social variables of regulations concerning set-back and regional development on future patterns of development.

Their analysis showed that small, frequent storms cause more damage than infrequent large storms, with the impacts falling more on individuals than on society. Including adaptation to sea-level rise in the model (protect or abandon coastal property) based on cost-benefit decisions with knowledge of risks reduced the potential U.S. cost by nearly 85%. Adding storms to the equation increased the expected cost attributable to seal-level rise by about 50% (from the low values), an increase that could be diminished by zoning practices – another form of adaptation

Such counterintuitive results were anticipated by CIS-HDGC researchers, based on their familiarity with the cumulative evidence showing the limits to traditional cost-benefit approaches, for handling the complex factors and cascading uncertainties that pervade our understanding of climate and climate policy. First, cost-benefit analyses cannot capture the political, social, cultural, and economic pressures shaping choices like coastal management and adaptation. For example, shorefront property owners may be politically so powerful that they can shift the costs for protecting or restoring their property to have the community or government. Second, cost-benefit approaches (the basis of many earlier climate change decision models) are not always well-suited to dealing with uncertainties, as well as the techniques of risk-analysis. Decisions about how to rebuild and enforce a retreat from the sea (to prevent repeated storm damage *and* second-best cost-benefit decisions to rebuild) are best viewed in terms of risk reduction.



With their combined expertise in climate and decision sciences, CIS-HDGC researchers have been leaders in thinking about how to improve decision making and adaptation by reframing the questions to ask: How should we respond to the risks of climate change, given that we don't really know very much about what might happen? How much "insurance" should one "buy" against the risks associated with climate change? How much should we invest in early mitigation, in significant research into energy conservation, and in building adaptive capacity

around the world? Thus, rather than trying to produce estimates of immediate or future economic benefits, they are trying to assess the role of uncertainty, itself, as the reason for doing something. Adopting a risk perspective has allowed uncertainty to be a reason to begin mitigation or adaptation rather than just a source of gridlock

By incorporating these new variables and uncertainties, CIS-HDGC has helped advance how adaptation can be better included in integrated assessments of climate change across a wide range of "not-implausible" futures – defined by climate social, economic, and political parameters. In so doing the Center has made progress toward developing methods that can handle a diversity of futures, when decision makers must consider adaptation in the face of multiple stresses and in an environment of enormous uncertainty.

Adaptive Capacities

Whereas adaptation considers specific responses to perceived or actual climate change, adaptive capacity is the ability of a system, region or community to adapt to that change. Whereas the manifestations of stress from climate change and climate variability are site specific, the capacity to adapt is both site-specific and path-dependent. CIS-HDGC scientists Richard Tol and Gary Yohe worked from the IPCC Third Assessment Report notions of vulnerability and adaptive capacity to produce a list of determinants of a system's adaptive capacity – its ability to expand its coping range vis-à-vis current climate variability and to expand the range of futures with which it might be reasonably comfortable. They include:

- (i) Availability of response options;
- (ii) Availability and distribution of resources;
- (iii) Structure of critical decision-making institutions;
- (iv) Ability of decision-makers to process information given uncertainty;
- (v) Stock of human capital (education, etc...);
- (vi) Stock of social capital (property rights, etc...);
- (vii) Access to risk-spreading mechanisms (broadly defined); and,
- (viii) Public perception of causality and exposure;

With these factors in mind, Tol and Yohe developed an indexing method of assessing relative vulnerabilities across locations based on a “weakest link” hypothesis (i.e., overall adaptive capacity is only as strong as its weakest determinant). The hypothesis has been well supported by subsequent work, but it is perhaps most significant because it formally organizes answering the question “Why does a measure work in one place and not another?” The work has found that enhancing adaptive capacity is more complicated than perhaps previously understood. It is not enough to strengthen one determinant if others are weak. For example, it is not enough to provide resources if institutions and decision makers cannot process information and/or will not assume responsibility. Nor is it enough to increase the stock of human capital, if the stock of social capital is underdeveloped. Taken together, these analyses show the need for integrated assessments of adaptive capacity; and conducted over a wide range of “not-implausible” futures.

A second hypothesis about the determinants of adaptive capacity is emerging through concern about administering adaptation funds and the 8th Conference of the Parties brings adaptation to the fore: the determinants of adaptive capacity match well with what might be called the precursors for sustainable development. If true, then the match between adaptive capacity and sustainable development might be the missing link needed to bring the long-term issues of climate change and adaptation into the realm of shorter-term development plans in developing countries. CIS-HDGC researchers are active participants in the IPCC and other processes attempting to develop the science base needed by policy makers

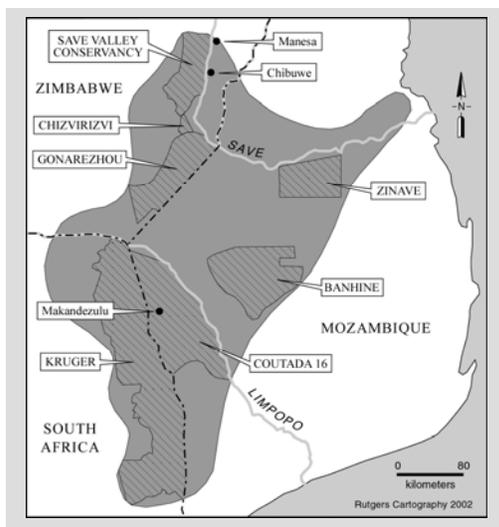
After completing a PhD in the Center on a set of issues related to sea-level rise, Anand Patwardhan, joined the faculty of IIT Bombay and began an extended collaboration with the Center. He undertook a number of climate related studies in the Indian context including a systematic examination of the risks posed by sea-level rise and storm surge in the Gulf of Bengal. He also played an important role, communicating insights from the Center's research to policymakers in the government of India, and participating as an Indian representative in a number of international scientific bodies.

Transboundary Protected Areas Research Initiative (TPARI). Over the past decade vast tracts of land throughout the world have been brought under the sway of large-scale regional planning and investment programs. Such programs operate across scales, traditional institutional frameworks, even territorial boundaries. They generally aim at achieving regional economic integration and meeting regional, national and subnational development objectives. Particularly in the southern African context these tend to focus on natural resource management, the development of vast new protected areas and opportunities for tourism investment. By emphasizing close collaboration between states, the private sector, civil society and local people, they create new and complex forms of governance.

The southern African region is characterized by high climate variability, with local populations being regularly exposed to extreme environmental conditions, ranging from massive floods to droughts and famine. Transboundary Protected Areas (TBPAs) can in themselves be viewed as adaptive responses to these conditions. By increasing connectivity and combining resources in areas projected to change significantly, TBPAs may not only have the benefit of increasing the reserve's resilience to current climate variability, they may actually also ameliorate some of the problems caused by climate change well beyond the park boundaries.

However, these proposed TBPA benefits are still predicated on a number of assumptions, some of which still need to be thoroughly tested, regarding (a) the way in which natural ecosystems will respond to changing climate and (b) the design and management of protected area systems. It is out of this need that the CIS-HDGC TPARI initiative was born to study the social and natural transformations brought about Transboundary Protected Areas (TBPAs) and related biogeographic and ecoregional planning processes in southern Africa. The project has focused on The Great Limpopo Transfrontier Park (GLTP) and the larger Great Limpopo Transfrontier Conservation Area (GLTCA). Not only has this geographical focus given a manageable case study approach to the project, but the controversy that has accompanied this park development process has also created scope for productive academic investigation. The ultimate objective of this work is to provide interdisciplinary perspectives on this TBPA as a coupled human-environment system and to assess its sustainability with reference to its social, economic and environmental dimensions through the use of Integrated Assessment (IA) methodologies.

Due to a combination of political, economic, and climatic factors, famine and starvation conditions are currently developing across the region. Climate change is likely to exacerbate the cyclical nature of environmental stress in the region, adding to the pressure on local natural resource management systems. Much attention has already been given to the biophysical aspects of the Greater Limpopo area, this research project has focused on developing the social science contribution to IA methodologies for understanding the interactions among these factors. In so doing, it has intended to provide an independent research service with the objective of making critical and constructive contributions to the policy decision-making process.



TPARI's first phase will be completed by June 2004. This consisted of four main activities:

1. Building a research and communications network for improved exchange and coordination among researchers.
2. Identifying and accessing existing data and databases dealing with the GLTP, and training staff for developing an integrated TPARI database.
3. Conducting sociological surveys and archival research as the foundation for integrated assessment;
4. Launching case studies for comparative work.

TPARI now runs as a programme under the auspices of the IUCN-South Africa. This provides it with a platform for networking with the wide range of institutions active in the GLTP. It also makes it easier to conduct comparative work at other TBPAs. It has provided the catalyst for a diverse network of scholars and policy makers, in the region and around the world. As a social institution, it is voluntary, politically independent, locally grounded, and academically based.

Okanagan Region. Center support has also enabled James Tansey, Hadi Dowlatabadi and graduate student, Philippa Sheppard to participate in a climate change adaptation project in the semi-arid Okanagan region of British Columbia. While the Canadian Climate Change and Adaptation Fund (CCAF) funded the core project, we were able to significantly extend the goals of the project in two ways. The first project sought to examine the factors influencing the uptake of adaptive water demand management strategies including metering and drip irrigation in the study region. Interviews were conducted with local experts who had played a significant role in the adoption of these technologies and techniques to identify the key enabling factors and barriers in each case. The assumption behind this study was that by understanding adaptation processes in related areas in the present, we can better inform policies for future adaptation to climate impacts, and perhaps more importantly, can identify viable sites for anticipatory adaptation.

A second project engaged regional stakeholders in a qualitative scenario analysis through a series of stakeholder workshops in the region. Participants were asked to consider a range of adaptation options. In each case they were asked to evaluate the options according to nine key questions related to legal and institutional factors, political support and public acceptance. The exercise generated a political map of the region, which suggests areas where adaptation policies might be successful and areas where serious challenges might be encountered. One of the unexpected findings of the study was that in the face of increasing scarcity of water supply, irrigators

can respond to shortfalls very rapidly by pumping groundwater. Since groundwater extraction is largely unregulated in BC, this adaptive strategy has the potential to create strong secondary negative impacts.

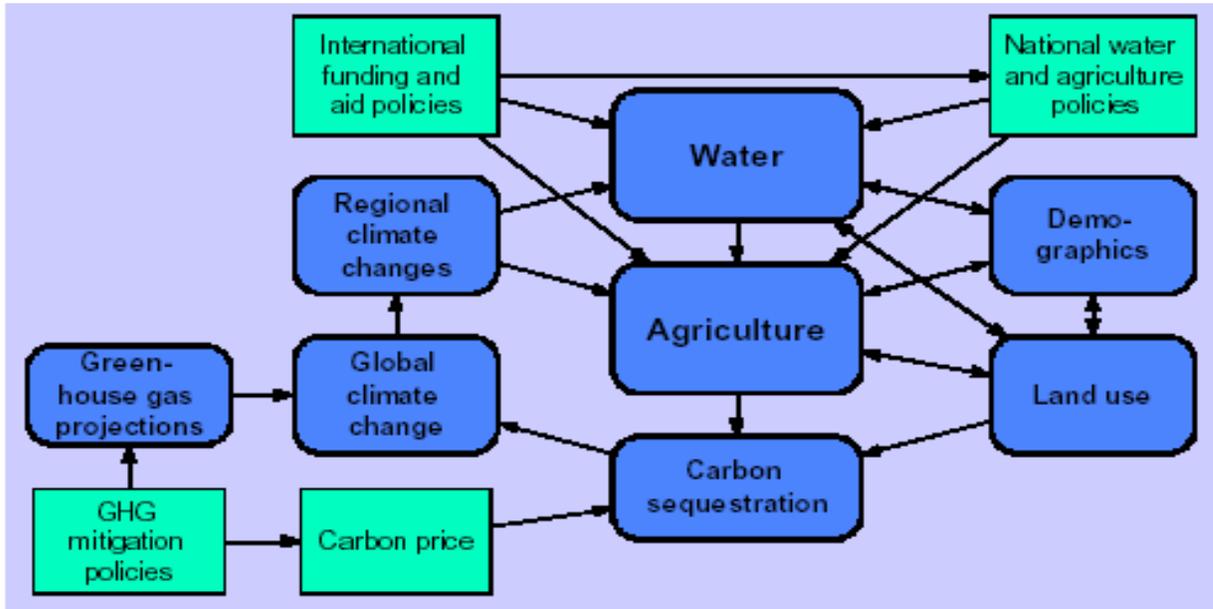
Integrated Assessment of Global Climate Change on Water and Food Availability in West Africa:

West Africa contains some of the poorest countries in the World that are especially vulnerable to climate changes. Over the last 50 years, rainfall has decreased as much as 30% in this region, which has been blamed for the desertification and the southward encroachment of the Sahara desert into the grass-lands of the Sahel. A major result has been reduction of pasture lands, and southward movement of traditional herders, resulting in conflict over land between herders and agriculturalists. During the decade of the 1990s, however, there has been some evidence of an encouraging reversal in these trends with increasing rainfall and a northward movement of the grass lands.

The reasons for these regional climate changes remain controversial. Some suggest that they are part of global climate change due to anthropogenic emissions of greenhouse gases. Most global circulation models project increases in *variability* from year to year, and especially the distribution of rainfall. But, most project *increases* in rainfall for tropical latitudes. However, they do not provide resolution over longitudes adequate to differentiate West Africa from other equatorial regions.

Some climatologists propose that the mid 20th Century was especially wet in Central and West Africa, and that the decline in rainfall since then represents a regression to long run climatic averages. Others suggest that the dryness may be due to regional deforestation and other changes in land use that reduce evapotranspiration and hence humidity, resulting in reduced precipitation. This is consistent with observations in other regions where deforestation is correlated with reduced rainfall, for example, in Central America (Still, Foster, & Schneider, 1999; Pounds, Fogden, & Campbell, 1999; Lawton, Nair, Pielke, & Welch, 2001) Another recent explanation for reduced rainfall, implicates particulate air pollution in the North, especially sulfates. This theory is consistent with the apparent increased rainfall in West Africa, due to increased particulate emissions controls in the North over the last decade or two.

In order to foster investigation of the effects of climate change in West Africa, and consequences for water availability and agriculture, HDGC provided seed money for a workshop on the issue by West African scientists. The workshop co-ordinated by Felix Dayo took place in October 2003, in Ile Ife, Nigeria. Participants included scientists and policy representatives from government agencies from four countries in the region: Burkina Faso, Ghana, Nigeria, and Senegal. As a focus for the synthesis and analysis of available understanding of the interrelated scientific and policy issues, the participants have developed an initial integrated assessment model. Max Henrion facilitated model building, using Analytica, creating a hierarchy of influence diagrams to represent key variables, including uncertainties and policy decisions, as proposed by team members.



Influence diagram showing the top level modules (bold) and policy variables (rectangles) of I-CWA (Integrated Assessment of global Change in West Africa).

The I-ACWA (Integrated Assessment of global Change in West Africa) model includes modules to project both global and regional climate changes, capable of addressing the effects of several scenarios, including effects of possible GHG mitigation policies. (See Figure #.) These feed into rainfall, water availability and agriculture, with associated demographics and land-use modules. The model addresses the interactions with national and international funding and policies for water and agriculture. A particular focus is on improved farming practices, including irrigation and measures to reduce water run-off and soil erosion, conserve soil fertility, and enhance soil organic carbon. These measures include increased use of mulch and other organic fertilizer, ridge cropping, cover crops, and alley cropping – hedgerows to reduce erosion, provide shade, and mulch. Such farming methods can substantially improve farmers’ capacity to improve with current and future climate variability – whether rainfall increases, decreases, or stays the same. There is, therefore, no need to await improvements in climate science to determine their value.

Increasing soil organic carbon has the dual benefit of improving soil fertility and sequestering carbon that would otherwise be released as carbon dioxide. Preliminary calculations suggest that improving soil fertility in this way in West Africa could sequester up to 1.35 billion tons C -- about 15% of current annual global carbon emissions. However, the continuing local benefits of improved agricultural productivity could be significantly larger than the one-time global benefits to GHG concentrations.

These results are based on initial work and a preliminary version of I-ACWA, seeded by HDGC. Perhaps the most important result has been in the creation of an active West Africa Global Change Study Network that already includes about 150 participants from academe, government, and the private sector in the four countries. The Network is seeking funding to extend this work, to further build regional capacity for multidisciplinary policy analysis, and expand participation to additional countries from the region.

CIS-HDGC – THE FUTURE

Participatory Assessment

TPARI represents a test for the applicability of integrated assessment methodologies (a) when problems are defined in terms of the needs of developing countries, with the participation of local residents; and (b) when the initial problem formulation comes from the social, rather than natural sciences. It might be seen as a transition in the evolving paradigm of integrated assessment, where the social sciences (except, sometimes economics) were initially ignored, then sought as providers of estimates for the values of social variables in natural science models, to one in which the roles are reversed, leading, eventually, to jointly developed models. This is one of the challenges recognized by Center researchers, in the last years of its existence, and guiding their work in the future.

One relevant experiment within TPARI has been the beginnings of a project by Justin Williams (Johns Hopkins) to adapt operations research (OR) procedures to the optimal design of nature reserves. OR optimization methods seek to provide a neutral platform for optimizing whatever goals stakeholders deem important and accommodating scientific results from whichever disciplines are important. TPARI provides an unusual opportunity for conducting such analyses, in a setting whose social and biophysical context is well characterized and whose stakeholders are readily accessible. This application would extend the traditional use of OR approaches which offer, in turn, a potentially fertile computational platform for integrated assessments, suited to problems with geographically distributed resources.

The multi-attribute philosophy of these OR techniques have been central to other participatory projects, notably those conducted by Tim McDaniels, Robin Gregory, James Tansey, and their colleagues at the University of British Columbia. In the context of (typically contentious) local planning processes, these problems have used an integrated assessment perspective as a vehicle for organizing complex information in a transparent, comprehensible, credible way, with informational priorities set by stakeholders need to know (rather than specialists need to tell). Brief descriptions will capture some of the richness of the applications, and the adaptability of the approach:

- (a) Compensation to Metis for energy developments on their lands. An amendment to the Alberta constitution calls for compensation for all manner of cultural, spiritual and traditional use impacts, but standard market-based approaches to compensation are not appropriate for addressing these kinds of losses – which introduced a fundamental, non-marginal change in the lives of these people, forced to radically change how they lived. We developed a multi-attribute approach and applied in community-based workshops involving settlement residents to addressing these difficult questions.
- (b) Thailand's economic and social development is torn between two contrasting and simultaneous trends. One is an increasing recognition of the special environmental and social values associated with the unique Thai culture. The other is modernization and industrialization, as Thailand joins the global marketplace and becomes a leader in south-Asia economic growth. Although traditionally extractive, the economy has featured an increasing role for tourism and programs for securing the sustainability of rural communities. The government (as personified by the King) has retained a strong interest in protecting indigenous plants and animals and their habitats. Our project seeks to help community residents to participate effectively in managing environmental and health risks. Our lead partner is GSEI (the Institute for Good Governance for Social Development and the Environment), based in Bangkok.
- (c) The Georgia Basin Futures Project attempts to facilitate citizen participation in the designing 40-year scenarios for the region surrounding Vancouver and Victoria in British Columbia. The UBC-based team has developed a decision tool known as "Georgia Basin Quest" that is a hybrid between traditional integrated assessment models and qualitative scenario-building exercises, grounded in social science research. It creates a scientifically sound possibility space within which users can explore the trade-offs of various development pathways. Our research considers models of consultation, dialogue coordinated by computer-based tools, the role of scenarios, and the divide between lay and expert cultures.

In a similar spirit, we have begun two collaborations that we hope will proceed, after the end of the Center. One is with a team at the University of Miami that has used anthropological approaches to coordinate community discussions over marine resources issues in Southeast Asia. The second involves the first phase in creating an integrated assessment model of the effects of global climate change in West Africa, focusing on water

availability and agriculture. In the face of declining rainfall and desertification, the model seeks to provide a comprehensive perspective on options such as expanded drip irrigation and adoption of farming methods to improve soil fertility and food production without major reliance on industrial fertilizers. Increasing soil organic carbon in arable lands could increase soil fertility, while also sequestering carbon from the atmosphere. Our first workshop convened an expert conference in Lagos, with individuals drawn from throughout the region, and moderated by two Center affiliates.

New Domains

Homeland security

An unanticipated (and unwelcomed) opportunity to extend the Center's approach arose after September 11th. Since then, we have shown how integrated assessment provides an approach for ensuring concurrent, coordinated treatment of risk analysis and risk communication. We have also conducted original empirical studies regarding risk perception and communication on these vital topics, showing the roles of cognitive and emotional factors. For example, we have found (a) that exposure to short media clips can induce enough fear to increase risk judgments and enough anger to decrease them; (b) that potential travelers had developed defensible (although perhaps somewhat high) estimates of the risks of terror, along with moderately consistent travel philosophies; (c) that people throughout the US saw themselves equally vulnerable to terror (except for a subpopulation of white males); and (d) public health officials had failed to communicate several critical and easily understood facts about bioterrorism. Embedded in integrated risk assessments, such results can focus communication and planning for homeland security. A Center member serves on the Department of Homeland Security's Science and Technology Advisory Committee, perhaps providing a venue for applying our approach.

Center research begun before Sept. 11th had been examining the vulnerability of national electric networks to malicious damage. This research has clear extensions to the new situation. In times of war, attacking infrastructure is a common military tactic. In an integrated electric system, a disruption can bring down large parts of the network. One possible way to mitigate the impacts of conflict (and other stresses) is changing the architecture of the system from the current large centralized generation with long-distance transmission to a more distributed system with small generators located close to end-users. Our research is evaluating the reliability and economic implications of large-scale distributed generation in areas of conflict.

Management of homeland security risks involves trade-offs between safety, wealth, privacy, convenience, and other social goods. With co-funding from the MacArthur Foundation, we've surveyed lay groups to determine how public preferences for managing mail security risks are satisfied by the measures implemented by the U.S. Postal Service. With the same complementary support, we are creating a behaviorally realistic methodology for identifying effective heuristics for coordinating emergency responses, looking specifically at the context of a radiological weapon attack.

Genomics

The proponents of new technologies sometimes promise benefits that will make life fundamentally different. Opponents often fear threats that will make fundamental differences of their own (e.g., violate moral codes, upset the balance of nature). With biologically active technologies, local decisions can quickly have global dimensions, as new practices and diseases spread. Two ongoing projects examine the human dimensions of the global changes associated with genomics, one concerned with its deeply uncertain risks, the other with the ethical dimensions that such risk analyses reveal.

Whatever the theoretical risks, genomic and biotechnological research is expanding rapidly and is producing a range of commercially viable technologies. Experience in Europe suggests that public concern about biotechnology often emerges independent of demonstrable scientific evidence of safety concerns; controversy has a moral rather than a scientific foundation. A Center study in Canada, involving Hadi Dowlatabadi, James Tansey and Tim McDaniels is applying three forms of ethical analysis to the support the development of public policy related to biotechnology. They are embedded in a series of public consultation exercises funded by Genome Canada and Genome BC. The network uses integrated assessment to structure a scientifically informed dialogue about ethical issues. <http://gels.ethics.ubc.ca>.

We are also conducting an in-depth analysis of xenotransplantation, the creation of animals designed to produce organs for humans, with minimal rejection risk. Although technological success will solve the painful shortage of organs, there are theoretical possibilities (of unknown probability) of novel diseases spreading in human populations. Assessing that risk requires expertise in microbiology (regarding the biology of the altered animals and of their human organ recipients, as well as the interaction between them), animal husbandry (regarding the

recruitment, treatment, and surveillance of the altered animals, and others in their environment), psychology (the behavior of patients and their associates), and public health (the testing, surveillance, and treatment of all those involved). We have adapted the techniques of integrated assessment to create a comprehensive model for the diverse factors determining the uncertain risks and benefits of xenotransplantation. We are working together with the HybridVigor Institute which has provided a working group of stakeholders, with varying expertise and fundamental beliefs about the viability of the technology.

Integrated Assessment Basic Methodological Research

A recurrent theme in the Center's narrative has been the need to conduct fundamental methodological research, in order to have the tools to address applied problems. One could tell the ICAM story in terms of the problems as a means to drive the end of producing rigorous, innovative methodology, as well as the methodology being a means to the end of understanding important issues of global change. SPYR's research within the Center has included developing a new generation of metrics for assessing change in a geographical context. The genomics focus has prompted basic research in applying real-option approaches, drawn from finance, to framing the risks taken by firms and societies investing in these technologies and the opportunity costs of avoiding them. Here, we describe several projects, creating basic social science research needed for integrated assessment.

Conditions for informed consent. Individuals and communities exposed to environmental and health risks are often held to have the right to being informed about the risks that they face – as sometimes captures in legally mandated procedures. However, these requirements are often fuzzy on what it means to be properly informed. Those exposed might be worse off as a result of these “protections” – if they lose their legal and political right to claim that they were not told, despite not receiving pertinent, useful information. Their “failure” to understand incompetent communications may be invoked to undermine their standing. An objective of several Center projects has been to determine the critical information set, for understanding risks. That case-specific experience is being translated into general rules for determining the adequacy of environmental and health risk communications. That work translates communication protocols into behavioral decision research terms. That means identifying essential assumptions regarding citizens' right to know, objectives, and decision-making competence. It also frames the policy choices embedded in the protections that citizens are afforded and the suboptimality that is tolerated. We are focusing on labels, as a structured form of risk communication, in order to simplify the analytical work. They are a common enough form, seen in green labeling, product warnings, etc. However, the project is conceptualized so that it could be extended to community consultations, and other mechanisms.

Scenario planning. Scenarios are a popular intellectual technology for addressing planning problems with great complexity and uncertainty. The claims made for scenarios often focus on somewhat intangible impacts, such as “stretching minds” and “gaining insight.” In addition to testimonials, support for these claims often invokes stylized psychological results, such as: (a) Stories takes advantage people's enhanced ability to process complex evidence that is integrated in concrete, causally coherent narratives. (2) Group interactions, like those associated with scenario planning, increase people's feelings of confidence, competence, and willingness to act. Skeptics often counter with their own stylized facts, such as: (1) Narratives evoke conjunction fallacies, exaggerating the apparent likelihood of focal scenarios (notwithstanding disclaimers, against assigning probabilities). (2) Scenarios' ambiguity can create an illusion of consensus, undermining decision-making processes. We are developing a graph-based approach to scenario planning, designed to formalize these concerns, in a way that should clarify their situation-specific validity. Used proactively, it should facilitate planning processes that “capture the magic” often attributed to scenarios, while conforming to the strengths and weaknesses of the cognitive processes of those who seek to rely on them. After some preliminary experimental research, it is being applied, in somewhat different ways, to two of the substantive projects described earlier. One is the integrated assessment of xenotransplantation, where scenarios will be used in converging operations, designed to test and communication the underlying model. The second is the design of effective heuristics for communicating about radiological weapons.

Value assessment under conditions of non-marginal change and uncertainty. Once changes have been understood, as best they can, they must be evaluated. We have conducted a series of projects developing the basic science for how people perform such evaluations, the theoretical building blocks for meaningful public participation. To this end, we have used a combination of laboratory experiments and studies of natural experiments, looking at individuals whose lives have dealt them non-marginal changes. Its overriding result is that people tend to under-appreciate their powers of adaptation, for even significant negative events. We are exploring the policy implications of these results. Although it may be consoling, in the short run, to accommodate to changes, recognizing one's ability to do could undermine the determination needed to defend a valued status quo. While individuals are sometimes sovereign to set the evaluations for their own lives, often

others have that right (e.g., policy makers, manufacturers). Self-other differences have been observed in many areas of psychology. In Center-supported work, we identified two common effects, interfering with these valuation processes. *Affective contamination* refers to the tendency to believe that other people share one's emotional states to a greater extent than they actually do. *Affective ignorance* refers to the tendency to underestimate the impact of visceral influences on one's own and on others' behavior. We have documented these effects for a wide range of visceral sensations, including hunger, thirst, and physical discomfort. Finally, we have completed a project understanding the "identifiable victim effect": the tendency to care more about, and allocate greater resources to, identifiable than to statistical victims. Understanding these processes facilitates identifying situations in which they are unwittingly in play. That, in turn, frames the philosophical question of which perspective is sought.

Environmental changes will have the most sustained effects on those who will live with them the longest, the young. Recent research, some partially supported by the Center, has demonstrated a higher level of decision-making competence adolescents than is often attributed to them. It has also found that, contrary to popular belief, adolescents are not possessed of a unique sense of invulnerability. Rather, if anything, they feel especially vulnerable, a pessimism that could alter their planning horizons. In survey research, examining possible correlates of these feelings, we found great pessimism about the future of the natural world. Recognizing the limits to the insight available through structured measurements, we have conducted a large set of in-depth interviews with a diverse sample of teens, regarding their view of the natural world, and their desires for it, in policy relevant terms. Our analyses reveal considerable variation in the extent of teens' previous thought about environmental issues and their importance. The transcribed interviews were analyzed qualitatively, using ethnographic perspectives, and quantitatively, using systematic coding drawn from mental models procedures. Many of the most articulate young people expressed awareness of many of the major global problems of our time and some personal concern about them, yet also the view that there was essentially nothing that they could do about them. When asked to explain changes or propose solutions, most teens did not place primary responsibility on institutions (government, corporations). Rather, they considered responsibility to be widely diffused, using terms like 'everybody,' 'just people,' and 'all of us. Anger and sadness, frequently in combination, were most commonly reported emotions. These fit the deep pessimism about the future of the natural world seen in the structured surveys. The most commonly proposed mitigation strategy was coded as 'increased public awareness.' The results will, we hope, provide guidance for parents, educators, and policy makers, concerned with both the cognitive and the emotional bases for environmental values.

The component of the project led by S. Jasanoff at Harvard University's John F. Kennedy School of Government focused on institutions of climate change science and policy. It used a variety of methods from science and technology studies (S&TS) to examine how a new form of environmental knowledge and practice—climate change science—is emerging and becoming institutionalized in relation to diverse national cultures of research and policymaking. One component of the project focused on national and comparative policymaking, including the delineation of various national environmental research strategies, in order to understand better the framing of climate change as a topic for research and policy. In keeping with theoretical ideas in S&TS, the project assumed that environmental problems are not intrinsically global or local, international or national, but that they are framed in specific ways through the work of diverse social actors (scientists, policymakers, stakeholders) who are active at multiple sites, including those of scientific assessment and policy formulation. Another component of the research sought to characterize in depth the national-level consequences of international scientific research and assessment, such as the work of the Intergovernmental Panel on Climate Change (IPCC). Brazil was selected as the site for such in-depth investigation, and ethnographic methods were used to study the production of climate change research and the emergence of associated cultural identities in Brazilian science and policy. A final component of the research examined ideas of precaution as they are being developed, articulated and taken up in the European Union (EU).

A major contribution of the project as a whole was to elaborate on theories of environmental globalization; contributions on this theme by three of the researchers supported by the grant were published in S. Jasanoff and M. Martello, eds., *Earthly Politics: Local and Global in Environmental Governance* (Cambridge, MA: MIT Press, 2004). The book recognizes that globalization today is as much a problem for international harmony as it is a necessary condition of living together on a planet of limited resources. Increasing interconnectedness in ecology, economy, technology, and politics has brought nations and societies into ever closer contact, creating acute demands for cooperation. Yet prospects for a consensual world order remain distant and elusive. Cutting against orthodox views of globalization, research supported by the CMU grant concluded that processes of localization are as important to understand and investigate as are processes of globalization. More specifically,

the research focused on knowledge making as an important driver of localization that is not necessarily destructively parochial and is not inevitably tied to geographical notions of “the local.”

Overall, the project concluded that global governance of the environment in the coming decades will have to accommodate local differences even if globalization seems, at one level, to overcome local particularities. Governance institutions and arrangements will have to tolerate, even respect, many aspects of the local while crafting practices that seek to transcend less beneficial forms of localism. Environmental governance has provided some interesting models for such balancing acts between the local and the global. The edited volume and other publications by the research team present and analyze a variety of these approaches in order to enrich our capacity to imagine new, more flexible frameworks of global governance.

The project was successful in advancing the professional careers of three junior scholars, both by attracting additional funds and by opening up new professional possibilities for them. Dr. M. Lahsen has continued her field work on climate science and scientists in Brazil as a research scholar supported by the National Science Foundation. Dr. M. Martello has remained as a research fellow at Harvard, working most recently with S. Jasanoff on a global environment research grant from the National Science Foundation. Dr. J. Dratwa completed his dissertation on the precautionary principle in European Union law and policy; he is currently employed by the EU Commission in its Research Directorate.

CONCLUSION

Many contemporary problems and opportunities require a fundamental reorganization of how science is organized. Scientists from diverse disciplines must learn to coordinate their work, conducting the bridging studies needed to fill the gaps between them. They must learn to collaborate with practitioners, in order to ensure that their work is focused, relevant and credible. They must establish communications methods, in order to warrant the public’s trust and address its concerns.

“Integrated assessment” is a collective noun for the family of procedures seeking to be means to this comprehensive approach to the human dimensions of global change. Although their underlying formalisms vary, all seek to link the sciences with one another and with the stakeholders concerned with their work. The Center for Integrated Study of Human Dimensions of Global Change has sought to be a home for creating the intellectual tools and working relationships needed to accomplish these goals. The core support provided by the National Science Foundation provided the time and breathing room essential to making this happen, for investigators willing to take the personal professional risks of leaving the fold of conventional research, bound to conversations within disciplines. The Foundation’s investment has been supported by supplementary funding from a wide variety of institutions, interested in have the evolving general approach applied to problems of particular concern to them. It has also passed the market test of the publications produced by the Center’s members and the advisory positions from which they have had an opportunity to interpret the research in policy terms. It has provided a home to many undergraduate and graduate students, as well as post-doctoral scholars and mid-career scientists, seeking to explore these ways or working or to recruit supplementary skills to their research problems.

Integrated assessment methods have been applied to a breathtaking range of problems: desertification, sea-level rise, malaria, genomics, wildlife conservation, cryptosporidiosis, deforestation, aquaculture, homeland security, carbon sequestration, electricity reliability, and many others. It is remarkable that scientists working in such diverse areas are even aware of one another’s work, much less willing to gather annually to learn about it, and occasionally seek collaborations that might otherwise be unimaginable. The domain-specific focus of Center projects has typically provided the incentive needed for scientists to abandon some of the details that are so precious to any discipline, in order to address problems of global concern. Yet, in this focus, they have often advanced their home discipline. On the one hand, the application of existing theories provides a reality check for theories and methods developed within more constrained settings. On the other hand, the confrontation with other disciplines and richly realized problems has generated basic research topics that might have emerged much more slowly through the endogenous processes of traditional disciplinary work. Our collective efforts have, we hope, been good for the sciences and for the world.

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