U.S. DEPARTMENT OF ENERGY

PNNL-20104

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

iRESM INITIATIVE: UNDERSTANDING DECISION SUPPORT NEEDS FOR CLIMATE CHANGE MITIGATION AND ADAPTATION

U.S. Midwest Region

J. Rice
P. Runci
R. Moss
K. Anderson

October 2010

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.
(9/2003)

PNNL - 20104

iRESM INITIATIVE: UNDERSTANDING DECISION SUPPORT NEEDS FOR CLIMATE CHANGE MITIGATION AND ADAPTATION
U.S. Midwest Region

J. Rice R. Moss
P. Runci K. Anderson

October 2010

Prepared for
The U.S. Department of Energy
under Contract DE-AC05-76RL01830
Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

The increasing interest in regional modeling of climate change and associated decisions regarding mitigation and adaptation highlights the need to address the uncertainties that persist in projecting future climate change. Decision makers need tools and information to evaluate the implications of uncertainty for decisions that must be made before uncertainties can be reduced or resolved.

Through its integrated Regional Earth System Model (iRESM) initiative, PNNL is developing a modeling framework to address regional human-environmental system interactions in response to climate change and related uncertainties. This framework is intended as a research tool for the scientific community to explore regional mitigation and adaptation decisions, constraints, and opportunities under alternate climate policy and climate change futures. The initiative is also intended to encompass research into regional decision makers' needs for information and analysis regarding mitigation and adaptation in the context of uncertainty. This research will help guide the development of iRESM's capabilities and the communication of its results. This paper presents the results of the initial research into decision support needs for the first iRESM pilot region: the US Midwest. The region is defined to include the following 14 states: Kentucky, Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, New York, North Dakota, Ohio, Pennsylvania, South Dakota, West Virginia, and Wisconsin.

The research includes interviews with regional stakeholders and a review of the published literature on mitigation and adaptation alternatives in the Midwest. The findings show that researchers as well as decision and policy makers in the Midwest are concerned about climate change impacts across a wide range of human and environmental systems and are focused on understanding the primary mitigation and adaptation opportunities and challenges within the region.

The primary systems of concern for adaptation are in the areas of water resources, urban infrastructure, agriculture, recreation, ecosystems, forest management, and transportation. Potential adaptations include infrastructure modifications, technological developments, institutional changes, and ecosystem protection, enhancement, and manipulation. In the area of mitigation, the primary issues and uncertainties generally are related to:

a. differential state renewable portfolio standards (RPS)
b. the relative economics of technologies that reduce or eliminate GHG emissions compared to traditional technologies
c. the viability of carbon storage alternatives (in both geological formations and terrestrial ecosystems).

The findings demonstrate a need for better information on the interactions of socioeconomic development, climate change, natural resources, and adaptation and mitigation options. To support policy, investment, and risk management decisions, models of human and environmental systems at the regional scale such as iRESM need to be developed to better integrate climate, ecosystem, and energy-economic processes.

Acronyms and Abbreviations

CCS	Carbon Capture and Sequestration
CDP	Carbon Disclosure Project
CH_4	Methane
CO_2	Carbon Dioxide
CSO	Combined Sewer Overflows
DOE	Department of Energy
GHG	Greenhouse Gas
GIS	Geographic Information System
GTSP	Global Technology Strategy Project
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
iRESM	integrated Regional Earth System Model
M&A	Mitigation and Adaptation
MRCSP	Midwest Regional Carbon Sequestration Partnership
NREL	National Renewable Energy Laboratory
RPS	Renewable Portfolio Standards
SEIMF	Spatially Explicit Integrative Modeling Framework

Contents

Figures

Tables

1.0 Introduction

The impacts of climate change are already affecting human and environmental systems worldwide, yet many uncertainties persist in the prediction of future climate changes and impacts due to limitations in scientific understanding of relevant causal factors. In particular, there is mounting urgency to efforts to improve models of human and environmental systems at the regional scale, and to integrate climate, ecosystem and energy-economic models to support policy, investment, and risk management decisions related to climate change mitigation (i.e., reducing greenhouse gas emissions) and adaptation (i.e., responding to climate change impacts).

The Pacific Northwest National Laboratory (PNNL) is developing a modeling framework, the integrated Regional Earth System Model (iRESM), to address regional human-environmental system interactions in response to climate change and the uncertainties therein. The framework will consist of a suite of integrated models representing regional climate change, regional climate policy, and the regional economy, with a focus on simulating the mitigation and adaptation decisions made over time in the energy, transportation, agriculture, and natural resource management sectors.

Framework development began in 2010 and is planned over five years. The research will include software development and evaluation through several regional case studies, including uncertainty characterization. While iRESM is intended for the scientific research community, it is critical that its scientific output is relevant and robust for regional planning. Hence, a key aspect of this effort is the development of an understanding of regional stakeholder decision support needs to inform model development and demonstration.

iRESM will address stakeholder decision support needs within a broad scientific context that links national and international climate change policy to regional stakeholder decisions in order to investigate the potential constraints and interactions between regional mitigation and adaptation under various climate futures. More specifically, the iRESM framework is being developed to advance scientific understanding in the following four areas:

1. How are regional mitigation and adaptation opportunities shaped, enhanced, or constrained by intrinsic regional characteristics?
2. How do projected changes in mean climate versus climate extremes affect the development of adaptation and mitigation strategies?
3. How might interactions between management decisions and natural processes contribute to rapid or nonlinear changes in the environment? Where might such nonlinearities occur, and do they contribute to climate feedbacks?
4. How will adaptation and mitigation strategies interact in the next few decades in terms of achieving their respective goals?

The goal of the stakeholder research (described here for the first pilot region) is to identify key issues of interest to stakeholders within the context of these four questions. This synthesis will serve to inform the development of iRESM capabilities and provide a framework for the pilot region numerical experiments.

Stakeholder needs are expected to include analysis of a range of policy scenarios, mitigation and adaptation decisions and their interactions, and uncertainty characterization. The research approach combines direct stakeholder interactions with a regional scientific literature review to identify critical regional mitigation and adaptation decisions and uncertainties. Ongoing stakeholder engagement activities such as an advisory group are also planned.

The U.S. Midwest is the first iRESM pilot region. As shown in Figure 1.1, the Midwest is defined as a 14-state area combining the Great Lakes states with selected contiguous states. This region exhibits a complex nexus of energy sector issues, land use questions, water availability concerns, and diverse demographic and economic characteristics, providing ample opportunity for iRESM to explore its four key science questions. For example, the framework will be able to investigate many complex and uncertain interactions between human system decisions and environmental systems in the Midwest, such as:

- The intermittency of wind resources and the impact of climate extremes on the ability to operate the electric grid safely, reliably, and cost-effectively.
- The combined impact of increased water demands by the energy and agricultural sectors with potential reductions in water availability due to climate change (absolute and/or temporal) on the ability to meet demand from other competing needs (e.g., drinking water, ecosystems).
- Changes in terrestrial carbon balances associated with changes in agricultural practices, other land use changes (e.g., wetlands restoration, forestry management), and climate change.
- The location of renewable energy production relative to energy demand centers and implications for energy transmission grids.
- The impacts of climate change on energy demand (e.g., heat waves) potentially requiring costly and/or controversial energy infrastructure enhancements (e.g., new transmission, new nuclear power plants).

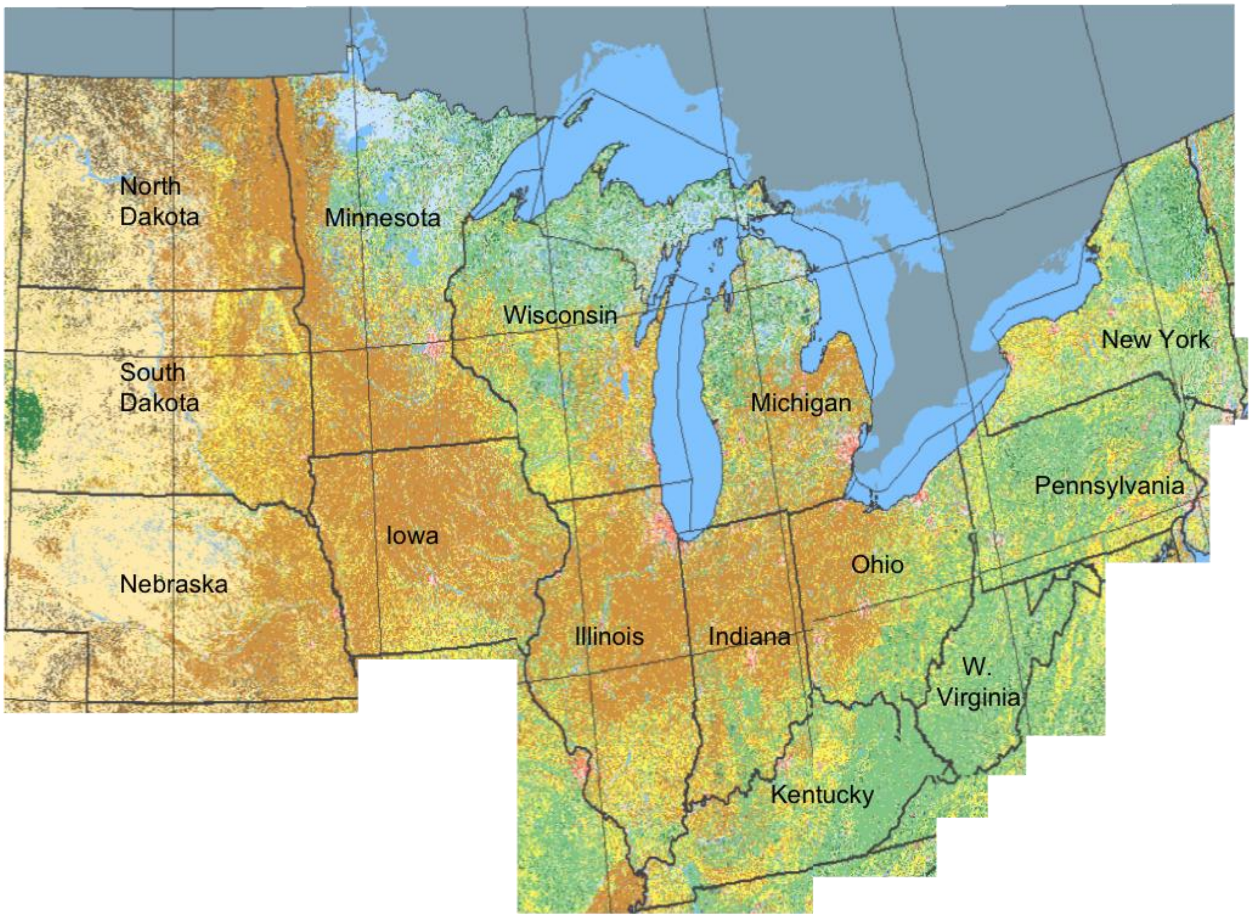

Figure 1.1. iRESM Midwest Region

The remainder of this report is organized follows:

- Section 2: Review of methods for stakeholder engagement
- Section 3: Summary of discussions with selected Midwest stakeholders
- Section 4: Summary of literature review on climate change-related decision-making in the Midwest
- Section 5: Synthesis of the findings to date and implications for iRESM model development and demonstration.

2.0 Review of Stakeholder Engagement Methods

In order to initiate interactions with stakeholder groups systematically and effectively, the iRESM team utilized a two-prong approach. First, the team consulted with several experienced stakeholder engagement professionals to gain insight into the nature of their interactions and their respective engagement methods. Second, the team surveyed the broad and well-developed peer-reviewed and grey literatures on stakeholder involvement. The results of this approach are summarized below.

2.1 Consultation with Stakeholder Engagement Professionals

Interviews were conducted with researchers and program managers at four NOAA Regional Integrated Sciences and Assessments (RISA) centers: the Climate Assessment for the Southwest (Arizona State University), the Climate Impacts Group (University of Washington); the Alaska Center for Climate Assessment and Policy (University of Alaska); and the Pacific Regional Sciences and Assessment program (East-West Center, HI). Additional interviewees included stakeholder engagement practitioners at the U.S. Department of the Interior, the University of Oregon, and the private consulting firm Resource Innovations. These discussions revealed a wide range of methods and practices, tailored to diverse stakeholder groups in different U.S. regions.

While each of these groups had unique insights and advice for the iRESM effort, virtually all stakeholder engagement professionals had one recommendation in common: to begin interactions with stakeholders as early as possible, and to make stakeholder interactions an ongoing and iterative process. In the opinion of many professionals, early engagement is important to the legitimacy of both process and products, while repeated and ongoing interaction creates opportunities for trust and relationship-building. Since research organizations often make the mistake of waiting until a product has been developed before they engage with users and stakeholders, most of the practitioners interviewed were supportive of the iRESM team's efforts to engage stakeholders as a resource early in the model development process and on an ongoing basis.

The iRESM initiative will expand its contacts with stakeholder engagement professionals and other key constituencies over the coming years and establish integral channels for ongoing stakeholder communication, including a stakeholder advisory group. PNNL has used advisory panels of this nature effectively in the past, for instance to elicit and incorporate expert stakeholder contributions to Human Choice and Climate Change (Rayner and Malone 1998), a multi-volume assessment of social science contributions to the study of climate change. More recently, over the past decade PNNL's Global Technology Strategy Project (GTSP) has relied upon the active support and participation of expert stakeholder groups for guidance, technical input and peer review of analytical outputs. Many of these stakeholders are also principal sponsors and consumers of GTSP research. Another ongoing international PNNL research project involves close one-on-one interaction with stakeholders in the energy industry, government, and academia in an effort to understand factors that facilitate or hinder large-scale energy technology transformations.

Many of these stakeholders are also principal sponsors and consumers of GTSP research. Another ongoing international PNNL research project involves close one-on-one interaction with stakeholders in the energy industry, government, and academia in an effort to understand factors that facilitate or hinder large-scale energy technology transformations.

2.2 Literature Review of Stakeholder Engagement Methodologies

A well-developed literature exists on stakeholder involvement as it relates to policy decision-making at the local, national, and international levels. This research focuses on stakeholders' self-organizing efforts to participate in and influence decision-making; actions on the part of decision-makers or third parties to involve citizens, expert communities, and under-represented groups in decision processes (*see*: Hemati 2002, Edelenbos & Klijn 2006); and corporate efforts to engage the public in product development, improvement, and marketing activities (Enright & Bourns 2010, Svendson & Laberge 2010). While a small subset of the literature addresses stakeholder involvement in climate change decision-making (*see*: Lim et al. 2005, Herricks & Eheart 2001), published studies documenting stakeholder involvement in the development of integrated human-environmental system models at the regional level are lacking.

As far as approaches to stakeholder engagement, the review of the open literature (see Appendix A) revealed several public domain and proprietary methodologies currently in use. As the illustrative set of methodologies and tools in Table 2.1 shows, a wide array of vehicles are available for stakeholder engagement. This broad spectrum underscores the fact that the choice of methodology depends on the objectives of stakeholder engagement in a given instance. Stakeholder engagement methodologies aim broadly either to share information with a target audience or to facilitate a collaborative process.

Table 2.1. Selected Stakeholder Engagement Tools: Objectives and Methodologies/Media

	Objectives			
	Information Dissemination	***Information Gathering***	***Brainstorming/Concept Development***	***Collaborative Decision Making***
Methodologies/Media	• Advertising • Press Releases • Newsletters • Websites • Social Media (e.g., Facebook, Twitter)	• Advisory Groups • Public Hearings • Focus Groups • Surveys • Interviews	• World Café© • Scenario Planning • Technology of Participation© • Study Circles	• Deliberative Polling© • Democs© • Appreciative Inquiry • Delphi Method • Design Charrettes

Adapted from: National Coalition for Dialogue and Deliberation; www.thatway.org

In stakeholder engagement processes, methodologies are matched to the objective that the user wants to achieve.[1] Right now, iRESM stakeholder activities fall predominantly in the Information Gathering category shown in the second column of Table 2.1. Consequently, the initiative's primary methods of

[1] Several of the methodologies included in the table span more than Objective categories, but have been listed here under a single column heading for illustrative purposes.

engagement have consisted of stakeholder interviews (presented in the following section) and will be broadened in FY11 to include the formation of a stakeholder advisory group. The iRESM stakeholder advisory group will consist of selected researchers, government officials and industry leaders with relevant expertise to provide expert input, guidance, and feedback to the initiative team.

The iRESM stakeholder engagement methodology will continue to evolve to meet the needs of the modeling framework and the iRESM team as the initiative progresses. In FY11, specific stakeholder engagement next steps will include:

- Continued and targeted interaction with key Midwest user and stakeholder groups as identified by the iRESM team, the Advisory Council, and other PNNL scientists;
- Roundtable discussions of Midwest stakeholder issues and uncertainties of interest to the broader iRESM team, and of related key information needs;
- Development of an iRESM communication strategy for outreach to/involvement of primary user and stakeholder groups;
- Development of a process for instituting and engaging an iRESM stakeholder advisory group to provide input and feedback on model development, experiment design, and outputs over the course of the initiative (currently planned to extend through 2014).

3.0 Summary of Findings from Discussions with Midwest Decision-Makers

The iRESM stakeholder engagement team travelled to Chicago, IL, in the summer of 2010 to meet with a small set of representatives of local municipal government, state government agencies, and private firms (*see:* Table 3.1, below). Although the number of meetings was small, the discussions revealed both a wide range of thinking about climate change and a surprising degree of consistency in the identification of key climate risks, uncertainties, and likely impacts. On the basis of these interactions, it appears likely that the degree to which these organizations consider climate change in their long-term planning and the relative emphasis on mitigation versus adaptation is a function of several factors, including their respective mission scopes, geographies, and leadership characteristics. As the research team consults with a broader set of stakeholders in the region, its understanding of decision-making needs, climate change uncertainties, and other relevant concerns is expected to grow accordingly. Nonetheless, the stakeholder discussions from which the following findings are drawn represent a limited but significant subregion of the Midwest, with Chicago at its center. More comprehensive findings will be presented later as this research progresses.

Table 3.1. iRESM Midwest Stakeholder Institution Contacts, Chicago, Illinois, July 2010

- Department of Environment, City of Chicago
- Illinois Energy Office/Department of Economic Opportunity
- Illinois Environmental Protection Agency
- Delta Institute
- Metropolitan Water Reclamation District of Greater Chicago
- Chesapeake Energy Corporation
- Illinois Department of Agriculture
- Great Lakes & St. Lawrence Cities Initiative

This section presents findings from these initial conversations with Midwest stakeholders regarding climate change decision-making. The first subsection discusses findings related to mitigation decision-making, while the second considers adaptation decision-making.

3.1 Mitigation Decision-Making in the Midwest

Stakeholders' primary mitigation-related concerns centered on two main topics: the development of renewable energy for electricity generation, and the role of the agricultural sector as a mitigation resource. More specifically, stakeholders identified the following issues:

- Implications of state-level renewable portfolio standards (RPS) for in-state/out-of-state siting, development, and sourcing of electricity from renewable resources, including:
    - Potential for, and constraints on, offshore wind siting & development
    - Implications for the regional economy and employment.
    - The energy-water nexus and the potential for emissions reductions related to water use changes.
- Role of Midwest agriculture in national and regional climate policies.

Each of these topics is addressed below.

3.1.1 The Implications of Renewable Energy Portfolio Standards

While many questions and uncertainties surround the expansion of renewable energy resources and the implications for critical resources in the Midwest, issues related to the impacts of differing state-level standards and the potential for new standards across the region appear to be the primary concern.

For example, under the State of Illinois' renewable portfolio standard (RPS), 25% of the state's electricity is to be generated from renewable sources by 2025. Representatives of the Illinois State Energy Office and the City of Chicago expressed concerns regarding the availability of sufficient sites for new wind and solar installations, and of renewable resources in general, to meet the statutory requirements of the Illinois RPS. On the other hand, a definite preference was expressed for the development of in-state renewable resources, smart grid, and green businesses from an economic development perspective.

These stakeholders also noted that existing and prospective RPSs in other Midwestern states compound the challenges to the State of Illinois, since Midwestern states' planning and future demand for renewable energy resources are developing largely in parallel to one another. Consequently, there are significant uncertainties associated with future renewable electricity prices, availability and reliability across the region.

The growth of renewable generation in the Midwest also raises difficult questions for transmission planning and siting. There is already significant transmission congestion in Illinois, where a major interchange is located. New high voltage transmission lines to deliver power from the Great Plains to demand centers in the eastern U.S. are unlikely to benefit Illinois customers, yet regional cost-sharing will likely be required.

Developing and integrating the region's on- and offshore wind resources is also likely to require significant investment in the regional transmission grid to relieve the region's rising transmission congestion, to extend the grid to wind generation sites, and to ensure grid stability as the share of wind-generated power expands. In addition to resource quality considerations, impacts of wind installations sited along migratory bird routes could be a significant constraint on future development.[1]

---

[1] Biomass and wind energy are the primary renewable resources for utility-scale power production in the Midwest. Solar resources do exist in the Midwest, but not at the required scale. *See*: http://www.nrel.gov/gis/images/map_csp_national_lo-res.jpg

Siting renewable generation in-state to the extent possible could alleviate some of these political and economic problems, although the constraints on individual states' renewable electricity resources indicate the need for a coordinated regional approach to renewable electricity.

3.1.2 The Role of Midwest Agriculture in Climate Change Mitigation

The Midwest has enormous agricultural resources that could be brought to bear in climate change mitigation. Yet the role that these resources might play in climate change policy is a major source of uncertainty for decision-makers in the region, according to a representative of the Illinois Department of Agriculture.

One uncertainty relates to carbon offsets. Since the region has a large number of coal-fired power plants, many stakeholders want to ensure that the agriculture sector can serve as a source of carbon offsets for fossil fuel emissions. For agricultural interests and governments in the region, agricultural offsets could be a major future revenue stream. Conversely, in the absence of an agricultural offsets program, the region's coal-fired power plants could face a difficult future under a climate policy regime.

Midwest agriculture could also be a major player in climate change mitigation as a producer of biofuels crops. The Midwest already produces the majority of the corn ethanol consumed in the United States, and many stakeholders anticipate that energy and climate policies will drive the expanded use of agricultural resources for the development of biodiesel and other biomass fuels. But stakeholders also expressed concerns about the potential for competition between fuel and food crops, and about the availability of the land and water resources needed to enable a large-scale expansion of biofuels production. There are also lingering uncertainties regarding the net economic impact of biofuels production and its implications for the region's overall carbon balance, considering the fossil fuel inputs that production could require.

Last, the City of Chicago, which has adopted an urban forestry program in conjunction with its Climate Change Action Plan, also hopes to sell offsets for carbon sequestered in the city's green roofs, expanding tree cover, and other green spaces. However, since there are still questions surrounding appropriate methods of accounting for urban terrestrial carbon sinks, the City's ability to exploit these resources fully is constrained.

3.2 Adaptation Decision-Making in the Midwest

Midwest decision-makers face many adaptation-related uncertainties alongside the mitigation challenges discussed above. While the City of Chicago understandably views the potential for more frequent and/or severe heat waves as a key challenge for adaptation, stakeholders overall mentioned questions related to water resource management more frequently than other adaptation challenges. Specific water-related issues include:

- Future Great Lakes water levels and implications for energy, water supply, agriculture and other industries.
- Changing precipitation patterns and potential for more extreme precipitation events leading to combined sewer overflows (CSOs) and flooding, with implications for urban infrastructure planning and management.

Other topics discussed included invasive species concerns, wetlands management, and human health issues related to the impacts of alternative fuels and climate change on air quality. This section first considers water-related adaptation uncertainties and then addresses the Midwest's ecosystem and other adaptation challenges.

3.2.1 Managing Water Resources in an Uncertain Climate

Stakeholders from multiple agencies, including the City of Chicago, the Metropolitan Water Reclamation District of Greater Chicago, and the Great Lakes and St. Lawrence Cities Initiative, noted that falling water levels in the Great Lakes will have variable impacts, affecting some areas and municipalities more severely than others. For example, under the Great Lakes Compact, a bilateral treaty governing distribution of water resources, some municipalities (such as Waukesha, Wisconsin) are not considered to lie administratively within the Great Lakes Basin and, consequently do not have water withdrawal rights despite their geographic proximity to the Great Lakes. Communities such as these may face uncertain futures if and when water resources in the region grow more constrained.

Other climate change impacts present more immediate water resource adaptation challenges in the Midwest. Of more immediate concern to agencies such as the Metropolitan Water Reclamation District of Greater Chicago is the increasing frequency and severity of extreme precipitation events and "microbursts" that can drop several inches of rain in a very short time. These storms are already occurring with increasing frequency, overwhelming the region's storm water management infrastructure. Since most Midwest municipalities have combined sewer systems dating to the early twentieth century, extreme precipitation often leads to CSOs that dump large volumes of untreated sewage and storm water into the Great Lakes and other waters.

Although CSOs present clear risks to ecosystems and public health, some of the largest economic impacts of extreme precipitation in the Chicago area in recent years have resulted from property damage arising from basement flooding. City officials are increasingly aware that major property losses resulting from basement flooding—especially in areas not designated historically as high risk—could be an unanticipated consequence of climate change. Similarly, Illinois state government officials worry that more frequent flooding of the Illinois and Mississippi Rivers could damage and disrupt the major rail hubs in the Chicago area, creating logistical problems nationwide.

Infrastructure planners are grappling with many important questions related to storm water management regarding, for example, the siting and sizing of storm water management systems. Planning demands that decision-makers make assumptions regarding the future location and frequency of 5-, 10- and 100-year storms—including their duration, an equally important variable for planners. As one government official noted, a precipitation event that drops two inches of precipitation over the course of two hours presents larger problems and different management challenges from a storm that drops the equivalent amount of water over twelve hours.

Decision-makers are also thinking about potential benefits and economic advantages that climate change might bring. Since the Great Lakes Basin is relatively less water-constrained than many other regions of the country, some wonder if the region might be able to take advantage of its resources to attract more water-intensive industries from other parts of the country and the world. In the minds of some stakeholders, the region's extensive waterways might also be better exploited for cost-effective freight transport, especially in a carbon-constrained world. However, a key question is the extent to which water resources will continue to be of sufficient quantity and quality to support these uses as climate changes.

At the same time, it would be premature to conclude that climate change figures prominently in all relevant water management and infrastructure planning agencies, even in major metropolitan areas with well-developed climate change action plans such as Chicago. For example, the rain data tables that the Metropolitan Water Reclamation District of Great Chicago currently uses for its precipitation forecasting were published in the mid-1960s and have not been updated. This illustrative example suggests that institutional cultures and inertia introduce additional uncertainties into adaptive decision-making.

3.2.2 Adaptation Challenges for Ecosystems

Midwest stakeholders also face ecosystem management challenges that are complicated by climate uncertainties. One of the most urgent ecosystem problems in the region is the rapid incursion of the invasive Asian carp in the Great Lakes and other Midwest waters. Representatives of each of the state and local agencies consulted expressed concerns that the explosive growth of the carp population is having a severe impact on the region's aquatic ecosystems and pushing some native fish species toward extinction. Decision-makers are particularly concerned that the increasing frequency of extreme precipitation events and related CSOs will provide even more opportunities for the carp's spread and for other invasive plant and animal species; there is evidence already that supports this impact related to the carp's spread. Moreover, rising lake temperatures, changing pH, and declining water quality all are climate-related factors that may impose additional stresses on native species and compound the decision-making uncertainties that Midwest aquatic ecosystem managers face.

Potential threats to terrestrial ecosystems in the Midwest arise from several observed and anticipated climate changes, including rising diurnal and nocturnal temperatures, more frequent and intense heat waves, and changing precipitation patterns. In the City of Chicago, where planners are actively promoting urban forestry efforts and green roof programs as tools for both climate change mitigation and adaptation, changing climate conditions are prompting urban planners to give careful consideration to their choices of plant species. Since plant hardiness zones are expected to shift along with changes in temperature and precipitation, city managers are doing as much as they can to select plant species that may be more resilient under anticipated future climate regimes.

Climate change uncertainties raise even harder questions about the management of wetland ecosystems in the Great Lakes Basin. For example, one City of Chicago official noted that some wetlands in and around the city already require continuous pumped water to sustain them. Considering the energy and water inputs that these efforts demand, and the resulting greenhouse gas emissions, some stakeholders questioned both the wisdom and the implications of continuing to sustain these ecosystems—and, conversely, of not sustaining them.

3.2.3 Adaptation to Rising Temperatures

Changing patterns in the frequency, intensity, and duration of heat waves is one of the adaptation uncertainties of greatest concern to urban officials. A 1995 heat wave that resulted in more than 700 deaths in Chicago and other Midwestern cities is still on the minds of area officials as they plan for a future of more frequent heat waves.

Since temperatures have continued to increase, and since models project that heat waves like that of 1995 are now likely to occur as frequently as every three years, Midwestern government officials are taking a variety of actions to prepare themselves. In Chicago, these measures include programs to cool urban heat islands through green roofs and urban forestry projects, emergency response systems, and the establishment of networks of cooling centers to ensure that all city residents have access to air-conditioned spaces. Yet the magnitude of the public health challenge associated with higher temperatures and more frequent heat waves is also complicated by indirect impacts, such as the likelihood that tick, mosquito, and other disease-carrying insects may be more capable of surviving future winters and thriving in hotter summers.

4.0 Review of Literature on Climate Change and Decision-Making under Uncertainty in the Midwest

As noted in the previous section, the iRESM team's initial interactions with stakeholders revealed a broad range of concerns about climate change and varying degrees of sophistication in thinking about the implications of climate change for Midwestern cities and the region's economy. This section presents the results of a literature review into climate change mitigation and adaptation decision-making issues in the Midwest.

Approximately fifty (50) mitigation-related studies and forty-four (44) adaptation-related studies were selected as representative for review.[1] These studies were chosen primarily because of their focus on Midwest mitigation and adaptation decision-making in response to climate change. Studies that focused on Midwest regional climate change impact assessment exclusively, without some discussion of mitigative or adaptive response, were generally not included. Several of the chosen studies span the entire US, but they contain results or other information relevant to one or more of the states in the Midwest region. In addition, some studies addressing Canadian Great Lakes issues were included for their regional relevance.

While this review emphasizes the peer-reviewed literature, a selection of the grey literature relating to regional climate action plans is also included. For example, several states in the Midwest region, intergovernmental institutions (e.g., the Midwestern Governors Association), and major urban areas have developed extensive climate change response strategies, addressing both mitigation and adaptation. New York City, Chicago, and Pittsburgh appear to be leaders among municipalities, having developed comprehensive strategies that incorporate climate change uncertainties into their respective long-term investment and infrastructure planning processes.[2]

The mitigation literature review results are presented first, followed by the adaptation literature.

4.1 Mitigation Literature

The majority of the mitigation-related literature reviewed in this effort addressed the topics of renewable portfolio standards, bioenergy/biofuels, carbon capture and sequestration (CCS), and wind power, followed by agricultural and forest management and hydropower. The following indicates the specific number of studies reviewed in each category:[3]

- Renewable Portfolio Standards (RPS), Energy Efficiency (EE), and other Related Policies (13)
- Bioenergy/Biofuels (10)
- Carbon Capture and Sequestration (CCS) (9)
- Wind Energy (8)

[1] In addition, a separate literature review was conducted focusing on RPS-related issues, including impacts on energy prices and water availability for competing uses. The summary of findings is presented in Appendix D.

[2] Across the Canadian border, the City of Toronto and the Provinces of Ontario and Manitoba have also developed comprehensive climate change mitigation and adaptation plans.

[3] The relative number of studies across the topics shown here is not necessarily representative of the full literature on mitigation in the region.

- Agricultural/Soil Management (4)
- Forest Management (3)
- Transmission (2) [4]
- Hydropower (1)

As of the fall of 2010, twelve of the fourteen Midwest region states have put some type of renewable and/or alternative energy portfolio standard or goal in place (Indiana and Kentucky are the exceptions).[5] Bioenergy/biofuels, CCS, and wind energy appear to be the primary GHG source reduction alternatives under consideration in the region, while agricultural/soil and forest management practices are the major alternatives under consideration to enhance regional GHG sinks. Approximately half of the relevant literature reviewed involved national-level analyses of mitigation with some specific treatment of the Midwest. The rest of the studies were specific to the Midwest region. Figure 4.1 illustrates the number of mitigation studies by topic, including the breakdown between region-specific and national studies. Appendix B contains the abstracts for the documents selected for the mitigation literature review.

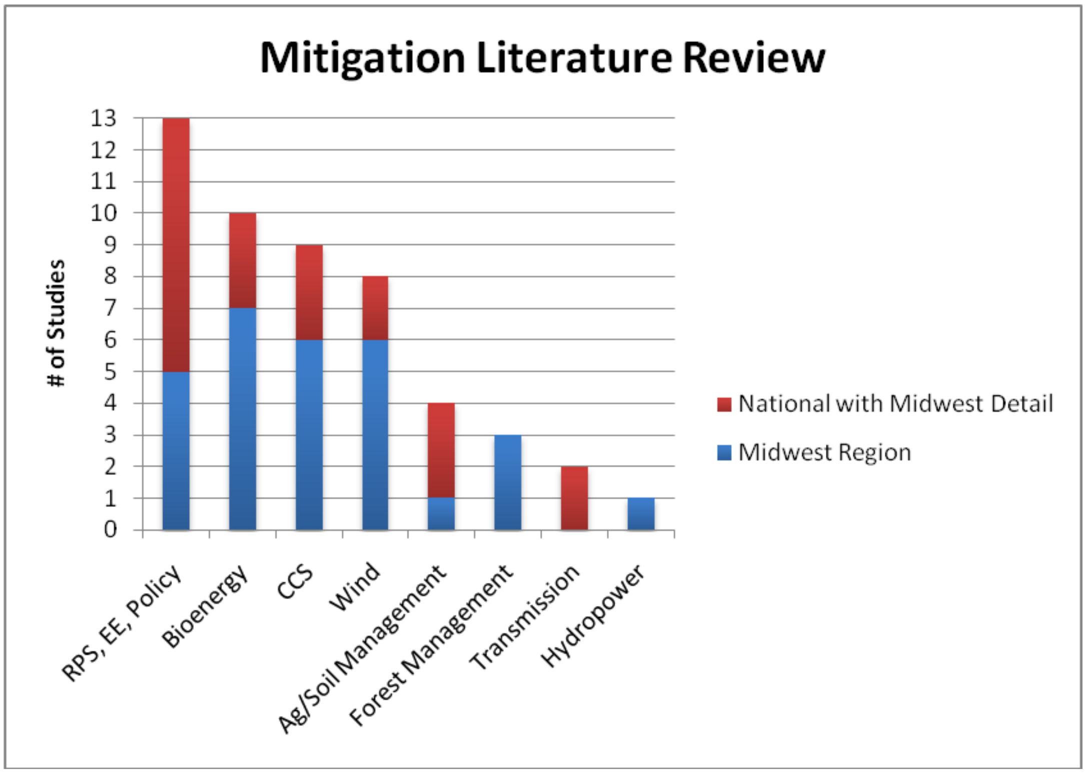

Figure 4.1. Mitigation Literature Review Results – Study Breakdown

In addition to identifying the types of mitigation under consideration in the Midwest, the literature review also identified key issues and uncertainties by economic sector. In general, these uncertainties surround the relative economics of technologies that reduce or eliminate GHG emissions compared to traditional technologies, and the amount and sustainability of carbon storage for alternatives that enhance GHG sinks. Table 4.1 documents the broad range of mitigation alternatives and associated key issues and uncertainties in the energy sector, while Table 4.2 summarizes this information for the buildings,

[4] Category included because of its importance in facilitating mitigation with renewable resources.
[5] http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm

transportation, forestry, and agricultural sectors. As described in Section 3, the stakeholder discussions to date regarding mitigation have focused on options in the energy and agricultural sectors.

Table 4.1. Literature Review Results – Energy Sector – Mitigation Alternatives, Key Issues and Uncertainties

Energy Sector **Mitigation Alternative**	**Key Issues and Uncertainties**
Energy Efficiency and Conservation	• Regulatory incentives needed for utility demand-side investments • Many technologies will pay for themselves over time
Renewable Portfolio Standards	• Energy cost increases are a concern • Dependence on coal is a challenge • In-state vs. out-of-state energy generation to meet RPS • Equity • State-by-state variations • Regional cooperation needed regarding regional transmission infrastructure, cost allocation • Uncertainty in national policy
Bioenergy Production	• Impacts of bioenergy crops on traditional crop prices and production • Land clearing for biofuels produces significant GHGs • Biofuels from waste biomass or grown on ag lands with perennials incur minimal carbon debt • Sustainability of forest biomass • Availability of biomass • Environmental policies, incentives • Technical and economic feasibility • Water resource availability
Wind Energy	• Inconsistent wind farm siting policies across region • Significant new transmission needed • Transmission siting issues • Grid integration/reliability; storage backup • Large off-shore wind potential • Aesthetic issues • Bird migration issues
Fuel Switching	• Fuel availability • Relative fuel costs
Carbon Capture and Sequestration	• Technology maturity perceptions • High capital costs • Storage capacity • Storage locations • Economics of coal w/ CCS vs. co-firing with biomass • IGCC w/CCS plus traditional coal w/CCS has great potential • Economics of transport from point source to storage site • Regulatory framework needed • Incentives for enhanced oil recovery with captured CO_2 • Potential conflicts over saline groundwater
Other Advanced Technologies (e.g., advanced nuclear)	• Regulatory policy • Market incentives

Table 4.2. Literature Review Results – Other Sectors – Mitigation Alternatives, Key Issues, and Uncertainties

Buildings	Transportation	Forests	Agriculture
Energy Efficient Technologies • Cost, payback period • Incentives **Building Code Changes** • Regulatory responsibility, enforcement **Smart Grid/Demand-response** • Installation costs • Effectiveness	**Electrification** • Cost • Availability of charging stations **Increased Fleet Efficiency** • Regional fuel standards **Promote Alternative Modes (e.g., rail, bicycling, walking)** • Public awareness • Access/proximity • Cost • Street design • Regulatory obstacles **Fuel Switching** • Fuel availability • Relative fuel costs **Mileage-Based Insurance** • Regulatory barriers	**Planting New Forests** • Land use conflicts • Carbon sequestration potential uncertain **Management of Existing Forests** • Forest clearing for biofuels produces significant GHGs/carbon debt • Sequestration potential is a complex function of forest structure, age, harvest practices • Ecological disruption due to climate change/warming • Data on ecosystem conditions needed	**Modified Tillage Practices** • Tillage reduction over several decades needed • Using crop residue as mulch is essential • Climate and CO_2 feedback impacts on terrestrial carbon **Reforestation** • Land use conflicts • Carbon sequestration potential uncertain

4.2 Adaptation Literature

The Midwest region literature related to adaptation is wide-ranging and includes infrastructure modifications, technological developments, institutional changes, and ecosystem protection, enhancement, and manipulation. The adaptation literature tends to be organized around the human or environmental system affected by climate change, rather than around a particular approach or technology, as is the case with mitigation. The adaptation literature also tends to be more regionally focused than the mitigation literature, because adaptation alternatives are typically identified and evaluated in terms of their ability to address local impacts.[6]

Water resources and urban infrastructure are the two systems most commonly addressed in our sample of the Midwest adaptation literature, followed by agriculture, recreation, ecosystems, forest management, and transportation. The document count below is organized into these categories, including a multi-sector category, because there were several studies that looked at a range of adaptation needs for a

[6] The exceptions are the US national assessment studies that explore detailed impacts and adaptation responses across the various regions of the US.

city, state, or region. The number of studies in each individual category is therefore effectively higher than shown here because of these multi-sector studies.

- Multiple Sector (11)
- Water Resources (11)
- Urban Infrastructure (7)
- Agriculture (5)
- Recreation (4)
- Ecosystems (3)
- Forest Management (2)
- Transportation (1)

Figure 4.2 presents the number of studies in each category graphically. Appendix C contains the abstracts for the documents selected for the adaptation literature review.

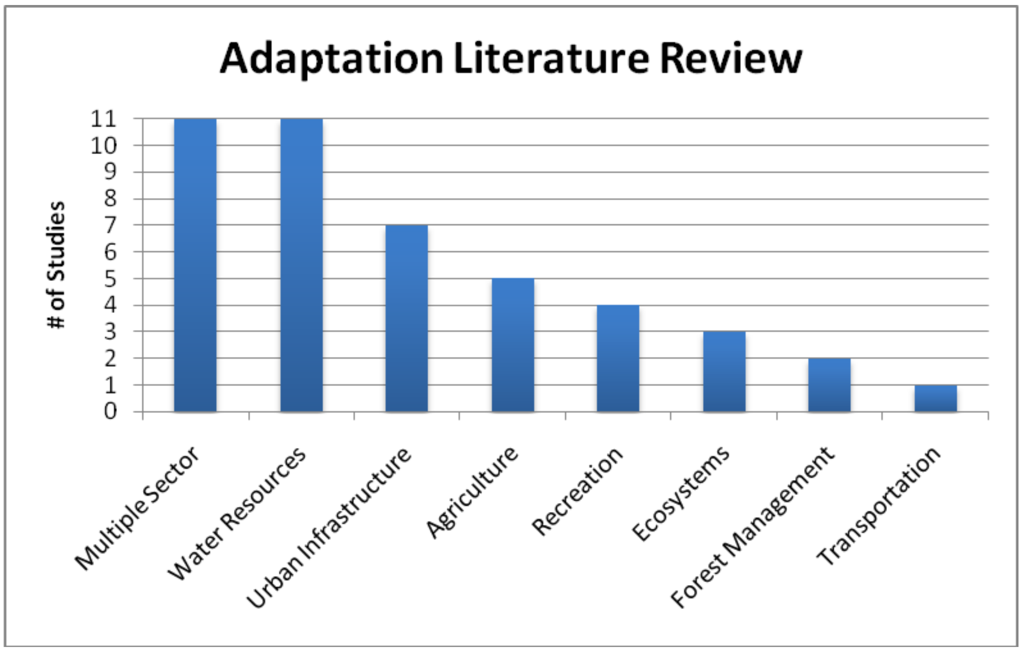

Figure 4.2. Adaptation Literature Review Results – Study Breakdown

Table 4.3 summarizes the potential climate change impacts of concern and the potential adaptation responses in each sector from the reviewed literature. Note that, as anticipated by the iRESM science questions presented in Section 1, the need to adapt to the potential for climate extremes such as drought and an increase in the frequency and severity of heavy precipitation, as well as to changes in average climate such as warmer temperatures, is reflected across both human and environmental system studies. The highlighted areas in Table 4.3 indicate which of these issues have come up so far in the stakeholder discussions.[7]

[7] As noted in Section 3, the stakeholder discussions to date (Fall 2010) have been limited and therefore the highlighted areas in Table 5 are not necessarily representative of general stakeholder concerns in the region.

Table 4.3. Literature Review Results – Potential Midwest Climate Change Impacts and Adaptation Responses (yellow-highlighted areas indicate topics raised in stakeholder discussions to date)

Human or Environmental System	Potential Impacts	Adaptation Alternatives
Water Resources	• Lower lake levels • Sea level rise • Drought/lower instream flows for drinking water, ecosystems, irrigation, power plant cooling; causing water quality problems as well • Extreme precip/CSO events affecting water quality	• Water conservation • Water quality monitoring • Lower water intakes • Alter reservoir release patterns • Purchase water rights • Water treatment facility investments • Limit floodplain development • Development of alternatives to hydropower • Alter hydro operations
Urban Infrastructure	• Increase in heat wave frequency and intensity • Increase in CSO frequency and intensity • Increase in Flooding	• Green roofs • Porous pavement • HVAC upgrade investments • Tree planting • Warning systems, emergency response • Riparian restoration • CSO infrastructure upgrades • Increase electric power reserves • Reduce transmission congestion
Agriculture	Drier, warmer summers; wetter, warmer springs and fall; warmer winters potentially causing: • Corn, soybean, other crop yield declines • Dairy production declines • Invasive species increases	• Land use management changes (e.g., revert to unmanaged) • Water conservation • Modify crop types • Crop insurance • Modify planting times
Recreation	• Diminished snowpack and water availability • Longer warm weather season • Lower lake levels	• Snowmaking • Extend warm weather recreation seasons • Create 4-season facilities • Extend boat ramps, lower docks

Table 4.3 (cont'd)

Human or Environmental System	Potential Impacts	Adaptation Alternatives
Ecosystems	• Higher annual average temperatures • Wetlands losses, especially coastal	• Create reserve buffers; expand reserves • Protect climate refuges • Manage forests for multi-species, multi-age • Rely on seeding • Include southern/dry region species • Monitor rare species • Invasive species management • Enhance wetlands
Forest Management	• Warming trend • Reductions in carbon storage	• Maximize stand complexity
Transportation	• Lower water levels affecting cargo capacities • More frequent heavy rain affecting roads, bridges	• Deepen water depths in harbors • Invest in vessels with less draft • Ships to carry less • Infrastructure improvements

5.0 Synthesis of Findings and Implications for iRESM Model Development and Demonstration.

As presented in the previous sections of this paper, the stakeholder research effort has included stakeholder interviews and a literature review encompassing approximately 175 documents (*see*: Appendices B, C, and D). This work has identified a range of needs and interests specific to the Midwest focused on the analysis of mitigation and adaptation alternatives, associated uncertainties, and related policies. These insights are critical for assuring the relevance of analyses conducted with iRESM for the region and for the capabilities of the framework in general. One or more additional pilot regions will be addressed over the next four years, and stakeholder research is expected to be an ongoing process that informs the evolution of the iRESM framework.

This section presents a synthesis of the Midwest results, including input from the iRESM team during a project roundtable discussion regarding model development timelines, features, and demonstration objectives for the Midwest. Since model development is well underway in the suite of models composing the first prototype of the framework, major new developments suggested by this research will need to be deferred to later versions of the prototype. On the other hand, the synthesis results highlight the breadth of modeling capabilities relevant to the Midwest that are already planned for the early prototype.

The Midwest synthesis is organized in terms of its implications for model development first, followed by the implications for model demonstration in terms of key decisions to explore with the first iRESM prototype.

5.1 Implications for Model Development

The Midwest stakeholder interactions and literature review raised a consistent set of mitigation and adaptation alternatives and uncertainties of interest to Midwest planners, policy makers, and the scientific community. Many of these issues will be able to be addressed with the first iRESM prototype, and the ones that are beyond the current scope may be planned for future versions. The following subsections summarize the research findings on mitigation and adaptation, respectively, as well as the ability of the near-term iRESM prototype to address them.

5.1.1 Mitigation Alternatives and Associated Uncertainties

Sections 3 and 4 have addressed several key issues and uncertainties associated with climate change mitigation in the Midwest. These considerations may be categorized on the basis of their relationship to efforts either to reduce GHG emissions or to enhance carbon sinks. These efforts are summarized below.

Reducing GHG Emissions

Most of the research on alternatives to reduce GHG emissions focused on three economic sectors: electricity generation, buildings and transportation. In the electricity sector, both the stakeholder interviews and literature reviews emphasized the issues surrounding the implementation, cost, and feasibility of renewable portfolio standards (RPS) across the region. These standards are the drivers for current and future renewable energy development within the region. The primary technologies with significant potential for the Midwest include wind (on-shore and off-shore), bioenergy (with or without CCS), and fossil fuel-based generation combined with CCS.

Regarding RPS in general, there is an interest in being able to model the effects of differences in policy across the states as well as the impacts of a potential regional RPS mandate. This includes gaining a better understanding of the impact of the existence or absence of financial, market, and/or regulatory incentives for renewables generation. In addition, individual states are interested in understanding the economic benefits of in-state investment to support the renewables supply chain (e.g., manufacturing, freight) and to demonstrate the perceived economic benefits of developing renewable generation resources in-state versus purchasing renewables from out of state. Addressing these issues in iRESM would involve:

- A state-based level of resolution in the energy modeling and the ability to represent state-by-state differences in RPS and related policies—this level of resolution is currently under discussion for the energy sector modeling.
- A state-based level of resolution in the overall economic modeling to represent state-level economic impacts—state-by-state economic impacts by sector are beyond the current iRESM scope.

Regarding renewable generation technologies in particular, the regional research shows a strong interest in addressing comparative costs and feasibility and the uncertainties therein. More specifically, the key areas of interest include:

- The overall costs of utilizing CCS in coal-fired power plants
- The potential for CCS, including the feasibility of accessing storage locations
- The costs and potential siting issues related to off-shore wind
- The potential for land use conflicts related to increasing renewables penetration (e.g., land suitability/availability for food crops versus bioenergy crops and power plant siting)
- The grid integration costs of renewables
- The cost, amount, and location of transmission system expansion
- The sustainability of biomass supplies for energy generation, primarily with respect to forest biomass and other woody residues
- The types of bioenergy/biofuel crops grown in terms of their impacts on food crop production, land use, water supply/demand, and water quality
- The net overall GHG impacts of bioenergy
- The overall availability of water to meet the demands of renewables, other energy generation, agriculture, and other demands, such as drinking water supply
- The impact of climate change—changes in average conditions as well as extremes--on the production of bioenergy/biofuel crops.

Each of these topics—excluding water quality per se—is currently planned to be addressed at some level within the framework. The key implication for iRESM is the need for a coordinated approach to uncertainty characterization and propagation in order to provide uncertainty analysis results across the integrated models in these areas.[1]

Other GHG emissions reductions alternatives identified in the research address the buildings and transportation sectors. In the buildings sector, the key mitigation alternatives involve energy efficient and smart grid/demand response technologies, while in the transportation sector the emphasis is on electrification, alternate fuels, increased fleet efficiencies, and reduced vehicle miles. There is also awareness in the region of the potential GHG reduction benefits of greater utilization of barge freight transport versus truck freight. As for the implications for iRESM, building energy efficiency can be addressed, as can most of the transportation alternatives, but iRESM is not currently scoped to address tradeoffs in modes of freight transport. Smart grid/demand response modeling will be part of iRESM's early prototype energy sector modeling.

Enhancing GHG Sinks

Forest management and agricultural lands/soil management appear to represent the two most important means to enhance GHG sinks in the region. The alternatives include:

- Planting new forests (afforestation)
- Reforestation
- Forest management/harvest practices
- Modified tillage practices

The key uncertainties in this area are:

- The complex interactions between climate, CO_2 feedbacks, species composition, ecosystem health, harvest and tillage practices, and subsequent changes in terrestrial carbon balances.
- The potential for land use conflicts affecting the ability to achieve sequestration goals.

The near-term version of iRESM will address agricultural and land use issues, while a later version of the framework will be expanded to incorporate a detailed forestry model.

Table 5.1 below summarizes the mitigation alternatives identified in the Midwest stakeholder research so far and highlights those areas that will be able to be addressed by iRESM in the near term.

[1] This is no small task, and such an approach is the objective of the parallel iRESM project, "Understanding the Sources and Consequences of Uncertainty."

Table 5.1. Midwest Mitigation Alternatives
(near-term iRESM capabilities highlighted in yellow)

Electric Utilities Sector	Buildings Sector	Transportation Sector	Forests	Agricultural Lands
• Energy Efficiency and Conservation • Renewable Portfolio Standards • Bioenergy Production • Wind Energy • Fuel Switching • Carbon Capture and Sequestration • Other Advanced Technologies (e.g., advanced nuclear)	• Energy Efficient Technologies • Building Code Changes • Smart Grid/Demand-response	• Electrification • Increased Fleet Efficiency • Fuel Switching • Promote Alternative Modes (e.g., rail, bicycling, walking) • Mileage-Based Insurance	• Planting New Forests • Management of Existing Forests	• Modified Tillage Practices • Reforestation

5.1.2 Adaptation Alternatives and Associated Uncertainties

As shown in Sections 3 and 4, the Midwest region is concerned about the need for climate change adaptation across a wide range of human and environmental systems. In contrast to the mitigation discussion just presented, for adaptation it makes more sense to review the key uncertainties identified first, as they are the drivers of the need for adaptation in the Midwest:

- Future water levels in the Great Lakes (timing and degree of change)
- Water availability (drought frequency, severity, duration, location)
- Extreme precipitation (frequency, severity, duration, location)
- Heat waves (frequency, severity, duration)
- Seasonal temperature and precipitation averages (changes in)

The climate modeling capability within iRESM is expected to be able to model each of these potential climate impacts and provide the relevant statistics.

Regarding adaptation alternatives in response to these potential impacts, the framework is expected to address adaptation in response to economic price signals and to the direct impacts of climate change on natural resource availability. For example:

- Water conservation, water rights purchases, and modified crop types will all occur to some extent given a market for water.
- The need for increased electric power reserves and reduced transmission congestion during heat waves will be addressed in iRESM's electric sector modeling in response to the increased energy demand.
- The ability to model hydroelectric production and reservoir management as a function of stream flows is planned as part of the water management model.

- Reductions in thermoelectric power production due to a lack of cooling water will be modeled in the electric sector.
- As described earlier, agricultural land use change is modeled within iRESM and reflects the complex interactions between climate change, natural resource availability, crop yields, and economic drivers such as the carbon price.

However, since the prototype iRESM is not designed with an explicit impacts /adaptation/ vulnerability (IAV) model, several of the adaptations discussed by stakeholders and in the literature are not feasible to address at the current time (e.g., reducing heavy precipitation impacts such as flooding and combined sewer-storm water overflows by increasing pervious surfaces within a city). However, the climate modeling can incorporate changes to the urban canopy associated with green roof programs and urban tree planting. Table 5.2 reviews the primary adaptations described by stakeholders and found in the literature; those that are likely to be feasible to address in iRESM are highlighted in yellow.

Table 5.2. Midwest Adaptation Alternatives
(near-term iRESM capabilities highlighted in yellow)

Water Resource Management	Urban Infrastructure Management	Agriculture
• Implement water conservation	• Install green roofs	• Make land use management changes (e.g., revert to unmanaged)
• Increase/improve water quality monitoring	• Install porous pavement	• Implement water conservation
• Lower water intakes	• Invest in HVAC upgrades	• Modify crop types
• Alter reservoir release patterns	• Plant urban trees	• Purchase crop insurance
• Purchase water rights	• Expand warning systems, emergency response	• Modify planting times
• Invest in new water treatment facilities	• Restore riparian areas	
• Limit floodplain development	• Upgrade CSO infrastructure	
• Reduce thermoelectric power production	• Increase electric power reserves	
• Alter hydro operations	• Expand transmission capacity or increase urban energy sources	
• Protect/enhance ecosystems dependent on river flows, lake levels		

Table 5.3 summarizes the key uncertainties discussed by stakeholders and found in the literature. yellow-highlighted uncertainties will be addressed in the prototype iRESM uncertainty characterization process.

Table 5.3. Key Uncertainties in the Midwest Region
(near-term iRESM capabilities highlighted in yellow)

General Uncertainties	Climate-Specific Uncertainties
• National climate policy	• Future water levels in the Great Lakes (timing and degree of change)
• State- or regional-level RPS	• Water availability (drought frequency, severity, duration, location)
• Energy resource potential and sustainability	• Extreme precipitation (frequency, severity, duration, location)
• Technology cost and performance	• Extreme temperature (frequency, severity, duration)
• Technology siting feasibility/policies	• Seasonal temperature and precipitation averages (changes, timing)
• Energy-water nexus emissions impacts	
• Land use availability/conflicts	
• Water availability, quality/conflicts	
• Grid integration/transmission expansion issues	
• The ultimate gain in carbon sequestration from enhancing agricultural sinks	
• Invasive species spread	
• Human health impacts	
• Impact of climate change on all of the above	

5.2 Implications for Model Demonstration

The iRESM team is currently planning a range of model demonstration activities for iRESM, including hindcast experiments and other evaluation procedures, as well as case study analyses with uncertainty characterization (UC) as a primary goal. The latter effort will combine the results of the stakeholder research with a parallel effort developing methods for UC appropriate for iRESM. The UC process is predicated on the importance of helping decision makers understand the robustness of results provided by iRESM, that is, which uncertainties have the biggest influence on key decision criteria.[2] The first step in this process is to identify a set of decisions and issues relevant to Midwest stakeholders that also will allow the iRESM demonstration case studies to explore one or more of the initiative's key science questions:

- How are regional mitigation and adaptation opportunities shaped, enhanced, or constrained by regional characteristics?
- How do potential changes in mean climate versus climate extremes affect the development of adaptation and mitigation strategies?

[2] A separate report will be published describing the uncertainty characterization process.

- How might interactions between management decisions and natural processes contribute to rapid or nonlinear changes in the environment? Where might such nonlinearities occur, and do they contribute to climate feedbacks?
- How will adaptation and mitigation strategies interact in the next few decades in terms of achieving their respective goals?

The iRESM project team considered these questions in conjunction with the topics raised from the Midwest stakeholder research during the project roundtable. Table 5.4 presents the intersection of Midwest stakeholder issues and iRESM science questions.

Table 5.4. Intersection of Key Midwest Issues and iRESM Science Questions

	iRESM Science Questions			
Midwest Stakeholder Issues	Regional opportunities or constraints on M&A?[3]	Impact of uncertainty in mean vs. extremes of climate change on M&A strategies?	M&A causing non-linear changes and climate feedbacks?	Interactions between M&A affecting outcomes of M&A?
Regional RPS policy requirements consistency	X	X		
Climate change impacts on water, temps, precipitation		X		X
Sustainability, cost, and performance of renewables, sequestration	X	X	X	X
Land and water use conflicts	X	X	X	X
Energy-water nexus	X	X		X
Ecosystem and human health impacts		X		

Based on an examination of this table, the project team decided that the Midwest region pilot study should explore renewable portfolio standards, the sustainability, cost, and performance of renewables and sequestration alternatives, and potential land-water-energy conflicts.

Appendix D contains the results of a targeted literature search focusing on RPS issues in the Midwest in support of both the FY11 stakeholder and UC research efforts. The FY11 stakeholder research effort will engage regional planners from the energy and agriculture sectors across the Midwest to discuss the proposed archetypal decision for the pilot study, and identify appropriate decision criteria, metrics, and objectives for evaluating alternatives. The UC analysis of the appropriate RPS level is expected to address a wide range of uncertainties such as the following, many of which involve land-water-energy interactions:

[3] M&A = mitigation and adaptation

- The impact of climate change (mean and extremes) on bioenergy and food crop production
- The impact of climate change (mean and extremes) on natural resource availability and the subsequent impacts on:
    - renewable energy generation (e.g., due to impacts on winds, water availability for hydro)
    - thermal power plant generation (e.g., due to restricted water availability for power plant cooling)
- The impact of climate change (mean and extremes) on electricity demand
- Land availability for bioenergy crops, food crops, new power plants, new transmission lines
- The impact of national climate policy (e.g., national carbon tax, cap and trade, emissions reduction targets)
- The impact of global climate policy

The iRESM team plans to continue to publish the results of its stakeholder-related research over the course of the initiative.

Appendix A

Bibliography of Stakeholder Engagement Research

Appendix A

Bibliography of Stakeholder Engagement Research

Adams CA and GR Frost. 2004. "Stakeholder Engagement Strategies: Possibilities for the Internet." In *Fourth Asia-Pacific Interdisciplinary Research in Accounting Conference*, July 4-6, 2004, Singapore. Accessed May 5, 2010 at www.smu.edu.sg/events/apira/2004/Final%20Papers/1158-Frost.pdf.

Allan C and A Curtis. 2003. "Learning to Implement Adaptive Management," *Natural Resource Management* 6(1): 25-30.

Carter LM. 2010. "Tipping Point: Art & Climate Change," Accessed May 5, 2010 at www.adaptationnetwork.org/assets/tippingPoint.pdf.

Cooperrider D and S Srivasta. 1987. "Appreciative Inquiry in Organizational Life." *Research in Organizational Change and Development* 129-169.

Brown J and D Isaacs. 2001. "The World Café: Living Knowledge through Conversations that Matter," The Systems Thinker 12(5). Accessed May 5, 2010 at http://thesystemsthinker.com/.

Climate Leadership Initiative. 2008. *The Climate Master Handbook*. The Climate Leadership Initiative, Institute for a Sustainable Environment, University of Oregon, Portland, Oregon. Accessed May 5, 2010 at http://www.theresourceinnovationgroup.org/storage/CMhandbookforindividuals.pdf

Edelenbo, J and E Klijn. 2006. "Managing stakeholder involvement in decision making: a comparative analysis of six interactive processes in the Netherlands." *Journal of Public Administration Research and Theory* 16: 417-446.

Enright KP and C Bourns. 2010. "The Case for Stakeholder Engagement." *Stanford Social Innovation Review* Spring: 40-45.

Gable C and B Shireman. 2005. "Stakeholder Engagement: A Three-Phase Methodology." *Environmental Quality Management* 14(3): 9-24. Accessed May 5, 2010 at http://www3.interscience.wiley.com/journal/110430857/abstract?CRETRY=1&SRETRY=0.

Hall J and S Hammond. "What is Appreciative Inquiry?" Thin Book Publishing Company, Bronx, New York. Accessed May 5, 2010 at www.thinbook.com/docs/doc-whatisai.pdf.

Hartley TW and RA Robertson. 2006. "Stakeholder Engagement, Cooperative Fisheries Research and Democratic Science: The Case of the Northeast Consortium." *Human Ecology Review* 13(2): 161-171.

Hemmati, M. 2002. *Multi-stakeholder Processes for Governance and Sustainability—Beyond Deadlock and Conflict.* Earthscan Publications, Ltd., London, United Kin

Herricks E and JW Eheart. 2001. "Assessing Multi-Sector Response to Climate Change through Stakeholder Involvement." *Bridging the Gap: Meeting the World's Water and Environmental Resources*

Challenges, Proceedings of World Water and Environmental Resources Congress, American Society of Civil Engineers, Reston, Virginia.

International Finance Corporation. 2007. *Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets.* Accessed May 5, 2010 at www.ifc.org/.

International Finance Corporation. 1998. *Doing Better Business through Effective Public Consultation and Disclosure: A Good Practice Manual.* Available at www.ifc.org.

Lim B, E Spanger-Sigfried, I Burton, E Malone, and S Huq. 2005. "Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies, and Measures." Cambridge University Press, Cambridge, United Kingdom.

Pike C, B Doppelt, and M Herr. 2010. *Climate Communications and Behavior Change: A Guide for Practitioners, The Climate Leadership Initiative*. Accessed May 5, 2010 at http://climlead.uoregon.edu/publications/climate-education-and-communication.

Rantavaara A, H Wallin, K Hanusen, K Harmala, H Kulmara, E Latvio, K Liskola, I Mustonen, I Nieminen, R Tainio. 2005. "Finnish Stakeholder Engagement in the Restoration of a Radioactively Contaminated Food Chain," *Journal of Environmental Radioactivity* 83: 305-317.

Rayner S and E Malone, eds. 1998. *Human Choice and Climate Change*. 4 Volume Set, Battelle Press, Columbus, Ohio.

Svendson AC and M Laberge. 2005. "Convening Stakeholder Networks." Accessed May 5, 2010 at www.sfu.ca/cscd/cli/jcc19svendsen.pdf.

Walker GB, S Senecah, and SE Daniels. 2006. "From the Forest to the River: Citizens' Views of Stakeholder Engagement." *Human Ecology Review* 13(2):193-202.

White A. 2006. *The Stakeholder Fiduciary: The CSR, Governance, and the Future of Boards.* Business for Social Responsibility Report. Accessed May 5, 2010 at www.bsr.org/reports/BSR_AW_Corporate-Boards.pdf.

Whitney D and J Trosten-Bloom. 2002. *The Power of Appreciative Inquiry*. Berrett-Koehler Publishers, San Francisco, California.

Appendix B

References for U.S. Midwest Mitigation Literature Review

Appendix B

References for U.S. Midwest Mitigation Literature Review

This document lists the abstracts[1] for the literature collected to date regarding GHG mitigation alternatives in the 14-state Midwest region of the U.S.—as defined for the iRESM initiative. This is meant to be a representative—not exhaustive—list of relevant peer-reviewed and grey literature focused on one or more of the Midwest states, primarily from the last 10 years. A few of the studies span the entire U.S., but contain results or other information relevant to one or more of the states in the Midwest region. The abstracts are divided into two broad groups:

a. reducing GHG sources
b. enhancing GHG sinks.

Within group a, sub-categories further organize the abstracts according to the type of mitigation alternative:

- Bioenergy/biofuels (10 documents)
- CCS (9 documents)
- Hydropower (1 document)
- RPS, Energy Efficiency, and other Policy-Related Studies (13 documents)
- Transmission (2 documents) [2]
- Wind (8 documents)

Within group b, the abstracts are divided into agricultural/soil management (4 documents) and forest management (3 documents) categories.

B.1 REDUCING GHG SOURCES

Bioenergy/Biofuels

Becker DR, K Skog, A Hellman, KE Halvorsen, and T Mace. 2009. "An Outlook for Sustainable Forest Bioenergy Production in the Lake States." Energy Policy 37: 5687-5693.

The Lake States region of Minnesota, Wisconsin and Michigan offers significant potential for bioenergy production. We examine the sustainability of regional forest biomass use in the context of existing thermal heating, electricity, and biofuels production, projected resource needs over the next decade including existing forest product market demand, and impacts on price and feasibility. Assuming \$36 per dry tonne at roadside, 4.1 million dry tonnes of forest biomass could be available region-wide. However, less is likely available due to localized environmental and forest cover type constraints, and landowner willingness to harvest timber. Total projected demand of 5.7 million dry tonnes, based on current and announced industry capacity, exceeds estimates of biomass availability, which suggests that

[1] Most of the article/paper descriptions are copied verbatim from the document abstract. Where abstracts were unavailable, a summary of the paper was drawn from the text and/or the researcher's knowledge of the paper.
[2] Category included because of its importance in facilitating mitigation.

anticipated growth in the forest-based bioeconomy may be constrained. Attaining projected demand will likely require a combination of higher cost feedstocks, integration of energy and non-energy uses, and careful management to meet environmental constraints. State distinctions in biomass harvest guidelines and the propensity for third-party forest certification will be critical in providing environmental safeguards. The cumulative effect of policy initiatives on biomass competition are discussed in the context of an emerging Lake States bioeconomy.

Cantrell KB, TF Ducey, KS Ro, PG Hunt. 2008. "Livestock Waste-to-Bioenergy Generation Opportunities." *Bioresource Technology* 99: 7941–7953.

The use of biological and thermochemical conversion (TCC) technologies in livestock waste-to-bioenergy treatments can provide livestock operators with multiple value-added, renewable energy products. These products can meet heating and power needs or serve as transportation fuels. The primary objective of this work is to present established and emerging energy conversion opportunities that can transform the treatment of livestock waste from a liability to a profit center. While biological production of methanol and hydrogen are in early research stages, anaerobic digestion is an established method of generating between 0.1 to 1.3 m3 m_3 d_1 of methane-rich biogas. The TCC processes of pyrolysis, direct liquefaction, and gasification can convert waste into gaseous fuels, combustible oils, and charcoal. Integration of biological and thermal-based conversion technologies in a farm-scale hybrid design by combining an algal CO_2-fixation treatment requiring less than 27,000 m2 of treatment area with the energy recovery component of wet gasification can drastically reduce CO_2 emissions and efficiently recycle nutrients. These designs have the potential to make future large scale confined animal feeding operations sustainable and environmentally benign while generating on-farm renewable energy.

De La Torre Ugarte DG, Walsh MW, Shapouri H, Slinsky SP. 2003. "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture." *Agricultural Economic Report No. 816*. U.S. Department of Agriculture Available at http://www.usda.gov/oce/oepnu/AER816Bi.pdf.

In response to energy security concerns, alternative energy programs such as biomass energy systems are being developed to provide energy in the 21st century. For the biomass industry to expand, a variety of feedstocks will need to be utilized. Large scale production of bioenergy crops could have significant impacts on the United States agricultural sector in terms of quantities, prices and production location of traditional crops as well as farm income. Though a number of scenarios were examined to study the impact of bioenergy crop production on the agricultural sector, two cropland scenarios are presented in this report. Under the wildlife management scenario, the analysis indicates that, at $30/dry ton (dt) for switchgrass, $31.74/dt for willow and $32.90 for poplar, an estimated 19.4 million acres of cropland (8.2 million from Conservation Reserve Program Acres (CRP)) could be used to produce 96 million dry tons of bioenergy crops annually at a profit greater than the profit created by existing uses for the land. In this scenario, traditional crop prices increase from 3 percent to 9 percent (depending on crop) and net farm income increases by $2.8 billion annually. At $40/dt of switchgrass, $42.32/dt for willow and $43.87/dt for poplar and assuming the production management scenario, an estimated 41.9 million acres (12.9 million from CRP) could be used to produce 188 million dry tons of biomass annually. Under this scenario, traditional crop prices increase by 8 to 14 percent and net farm income increases by $6 billion annually.

Jeanty PW, D Warren, and F Hitzhusen. 2004. *Assessing Ohio's Biomass Resources for Energy Potential Using GIS*. Prepared by Ohio State University for the Ohio Department of Development.

This Agricultural, Environmental, and Development Economics (AEDE) study funded by Ohio Department of Development (DOD) involves a geo-referenced inventory by county of Ohio biomass resources for energy. Categories include forest and crop residues, livestock manure, municipal solid waste and food processing waste. This is an update and expansion of an earlier (1982) inventory of biomass by Hitzhusen et al. It also disaggregates and expands a study by Walsh et al. in 2000 which ranked Ohio 11th among the 50 states in total biomass availability. By estimating and geo-referencing the sustainable quantities of various categories of biomass for energy by county, it is possible to identify the spatial concentrations of various biomass renewable energy feedstocks that may be economically viable for various processes for conversion. These conversion processes in turn have implications for environmental improvement and reduced dependence on foreign oil imports. A better understanding of the technical and economic pros and cons of the most promising conversion processes will be required along with further data collection and refinements of this inventory (particularly the food processing waste subset) before detailed policy recommendations can be made. However, this study is hopefully a good start toward that goal and should provide direction and focus for future analysis and recommendations for a more renewable and sustainable energy and environmental future for Ohio.

Khanna, M, B Dhungana, and J Clifton-Brown. 2008. "Costs of Producing Miscanthus and Switchgrass for Bioenergy in Illinois." ***Biomass and Bioenergy*** **32(6): 482-493. DOI: 10.1016/j.biombioe.2007.11.003.**

There is growing interest in using perennial grasses as renewable fuels for generating electricity and for producing bio-ethanol. This paper examines the costs of producing two bioenergy crops, switchgrass and miscanthus, in Illinois for co-firing with coal to generate electricity. A crop-productivity model, MISCANMOD, is used together with a GIS to estimate yields of miscanthus across counties in Illinois. Spatially variable yields, together with county-specific opportunity costs of land, are used to determine the spatial variability in the breakeven farm-gate price of miscanthus. Costs of transporting bioenergy crops to the nearest existing power plant are incorporated to obtain delivered costs of bioenergy. The breakeven delivered cost of miscanthus for an average yield of 35.76 t ha-1 in Illinois is found to be less than two-thirds of the breakeven price of switchgrass with an average yield of 9.4 t ha-1. There is considerable spatial variability in the breakeven farm-gate price of miscanthus, which ranges between 41 and 58 $ t-1 across the various counties in Illinois. This together with differences in the distances miscanthus has to be shipped to the nearest power plant causes variability in the costs of using bioenergy to produce electricity. The breakeven cost of bioenergy for electricity generation ranges from 44 to 80 $ t-1 DM and is considerably higher than the coal energy-equivalent biomass price of 20.22 $ t-1 DM that power plants in Illinois might be willing to pay. These findings imply a need for policies that will provide incentives for producing and using bioenergy crops based on their environmental benefits in addition to their energy content.

LaCourt, Donna. 2009. "Ensuring Forest Sustainability in the Development of Wood Biofuels and Bioenergy in the Great Lakes States. Panel 3 Options For Build-Out Of A Sustainable Bioenergy/Biofuels Industry In The Great Lakes." Michigan Economic Development Corporation (Powerpoint).

Economic development perspective on opportunities for biofuels and bioenergy in Michigan.

National Renewable Energy Laboratory. 2005. A Geographic Perspective on the Current Biomass Resource Availability in the United States. Technical Report NREL/TP-560-39181 December 2005.

This research attempted to estimate the biomass resources currently available in the United States, and to examine their geographic distribution. It also addresses the use of GIS as a powerful method for collecting, exploring, analyzing, and visualizing the biomass data. The results of this study show that an estimated 423 million tonnes of biomass are technically available in the country (Table 10). The geographic pattern of this resource availability by county is shown on Figure 25, and Figure 26 illustrates the numbers normalized by county area. The crop, forest, and primary mill residues provide about 70% of the total biomass resources (Figure 28 and Figure 29). While the resources from other feedstocks are relatively insignificant, they could play an important role at a regional and local level.

National Renewable Energy Laboratory. 2005. "Minnesota Biomass - Hydrogen and Electricity Generation Potential."

As a State, Minnesota is rich in natural resources, a majority of which are in the agricultural and forestry sectors. As a consequence of these resources, significant quantities of residual biomass is available. A study was conducted by the National Renewable Energy Laboratory to determine the total amount of biomass-derived hydrogen and electricity that could be produced in the State of Minnesota from its energy crops and residual biomass. Additionally, the percents of today's gasoline consumption and electricity consumption were calculated, as well as the resulting reductions in greenhouse gas emissions.

Stone, KC, PG Hunt, KB Cantrell, KS Ro. 2009. "The Potential Impacts of Biomass Feedstock Production on Water Resource Availability." ***Bioresource Technology*** **101: 2014–2025.**

Biofuels are a major topic of global interest and technology development. Whereas bioenergy crop production is highly dependent on water, bioenergy development requires effective allocation and management of water. The objectives of this investigation were to assess the bioenergy production relative to the impacts on water resource related factors:

1. climate and weather impact on water supplies for biomass production
2. water use for major bioenergy crop production
3. potential alternatives to improve water supplies for bioenergy.

Shifts to alternative bioenergy crops with greater water demand may produce unintended consequences for both water resources and energy feedstocks. Sugarcane and corn require 458 and 2036 m3 water/m3 ethanol produced, respectively. The water requirements for corn grain production to meet the US-DOE Billion-Ton Vision may increase approximately 6-fold from 8.6 to 50.1 km3. Furthermore, climate change is impacting water resources throughout the world. In the western US, runoff from snowmelt is occurring earlier altering the timing of water availability. Weather extremes, both drought and flooding, have occurred more frequently over the last 30 years than the previous 100 years. All of these weather events impact bioenergy crop production. These events may be partially mitigated by alternative water management systems that offer potential for more effective water use and conservation. A few potential alternatives include controlled drainage and new next-generation livestock waste treatment systems. Controlled drainage can increase water available to plants and simultaneously improve water quality. New livestock waste treatments systems offer the potential to utilize treated wastewater to produce bioenergy crops. New technologies for cellulosic biomass conversion via thermochemical conversion offer the potential for using more diverse feedstocks with dramatically reduced water requirements. The development of bioenergy feedstocks in the U.S. and throughout the world should carefully consider water resource limitations and their critical connections to ecosystem integrity and sustainability of human food.

Zhang X, RC Izaurralde, D Manowitz, TO West, WM Post, AM Thomson, VP Bandaru, J Nichols, and JR Williams. 2010. "An Integrative Modeling Framework to Evaluate the Productivity and Sustainability of Biofuel Crop Production Systems." ***GCB Bioenergy.*** **DOI: 10.1111/j.1757-1707.2010.01046.x.**

The potential expansion of biofuel production raises food, energy, and environmental challenges that require careful assessment of the impact of biofuel production on greenhouse gas (GHG) emissions, soil erosion, nutrient loading, and water quality. In this study, we describe a spatially explicit integrative modeling framework (SEIMF) to understand and quantify the environmental impacts of different biomass cropping systems. This SEIMF consists of three major components:

1. a geographic information system (GIS)-based data analysis system to define spatial modeling units with resolution of 56 m to address spatial variability,
2. the biophysical and biogeochemical model Environmental Policy Integrated Climate (EPIC) applied in a spatially-explicit way to predict biomass yield, GHG emissions, and other environmental impacts of different biofuel crops production systems, and
3. an evolutionary multiobjective optimization algorithm for exploring the trade-offs between biofuel energy production and unintended ecosystem-service responses.

Simple examples illustrate the major functions of the SEIMF when applied to a nine-county Regional Intensive Modeling Area (RIMA) in S.W. Michigan to

1. simulate biofuel crop production,
2. compare impacts of management practices and local ecosystem settings, and
3. optimize the spatial configuration of different biofuel production systems by balancing energy production and other ecosystem-service variables.

Potential applications of the SEIMF to support life cycle analysis and provide information on biodiversity evaluation and marginal-land identification are also discussed. The SEIMF developed in this study is expected to provide a useful tool for scientists and decision makers to understand sustainability issues associated with the production of biofuels at local, regional, and national scales.

CCS

Balaskowitz A. 2009. ***Carbon Capture and Sequestration (Michigan).*** **Available at web archive:** www.greatlakeswiki.org.

The Federal government recognizes CO_2 as a greenhouse gas and contributor to global warming. In Michigan, stationary sources like coal plants emit about 100 million tons of CO_2 annually. In 2007, the U.S. emitted 21.5 billion metric tons of CO_2 from coal-fired power plants, according to the Energy Information Administration. However, the DOE estimates beneath Michigan's surface is a storage capacity of between 22 billion and 87 billion metric tons for CO_2. "Cautiously, we're looking at about 40 billion tons worth of capacity. If we can get 100 million tons per year underground, that's 400 years worth of storage," said Dave Barnes, a geologist at Western Michigan University and contributor to the

DOE's studies in Gaylord. "That's a lot. Certainly Michigan is unique for the Midwest region." That is why the DOE looks to Michigan and the surrounding region to store CO_2 far below the surface. Government funding for the region has passed $100 million over the past 5 years.

Dahowski RT, JJ Dooley, and CL Davidson. 2005. "Developing CO_2 Sequestration Cost Curves for the MRCSP." Midwest Regional Carbon Sequestration Partnership (MRCSP) Report PNWD-3644.

The seven states of the Midwest Regional Carbon Sequestration Partnership (MRCSP) represent a prime location for the potential large scale commercial adoption of terrestrial and geologic sequestration technologies. While the MRCSP's geologic and terrestrial sequestration options vary in terms of their technological maturity, costs, available capacity, and other key factors, these "sequestration natural resources" represent feasible, cost-effective options for bringing about sustained and large-scale emissions reductions within these states, and value to their economies, for many decades to come. This report summarizes the development and application of a methodology to assess the costs at which varying levels of emissions reductions can be made within the region, via the variety of abundant CO_2 sequestration options that appear to be available. The key components of this methodology are discussed, and preliminary results for the region are presented, which act to illustrate its value, and what the resulting CO_2 sequestration supply curves reveal about the nature, distribution, and economics of deploying CO_2 sequestration within this vital region.

Davidson CL, JJ Dooley, RT Dahowski. 2009. "Assessing the impacts of future demand for saline groundwater on commercial deployment of CCS in the United States." ***Energy Procedia*** **1: 1949-1956.**

This paper provides a preliminary assessment of the potential impact that future demand for groundwater might have on the commercial deployment of carbon dioxide capture and storage (CCS) technologies within the United States. A number of regions within the U.S. have populations, agriculture and industries that are particularly dependent upon groundwater. Moreover, some key freshwater aquifers are already over-utilized or depleted, and others are likely to be moving toward depletion as demand grows. The need to meet future water demands may lead some parts of the nation to consider supplementing existing supplies with lower quality groundwater resources, including brackish waters that are currently not considered sources of drinking water but which could provide supplemental water via desalination. In some areas, these same deep saline-filled geologic formations also represent possible candidate carbon dioxide (CO_2) storage reservoirs. The analysis presented here suggests that future constraints on CCS deployment – due to potential needs to supplement conventional water supplies by desalinating deeper and more brackish waters – are likely to be necessary only in limited regions across the country, particularly in areas that are already experiencing water stress.

Dooley JJ, CL Davidson, MA Wise, and RT Dahowski. 2005. "Accelerated Adoption Of Carbon Dioxide Capture And Storage Within The United States Electric Utility Industry: The Impact Of Stabilizing At 450 PPMV And 550 PPMV." In ***Greenhouse Gas Control Technologies 7.*** **Elsevier Science, Oxford, England, pp. 891-899.**

By combining the capabilities of two separate energy and economic models, the top-down MiniCAM and the bottom-up Battelle CO_2-GIS, the significant potential impact that policies to stabilize atmospheric concentrations of carbon dioxide (CO_2) at 450 parts per million by volume (ppmv) and 550 ppmv would have on the existing asset base of the U.S. electric utility industry can be examined at a finer level of resolution. Even after allowing for large penetrations of nuclear power and renewable energy as well as continued energy efficiency improvements throughout the economy as a whole, as much as 96% of the capital stock of U.S. fossil power plants would need to be replaced with state-of-the-art carbon dioxide capture and storage (CCS)-enabled power plants by the year 2050. By 2050, these two cases result in approximately 54 $GtCO_2$ being stored in various geologic formations in the more stringent 450 ppmv case and 19 $GtCO_2$ being stored in the 550 ppmv case. Because of the heterogeneous distribution of the electric power plants across the U.S., this demand for CO_2 storage places varying demands on candidate CO_2 reservoirs with the storage capacity of some reservoirs being significantly depleted by the year 2050.

Dooley JJ, CL Davidson, RT Dahowski. 2009. "An Assessment of the Commercial Availability of Carbon Dioxide Capture and Storage Technologies as of June 2009." Pacific Northwest National Laboratory, PNNL-18520, Richland, Washington.

Currently, there is considerable confusion within parts of the carbon dioxide capture and storage (CCS) technical and regulatory communities regarding the maturity and commercial readiness of the technologies needed to capture, transport, inject, monitor and verify the efficacy of carbon dioxide (CO_2) storage in deep, geologic formations. The purpose of this technical report is to address this confusion by discussing the state of CCS technological readiness in terms of existing commercial deployments of CO_2 capture systems, CO_2 transportation pipelines, CO_2 injection systems and measurement, monitoring and verification (MMV) systems for CO_2 injected into deep geologic structures. To date, CO_2 has been captured from both natural gas and coal fired commercial power generating facilities, gasification facilities and other industrial processes. Transportation via pipelines and injection of CO_2 into the deep subsurface are well established commercial practices with more than 35 years of industrial experience. There are also a wide variety of MMV technologies that have been employed to understand the fate of CO_2 injected into the deep subsurface. The four existing end-to-end commercial CCS projects – Sleipner, Snøhvit, In Salah and Weyburn – are using a broad range of these technologies, and prove that, at a high level, geologic CO_2 storage technologies are mature and capable of deploying at commercial scales. Whether wide scale deployment of CCS is currently or will soon be a cost-effective means of reducing greenhouse gas emissions is largely a function of climate policies which have yet to be enacted and the public's willingness to incur costs to avoid dangerous anthropogenic interference with the Earth's climate. There are significant benefits to be had by continuing to improve through research, development, and demonstration suite of existing CCS technologies. Nonetheless, it is clear that most of the core technologies required to address capture, transport, injection, monitoring, management and verification for most large CO_2 source types and in most CO_2 storage formation types, exist.

Froese R, D Shonnard, C Miller, K Koers, and D Johnson. 2010. "An Evaluation of Greenhouse Gas Mitigation Options for Coal-Fired Power Plants in the US Great Lakes States." ***Biomass and Bioenergy*** **34(3): 251-262 ISSN 0961-9534, DOI: 10.1016/j.biombioe.2009.10.013.**

We assessed options for mitigating greenhouse gas emissions from electricity generation in the US Great Lakes States, a region heavily dependent on coal-fired power plants. A proposed 600 MW power plant in northern Lower Michigan, U.S.A. provided context for our evaluation. Options to offset fossil CO_2 emissions by 20% included biomass fuel substitution from:

1. forest residuals
2. short-rotation woody crops
3. switchgrass

4. biologic sequestration in forest plantations
5. geologic sequestration using CO_2 capture.

Review of timber product output data, land cover data, and expected energy crop productivity on idle agriculture land within 120 km of the plant revealed that biomass from forestry residuals has the potential to offset 6% and from energy crops 27% of the annual fossil fuel requirement. Furthermore, annual forest harvest in the region is only 26% of growth and the surplus represents a large opportunity for forest products and bioenergy applications. We used Life Cycle Assessment (LCA) to compare mitigation options, using fossil energy demand and greenhouse gas emissions per unit electricity generation as criteria. LCA results revealed that co-firing with forestry residuals is the most attractive option and geologic sequestration is the least attractive option, based on the two criteria. Biologic sequestration is intermediate but likely infeasible because of very large land area requirements. Our study revealed that biomass feedstock potentials from land and forest resources are not limiting mitigation activities, but the most practical approach is likely a combination of options that optimize additional social, environmental and economic criteria.

Wickstrom LH et al. 2005. ***"Characterization of Geologic Sequestration Opportunities in the MRCSP Region."*** **Prepared by the Ohio Division of Geological Survery for Midwest Regional Carbon Sequestration Partnership. DOE Cooperative Agreement No. DE-PS26-056NT42255.**

The Midwest Regional Carbon-Sequestration Partnership (MRCSP) Phase-1 geologic team conducted a preliminary assessment of the region's geologic CO_2 sequestration potential for the Paleozoic geologic sequence in Indiana, eastern Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia and for Cenozoic-age strata in the Maryland coastal plain. Nine potential reservoir, and five potential confining cap-rock, intervals (this includes organic shales) were identified, their structure, depth, and thickness mapped, and other physical and chemical data pertinent to CO_2 sequestration compiled. A comprehensive series of digital maps and tabular databases were constructed to facilitate regional sequestration planning and modeling. The Phase-1 assessment indicates the MRCSP region has the potential to sequester in excess of 450 gigatonnes of CO_2 in deep, subsurface geologic formations. This estimate of the CO_2-storage capacity is very large when compared to the present level of CO_2 emissions for the region. Furthermore, geologic mapping and calculations of the storage capacity conducted during Phase-I reveals that the geologic storage capacity for CO_2 is disproportionately distributed, both between and within the partnership states; some areas have high storage potential, while others have little or no known capacity. Hence, for CO_2 sequestration technology to be practical, it is essential that any future CO_2 point-source is located in an area where the subsurface geology is amenable to large-scale CO_2 injection, or, at the least, that the economics of transporting the CO_2 from the point-source to the geologic CO2 reservoir is included in the site planning. Future research, to be conducted during Phase-2 of the partnership, will include additional geologic mapping and modeling of additional stratigraphic intervals determined to be viable sequestration targets as well as the refinement of those maps and models developed during Phase-1. Future MRCSP CO_2 sequestration research will also contain components investigating the economic variables associated with transporting CO_2 from existing point-sources to any potential CO_2-storage site. These additional analyses will provide the region with the geologic and economic foundation necessary to advance with CO_2 sequestration technology.

Wise MA and JJ Dooley. 2005. "Baseload and Peaking Economics and the Resulting Adoption of Carbon Dioxide Capture and Storage Systems for Electric Power Plants," In *Greenhouse Gas Control Technologies.* Elsevier Science, Oxford, England, pp. 303-311.

The Battelle Carbon Management Electricity Model (CMEM), a new electricity generation and dispatch optimization model, is used to explore the effects of carbon taxes and constraints on investment and operating decisions for new electric generating capacity as well as on the operation and market value of existing plants in a specific region of the United States and across three carbon dioxide emission-control scenarios. By modelling a specific region East Central Area Reliability Coordination Agreement (ECAR) with its unique hourly load profile and generating capacity mix, the authors demonstrate that adopting CO_2 capture-and-storage (CCS) technologies is much more nuanced than simply comparing the costs of building and operating power-plant technologies with and without CCS would seem to imply. The analysis shows that, in the face of carbon constraints, baseload units are the first to be significantly decarbonized, with a significant portion of the allowable emissions consistent with the emissions-reduction mandate being allocated to peaking and intermediate loads. In the face of tighter emissions restrictions (and consequently higher carbon prices), a large and growing spread between peak and off-peak prices for electricity is observed, which could create powerful incentives for changing seasonal and perhaps even diurnal electricity-use patterns. It is only under very stringent emissions reductions that the retirement of otherwise productive capital stock occurs. In all other cases, electricity demand is met with a mix of baseload plants that employ CCS, existing coal- and gas-fired plants that vent their emissions directly to the atmosphere, and new, more efficient versions of conventional (non-CCS-enabled) power plants.

Wise MA and JJ Dooley. 2009. "The Value of Post-Combustion Carbon Dioxide Capture and Storage Technologies in a World with Uncertain Greenhouse Gas Emissions Constraints." ***International Journal of Greenhouse Gas Control*** **3: 39-48.**

By analyzing how the largest CO_2 emitting electricity-generating region in the United States, the East Central Area Reliability Coordination Agreement (ECAR), responds to hypothetical constraints on greenhouse gas emissions, the authors demonstrate that there is an enduring role for post-combustion CO_2 capture technologies. The utilization of pulverized coal generation with carbon dioxide capture and storage (PC + CCS) technologies is particularly significant in a world where there is uncertainty about the future evolution of climate policy and in particular uncertainty about the rate at which the climate policy will become more stringent. The paper's analysis shows that within this one large, heavily coal-dominated electricity-generating region, as much as 20–40 gigawatts (GW) of PC + CCS could be operating before the middle of this century. Depending upon the state of PC + CCS technology development and the evolution of future climate policy, the analysis shows that these CCS systems could be mated to either pre-existing PC units or PC units that are currently under construction, announced and planned units, as well as PC units that could continue to be built for a number of decades even in the face of a climate policy. In nearly all the cases analyzed here, these PC + CCS generation units are in addition to a much larger deployment of CCS-enabled coal-fueled integrated gasification combined cycle (IGCC) power plants. The analysis presented here shows that the combined deployment of PC + CCS and IGCC + CCS units within this one region of the U.S. could result in the potential capture and storage of between 3.2 and 4.9 Gt of CO_2 before the middle of this century in the region's deep geologic storage formations.

Hydropower

Kosnik L. 2008. "The Potential of Water Power in the Fight Against Global Warming in the U.S." ***Energy Policy*** **36(9): 3252-3265. DOI: 10.1016/j.enpol.2008.05.009.**

The leading cause of climate change today is the burning of fossil fuels related to energy production. One approach to reducing greenhouse gas emissions, therefore, is to more actively switch to renewable technologies in the production of electricity, and reduce the use of fossil fuels in electricity production. This is the goal of renewable portfolio standard (RPS) legislation, currently in effect in 28 states across the country. In this paper we discuss the potential for water power development as one method to reduce U.S. greenhouse gas emissions. We look at the potential from:

1. new small/micro hydropower dams
2. uprating facilities at existing large hydropower dams
3. new generating facilities at existing non-hydropower dams
4. hydrokinetics.

We analyze this potential by type, by state, and by its ability to satisfy current RPS goals. Finally, we consider the cost-effectiveness of developing these sources of water-based energy. We find that while water power will never be the complete answer to emissions-free energy production, a strong case can be made that it can be a useful part of the answer.

RPS, Energy Efficiency, and Related Policy Studies

Brown M, M Levine, W Short, and J Koomey. 2001. "Scenarios for a Clean Energy Future." *Energy Policy* 29(14): 1179-1196. DOI: 10.1016/S0301-4215(01)00066-0.

This paper summarizes the results of a study—Scenarios for a Clean Energy Future—that assess how energy-efficient and clean energy technologies can address key energy and environmental challenges facing the U.S.. A particular focus of this study is the energy, environmental, and economic impacts of different public policies and programs. Hundreds of technologies and approximately 50 policies are analyzed. The study concludes that policies exist that can significantly reduce oil dependence, air pollution, carbon emissions, and inefficiencies in energy production and end-use systems at essentially no net cost to the U.S. economy. The most advanced scenario finds that by the year 2010, the U.S. could bring its carbon dioxide emissions three-quarters of the way back to 1990 levels. The study also concludes that over time energy bill savings in these scenarios can pay for the investments needed to achieve these reductions in energy use and associated greenhouse gas emissions. (not Midwest-specific per se; U.S.-wide study)

Carbon Disclosure Project. 2009. "CDP Cities Pilot Project 2008."

The CDP U.S. Cities Pilot Project was launched by the Carbon Disclosure Project (CDP) and ICLEI – Local Governments for Sustainability in 2008 to encourage cities to voluntarily report their greenhouse gas emissions and disclose other information related to climate change. Local governments own and operate a considerable portfolio of buildings, fleets, and other infrastructure and through their progressive actions to reduce emissions have a great potential to lead by example. CDP's standardized and proven process has enabled the 18 participating cities to publicly disclose information in a form recognized around the world, providing a snapshot of engagement in the issues. The 18 participating cities were Annapolis, MD; Arlington, VA; Atlanta, GA; Burlington, VT; Chicago, IL; Denver, CO; Edina, MN; Fairfield, IA; Haverford, PA; Las Vegas, NV; New Orleans, LA; New York, NY; North Little Rock, AR; Park City, UT; Portland, OR; Rohnert Park, CA; Washougal, WA; and West Palm Beach, FL.

Chen C, R Wiser, A Mills, and M Bolinger. 2009. "Weighing the Costs and Benefits of State Renewables Portfolio Standards in the United States: A Comparative Analysis of State-Level Policy Impact Projections." ***Renewable and Sustainable Energy Reviews*** **13(3): 552-566. DOI: 10.1016/j.rser.2008.01.005.**

State renewables portfolio standards (RPS) have emerged as one of the most important policy drivers of renewable energy capacity expansion in the U.S. As RPS policies have been proposed or adopted in an increasing number of states, a growing number of studies have attempted to quantify the potential impacts of these policies, focusing primarily on cost impacts, but sometimes also estimating macroeconomic, risk reduction, and environmental effects. This article synthesizes and analyzes the results and methodologies of 31 distinct state or utility-level RPS cost-impact analyses completed since 1998. Together, these studies model proposed or adopted RPS policies in 20 different states. We highlight the key findings of these studies on the projected costs of state RPS policies, examine the sensitivity of projected costs to model assumptions, evaluate the reasonableness of key input assumptions, and suggest possible areas of improvement for future RPS analyses. We conclude that while there is considerable uncertainty in the study results, the majority of the studies project modest cost impacts. Seventy percent of the state RPS cost studies project retail electricity rate increases of no greater than 1%. Nonetheless, there is considerable room for improving the analytic methods, and therefore accuracy of these estimates.

Jiusto S. 2008. "An Indicator Framework for Assessing U.S. State Carbon Emissions Reduction Efforts (With Baseline Trends From 1990 To 2001)." ***Energy Policy*** **36(6): 2234-2252. DOI: 10.1016/j.enpol.2008.02.034.**

States are at the forefront of climate-related energy policy in the U.S., developing innovative policy and regional institutions for reducing carbon dioxide and other greenhouse gases. States matter because the larger ones use more energy and produce more carbon emissions than most nations and because their policies, though heterogeneous and until recently quite limited in scope, are shaping the context for national climate action. Despite this significance, little is known about trends in state carbon emissions or the effectiveness of state policies in reducing emissions. This paper describes a framework for analyzing and comparing state carbon emissions performance using sectoral indicators of emissions, energy consumption and carbon intensity linked to key policy domains. The paper also describes the range of state experience across indicators during the period 1990-2001, establishing a baseline of leading, lagging and average experience against which future state and regional change can be assessed. The conceptual framework and the empirical analysis of emission trends are intended to provide a better understanding of, and means for monitoring, state contributions toward achieving energy system sustainability.

Johannes C. 2008. "Renewable Energy Background and Outlook for Nebraska Electricity Consumers Report: A Reference Document on Renewable Energy Resources in Nebraska." ***Nebraska Power Association.*** **Accessed August 9, 2010 at** http://www.nepower.org/NPA_presentations/renewable.pdf /.

Midwest Governors Association. 2009. "Midwestern Energy Security and Climate Stewardship Roadmap—Advisory Group Recommendations."

This Energy Security and Climate Stewardship Roadmap: Advisory Group Recommendations (Energy Roadmap) outlines strategies for capturing the enormous opportunity for the Midwest to build on its historic strengths and reclaim its position as a manufacturing powerhouse and a place of innovation and meaningful work. We have the opportunity to improve and expand our region's electric grid, reduce our dependence on foreign oil, and mitigate environmental impacts of conventional energy sources. The recommendations found in this document represent nothing short of a new industrial revolution that will reshape this century and beyond. The Midwest has the human, intellectual and natural capital to lead this new economy. Smoothly transitioning to a fundamentally new, lower-carbon energy economy in the region will require a commitment for:

- Immediate adoption of policies capitalizing on existing low-cost, low-carbon opportunities such as energy efficiency measures in multiple sectors;
- Modifications of the existing regulatory framework for energy supply to remove disincentives for reduced energy use;
- Establishment of a stable regulatory environment for development of renewable energy, the regional transmission infrastructure needed to bring it to market, and advanced technologies such as carbon capture and storage;
- Adoption of additional market policies to expedite research, development and commercialization of existing and advanced renewable and fossil energy technologies; and
- Large-scale investment in the human capital necessary for an advanced energy economy to thrive, including consumer education, workforce and regulator training, and technical assistance for business interests and entrepreneurs.

New York State Energy Research and Development Authority (NYSERDA). 2009. "The New York Renewable Portfolio Standard: A Clean, Green Tomorrow Starts Today." Accessed August 9, 2010 at http://www.nyserda.org/rps/index.asp.

Ohler A and K Radusewicz. 2010. "Indirect Impacts in Illinois from a Renewable Portfolio Standard." *The Electricity Journal*. DOI: 10.1016/j.tej.2010.07.003.

Indirect impacts associated with Illinois' RPS include a change in the laws concerning the planning and zoning for wind development, a market for renewable energy credits, and awareness of problems with the transmission grid.

Olabisi, LS, PB Reich, KA Johnson, AR Kapuscinski, S Suh, and EJ Wilson. 2009. "Reducing Greenhouse Gas Emissions for Climate Stabilization: Framing Regional Options." *Environmental Science & Technology* 43(6):1696-703. DOI: 10.1021/es801171a.

The Intergovernmental Panel on Climate Change (IPCC) has stated that stabilizing atmospheric CO_2 concentrations will require reduction of global greenhouse gas (GHG) emissions by as much as 80% by 2050. Subnational efforts to cut emissions will inform policy development nationally and globally. We projected GHG mitigation strategies for Minnesota, which has adopted a strategic goal of 80% emissions reduction by 2050. A portfolio of conservation strategies, including electricity conservation, increased vehicle fleet fuel efficiency, and reduced vehicle miles traveled, is likely the most cost-effective option for Minnesota and could reduce emissions by 18% below 2005 levels. An 80% GHG reduction would require complete decarbonization of the electricity and transportation sectors, combined with carbon capture and sequestration at power plants, or deep cuts in other relatively more intransigent GHG-emitting sectors. In order to achieve ambitious GHG reduction goals, policymakers should promote aggressive conservation efforts, which would probably have negative net costs, while phasing in alternative fuels to replace coal and motor gasoline over the long-term.

Peterson, TC and AZ Rose. 2006. "Reducing Conflicts between Climate Policy and Energy Policy in the U.S.: The Important Role of the States." *Energy Policy* 34(5): 619-31.

The absence of U.S. national action on global climate change policy has prompted initiatives by the U.S. Congress, cities, states, and regions toward what is likely to become a long-term, collaborative effort to harmonize national energy and climate policies. This upward evolution in the face of a reluctant administration is historically consistent with the development of national legislation on other environmental and social issues in the U.S. At the heart of this movement is the need to resolve conflicts between high-intensity use of low-cost fossil energy supplies, and the dominating impact of carbon dioxide emissions on global climate change. U.S. states are among the largest carbon dioxide emitters in the world and play a critical role in supplying and transforming energy, as well as consuming it, for economic advantage. State governments are also likely to have to shoulder some of the cost of potentially extensive climate damages and bear the brunt of the cost of implementing future federal mandates. As a result, many are taking proactive stances on the development of climate mitigation policy to prepare for, accelerate, and/or guide national policy. As U.S. states show leadership on addressing greenhouse gas emissions, they also play an important role in forging policies and measures that reduce economic conflict between energy and climate goals. A number have launched or completed greenhouse gas mitigation plans and other major policies in the past few years that address these conflicts through:

1. finding ways to reduce mitigation costs, including the use of incentive-based policy instruments;
2. promoting an open and democratic policy process that includes major stakeholders;
3. promoting equity across socioeconomic groups, regions, and generations; and
4. promoting interregional cooperation.

The results are promising and suggest that the state arena for climate and energy policy is evolving quickly and constructively toward alternatives that reduce conflict. Regional efforts are also unfolding, along with greater congressional attention to the lessons learned and commitments made by sub-federal actions. In the next few years many national energy and climate conflicts are likely to be tested and addressed by states. Among these, Pennsylvania is likely to be an important player due to its high profile of energy production and potential for leadership.

Pew Center on Global Climate Change. 2009. "Renewable and Alternative Energy Portfolio Standards." Accessed August 9, 2010 at
http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm.

Polich R. 2007. "A Study of Economic Impacts from the Implementation of a Renewable Portfolio Standard and an Energy Efficiency Program in Michigan." *NextEnergy Center.* Detroit, Michigan.

The focus of this Study is on how energy efficiency programs and Renewable Portfolio Standard (RPS) policies, both separately and combined, will affect Michigan's economy. In addition, the modeling in this Study also provides critical information on how the implementation of energy efficiency programs and RPS policies will impact air emissions, and this report also discusses the potential economic and environmental impacts of these two policy courses with respect to a reduction in CO_2 emissions. This study shows that Michigan will economically benefit significantly from implementation of energy efficiency programs. In addition, even with the conservative assumptions utilized, RPS impacts are moderately positive. The primary cause for concern regarding future electric power supplies are associated with fossil generation cost uncertainties. Projections for the capital cost of new coal generation continue to increase and coal supply constraints are likely to increase fuel costs. The potential for a national cap on CO_2 emissions is real and, if enacted, will cause an increase in electric costs from fossil generation.

Wheeler SM. 2008. "State and Municipal Climate Change Plans: The First Generation " *Journal of the American Planning Association* 74(4):481-96. DOI: 10.1080/01944360802377973.

Problem: Global warming has emerged as one of the new century's top planning challenges. But it is far from clear how state and local governments in the United States can best address climate change through planning.

Purpose: As of 2008, 29 states had prepared some sort of climate change plan, and more than 170 local governments had joined the Cities for Climate Protection (CCP) campaign that requires that a plan be developed. This article analyzes this first generation of climate change plans and seeks to assess the goals being set, the measures included or left out, issues surrounding implementation, and the basic strengths and weaknesses of state and local climate change planning to date.

Methods: I conducted this research by analyzing planning documents as well as interviewing state and local officials by telephone. I analyzed the plans of three types of governments: all states with planning documents on climate change; cities with populations of over 500,000 that are members of the CCP campaign; and selected smaller cities that are CCP members.

Results and conclusions: Most plans set emissions-reduction goals, establish emission inventories, green public sector operations, and recommend a range of other measures. Many recent plans have been developed through extensive stakeholder processes and present very detailed lists of recommendations with quantified emissions benefits. But emissions-reduction goals vary widely, many proposed actions are voluntary, few resources have been allocated, and implementation of most measures has not yet taken place. Most plans do not address adaptation to a changing climate. Officials see rapidly growing public awareness of the issue and general support for climate change planning, but reluctance to change personal behavior.

Takeaway for practice: Future climate change planning should

a. set goals that can adequately address the problem
b. establish long-term planning frameworks in which progress toward these goals can be monitored on a regular basis and actions revised as needed
c. include the full range of measures needed to reduce and adapt to climate change
d. ensure implementation of recommended actions through commitment of resources, revised regulation, incentives for reducing emissions, and other means
e. develop strategies to deepen public awareness of the need for fundamental changes in behavior, for example regarding motor vehicle use.

Transmission

(There are highly technical, Midwest-specific studies as well, but these two U.S.-wide studies are included to provide an overview of the issues.)

Department of Energy. 2002. *National Transmission Grid Study*.

There is growing evidence that the U.S. transmission system is in urgent need of modernization. The system has become congested because growth in electricity demand and investment in new generation facilities have not been matched by investment in new transmission facilities. Transmission problems have been compounded by the incomplete transition to fair and efficient competitive wholesale electricity markets. Because the existing transmission system was not designed to meet present demand, daily transmission constraints or "bottlenecks" increase electricity costs to consumers and increase the risk of blackouts. DOE's analysis confirms the tendency for transmission congestion to develop at many locations within the Eastern Interconnection. Out of a total of 186 transmission paths modeled in the East, 50 are used to their maximum capacity at some point during the year, and 21 paths are congested during more than 10 percent of the hours of the year. The highest levels of congestion are found along transmission corridors from Minnesota to Wisconsin, the Midwest into the Mid-Atlantic, from the Mid-Atlantic to New York, and from the Southeast into Florida. In general, DOE's findings are very similar to historical data on transmission congestion, which also indicate that there is substantial congestion in the Midwest and upper Midwest, and from the Mid-Atlantic to the Northeast. In addition, solving the problem of transmission constraints within the United States will also require cooperation with Canada. Many scheduled power transactions within the U.S., particularly east-to-west transactions within the Eastern Interconnection, flow over transmission lines located in Canada before reaching loads in the U.S. This is a particular problem at points in the upper Midwest where the transmission systems of the two countries interconnect. These unintended flows (or "loop flows") often require transmission service curtailments in the U.S.

Department of Energy. 2009. *National Electric Transmission Congestion Study*.

Several large transmission projects, comprising a group called the Capacity Expansion (CapX) 2020 Project, are being planned to enable development of wind resources in North Dakota, South Dakota, Minnesota and Iowa. The first phase of this project—consisting of three 345 kV lines—has been approved as a reliability project for cost allocation under MISO's 2008 Transmission Expansion Plan and granted Certificates of Need by the Minnesota Public Utilities Commission.151 Other large projects have been proposed to serve renewables, including the Green Power Express, a merchant transmission proposal to move 12,000 MW of power from the Dakotas, Minnesota and Iowa to load centers including Chicago, southeastern Wisconsin and Minneapolis. 152 Further, the Midwest ISO is working with the other eastern system planning organizations to study alternative renewable energy development scenarios and associated transmission plans.

Transportation

(There is obviously a huge literature on ethanol that is beyond our scope to include here. See the bioenergy/biofuels and the RPS-Policy sections above for info related to the transportation sector.)

Wind

Brower M. 2009. "Development of Eastern Regional Wind Resource and Wind Plant Output Datasets." Subcontract Report NREL/SR-550-46764 prepared by AWS Truewind, LLC.

AWS Truewind has produced a wind plant output dataset spanning three years at 10-minute time resolution for over 580 GW of onshore wind projects and 208 GW of offshore wind projects in the eastern United States. Comparison of the data with observed plant output at three existing wind projects indicate that the diurnal and seasonal patterns as well as the dynamic behavior (ramp rates) are represented with acceptable accuracy. Hourly synthetic wind plant forecasts for four, six, and 24 hours ahead were also produced using a probabilistic method based on actual forecasts, and the autocorrelations and correlations between projects were found to be captured with acceptable accuracy. An adjustment was later applied to correct for an overly optimistic next-day forecast error margin relative to the other time horizons. Last, one-minute plant output data for the same onshore and offshore sites were produced for several time windows selected by NREL.

Denholm P. 2006. "Improving the technical, environmental and social performance of wind energy systems using biomass-based energy storage." ***Renewable Energy*** **31(9): 1355-1370, ISSN 0960-1481, DOI: 10.1016/j.renene.2005.07.001.**

A completely renewable baseload electricity generation system is proposed by combining wind energy, compressed air energy storage, and biomass gasification. This system can eliminate problems associated with wind intermittency and provide a source of electrical energy functionally equivalent to a large fossil or nuclear power plant. Compressed air energy storage (CAES) can be economically deployed in the Midwestern U.S., an area with significant low-cost wind resources. CAES systems require a combustible fuel, typically natural gas, which results in fuel price risk and greenhouse gas emissions. Replacing natural gas with synfuel derived from biomass gasification eliminates the use of fossil fuels, virtually eliminating net CO_2 emissions from the system. In addition, by deriving energy completely from farm sources, this type of system may reduce some opposition to long distance transmission lines in rural areas, which may be an obstacle to large-scale wind deployment.

Department of Energy. 2008. "20% Wind Energy by 2030 Increasing Wind Energy's Contribution to U.S. Electricity Supply." DOE/GO-102008-2567.

As estimated by the NREL WinDS model, given optimistic assumptions, the specific cost of the proposed transmission expansion for the 20% Wind Scenario is $20 billion in net present value (NPV). The actual required grid investment could also involve significant costs for permitting delays, construction of grid extensions to remote areas with wind resources, and investments in advanced grid controls, integration, and training to enable regional load balancing of wind resources. The total installed costs for wind plants include costs associated with siting and permitting of these plants. It has become clear that wind power expansion would require careful, logical, and fact-based consideration of local and environmental concerns, allowing siting issues to be addressed within a broad risk framework. Experience in many regions has shown that this can be done, but efficient, streamlined procedures will likely be needed to enable installation rates in the range of 16 GW per year. There are significant costs, challenges, and impacts associated with the 20% Wind Scenario presented in this report. There are also substantial positive impacts from wind power expansion on the scale and pace described in this chapter that are not likely to be realized in a business-as-usual future. Achieving the 20% Wind Scenario would involve a major national commitment to clean, domestic energy sources with minimal emissions of GHGs and other environmental pollutants.

Great Lakes Wind Collaborative. 2010. "State and Provinicial Land-Based Wind Farm Siting Policy in the Great Lakes Region: Summary and Analysis." Great Lakes Commission.

The Great Lakes region has a widely varied policy framework to govern the development of wind energy facilities on the land. A wind energy facility can be a single turbine, but more often it is a group of turbines that are constructed as part of a single development project, commonly known as a "wind farm." This document compares and contrasts Great Lakes states and provincial policies that affect wind farm development. Some jurisdictions have developed siting guidelines for local implementation; others have developed enforceable regulations while still others have a hybrid approach. The process also varies: some jurisdictions have relatively streamlined processes, while others have a more complex decisionmaking structure. The type of developer (i.e., utility or independent power producer) or the size of the project can also affect which regulations, if any, apply. Siting policies and associated regulatory structures are heavily influenced by state-specific factors such as state government organization, level of electric utility regulation how much authority is delegated to the local level. Effective wind siting policy will provide a clear process that maximizes the benefits to society, and minimizes adverse environmental and community impacts and costs. Beyond state and provincial wind farm siting, other policies, such as transmission siting and local zoning, can have a significant impact on whether a wind farm gets developed. By examining the policy approaches that exist among the states and provinces in the region, this paper is a first step toward identifying those policies which are most effective and innovative. To that end, this document is a starting point upon which further research and analysis will be conducted to identify various polices and practices that are most promising to accelerate sustainable wind development across the Great Lakes region. The GLWC is a large, multi-sector coalition of wind energy stakeholders.

National Renewable Energy Laboratory. 2010. *"Eastern Wind Integration and Transmission Study."* Prepared by EnerNex Corporation, Subcontract Report NREL/SR-550-47078.

DOE commissioned the Eastern Wind Integration and Transmission Study (EWITS) through its National Renewable Energy Laboratory (NREL). The investigation, which began in 2007, was the first of its kind in terms of scope, scale, and process. The study was designed to answer questions posed by a variety of stakeholders about a range of important and contemporary technical issues related to a 20% wind scenario for the large portion of the electric load (demand for energy) that resides in the Eastern Interconnection (Figure 1). The Eastern Interconnection is one of the three synchronous grids covering the lower 48 U.S. states. It extends roughly from the western borders of the Plains states through to the Atlantic coast, excluding most of the state of Texas.

Pebbles V. 2009. "Wind in the Great Lakes Region and the Great Lakes Wind Collaborative." Great Lakes Commission. (Powerpoint)

This Powerpoint provides an overview of wind potential in the region, the benefits and challenges of wind, with a focus on off-shore wind. The GLWC is a large, multi-sector coalition of wind energy stakeholders.

Pryor S, M Shahinian, and M Stout. 2005. "Offshore Wind Energy Development in the Great Lakes: A Preliminary Briefing Paper for the Michigan Renewable Energy Program." Michigan Renewable Energy Program, Michigan Public Service Commission.

The State of Michigan possesses significant wind resources, especially within its boundaries over the Great Lakes. These resources, combined with recent offshore wind energy successes in Europe, have encouraged this preliminary assessment of the potential for offshore wind energy development in Michigan and the Great Lakes. Wind energy technology has improved significantly over the last few decades and commercial offshore turbines are now approaching 3.6 megawatts (MW) in capacity. Technological advancements combined with government incentives have made wind energy fully cost-competitive with traditional sources of electricity. The advantages of offshore wind in Michigan include higher average wind speeds compared to onshore sites, proximity to population centers and grid connections, at least somewhat mitigated aesthetic and noise concerns, and the ability to transport and deliver very large pieces of wind energy equipment using a well-established water transportation infrastructure.

Wilson EJ and JC Stephens. 2009. "Wind Deployment in the United States: States, Resources, Policy, and Discourse." ***Environmental Science & Technology*** **43(24):9063-70. DOI: 10.1021/es900802s.**

A transformation in the way the United States produces and uses energy is needed to achieve greenhouse gas reduction targets for climate change mitigation. Wind power is an important low-carbon technology and the most rapidly growing renewable energy technology in the U.S. Despite recent advances in wind deployment, significant state-by-state variation in wind power distribution cannot be explained solely by wind resource patterns nor by state policy. Other factors embedded within the state-level socio-political context also contribute to wind deployment patterns. We explore this sociopolitical context in four U.S. states by integrating multiple research methods. Through comparative state-level analysis of the energy system, energy policy, and public discourse as represented in the media, we examine variation in the context for wind deployment in Massachusetts, Minnesota, Montana, and Texas. Our results demonstrate that these states have different patterns of wind deployment, are engaged in different debates about wind power, and appear to frame the risks and benefits of wind power in different ways. This comparative assessment highlights the complex variation of the state-level socio-political context and contributes depth to our understanding of energy technology deployment processes, decision-making, and outcomes.

Enhancing GHG Sinks[3]

Ag/Soil Management

Fargione J, J Hill, D Tilman, S Polasky, and P Hawthorne. 2008. "Land Clearing and the Biofuel Carbon Debt." ***Science*** **319: 235–238.**

Increasing energy use, climate change, and carbon dioxide (CO_2) emissions from fossil fuels make switching to low-carbon fuels a high priority. Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced. Converting rainforests, peatlands, savannas, or grasslands to produce food crop–based biofuels in Brazil, Southeast Asia, and the United States creates a "biofuel carbon debt" by releasing 17 to 420 times more CO_2 than the annual greenhouse gas (GHG) reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages.

[3] Note there is some overlap between this group and the bioenergy/biofuels category above.

Jacinthe PA and R Lal. 2005. "Labile Carbon and Methane Uptake as Affected by Tillage Intensity in a Mollisol." *Soil & Tillage Research* 80: 35–45.

Methane (CH_4) oxidation potential of soils decreases with cultivation, but limited information is available regarding the restoration of that capacity with implementation of reduced tillage practices. A study was conducted to assess the impact of tillage intensity on CH_4 oxidation and several C-cycling indices including total and active microbial biomass C (t-MBC, a-MBC), mineralizable C (Cmin) and N (Nmin), and aggregate-protected C. Intact cores and disturbed soil samples (0–5 and 5–15 cm) were collected from a corn (Zea mays L.)–soybean (Glycine max L. Merr.) rotation under moldboard-plow (MP), chisel-plow (CP) and no-till (NT) for 8 years. An adjacent pasture (<25 years) and secondary growth forest (>60 years) soils were also sampled as references. At all sites, soil was a Kokomo silty clay loam (mesic Typic Argiaquolls).

Significant tillage effects on t-MBC and protected C were found in the 0–5 cm depth. Protected C, a measure of C retained within macro-aggregates and defined as the difference in Cmin (CO_2 evolved in a 56 days incubation) between intact and sieved (<2 mm) soil samples, amounted to 516, 162 and 121 mg C kg−1 soil in the 0–5 cm layer of the forest, pasture and NT soils, respectively. Protected C was negligible in the CP and MP soils. Methane uptake rate (g CH_4 -C kg−1 soil per day, under ambient CH_4) was higher in forest (2.70) than in pasture (1.22) and cropland (0.61) soils. No significant tillage effect on CH_4 oxidation rate was detected (MP: 0.82; CP: 0.41; NT: 0.61). These results underscore the slow recovery of the CH4 uptake capacity of soils and suggest that, to have an impact, tillage reduction may need to be implemented for several decades.

Jain AK, TO West, X Yang, and WM Post. 2005. "Assessing the Impact of Changes in Climate and CO2 on Potential Carbon Sequestration in Agricultural Soils." *Geophysical Research Letters* 32(19): L19711.

Changes in soil management can potentially increase the accumulation of soil organic carbon (SOC), thereby sequestering CO_2 from the atmosphere. However, the amount of carbon sequestered in soils can be augmented or lessened due to changes in climate and atmospheric CO_2 concentration. The purpose of this paper is to study the influence of climate and CO_2 feedbacks on soil carbon sequestration using a terrestrial carbon cycle model. Model simulations consist of observed adoption rates of no-tillage practices on croplands in the U.S. and Canada between 1981-2000. Model results indicate potential sequestration rates between 0.4-0.6 MgC/ha/yr in the Midwestern U.S. with decreasing rates towards the western, dryer regions of the U.S. It is estimated here that changes in climate and CO_2 between 1981-2000 could be responsible for an additional soil carbon sequestration of 42 Tg. This is 5% of the soil carbon estimated to be potentially sequestered as the result of conversion to no-tillage in the U.S. and Canada.

Lal R, DC Reicosky, JD Hanson. 2007. "Evolution of the Plow over 10,000 Years and the Rationale for No-Till Farming." *Soil & Tillage Research* 93: 1–12.

Agriculture and the plow originated 10–13 millennia ago in the Fertile Crescent of the Near East, mostly along the Tigris, Euphrates, Nile, Indus and Yangtze River valleys, and were introduced into Greece and southeastern Europe 8000 years ago. The wooden plow, called an ard, evolved into the ''Roman plow,'' with an iron plowshare, described by Virgil around 1 AD and was used in Europe until the fifth century. It further evolved into a soil inverting plow during the 8th to 10th century. In the U.S., a moldboard plow was designed by Thomas Jefferson in 1784, patented by Charles Newfold in 1796, and marketed in the 1830s as a cast iron plow by a blacksmith named John Deere. Use of the plow expanded rapidly with the introduction of the ''steam horse'' in 1910 that led to widespread severe soil erosion and environmental degradation culminating in the Dust Bowl of the 1930s. A transition from moldboard plow to various forms of conservation tillage began with the development of 2, 4-D after World War II. No-till is presently practiced on about 95 million hectares globally. No-till technologies are very effective in minimizing soil and crop residue disturbance, controlling soil evaporation, minimizing erosion losses, sequestering C in soil and reducing energy needs. However, no-till is effective only with the use of crop residue as mulch, which has numerous competing uses. No-till farming can reduce yield in poorly drained, clayey soils when springtime is cold and wet. Soil-specific research is needed to enhance applicability of no-till farming by alleviating biophysical, economic, social and cultural constraints. There is a strong need to enhance sustainability of production systems while improving the environmental quality.

Forest Management

Bradford JB and DN Kastendick. 2010. "Age-Related Patterns of Forest Complexity and Carbon Storage in Pine and Aspen-Birch Ecosystems of Northern Minnesota, U.S.A." ***Canadian Journal of Forest Research/ Revue Canadienne de Recherche Forestiere*** **40(3): 401-09. DOI: 10.1139/x10-002.**

Forest managers are seeking strategies to create stands that can adapt to new climatic conditions and simultaneously help mitigate increases in atmospheric CO_2. Adaptation strategies often focus on enhancing resilience by maximizing forest complexity in terms of species composition and size structure, while mitigation involves sustaining carbon storage and sequestration. Altered stand age is a fundamental consequence of forest management and stand age is a powerful predictor of ecosystem structure and function in even-aged stands. However, the relationship between stand age and either complexity or carbon storage and sequestration, especially trade-offs between the two, are not well characterized. We quantified these relationships in clearcut-origin, unmanaged pine and aspen chronosequences ranging from <10 to >130 years in northern Minnesota. Complexity generally increased with age, although compositional complexity changed more over time in aspen forests and structural complexity changed more over time in pine stands. Although individual carbon pools displayed various relationships with stand age, total carbon storage increased with age, whereas carbon sequestration, inferred from changes in storage, decreased sharply with age. These results illustrate the carbon and complexity consequences of varying forest harvest rotation length to favor younger or older forests and provide insight into trade-offs between these potentially conflicting management objectives.

Papadopol CS. 2000. "Impacts of Climate Warming on Forests in Ontario: Options for Adaptation and Mitigation." ***Forestry Chronicle*** **76(1): 139-49.**

This paper summarizes current knowledge about the optical properties of greenhouse gases and general climate-warming influences. It explains the influence of this new phenomenon on the major ecosystems of the world, and considers the process of deforestation. It then analyzes the warming trends in Ontario based on data from two weather stations with continuous records of more than 120 years, to determine the rate of warming in the Great Lakes-St. Lawrence Region. The results indicate a temperature increase of about 0.76 degrees C per century and an 8% increase in annual total precipitation. Current climate change models indicate that for a scenario of 2 x CO_2 levels some general, probable prognoses can be made, including a temperature increase of up to 4.5 degrees C, which might be disastrous for existing forest ecosystems. Specifically, the consequences of climate warming on:

a. northward shifts of ecological conditions,
b. forest productivity, and
c. forest physiology and health, are examined.

In the context of global warming, the paper then recommends practical management measures necessary to ensure adaptation of existing forest ecosystems to the warming that is already developing. These measures are intended to provide a no-risk environment for existing forests until rotation age. Next, a wide range of mitigative measures is examined with a view to securing the long-term preservation of forest ecosystems to avoid major ecological disruptions and, gradually, to reverse climate warming. Application of these measures requires international consensus, but countries that apply these recommendations first have a chance to profit from them due to the "CO_2 fertilization" effect.

Rhemtulla JM, DJ Mladenoff, and MK Clayton. 2009. "Historical Forest Baselines Reveal Potential for Continued Carbon Sequestration." *Proceedings of the National Academy of Sciences of the United States of America* 106(15): 6082-6087.

One-third of net CO_2 emissions to the atmosphere since 1850 are the result of land-use change, primarily from the clearing of forests for timber and agriculture, but quantifying these changes is complicated by the lack of historical data on both former ecosystem conditions and the extent and spatial configuration of subsequent land use. Using fine-resolution historical survey records, we reconstruct pre-Euro-American settlement (1850s) forest carbon in the state of Wisconsin, examine changes in carbon after logging and agricultural conversion, and assess the potential for future sequestration through forest recovery. Results suggest that total above-ground live forest carbon (AGC) fell from 434 TgC before settlement to 120 TgC at the peak of agricultural clearing in the 1930s and has since recovered to approximately 276 TgC. The spatial distribution of AGC, however, has shifted significantly. Former savanna ecosystems in the south now store more AGC because of fire suppression and forest ingrowth, despite the fact that most of the region remains in agriculture, whereas northern forests still store much less carbon than before settlement. Across the state, continued sequestration in existing forests has the potential to contribute an additional 69 TgC. Reforestation of agricultural lands, in particular, the formerly high C-density forests in the north-central region that are now agricultural lands less optimal than those in the south, could contribute 150 TgC. Restoring historical carbon stocks across the landscape will therefore require reassessing overall land-use choices, but a range of options can be ranked and considered under changing needs for ecosystem services.

Appendix C

References for U.S. Midwest Adaptation Literature Review

Appendix C

References for U.S. Midwest Adaptation Literature Review

This document lists the abstracts[1] for the literature collected to date regarding climate change adaptation alternatives in the 14-state Midwest region of the U.S.—as defined for the iRESM initiative. This is meant to be a representative—not exhaustive—list of relevant peer-reviewed and grey literature focused on one or more of the Midwest states, primarily from the last 10 years. The literature is organized according to the relevant economic sector. Several studies addressed multiple sectors; they are listed at the end under "Multiple Sector Adaptation Studies." The counts of documents in each category are as follows:

- Agriculture (5)
- Ecosystems (3)
- Forest Management (2)
- Recreation (4)
- Transportation (1)
- Urban Infrastructure (7)
- Water Resources (11)
- Multiple Sector (11)

Agriculture

Cai X, D Wang, and R Laurent. 2009. "Impact of Climate Change on Crop Yield: A Case Study of Rainfed Corn in Central Illinois." ***Journal of Applied Meteorology and Climatology*** **48(9): 1868. Available at** http://journals.ametsoc.org/doi/abs/10.1175/2009JAMC1880.1.

This paper assesses the effect of climate change on crop yield from a soil water balance perspective. The uncertainties of regional-scale climate models, local-scale climate variability, emissions scenarios, and crop growth models are combined to explore the possible range of climate change effects on rainfed corn yield in central Illinois in 2055. The results show that a drier and warmer summer during the corn growth season and wetter and warmer precrop and postcrop seasons will likely occur. Greater temperature and precipitation variability may lead to more variable soil moisture and crop yield, and larger soil moisture deficit and crop yield reduction are likely to occur more frequently. The increased water stress is likely to be most pronounced during the flowering and yield formation stages. The expected rainfed corn yield in 2055 is likely to decline by 23%-34%, and the probability that the yield may not reach 50% of the potential yield ranges from 32% to 70% if no adaptation measures are instituted. Among the multiple uncertainty sources, the greenhouse gas emissions projection may have the strongest effect on the risk estimate of crop yield reduction. The effects from the various uncertainties can be offset to some degree when the uncertainties are considered jointly. An ensemble of GCMs with an equal weight may overestimate the risk of soil moisture deficits and crop yield reduction in comparison with an ensemble of GCMs with different weight determined by the root-mean-square error minimization

[1] Most of the article/paper descriptions are copied verbatim from the document abstract. Where abstracts were unavailable, a summary of the paper was drawn from the text and/or the researcher's knowledge of the paper.

method. The risk estimate presented in this paper implies that climate change adaptation is needed to avoid reduced corn yields and the resulting profit losses in central Illinois. [PUBLICATION ABSTRACT]

Read full article at http://findarticles.com/p/articles/mi_7594/is_200909/ai_n42040068/.

Kucharik CJ and SP Serbin. 2008. "Impacts of Recent Climate Change on Wisconsin Corn and Soybean Yield Trends." *Environmental Research Letters* 3(3): 034003. http://dx.doi.org/10.1088/1748-9326/3/3/034003.

The U.S. Corn Belt supports agroecosystems that flourish in a temperate climate regime that could see significant changes in the next few decades. Because Wisconsin is situated on the northern, cooler fringes of this region, it may be the beneficiary of a warmer climate that could help support higher corn and soybean yields. Here we show that trends in precipitation and temperature during the growing season from 1976-2006 explained 40% and 35% of county corn and soybean yield trends, respectively. Using county level yield information combined with climate data, we determined that both corn and soybean yield trends were enhanced in counties that experienced a trend towards cooler and wetter conditions during the summer. Our results suggest that for each additional degree (C) of future warming during summer months, corn and soybean yields could potentially decrease by 13% and 16%, respectively, whereas if modest increases in total summer precipitation (i.e. 50 mm) were to occur, yields may be boosted by 5-10%, counteracting a portion of the negative effects associated with increased temperature. While northern U.S. Corn Belt regions such as Wisconsin may benefit from a warmer climate regime and management changes that lengthen the crop-growing period in spring and autumn, mid- to high-latitude crop productivity may be challenged by additional summertime warming unless adaptive measures are taken.

McLeman R, D May, E Strebeck, and B Smit. 2008. "Drought Adaptation in Rural Eastern Oklahoma in the 1930s: Lessons for Climate Change Adaptation Research." *Mitigation and Adaptation Strategies for Global Change* 13(4): 379-400. DOI: 10.1007/s11027-007-9118-1. http://www.springerlink.com/content/52mv1v1241541125/fulltext.pdf.

In the mid-1930s, eastern Oklahoma, U.S.A., suffered an unusually harsh mixture of droughts and extreme rainfall events that led to widespread crop failure over several years. These climatic conditions coincided with low commodity prices, agricultural restructuring and general economic collapse, creating tremendous hardship in rural and agriculturally dependent areas. Using a previously developed typology of agricultural adaptation, this paper reports empirical research conducted to identify the ways by which the rural population of Sequoyah County adapted to such conditions. Particular attention is given to categorizing the scale at which adaptation occurred, the actors involved and the constraints to implementation. The findings identify successes and opportunities missed by public policy makers, and suggest possible entry points for developing adaptation strategies for current and future, analogous situations that may arise as a result of climate change.

Voldseth RA, WC Johnson, GR Guntenspergen, T Gilmanov, and BV Millett. 2009. "Adaptation of Farming Practices Could Buffer Effects of Climate Change on Northern Prairie Wetlands." *Wetlands* 29(2): 635-47.

Wetlands of the Prairie Pothole Region of North America are vulnerable to climate change. Adaptation of farming practices to mitigate adverse impacts of climate change on wetland water levels is a potential watershed management option. We chose a modeling approach (WETSIM 3.2) to examine the effects of changes in climate and watershed cover on the water levels of a semi-permanent wetland in eastern South Dakota. Land-use practices simulated were unmanaged grassland, grassland managed with moderately heavy grazing, and cultivated crops. Climate scenarios were developed by adjusting the historical climate in combinations of 2 degrees C and 4 degrees C air temperature and +/- 10% precipitation. For these climate change scenarios, simulations of land use that produced water levels equal to or greater than unmanaged grassland under historical climate were judged to have mitigative potential against a drier climate. Water levels in wetlands surrounded by managed grasslands were significantly greater than those surrounded by unmanaged grassland. Management reduced both the proportion of years the wetland went dry and the frequency of dry periods, producing the most dynamic vegetation cycle for this modeled wetland. Both cultivated crops and managed grassland achieved water levels that were equal or greater than unmanaged grassland under historical climate for the 2 degrees C rise in air temperature, and the 2 degrees C rise plus 10% increase in precipitation scenarios. Managed grassland also produced water levels that were equal or greater than unmanaged grassland under historical climate for the 4 degrees C rise plus 10% increase in precipitation scenario. Although these modeling results stand as hypotheses, they indicate that amelioration potential exists for a change in climate up to an increase of 2 degrees C or 4 degrees C with a concomitant 10% increase in precipitation. Few empirical data exist to verify the results of such land-use simulations; however, adaptation of farming practices is one possible mitigation avenue available for prairie wetlands.

Wolfe D, L Ziska, C Petzoldt, A Seaman, L Chase, and K Hayhoe. 2008. "Projected Change in Climate Thresholds in the Northeastern U.S.: Implications for Crops, Pests, Livestock, and Farmers." ***Mitigation and Adaptation Strategies for Global Change*** **13(5): 555-75. DOI:** http://dx.doi.org/10.1007/s11027-007-9125-2.

Most prior climate change assessments for U.S. agriculture have focused on major world food crops such as wheat and maize. While useful from a national and global perspective, these results are not particularly relevant to the Northeastern U.S. agriculture economy, which is dominated by dairy milk production, and high-value horticultural crops such as apples (Malus domestica), grapes (Vitis vinifera), sweet corn (Zea mays var. rugosa), cabbage (Brassica oleracea var. capitata), and maple syrup (sugar maple, Acer saccharum). We used statistically downscaled climate projections generated by the HadCM3 atmosphere–ocean general circulation model, run with Intergovernmental Panel on Climate Change future emissions scenarios A1fi (higher) and B1 (lower), to evaluate several climate thresholds of direct relevance to agriculture in the region. A longer (frost-free) growing season could create new opportunities for farmers with enough capital to take risks on new crops (assuming a market for new crops can be developed). However, our results indicate that many crops will have yield losses associated with increased frequency of high temperature stress, inadequate winter chill period for optimum fruiting in spring, increased pressure from marginally over-wintering and/or invasive weeds, insects, or disease, or other factors. Weeds are likely to benefit more than cash crops from increasing atmospheric carbon dioxide. Projections of thermal heat index values for dairy cows indicate a substantial potential negative impact on milk production. At the higher compared to lower emissions scenario, negative climate change effects will occur sooner, and impact a larger geographic area within the region. Farmer adaptations to climate change will not be cost- or risk-free, and the impact on individual farm families and rural communities will depend on commodity produced, available capital, and timely, accurate climate projections.

Ecosystems

Galatowitsch S, L Frelich, and L Phillips-Mao. 2009. "Regional Climate Change Adaptation Strategies for Biodiversity Conservation in a Midcontinental Region of North America." Biological Conservation 142(10): 2012-22. DOI: 10.1016/j.biocon.2009.03.030.

Scenario planning should be an effective tool for developing responses to climate change but will depend on ecological assessments of broad enough scope to support decision-making. Using climate projections from an ensemble of 16 models, we conducted an assessment of a midcontinental area of North America (Minnesota) based on a resistance, resilience, and facilitation framework. We assessed likely impacts and proposed options for eight landscape regions within the planning area. Climate change projections suggest that by 2069, average annual temperatures will increase 3 degrees C with a slight increase in precipitation (6%). Analogous climate locales currently prevail 400-500 km SSW. Although the effects of climate change may be resisted through intensive management of invasive species, herbivores, and disturbance regimes, conservation practices need to shift to facilitation and resilience. Key resilience actions include providing buffers for small reserves, expanding reserves that lack adequate environmental heterogeneity, prioritizing protection of likely climate refuges, and managing forests for multi-species and multi-aged stands. Modifying restoration practices to rely on seeding (not plants), enlarge seed zones, and include common species from nearby southerly or drier locales is a logical low-risk facilitation strategy. Monitoring "trailing edge" populations of rare species should be a high conservation priority to support decision-making related to assisted colonization. Ecological assessments that consider resistance, resilience, and facilitation actions during scenario planning is a productive first step towards effective climate change planning for biodiversity with broad applicability to many regions of the world.

Pyke CR, R Thomas, RD Porter, JJ Hellmann, JS Dukes, DM Lodge, and G Chavarria. 2008. "Current Practices and Future Opportunities for Policy on Climate Change and Invasive Species." ***Conservation Biology*** **22(3): 585-92. DOI: 10.1111/j.1523-1739.2008.00956.x**

Climate change and invasive species are often treated as important, but independent, issues. Nevertheless, they have strong connections: changes in climate and societal responses to climate change may exacerbate the impacts of invasive species, whereas invasive species may affect the magnitude, rate, and impact of climate change. We argue that the design and implementation of climate-change policy in the United States should specifically consider the implications for invasive species; conversely, invasive-species policy should address consequences for climate change. The development of such policies should be based on:

a. characterization of interactions between invasive species and climate change
b. identification of areas where climate-change policies could negatively affect invasive-species management
c. identification of areas where policies could benefit from synergies between climate change and invasive-species management.

Zedler JB. 2004. "Compensating for Wetland Losses in the United States." ***Ibis*** **146(s1): 92-100.**

Impacts of climate change on U.S. wetlands will add to those of historical impacts due to other causes. In the U.S., wetland losses and degradation result from drainage for agriculture, filling for urbanization and road construction. States that rely heavily on agriculture (California, Iowa, Illinois, Missouri, Ohio, Indiana) have lost over 80% of their historical area of wetlands, and large cities, such as Los Angeles and New York City, have retained only tiny remnants of wetlands, all of which are highly disturbed. The cumulative effects of historical and future degradation will be difficult to abate. A recent review of mitigation efforts in the U.S. shows a net loss of wetland area and function, even though 'no net loss' is the national policy and compensatory measures are mandatory. U.S. policy does not include mitigation of losses due to climate change. Extrapolating from the regulatory experience, one can expect additional losses in wetland areas and in highly valued functions. Coastal wetlands will be hardest hit due to sea-level rise. As wetlands are increasingly inundated, both quantity and quality will decline. Recognition of historical, current and future losses of wetland invokes the precautionary principal: avoid all deliberate loss of coastal wetland area in order to reduce overall net loss. Failing that, our ability to restore and sustain wetlands must be improved substantially.

Forest Management

Bradford JB, and DN Kastendick. 2010. "Age-Related Patterns of Forest Complexity and Carbon Storage in Pine and Aspen-Birch Ecosystems of Northern Minnesota, U.S.A." ***Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere*** **40(3): 401-09. DOI: 10.1139/x10-002.**

Forest managers are seeking strategies to create stands that can adapt to new climatic conditions and simultaneously help mitigate increases in atmospheric CO_2. Adaptation strategies often focus on enhancing resilience by maximizing forest complexity in terms of species composition and size structure, while mitigation involves sustaining carbon storage and sequestration. Altered stand age is a fundamental consequence of forest management, and stand age is a powerful predictor of ecosystem structure and function in even-aged stands. However, the relationship between stand age and either complexity or carbon storage and sequestration, especially trade-offs between the two, are not well characterized. We quantified these relationships in clearcut-origin, unmanaged pine and aspen chronosequences ranging from <10 to >130 years in northern Minnesota. Complexity generally increased with age, although compositional complexity changed more over time in aspen forests and structural complexity changed more over time in pine stands. Although individual carbon pools displayed various relationships with stand age, total carbon storage increased with age, whereas carbon sequestration, inferred from changes in storage, decreased sharply with age. These results illustrate the carbon and complexity consequences of varying forest harvest rotation length to favor younger or older forests and provide insight into trade-offs between these potentially conflicting management objectives.

Papadopol CS. 2000. "Impacts of Climate Warming on Forests in Ontario: Options for Adaptation and Mitigation." ***Forestry Chronicle*** **76(1): 139-49.**

Abstract only

This paper summarizes current knowledge about the optical properties of greenhouse gases and general climate-warming influences. It explains the influence of this new phenomenon on the major ecosystems of the world, and considers the process of deforestation. It then analyzes the warming trends in Ontario based on data from two weather stations with continuous records of more than 120 years, to determine the rate of warming in the Great Lakes-St. Lawrence Region. The results indicate a temperature increase of about 0.76 degrees C per century and an 8% increase in annual total precipitation. Current climate change models indicate that for a scenario of 2 x CO_2 levels some general, probable prognoses can be made, including a temperature increase of up to 4.5 degrees C, which might be disastrous for existing forest ecosystems. Specifically, the consequences of climate warming on:

a. northward shifts of ecological conditions,
b. forest productivity, and
c. forest physiology and health, are examined.

In the context of global warming, the paper then recommends practical management measures necessary to ensure adaptation of existing forest ecosystems to the warming that is already developing. These measures are intended to provide a no-risk environment for existing forests until rotation age. Next, a wide range of mitigative measures is examined with a view to securing the long-term preservation of forest ecosystems to avoid major ecological disruptions and, gradually, to reverse climate warming. Application of these measures requires international consensus, but countries that apply these recommendations first have a chance to profit from them due to the "CO_2 fertilization" effect.

Recreation

Scott D, J Dawson, and B Jones. 2008. "Climate Change Vulnerability of the U.S. Northeast Winter Recreation–Tourism Sector." ***Mitigation and Adaptation Strategies for Global Change*** **13(5): 577-96. DOI: 10.1007/s11027-007-9136-z** http://dx.doi.org/10.1007/s11027-007-9136-z.

Abstract

Winter recreation is an important part of the cultural identity of the Northeast United States and is a multibillion dollar contributor to the regional economy. This study examined the vulnerability of the two largest winter recreation industries, snowmobiling and alpine skiing, to four climate change scenarios for the twenty-first century. Under all scenarios, natural snow became an increasingly scarce resource. The diminished natural snow pack had a very negative impact on the snowmobile industry. As early as 2010–2039, 4 to 6 of the 15 snowmobile study areas were projected to lose more than half of the current season. Reliable snowmobile seasons (>50 days) were virtually eliminated in the region under the A1Fi scenarios by 2070–2099. The large investment in snowmaking substantially reduced the vulnerability of the ski industry and climate change posed a risk to only 4 of the 14 ski areas in 2010–2039, where average ski seasons declined below 100 days and the probability of being open for the entire Christmas–New Year's holiday declined below 75%. Conversely, by 2070–2099 only four ski study areas had not reached these same economic risk criteria. In order to minimize ski season losses, snowmaking requirements are projected to increase substantially, raising important uncertainties about water availability and cost. Climate change represents a notable threat to the winter recreation sector in the Northeast, and the potential economic ramifications for businesses and communities heavily invested in winter tourism and related real estate is sizeable.

Scott D and B Jones. 2007. "A Regional Comparison of the Implications of Climate Change for the Golf Industry in Canada." ***Canadian Geographer*** **51(2): 219.**

Abstract Only

Golf is a recreation industry particularly sensitive to climate, yet the potential implications of climate change for the industry remain largely unexamined. This study presents findings of the first known impact assessment to compare the regional impacts of projected changes in the climate on the golf industry in Canada (or internationally). Empirical relationships between daily rounds played and four weather variables were defined through multiple regression analysis and then used to examine the potential impacts of two climate change scenarios on the length of the golf season and the number of rounds played in three regions of Canada (West Coast, Great Lakes, East Coast). Regionally, the West Coast region was projected to benefit the least from projected climate change, as golf courses that are currently open year round experienced only slight projected increases in rounds played in the 2020s and 2050s. Golf courses in the Great Lakes region could experience a 10- to 51-day longer average golf season and a 21 percent to 3 percent increase in rounds as early as the 2020s, and an even more pronounced increase in the 2050s. East Coast golf courses were projected to benefit the most under both climate change scenarios, experiencing larger gains in average operating seasons (25 to 45 days in the 2020s) and a 40 percent to 48 percent increase in rounds played by as early as the 2020s. [PUBLICATION ABSTRACT]

Scott D, G McBoyle, and B Mills. 2003. "Climate Change and the Skiing Industry in Southern Ontario (Canada): Exploring the Importance of Snowmaking as a Technical Adaptation." ***Climate Research*** **23(2): 171-81.**

The winter tourism industry has been repeatedly identified as potentially vulnerable to global climate change. Climate change impact assessments of ski areas in Australia, Europe and North America all project negative consequences for the industry. An important limitation of earlier studies has been the incomplete consideration of snowmaking as a climate adaptation strategy. Recognising that snowmaking is an integral component of the ski industry, this study examined how current and improved snowmaking capacity affects the vulnerability of the ski industry in southern Ontario (Canada) to climate variability and change. A 17 yr record of daily snow conditions and operations from a primary ski area in the region was used to calibrate a ski season simulation model that included a snowmaking module with climatic thresholds and operational decision rules based on interviews with ski area managers. Climate change scenarios (2020s, 2050s, 2080s) were developed by downscaling climate variables from 4 general circulation models (using both IS92a and SIZES emission scenarios) with the LARS weather generator (parameterized to local climate stations) for input into a daily snow depth simulation model. In contrast to earlier studies, the results indicate that ski areas in the region could remain operational in a warmer climate, particularly within existing business planning and investment time horizons (into the 2020s). The economic impact of additional snowmaking requirements remains an important uncertainty. Under climate change scenarios and current snowmaking technology, the average ski season at the case study ski area was projected to reduce by 0-16 % in the 2020s, 7-32 % in the 2050s and 11-50 % in the 2080s. Concurrent with the projected ski season losses, the estimated amount of snowmaking required increased by 36-144 % in the scenarios for the 2020s. Required snowmaking amounts increased by 48-187 % in the scenarios for the 2020s. The ability of individual ski areas to absorb additional snowmaking costs and remain economically viable in addition to the relative impact of climate change on other nearby ski regions (Quebec, Michigan and Vermont) remain important avenues of further research. The findings reveal the importance of examining a wide range of climate change scenarios and the necessity of including snowmaking and other adaptation strategies in future climate change vulnerability assessments of the ski industry and winter tourism in other regions of the world.

Wall G. 2005. "The Tourism Industry: Its Vulnerability and Adaptability to Climate Change." In *Climate Change and Ontario's Parks,* pp. 39-47.

In the consideration of climate change and tourism, it is suggested that more emphasis be placed on risk assessment. The vulnerability of tourism to climate change is discussed briefly and the difficulty of generalizing across a multitude of locations and activities is stressed. Mitigation and adaptation are discussed and the need for both is acknowledged Case studies of skiing and marinas and recreational boating from the Great Lakes region of North America are presented and a variety of research needs and opportunities is suggested.

Transportation

Millerd F. 2006. "Possible Locations for Adaptation to Climate Change by Canadian Commercial Navigation on the Great Lakes." In *2006 IEEE EIC Climate Change Conference*, pp. 1-10. IEEE, Piscataway, New Jersey.

Climate change is expected to bring about lower water levels and reduced depths in the Great Lakes, with consequent reductions in vessel cargo capacities and increases in shipping costs. Under the most severe conditions annual transportation costs for Great Lakes — St. Lawrence River commercial navigation could increase by 29 percent; more moderate climate change could result in a 13 percent increase, based on current prices. The impacts vary between commodities and routes. Cost increases of this magnitude suggest that adaptation measures may be worthwhile. The most obvious form of adaptation, and likely the least expensive, is deepening or increasing water depths at harbors and other shallow water points. Depth improvements should be carried out where benefits are highest. A small number of ports and shallow water points are responsible for most of the cost increases. A method of determining the most beneficial depth improvements is proposed.

Urban Infrastructure

Carbon Disclosure Project. 2009. "CDP Cities Pilot Project 2008."

The CDP U.S. Cities Pilot Project was launched by the Carbon Disclosure Project (CDP) and ICLEI – Local Governments for Sustainability in 2008 to encourage cities to voluntarily report their greenhouse gas emissions and disclose other information related to climate change. Local governments own and operate a considerable portfolio of buildings, fleets, and other infrastructure and through their progressive actions to reduce emissions have a great potential to lead by example. CDP's standardized and proven process has enabled the 18 participating cities to publicly disclose information in a form recognized around the world, providing a snapshot of engagement in the issues. The 18 participating cities were Annapolis, MD; Arlington, VA; Atlanta, GA; Burlington, VT; Chicago, IL; Denver, CO; Edina, MN; Fairfield, IA; Haverford, PA; Las Vegas, NV; New Orleans, LA; New York, NY; North Little Rock, AR; Park City, UT; Portland, OR; Rohnert Park, CA; Washougal, WA; and West Palm Beach, FL.

City of New York. 2008. "Assessment and Action Plan, Report 1." New York City Department of Environmental Protection Climate Change Program.

The action plan includes four tasks:

1. Work with climate scientists to improve regional climate change projections
2. Enhance DEP's understanding of the potential impacts of climate change on the department's operations
3. Determine and implement appropriate adaptations to DEP's water systems
4. Inventory and manage greenhouse gas emissions.

Coffee JE, J Parzen, M Wagstaff, and RS Lewis. 2010. "Preparing for a Changing Climate: The Chicago Climate Action Plan's Adaptation Strategy." ***Journal of Great Lakes Research.*** **In Press, Corrected Proof. DOI: 10.1016/j.jglr.2009.11.011.**
http://www.sciencedirect.com/science/article/B984D4Y7KWKM1/2/358492e8798dbdc9bec9367cf48bef9f.

The Chicago Climate Action Plan (CCAP), Chicago's roadmap for reducing climate change impacts and adapting to the changes already occurring, relied on rigorous analysis to formulate policy decisions through stakeholder coordination and public engagement. Three key pieces of analysis contributed to Chicago's adaptation strategy: an evaluation of Chicago's higher and lower greenhouse gas emissions scenarios; an assessment of Chicago's economic risk under both emissions scenarios; and a prioritization of potential impacts using a scoring system that included likelihood of occurrence and local consequences of occurrence. Potential adaptation tactics were categorized according to their expected benefits and costs and led to the creation of working groups to develop action plans that will include primary actors, timelines, budgets, and performance measures that the City will monitor. While not essential for all cities, the impacts analysis was of high value to the adaptation strategy. However, a strategy for stakeholder engagement is crucial in ensuring that the implications of climate impacts are properly understood.

Corburn J. 2009. "Cities, Climate Change and Urban Heat Island Mitigation: Localising Global Environmental Science." ***Urban Studies*** **46(2): 413.**

Abstract Only—have emailed author for PDF

This paper explores how city planners engaged with global climate scientists to devise contextually relevant strategies to address the urban heat island effect - a potentially dangerous heat event expected to increase along with global warming. Drawing original data from the New York City Regional Heat Island Initiative, a collaborative effort between scientists and urban planners, the paper highlights how global climate science is 'localised' as researchers and policy-makers struggle to make technically legitimate and politically accountable decisions. The paper argues that the localisation of global science often involves a process of co-production, where technical issues are not divorced from their social setting and a diverse set of stakeholders engage in analytical reviews and the crafting of policy solutions. The paper argues that the co-production framework can contribute to more scientifically legitimate and publicly accountable decision-making related to urban climate change. [PUBLICATION ABSTRACT]

Ebi KL, GA Meehl, D Bachelet, JM Lenihan, RP Neilson, RR Twilley, DF Boesch, VJ Coles, DG Kimmel, and WD Miller. 2007. Regional Impacts of Climate Change: Four Case Studies in the United States, Pew Center on Global Climate Change, Arlington, Virginia.
http://media.eurekalert.org/aaasnewsroom/2008/FIL_000000000300/PewRegional%20Impacts_wetlands.pdf**.**

Each case study focuses on a specific type of impact that is of particular concern for a region, but is not unique to that region. Each study also considers non-climatic factors, such as development and management practices, that are likely to interact with climate change. Consequently, cross-cutting themes emerge that are relevant to a wide array of regional and local climate change impacts beyond those examined here.

Environmental Protection Agency. 2008. Screening Assessment of the Potential Impacts of Climate Change on Combined Sewer Overflow (CSO) Mitigation in the Great Lakes and New England Regions. EPA/600/R-07/033F, Environmental Protection Agency, Washington, DC.

The U.S. Environmental Protection Agency's Global Change Research Program (GCRP) is an assessment-oriented program within the Office of Research and Development that focuses on assessing how potential changes in climate and other global environmental stressors may impact water quality, air quality, aquatic ecosystems, and human health in the United States. The Program's focus on water quality is consistent with the Research Strategy of the U.S. Climate Change Research Program—the federal umbrella organization for climate change science in the U.S. government and is responsive to U.S. EPA's mission and responsibilities as defined by the Clean Water Act and the Safe Drinking Water Act. The GCRP's water quality assessments also address an important research gap. In the 2001 National Assessment of the Potential Consequences of Climate Change in the United States (Gleick, 2000), water quality was addressed only in the context of the health risks associated with contaminated drinking water. A comprehensive assessment of the potential impacts of global change on water quality was not included. This report is a screening-level assessment of the potential implications of future climate change on combined sewer overflows (CSOs) in the New England and the Great Lakes Regions.

Knowlton KD, BP Lynn, RM Goldberg, CP Rosenzweig, CP Hogrefe, JMM Rosenthal, and PS Kinney. 2007. "Projecting Heat-Related Mortality Impacts under a Changing Climate in the New York City Region." ***American Journal of Public Health*** **97(11): 2028.**

We sought to project future impacts of climate change on summer heat-related premature deaths in the New York City metropolitan region. Current and future climates were simulated over the northeastern United States with a global-to-regional climate modeling system. Summer heat-related premature deaths in the 1990s and 2050s were estimated by using a range of scenarios and approaches to modeling acclimatization (e.g., increased use of air conditioning, gradual physiological adaptation). Projected regional increases in heat-related premature mortality by the 2050s ranged from 47% to 95%, with a mean 70% increase compared with the 1990s. Acclimatization effects reduced regional increases in summer heat-related premature mortality by about 25%. Local impacts varied considerably across the region, with urban counties showing greater numbers of deaths and smaller percentage increases than less-urbanized counties. Although considerable uncertainty exists in climate forecasts and future health vulnerability, the range of projections we developed suggests that by midcentury, acclimatization may not completely mitigate the effects of climate change in the New York City metropolitan region, which would result in an overall net increase in heat-related premature mortality.

OBJECTIVES: We sought to project future impacts of climate change on summer heat-related premature deaths in the New York City metropolitan region.

METHODS: Current and future climates were simulated over the northeastern United States with a global-to-regional climate modeling system. Summer heat-related premature deaths in the 1990s and

2050s were estimated by using a range of scenarios and approaches to modeling acclimatization (e.g., increased use of air conditioning, gradual physiological adaptation).

RESULTS: Projected regional increases in heat-related premature mortality by the 2050s ranged from 47% to 95%, with a mean 70% increase compared with the 1990s. Acclimatization effects reduced regional increases in summer heat-related premature mortality by about 25%. Local impacts varied considerably across the region, with urban counties showing greater numbers of deaths and smaller percentage increases than less-urbanized counties.

CONCLUSIONS: Although considerable uncertainty exists in climate forecasts and future health vulnerability, the range of projections we developed suggests that by midcentury, acclimatization may not completely mitigate the effects of climate change in the New York City metropolitan region, which would result in an overall net increase in heat-related premature mortality.

Water Resources

Crabbe P and M Robin. 2006. "Institutional Adaptation of Water Resource Infrastructures to Climate Change in Eastern Ontario." *Climate Change* 78(1): 103-33. DOI: 10.1007/s10584-006-9087-5. http://www.springerlink.com/content/p8l3106434t23jk3/fulltext.pdf.

Institutional barriers and bridges to local climate change impacts adaptation affecting small rural municipalities and Conservation Authorities (CAs are watershed agencies) in Eastern Ontario (Canada) are examined, and elements of a community-based adaptation strategy related to water infrastructures are proposed as a case-study in community adaptation to climate change. No general water scarcity is expected for the region even under unusually dry weather scenarios. Localized quantity and quality problems are likely to occur especially in groundwater recharge areas. Some existing institutions can be relied on by municipalities to build an effective adaptation strategy based on a watershed/region perspective, on their credibility, and on their expertise. Windows of opportunity or framing issues are offered at the provincial level, the most relevant one in a federal state, by municipal emergency plan requirements and pending watershed source water protection legislation. Voluntary and soon to be mandated climate change mitigation programs at the federal level are other ones.

de Loe R, R Kreutzwiser, and L Moraru. 2001. "Adaptation Options for the near Term: Climate Change and the Canadian Water Sector." *Global Environmental Change-Human and Policy Dimensions* 11(3): 231-45.

Climate change poses significant challenges for the Canadian water sector. This paper discusses issues relating to the selection of proactive, planned adaptation measures for the near term (next decade). A set of selection criteria is offered, and these are used in three cases to illustrate how stakeholders can identify measures appropriate for the near term. Cases include municipal water supply in the Grand River basin, Ontario; irrigation in southern Alberta and commercial navigation on the Great Lakes. In all three cases, it is possible to identify adaptations to climate change that also represent appropriate responses to existing conditions; these should be pursued first.

de Loe, R, R Kreutzwiser, and L Moraru. 2000. “Climate Variability, Climate Change and Water Resource Management in the Great Lakes.” *Climate Change* 45: 163-179.

This paper examines the question of adaptation to climate change in the context of Canadian water resources management, emphasizing issues in the context of the Great Lakes, an important binational water resource.

Hobbs BF, PT Chao, and BN Venkatesh. 1997. "Using Decision Analysis to Include Climate Change in Water Resources Decision Making." ***Climatic Change*** **37: 177-202.**

The authors analyze two investments in the Great Lakes region and find that, while the consequences of climate change uncertainty are important for the decisions, the risks are not qualitatively different from other risks addressed under U.S. federal guidelines for water management and so the current planning methods of sensitivity analysis, scenario planning, and decision analysis are applicable and should be used.

Ivey JL, J Smithers, RC De Loe, and RD Kreutzwiser. 2004. "Community Capacity for Adaptation to Climate-Induced Water Shortages: Linking Institutional Complexity and Local Actors." ***Environmental Management*** **33(1): 36-47. DOI: 10.1007/s00267-003-0014-5.**

There is growing concern for the capacity of urban and rural communities to manage current water shortages and to prepare for shortages that may accompany predicted changes in climate. In this paper, concepts relating to the notion of climate adaptation and particularly "capacity building" are used to elucidate several determinants of community-level capacity for water management. These concepts and criteria are then used to interpret empirically derived insights relating to local management of water shortages in Ontario, Canada. General determinants of water-related community capacity relate to upper tier political and institutional arrangements; the characteristics of, and relationships among, pertinent agencies, groups, or individuals involved in water management; and the adequacy of financial, human, information, and technical resources. The case analysis illustrates how general factors play out in local experience. The findings point to geographically specific factors that influence the effectiveness of management. Key factors include collaboration between water managers, clarification of agency roles and responsibilities, integration of water management and land-use planning, and recognition and participation of both urban and rural stakeholders, whose sensitivities to water shortages are spatially and temporally variable.

Palmer, MA, DP Lettenmaier, NL Poff, SL Postel, B Richter, and R Warner. 2009. "Climate Change and River Ecosystems: Protection and Adaptation Options." ***Environmental Management*** **44(6): 1053-68. DOI: 10.1007/s00267-009-9329-1.**
http://www.springerlink.com/content/w127102unh15p153/fulltext.pdf.

Rivers provide a special suite of goods and services valued highly by the public that are inextricably linked to their flow dynamics and the interaction of flow with the landscape. Yet most rivers are within watersheds that are stressed to some extent by human activities including development, dams, or extractive uses. Climate change will add to and magnify risks that are already present through its potential to alter rainfall, temperature, runoff patterns, and to disrupt biological communities and sever ecological linkages. We provide an overview of the predicted impacts based on published studies to date, discuss both reactive and proactive management responses, and outline six categories of management actions that will contribute substantially to the protection of valuable river assets. To be effective, management must be place-based focusing on local watershed scales that are most relevant to management scales. The first priority should be enhancing environmental monitoring of changes and river responses coupled with the development of local scenario-building exercises that take land use and water use into account. Protection of a greater number of rivers and riparian corridors is essential, as is conjunctive groundwater/surface water management. This will require collaborations among multiple partners in the respective river basins and wise land use planning to minimize additional development in watersheds with valued rivers. Ensuring environmental flows by purchasing or leasing water rights and/or altering reservoir release patterns will be needed for many rivers. Implementing restoration projects proactively can be used to protect existing resources so that expensive reactive restoration to repair damage associated with a changing climate is minimized. Special attention should be given to diversifying and replicating habitats of special importance and to monitoring populations at high risk or of special value so that management interventions can occur if the risks to habitats or species increase significantly over time.

Patz JA, SJ Vavrus, CK Uejio, and SL McLellan. 2008. "Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S." ***American Journal of Preventive Medicine*** **35(5): 451-58. DOI: 10.1016/j.amepre.2008.08.026** http://www.sciencedirect.com/science/article/B6VHT-4TMSJS2-B/2/6cbffbdbede3e07b932d3daa5ea81668

Abstract

Extremes of the hydrologic cycle will accompany global warming, causing precipitation intensity to increase, particularly in middle and high latitudes. During the twentieth century, the frequency of major storms has already increased, and the total precipitation increase over this time period has primarily come from the greater number of heavy events. The Great Lakes region is projected to experience a rise these extreme precipitation events. For southern Wisconsin, the precipitation rate of the 10 wettest days was simulated using a suite of seven global climate models from the UN Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. For each ranking, the precipitation rate of these very heavy events increases in the future. Overall, the models project that extreme precipitation events will become 10% to 40% stronger in southern Wisconsin, resulting in greater potential for flooding, and for the waterborne diseases that often accompany high discharge into Lake Michigan. Using 6.4 cm (2.5 in) of daily precipitation as the threshold for initiating combined sewer overflow into Lake Michigan, the frequency of these events is expected to rise by 50% to 120% by the end of this century. The combination of future thermal and hydrologic changes may affect the usability of recreational beaches. Chicago beach closures are dependent on the magnitude of recent precipitation (within the past 24 hours), lake temperature, and lake stage. Projected increases in heavy rainfall, warmer lake waters, and lowered lake levels would all be expected to contribute to beach contamination in the future. The Great Lakes serve as a drinking water source for more than 40 million people. Ongoing studies and past events illustrate a strong connection between rain events and the amount of pollutants entering the Great Lakes. Extreme precipitation under global warming projections may overwhelm the combined sewer systems and lead to overflow events that can threaten both human health and recreation in the region.

Ravin AL, GN McCurry, and CS Hibbard. 2007. "Climate Change Adaptation Planning for Water Resources and Wastewater Management." In ***Proceedings of the Water Environment Federation (WEFTEC 2007),*** **2666-71. Water Environment Federation, Alexandria, Virginia. DOI: 10.2175/193864707787960413,** http://dx.doi.org/10.2175/193864707787960413.

Climate change poses multiple challenges to water resources and wastewater management. Changes in the frequency and intensity of extreme weather and even the regular precipitation patterns, as well as sea level rise, are serious issues for water resources, stormwater infrastructure, floodplain development, and wastewater management. Changing weather patterns will impact the way local governments manage water resources, land use, flood control, agriculture, fisheries, disaster planning, and many other issues of economic importance. This paper explores the science available for more proactive resources and infrastructure management, and provides some real-world solutions to these challenges through case studies in climate adaptation planning for water and wastewater management. Three important learning objectives are addressed in this paper: understand the range and significance of challenges to water resources, wastewater management, and infrastructure posed by climate change; become familiar with sources of relevant scientific data to support decision making, planning, and policy development; and learn from examples implemented by local governments how to address these challenges.

Rosenzweig C, DC Major, K Demong, C Stanton, R Horton, and M Stults. 2007. "Managing Climate Change Risks in New York City's Water System: Assessment and Adaptation Planning." Mitigation and Adaptation Strategies for Global Change 12(8): 1391-409. DOI: 10.1007/s11027-006-9070-5. http://www.springerlink.com/content/u1k8435q45q47615/fulltext.pdf.

Managing risk by adapting long-lived infrastructure to the effects of climate change must become a regular part of planning for water supply, sewer, wastewater treatment, and other urban infrastructure during this century. The New York City Department of Environmental Protection (NYCDEP), the agency responsible for managing New York City's (NYC) water supply, sewer, and wastewater treatment systems, has developed a climate risk management framework through its Climate Change Task Force, a government-university collaborative effort. Its purpose is to ensure that NYCDEP's strategic and capital planning take into account the potential risks of climate change—sea-level rise, higher temperature, increases in extreme events, changes in drought and flood frequency and intensity, and changing precipitation patterns—on NYC's water systems. This approach will enable NYCDEP and other agencies to incorporate adaptations to the risks of climate change into their management, investment, and policy decisions over the long term as a regular part of their planning activities. The framework includes a 9-step Adaptation Assessment procedure. Potential climate change adaptations are divided into management, infrastructure, and policy categories, and are assessed by their relevance in terms of climate change time-frame (immediate, medium, and long term), the capital cycle, costs, and other risks. The approach focuses on the water supply, sewer, and wastewater treatment systems of NYC, but has wide application for other urban areas, especially those in coastal locations.

Scheraga JD. 2008. "Opportunities to Anticipate and Adapt to the Effects of Climate Change on Water Quality." In *Coping with Climate Change: National Summit Proceedings,* 62-74. Ann Arbor, Michigan. University of Michigan, School of Natural Resources and Environment, Ann Arbor, MI http://scheraga.com/1G_Scheraga_WaterQuality.pdf**.**

Climate change is affecting the global water cycle. As the earth warms, the hydrologic cycle is intensifying, leading to changes in the amount, timing, and distribution of precipitation. Also, it is leading to more extremes, such as intense storms and droughts. Combined with the direct effects of temperature on evapotranspiration and sea level rise, the availability and quality of water will be affected.

University of Missouri-Columbia. 2004. *"Influence of Missouri River on Power Plants and Commodity Crop Prices."* Food and Agricultural Policy Research Institute.

An evaluation of 100 years of daily inflow data from the Missouri River tributaries suggests that when summer releases from Gavins Point fall below minimum navigation levels of 28-30,000 cubic feet per second, some power plants experience losses in efficiency. During periods of low inflows from Missouri River tributaries, a relatively low sustained summer release of 21,000 cubic feet per second at Gavins Point will cause electric power losses that would have to be made up by purchasing from the grid or from peaking units at a significantly higher cost. Ultimately, these higher costs will be passed on to consumer in the form of higher utility bills. Changes in local prices due to changes in Missouri River navigation, impact all production in the region, not just that which is transported via the river. Approximately 540 million bushels of corn, 160 million bushels of soybeans, 14 million bushels of sorghum and 12 million bushels of wheat produced within the economic reach of the Missouri River can be impacted by barge transportation in the Missouri river. Seasonality analysis suggests that prices along the Missouri River are closer to the St Louis price at times when the river is open.

Multi-Sector Adaptation Studies

Center for Integrative Environmental Research (CIER). 2007. "The U.S. Economic Impacts of Climate Change and the Costs of Inaction." University of Maryland, College Park, Maryland.

Looks at economic impacts for separate regions of the U.S.

This report presents a review of economic studies for the United States and relates them to predicted impacts of climate change. The summary findings are organized by region and identify the key sectors likely to be affected by climate change, the main impacts to be expected, as well as estimates of costs. Five key lessons emerge from the review and quantification:

1. Economic impacts of climate change will occur throughout the country
2. Economic impacts will be unevenly distributed across regions and within the economy and society
3. Negative climate impacts will outweigh benefits for most sectors that provide essential goods and services to society
4. Climate change impacts will place immense strains on public sector budgets
5. Secondary effects of climate impacts can include higher prices, reduced income and job loss.

The Great Plains and Midwest will suffer particularly from increased frequency and severity of flooding and drought events, causing billions of dollars in damages to crop and property. For example, the North Dakota Red River floods in 1997 caused $1 billion in agricultural production losses, and the Midwest floods of 1993 inflicted $6-8 billion in damages to farmers alone.

Easterling DR and TR Karl. "Potential Consequences of Climate Variability and Change for the Midwestern United States." ***U.S. National Assessment*****, Chapter 6.**

Key Findings

- A reduction in lake and river levels is likely to occur as higher temperatures drive increased evaporation,with implications for transportation, power generation,and water supply.
- Agriculture as a whole in this region is likely to be able to adapt and increase yields with the help of biotechnology and other developments.

- For both humans and other animals,a reduction in extremely low temperatures is likely to reduce cold-weather stress and mortality due to exposure to extreme cold,while an increase in extremely high temperatures is likely to decrease comfort and increase the likelihood of heat stress and mortality in summer.
- Preventative measures such as adequate storm- water discharge capacity and water treatment could help offset the likely increased incidence of water-borne diseases due to an increase in heavy precipitation events. As temperatures increase there is also a chance of more pest- borne diseases, such as St.Louis encephalitis.
- Changes in seasonal recreational opportunities are likely, with an expansion of warm weather activities during spring and fall, and a reduction during summer due to excessively hot days. Cold weather activities are likely to decline as warmer weather encroaches on the winter season.
- Boreal forest acreage is likely to be reduced under projected changes in climate. There is also a chance that the remaining forestlands would be more susceptible to pests,diseases,and forest fires.
- Major changes in freshwater ecosystems are likely, such as a shift in fish composition from cold water species, such as trout, to warm water species, such as bass and catfish.
- Higher water temperatures are likely to create an environment more susceptible to invasions by non-native species.
- The current extent of wetlands is likely to decrease due to declining lake levels.
- Changes in bird populations and other native wildlife have already been linked to increases in temperature and more changes are likely in the future
- Eutrophication of lakes is likely to increase as runoff of excess nutrients due to heavy precipitation events increases and warmer lake temperatures stimulate algae growth.

Environmental Adaptation Research Group (EARG). 1998. *Adapting to Climate Change and Variability in the Great Lakes-St. Lawrence Basin--Proceedings of a Binational Symposium*, Toronto, Ontario May 13-15, 1997.

The Great Lakes-St. Lawrence Basin (GLSLB) Project was launched in 1992 as a joint American-Canadian effort to improve our understanding of the complex interactions between climate and society, so that informed regional adaptation strategies could be developed in response to potential climate change and variability. To date (1998), approximately thirty component research projects form part of the broader regional Project. This report documents the results of a symposium involving 150 stakeholders from industry, research and government departments and non-governmental organizations.

Green Building Alliance. 2008. *Pittsburgh Climate Action Plan*. Pittsburgh Climate Initiative, Pittsburgh, Pennsylvania.

Report addresses both mitigation and adaptation measures in the following sectors: municipal, community, business, and higher education and in the following categories: general, energy, recycling and waste management, transportation, green building practices, and student engagement and education.

Krumenaker B. *Adapting to Climate Change in the Great Lakes*. Presentation, National Park Service, Apostle Islands National Lakeshore, Bayfield, Wisconsin.

Examples of current climate change impacts in the region, review of projected future impacts from a range of recent studies, discussion of need for adaptation with three examples: recreational infrastructure, commercial shipping, ephemeral wetlands.

Lemman DS and FJ Warren, eds. 2004. *Climate Change Impacts and Adaptation: A Canadian Perspective.* Climate Change Impacts and Adaptation Directorate, Natural Resources Canada. Available at http://adaptation.nrcan.gc.ca/perspective/index_e.php.

This report examines seven sectors in detail addressing potential impacts and potential adaptive responses. The sectors are: water resources, agriculture, forestry, fisheries, coastal zone, transportation, and human health and well-being. It emphasizes the importance of understanding vulnerabilities and that effective adaptation strategies should consider current and future vulnerabilities.

Moser S, R Kasperson, G Yohe, and J Agyeman. 2008. "Adaptation to Climate Change in the Northeast United States: Opportunities, Processes, Constraints." *Mitigation and Adaptation Strategies for Global Change* 13(5): 643-59. DOI: 10.1007/s11027-007-9132-3 http://dx.doi.org/10.1007/s11027-007-9132-3.

Abstract

Scientific evidence accumulating over the past decade documents that climate change impacts are already being experienced in the U.S. Northeast. Policy-makers and resource managers must now prepare for the impacts from climate change and support implementing such plans on the ground. In this paper we argue that climate change challenges the region to maintain its economic viability, but also holds some opportunities that may enhance economic development, human well-being, and social justice. To face these challenges and seize these opportunities effectively we must better understand adaptation capacities, opportunities and constraints, the social processes of adaptation, approaches for engaging critical players and the broader public in informed debate, decision-making, and conscious interventions in the adaptation process. This paper offers a preliminary qualitative assessment, in which we emphasize the need for:

1. assessing the feasibility and side effects of technological adaptation options,
2. increasing available resources and improving equitable access to them,
3. increasing institutional flexibility, fit, cooperation and decision-making authority
4. using and enhancing human and social capital
5. improving access to insurance and other risk-spreading mechanisms, and
6. linking scientific information more effectively to decision-makers while engaging the public.

Throughout, we explore these issues through illustrative sectoral examples. We conclude with a number of principles that may guide the preparation of future adaptation plans for the Northeast.

Penney J. 2008. *Climate Change Adaptation in the City of Toronto: Lessons for Great Lakes Communities*. Clean Air Partnership. Toronto, Ontario. Available at http://www.cleanairpartnership.org.

Like other communities in the Great Lakes region, Toronto is undergoing significant changes in its climate. The city is becoming hotter, weather is becoming more variable, extreme weather is more common, and insect pests are multiplying as a result of warmer winters. Because of the millions of tonnes of greenhouse gases already released to the atmosphere, these changes will continue for the next century or more, even if we are successful in dramatically reducing emissions in the near future.

Many municipalities in the Great Lakes and elsewhere in Canada have developed climate change mitigation strategies designed to reduce greenhouse gas emissions. However, most of these municipalities have not yet begun to develop plans to reduce the impacts of climate change that is already underway and is unavoidable. The City of Toronto is one of the first cities in Canada to develop a comprehensive climate change adaptation plan, as a result of a lengthy and thoughtful process. The report examines the principle actors involved in development of Toronto's adaptation strategy, how they organized themselves and how they reached out to City staff, external experts and the public. It summarizes the major features of the adaptation strategy itself, and activities that are currently underway to implement the strategy.

One section of the report takes a closer look at one of the primary areas of vulnerability for the City of Toronto under a changing climate – stormwater management. It describes how more intense storms as a result of climate change add to the existing challenges of preventing floods, erosion and water pollution in Toronto. The section examines ways in which Toronto Water is trying to address these problems and short-term adaptation actions it is preparing to take. The report also proposes further actions that Toronto Water could take to adapt to climate change and enhance the city's resilience to intense storms. The report ends with observations about the strengths and weaknesses of the Toronto adaptation process, and identifies 19 lessons for other Great Lakes communities that are looking to develop their own adaptation strategies and processes.

Schmidt CW. 2009. "Beyond Mitigation: Planning for Climate Change Adaptation." *Environmental Health Perspectives* 117: A306-A09. DOI: 10.1289/ehp.117-a306.
http://ehsehplp03.niehs.nih.gov/article/fetchArticle.action?articleURI=info%3Adoi%2F10.1289%2Fehp.117-a306.

Consider the floods, plagues, famines, and other calamities we can expect from climate change, and an apocalyptic prophecy might come to mind, perhaps rightfully so. An expert panel convened to assess risks from climate change put it this way in the 16 May 2009 issue of *The Lancet*: Should global mean temperatures rise an additional 5–6°C, "more than a billion people could be dispersed in environmental mass migration. An additional 2 billion would be water stressed while billions more would face hunger or starvation. The risk of armed conflict would rise. Public health systems around the world would be damaged, some to the point of collapse."

Alarming scenarios like this have fueled efforts to lower heat-trapping greenhouse gas emissions and limit future impacts [see "Climate Change Abatement Strategies: Which Way Is the Wind Blowing?" p. A296 this issue]. But more recently, scientists have acknowledged that some degree of global warming is now inevitable. "Climate change models tell us that even if we blocked all emissions now, the amounts of greenhouse gases already in the atmosphere would raise global temperatures by an additional 2°C by 2100," says Robert Corell, Vice President of the John Heinz III Center for Science, Economics, and Environment, in Washington, DC. In light of this probability, Corell says, mitigation has begun sharing the global policy stage with a new challenge: how to adapt to climate change that is already munder way.

Taylor J. 2000. ***Workshop Report - Bridging the Climate Information Held at Argonne National Laboratory September 29, 1999*****. ANL/CGC-001-0200, Argonne National Laboratory, Argonne, Illinois.** http://www.osti.gov/energycitations/servlets/purl/752914-0B0INp/webviewable/.

In a recent report entitled The Regional Impacts of Climate Change it was concluded that the technological capacity to adapt to climate change is likely to be readily available in North America, but its application will be realized only if the necessary information is available (sufficiently far in advance in relation to the planning horizons and lifetimes of investments) and the institutional and financial capacity to manage change exists. The report also acknowledged that one of the key factors that limit the ability to understand the vulnerability of subregions of North America to climate change, and to develop and implement adaptive strategies to reduce that vulnerability, is the lack of accurate regional projections of climate change, including extreme events. In particular, scientists need to account for the physical-geographic characteristics (e.g., the Great Lakes, coastlines, and mountain ranges) that play a significant role in the North America climate and also need to consider the feedback between the biosphere and atmosphere.

U.S. Climate Change Science Program. 2009. "Global Climate Change Impacts in the United States." 2nd Public Review Draft. ***Do Not Cite or Quote.***

Appendix D

Targeted Literature Review: RPS and Energy Efficiency

Appendix D

Targeted Literature Review: RPS and Energy Efficiency

A second, more targeted literature review was conducted to focus on topics related to the first proposed numerical experiment with iRESM. This experiment will investigate the impacts of an aggressive RPS and energy efficiency policy throughout the region to derive insights into one of iRESM's key science questions: is mitigation more regionally constrained than currently anticipated? More specifically, the numerical experiment hopes to be able to explore the following questions:

Given this aggressive policy,

1. How likely is it that water for energy, agriculture, domestic uses, and ecosystems will be constrained within the region?
2. Considering policy, climate change, and other uncertainties, what is the expected regional cost and reliability of electricity?
3. How much is the answer affected by uncertainty in future temperature on the demand for residential and commercial energy? In the effects of temperature and precipitation on productivity of energy crops?

The targeted literature review searched for Midwest region studies relevant to the above questions. The studies identified will provide useful points of reference and/or validation for iRESM results. The following section presents a summary of the relevant findings related to water constraints, the cost and reliability of electricity, and the impact of climate change on energy demand and energy crops. Appendix C contains the reference list from the targeted review.

D.1 Water Constraints

The literature identified on water issues is organized as follows: general summary; water supply issues (surface and groundwater); water demand issues by energy technology/sector.

General

The Great Lakes account for almost 90 percent of the U.S. supply of surface freshwater, and 10 percent of the U.S. population lives in the Great Lakes Basin (http://www.epa.gov/glnpo/basicinfo.html). Going forward, policies will have to carefully manage water in order to meet the needs of growing populations, declining water levels within key aquifers, and changing precipitation patterns. As more agricultural products are used for transportation and meeting renewable portfolio requirements, the U.S. is increasing the link between water consumption, energy, and driving habits. Water-intensive biofuels production in the Midwest could negatively impact water availability and quality in that region (King, Webber, & Duncan 2010).

In addition, increasing water demands in the areas surrounding the Great Lakes are overtaxing regional groundwater supplies, and even in some cases reversing groundwater flows which had previously recharged the Great Lakes (Gaumnitz, Asplund, & Matthews 2004). Further, about 50 percent of the supply of freshwater to the lakes comes from land surface runoff from the Great Lakes drainage basin, meaning that land usage has the potential to greatly impact water quality and lake levels (Cherkauer & Sinha 2010).

The potential for increased frequency and/or severity of droughts is another broad issue for the region. Droughts may require tradeoffs to be made between water used for urban, industrial, environmental, and agricultural needs. Some cities have purchased water rights from farmers to meet industrial and urban needs, and competition for water will only be increased by energy crop production (Stone, Hunt, Cantrell, & Ro 2010). In Nebraska in 2005 and 2007, farmers were paid not to irrigate along the Republican and Platte Rivers (U.S.-Water News Online 2005, NE-DNR 2005, NE-FSA 2007).

Water Supply—Surface Water

The U.S. Global Change Research Program (2009) found that climate change is expected to have significant impacts on the overall availability of water in the Great Lakes Basin, as well as on its quality and distribution, especially in a high emissions case. Some anticipated climate change impacts, such as falling water levels in the Great Lakes, are still speculative and have not yet manifested themselves in consequential ways, but have major implications for the region's infrastructure investments and will require prior planning years or decades ahead. The uncertainties associated with long-term planning for the management of the Great Lakes water resources are particularly difficult, since they require the coordinated efforts of eight or more U.S. states and three Canadian provinces through international institutions such as the Great Lakes Commission, which oversees the allocation of water resources. Under lower emissions scenarios and low to moderate water temperature increases, water levels are projected to fall less than 12 inches by 2100, but higher emissions scenarios with corresponding higher temperatures show levels falling by as much as 24 inches this century (see Figure D.1 below). This broad uncertainty band has far reaching implications for the region's ecosystems and for many of the Midwest's most important economic sectors and industries including energy, agriculture, navigation, recreation and tourism (USGCRP 2009).

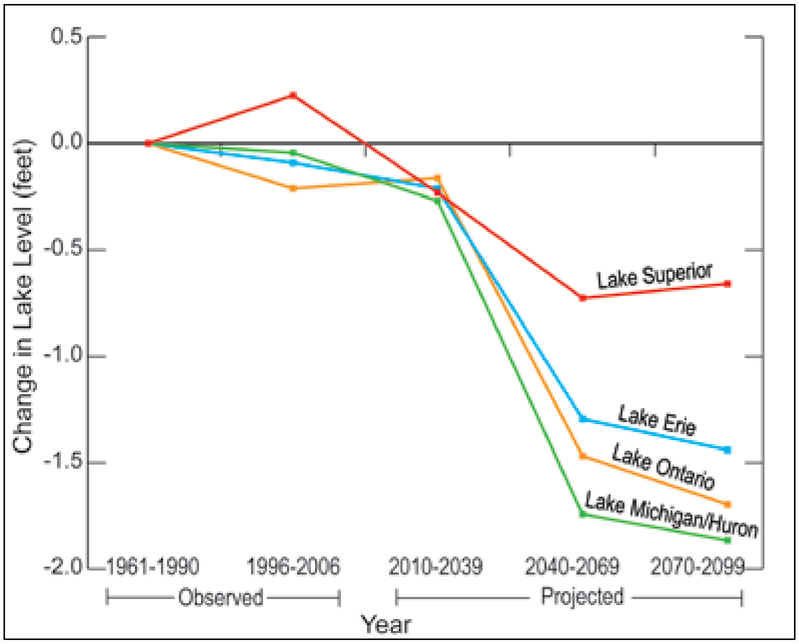

Figure D.1. Projected Changes in Great Lakes Levels under High Emissions Scenarios
Source: U.S. Global Change Research Program, 2009.

Further, a more recent study, which used a broad range of models and emissions scenarios, found a majority of the projections indicating a decrease of lake levels with time (Angel and Kunkel 2010). The negative impacts of decreased water levels in the Great Lakes range from a decrease in the efficiency of shipping, negative environmental impacts (loss of wetlands, changes in shoreline), a worsened socioeconomic situation due to loss of hydropower, increased navigation challenges, loss of shipping, reduced marina access, to a reduction in the biotic primary production within lakes (Lofgren et al. 2002, Hartmann 1990, Injerd 1998).

Water Supply—Groundwater

In certain parts of the Midwest, groundwater provides a large fraction of the total public water supply, well over 50 percent in many areas (see Figure D.2). The Ogallala/High Plains aquifer plays a crucial role in providing water to populations and agriculture in key agricultural states, including Kansas, Nebraska and Oklahoma, but withdrawals exceed the recharge rate throughout the region. Withdrawal rates range from a low of twice the recharge rate to 100 times the recharge rate, indicating a severe sustainability problem (Davidson, Dooley, & Dahowski 2009).

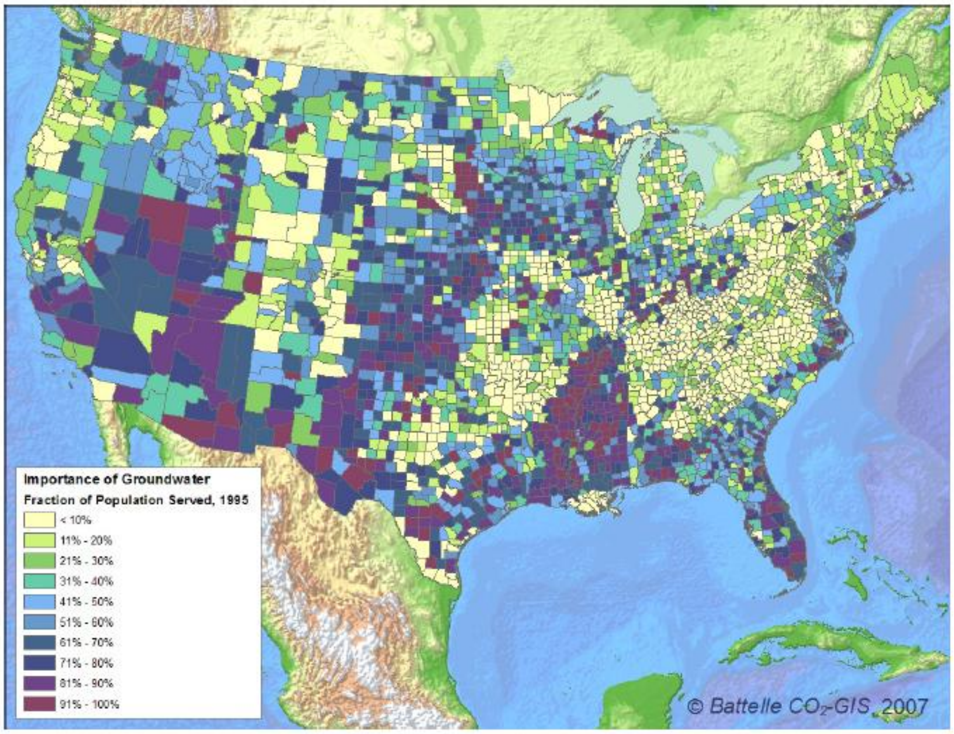

Figure D.2. Importance of Groundwater for Public Drinking Water Supply
Source: Davidson, Dooley, & Dahowski 2009)

Water Demand—Urban

The level of the Great Lakes is of crucial importance for Illinois residents who live within the Lake Michigan basin and on down the Chicago River. Lake Michigan supplies about 68000 milliliters (ML)/day to northeastern Illinois residents, and that water is used for industry, agriculture, domestic consumption, commerce, and energy production. Water demand is expected to increase by 20 to 50 percent by 2050 compared to 2005 (Angel and Kunkel 2010). Illinois has approximately 27 water supply intakes, and lower lake levels would increase energy costs to pump the water to the plants.

Water Demand—Biofuels, Biomass

The current and ongoing increase in biofuel production could result in a significant increase in the overall "water footprint" of fuel crops; the washing of plants and seeds, irrigation, and evaporative cooling could worsen local and regional water shortages. For example, many of the crops currently used for biofuel production, such as corn, sugarcane, and oil palm have relatively high water requirements (Stone, Hunt, Cantrell, & Ro 2010). Cellulosic ethanol would have a much smaller water footprint. Potentially mitigating the water footprint issue is that fuels made from biomass, irrigated or not, are likely to be centered heavily in the Midwest and Eastern U.S. which have the comparative advantage of good soil and abundant rainfall (King, Webber, & Duncan 2010).

According to Dominguez-Faus et al. (2009), the ideal fuel crops would be drought-tolerant, high-yield plants grown on little irrigation water. Figure D.3 shows that both corn grain and switchgrass, which is a lignocellulosic crop, compare favorably to other fuel crops in terms of water and land usage. The theoretical irrigation water requirement for prairie-grown switchgrass is zero, making it the optimal water footprint crop. However, it is not yet economically feasible to meet our large biofuel requirements from such feedstocks as current technology is not up to scale (Baker Institute 2008). Therefore, corn ethanol will probably meet the current Energy Independence and Security Act (EISA) mandate.

Research shows that generation of bioelectricity has a smaller water footprint than the production of biofuels because the whole plant is used, instead of just the sugar, starch, or oil. Biofuels also appear problematic when compared to energy generated from fossil fuels in terms of their water use. As shown in Table D.1, the water requirements to produce an equivalent amount of energy from corn and soybean are larger than the water requirements of fossil-fueled generation (fossil fuel-related water use includes water for pumping petroleum out of the ground, generating steam to turn turbines, and cooling water) (Dominguez-Faus, et al. 2009).

In summary, it appears from the literature that corn-based ethanol is likely to be the biofuel of choice in the short term, while lignocellulosic crops such as switchgrass, would gain market share in the long term as water supplies, specifically in the Ogallala Aquifer, diminish and cause water intensive crops to become relatively more expensive. In addition, it appears that a likely impact of including a market for water in iRESM would be to promote the production of biofuels with higher water footprints in areas where rainfall can supply the majority of the water requirements.

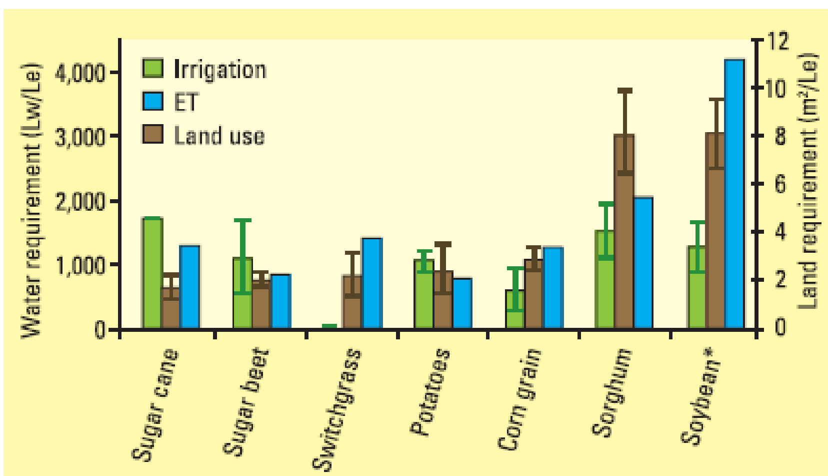

Figure D.3. Water and Land Requirements for Biofuels Crops. Source: Dominguez-Faus 2009, p.3007.

Table D.1. Water Requirements for Energy Production by Different Processes Source: Dominguez-Faus 2009, p. 3006.

Process	L/MWh
petroleum extraction	10–40
oil refining	80–150
oil shale surface retort	170–681
NGCC[a] power plant, closed loop cooling	230–30,300
coal IGCC[b]	~900
nuclear power plant, closed loop cooling	~950
geothermal power plant, closed loop tower	1900–4200
EOR[c]	~7600
NGCC, open loop cooling	28,400–75,700
nuclear power plant, open loop cooling	94,600–227,100
corn ethanol irrigation	2,270,000–8,670,000
soybean biodiesel irrigation	13,900,000–27,900,000

[a] Natural gas combined cycle. [b] Integrated gasification combined-cycle. [c] Enhanced oil recovery.

Water Demand-Thermoelectric Power

As can be seen from Table D-1, different types of power require differing amounts of water for the same amount of energy produced. If water supplies are constrained in the region, then technologies with high water requirements, such as nuclear power, may be infeasible, even if they would help the region to meet GHG targets.

Another potential power generation-related water issue involves carbon capture and sequestration (CCS). According to Dooley et al. 2006, and NETL 2007, there is potential for CCS in deep saline sedimentary formations throughout Michigan, Illinois, Indiana, Ohio, Kentucky, West Virginia, Pennsylvania, and New York. However, these formations also provide a source of lower quality groundwater that could be utilized to meet water needs. This potential conflict over the use of these deep saline formations could affect CCS deployment in these parts of the U.S. (Davidson, Dooley, & Dahowski 2009).

Ecosystems Water-Related Impacts

Ecosystems are clearly greatly affected by changes in water quantity and water quality. Relating to biofuel crops, a substantial increase in water pollution by fertilizers and pesticides is also likely, with the potential to exacerbate eutrophication and hypoxia in inland waters and coastal areas (Galloway et al. 2003, Rabalais 2002, EPA 2008, USDA 2008, NRC 2007, Rabalais et al. 2007, Twomey et al 2009; Goolsby, Battaglin, Aulenbach, & Hooper 2000). In addition, land use and crop selection will greatly impact the amount of nutrient runoff reaching surface waters. Nutrient discharges are greatest in the more humid corn and soybean regions across Illinois, Indiana, and Ohio (Donner, Kucharik, & Foley 2004, Donner & Kucharik 2008, Burkart, James, Liebman, & van Ouwerkerk 2006). The presence of tile drainage in these areas of higher rainfall increases transport fluxes. Of interest, the eastern regions of the Corn Belt contribute less to the water consumption aspect of the water footprint, but they contribute more to the water pollution component (Powers et al. 2008).

High fertilizer application rates, especially for row crops in the Midwestern U.S., generate the largest fluxes of nitrogen (N) and phosphorus (P) to local waterways and the Mississippi River basin (Powers 2007) and are therefore considered one of the primary contributors to the growing hypoxic zone in the Gulf of Mexico (LUMCON 2008, U.S. Geological Survey 2008). Switchgrass uses applied N efficiently (Parrish & Fike 2005), and appears able to obtain nitrogen from sources that other crops cannot tap, and a much lower fraction of fertilizer is lost to surface water with switchgrass than with corn (Simpson et al. 2008, Powers et al. 2008). The U.S. EPA Chesapeake Bay office (Chesapeake Bay Commission 2007) modeled changes in nutrient loads resulting from increased biofuel production in the watershed, and projected a substantial reduction in N loads to the Chesapeake Bay if farmland were converted to switchgrass without fertilizer.[1]

D.2 Impact of Policy, Climate, and Other Uncertainties on Cost and Reliability of Electricity

RPS

According to Chen, Wiser, Mills, & Bolinger (2009), the cost of RPS policies will largely depend on the cost of the technologies employed to meet the RPS targets, the availability of incentives to reduce the cost of renewable resources, the cost of energy that is displaced by the increase in renewable resources, and the associated secondary costs of technology deployment. This study synthesized analyses of state RPS plans completed since 1998 to compare the projected mix of renewable technologies in each state as well as the estimated impacts on electricity costs. The comparison is based on the first year each state meets its RPS goal/mandate. As shown in Figure D.4, wind is expected to be the dominant technology, representing 60% of incremental state RPS generation across all of the studies combined, and the Midwest is projected to rely heavily on wind deployment.

[1] Even though Chesapeake Bay itself is not within the study region, its drainage basin includes New York, Pennsylvania, and West Virginia.

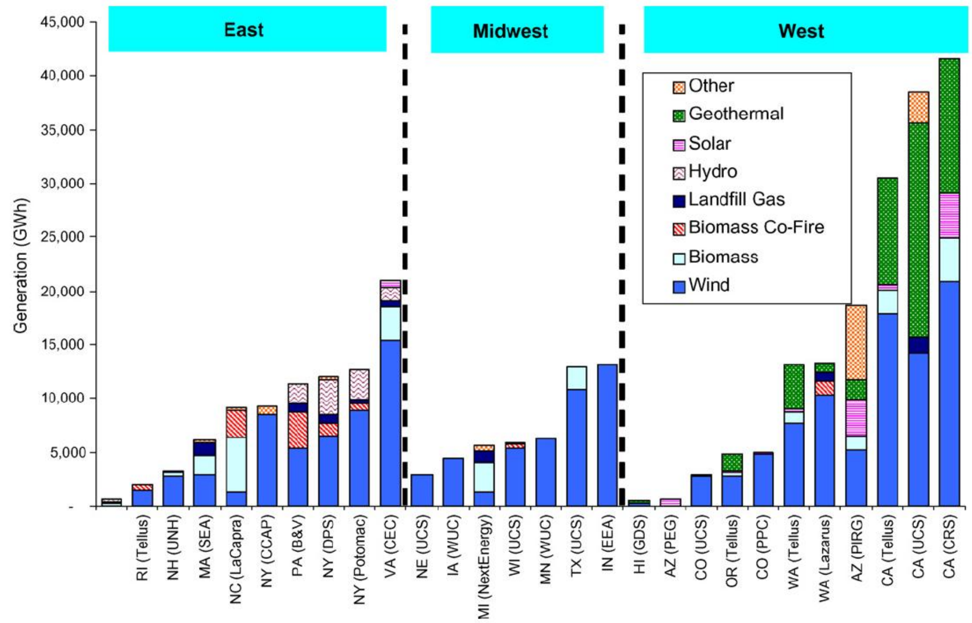

Figure D.4. Incremental Renewable Energy Deployment by Study and Technology (Chen et al. 2009, p. 557).

Chen et al. (2009) go on to show that rate impacts are expected to be modest, with more than half of the reviewed studies reporting base-case rate increases of between 0 and 1% (see Figure D-5). In the iRESM Midwest region, only New York and Indiana are projected to have higher increases. However, there are uncertainties in projected rate impacts as illustrated by the divergent results for the three New York studies, as well as from the scenario analysis results presented in Figure D-6. In general, the study reports that rate impacts tend to be higher in the Northeastern part of the U.S. due to the lower potential for renewables and the higher costs of developing renewables projects in this region.

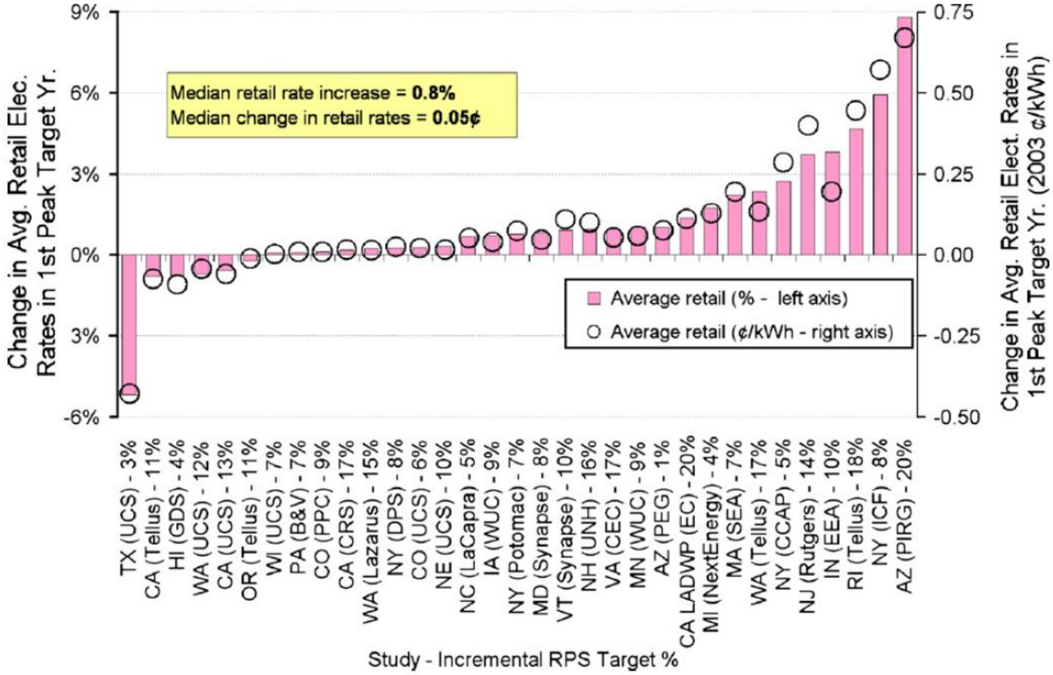

Figure D.5. Projected Electricity Rate Impacts by RPS Cost Study (Chen et al. 2009, p. 558).

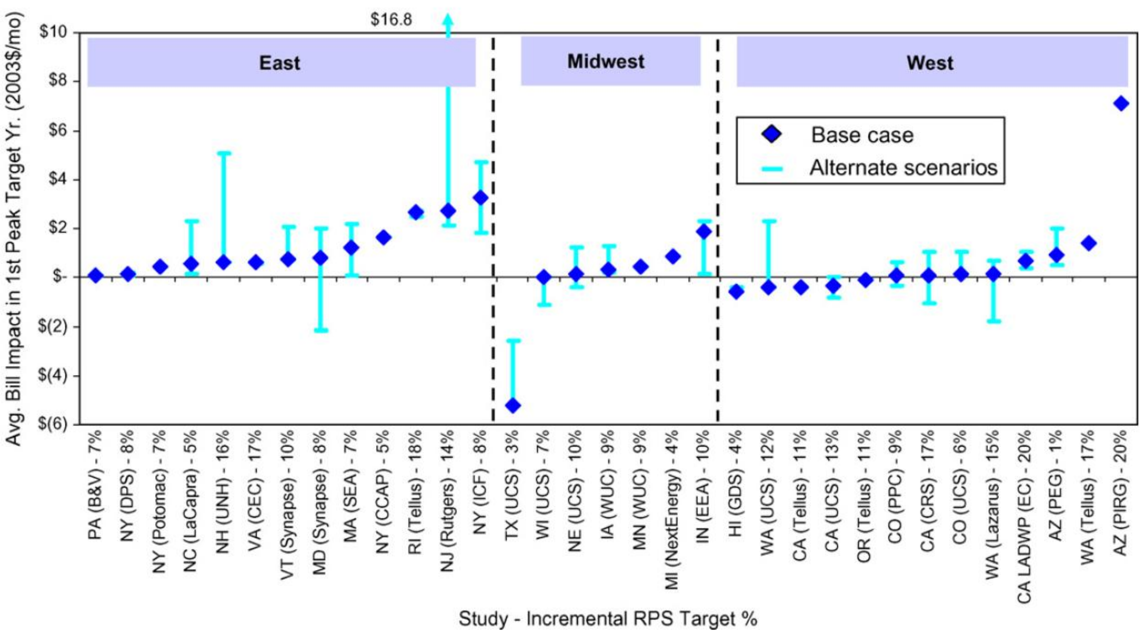

Figure D.6. Typical Residential Electricity Bill Impacts Projected by RPS Cost Studies (Chen et al. 2009, p. 588).

Vries, Vuuren, & Hoogwijk (2007) investigated the potential for wind, solar-PV and biomass (WSB) to deliver energy, given land, production costs, resource availability, and innovation dynamics, and found that many parameters in geographic and techno-economic estimates of renewable energy potentials are uncertain and dependent on broader developments such as future land use. The competition for land between the WSB options could significantly affect their ability to produce electricity. In other words, it is not possible to determine the combined potential by adding up the individual potentials because interaction effects could reduce the WSB-potential up to 70%. In addition, there are other crucial uncertainties like the suitability or availability of land and technology-induced cost reductions.

Transmission

Here is an excerpt from the ***National Transmission Grid Study*** of May 2002:

"DOE's analysis confirms the tendency for transmission congestion to develop at many locations within the Eastern Interconnection. Out of a total of 186 transmission paths modeled in the East, 50 are used to their maximum capacity at some point during the year, and 21 paths are congested during more than 10 percent of the hours of the year.[11] The highest levels of congestion are found along transmission corridors from Minnesota to Wisconsin, the Midwest into the Mid-Atlantic, from the Mid-Atlantic to New York, and from the Southeast into Florida. In general, DOE's findings are very similar to historical data on transmission congestion, which also indicate that there is substantial congestion in the Midwest and upper Midwest, and from the Mid-Atlantic to the Northeast. In addition, solving the problem of transmission constraints within the United States will also require cooperation with Canada. Many scheduled power transactions within the U.S., particularly east-to-west transactions within the Eastern Interconnection, flow over transmission lines located in Canada before reaching loads in the U.S. This is a particular problem at points in the upper Midwest where the transmission systems of the two countries interconnect. These unintended flows (or "loop flows") often require transmission service curtailments in the U.S."

And from the 2009 ***National Electric Transmission Congestion Study***:

"Several large transmission projects, comprising a group called the Capacity Expansion (CapX) 2020 Project, are being planned to enable development of wind resources in North Dakota, South Dakota, Minnesota and Iowa. The first phase of this project— consisting of three 345 kV lines—has been approved as a reliability project for cost allocation under MISO's 2008 Transmission Expansion Plan and granted Certificates of Need by the Minnesota Public Utilities Commission.[151] Other large projects have been proposed to serve renewables, including the Green Power Express, a merchant transmission proposal to move 12,000 MW of power from the Dakotas, Minnesota and Iowa to load centers including Chicago, southeastern Wisconsin and Minneapolis.[152] Further, the Midwest ISO is working with the other eastern system planning organizations to study alternative renewable energy development scenarios and associated transmission plans."

D.3 Effect of Changing Temperatures and Precipitation on Energy Demand and Energy Crops

Energy Demand

Looking at the economic impact that climate change could have on energy demand requires analysis at the local and the regional scale (Wilbanks et al. 2007). For example, Chicago's vulnerabilities to climate change are specific to its location, which tends to magnify projected summer temperature increases relative to the global average (Meehl et al. 2007). Chicago is vulnerable to increases in temperature, and extremely hot days and heat waves, in addition to heavy rainfall events and flooding (NRC 2008). For example, during a heat wave in 1995, city streets buckled, electricity usage records were exceeded, and power failures left some residents without electricity for up to 2 days (Klinenberg 2002). For Chicago, temperature increases are projected by the end of the century, as well as winter and spring precipitation increases (Hayhoe et al. 2010), and these increases are likely to have a significant impact on energy use, electricity demand, and transportation. More broadly, Chicago's experience could be looked at as an example for other urban centers where vulnerabilities depend on the nature of the infrastructure and its ability to cope with future changes. In general, it is expected that urban centers are more vulnerable to changes in extreme weather (Wilbanks et al. 2007).

There are observed correlations elsewhere in the world between daily temperature and peak electricity demand during the summer, which suggest the potential for large increases in future electricity demand for air conditioning (Belzer et al. 1996, Amato et al. 2005, Mendelsohn and Neumann 1999, Rosenthal et al. 1995, Henley and Peirson 1998, Cartalis et al. 2001, Sailor 2001, Valor et al. 2001, Colombo et al. 1999, Ruth and Lin 2006). These projected increases in peak electricity demand raise concerns about energy shortages and the ability of energy infrastructure, refinery capacity, and electricity line transmission system to meet such increased demand. During the 2003 summer, a system failure resulted in the largest blackout in U.S. history, with approximately 50 million people across the Great Lakes states and Northeast left without power for several days. In addition, there were disruptions in the water supply; flooding and water contamination from heavy rains and malfunctioning sewage pumps; major transportation interruptions and delays; major drops in river levels due to increased hydroelectric generation on the Niagara River; and emergency shutdowns, increased pollution release, and explosions at refinery plants in Michigan and Ontario (Hayhoe et al. 2010).

Energy Crops

Forecasting the impact of climate change on agriculture in the Great Lakes region is crucial as it is heavily invested in this sector. Climate change in the Great Lakes region has made winters shorter and increased annual average temperatures, extreme heat events, and heavy precipitation. A national assessment conducted by Izaurralde, Rosenberg, Brown, & Thomson (2003) evaluated the potential consequences of climate change on agriculture and water resources in the United States. The model projections as they related to the Midwest saw uniform precipitation increases by 2030. With respect to agriculture, the Environmental Policy Integrated Climate (EPIC) model simulated yield increases for the Great Lakes, Corn Belt and Northeast regions. Corn yield increases were predicted for the Lakes, Corn Belt and Northeast regions of the U.S. In 2030, corn production is expected to increase in the Corn Belt and Lakes regions and to decrease in the Northern Plains.

Wuebbles & Hayhoe (2004) estimated that heavy rainfall events will double by the end of the next century, and that regional temperatures will increase by 1 to 7 degrees Celsius in the winter and 3 to 11 degrees Celsius in the summer. The changes to annual precipitation might be minor, as the seasonal distribution will probably shift so that more precipitation falls in the winter and less in the summer. The increase in extreme precipitation will lead to higher runoff and increased risk of flooding and more evaporation and transpiration, meaning lower summertime soil moisture levels. Changes in extreme events, especially in precipitation, flooding, and drought all will seriously negatively impact production (Kling et al. 2003). Wetter springs might affect planting dates, increased flooding and storms could damage crops, and drier summers or longer drought could reduce yields. (Cherkauer & Sinha, 2010). In 2008, the major corn producing states of the upper Midwest experienced extreme flooding due to excess rainfalls. The flooding negatively affected early-season planting operations (Kangas and Brown 2007). The increased variability in temperature and rainfall extremes means the productivity of biomass and bioenergy will differ depending on location (Slingo et al. 2005, Negri et al. 2005).

Appendix D

Bibliography

Adkins D. 2004. "Answer Blowing in the Wind? Indiana has More Wind for Power Generation than Previously Thought." *Indiana Business Magazine.* Accessed August 9, 2010 at http://www.allbusiness.com/north-america/united-states-indiana/139691-1.html.

Amato A, M Ruth, P Kirshen, J Horwitz. 2005. "Regional Energy Demand Responses to Climate Change: Methodology and Application to the Commonwealth of Massachusetts." *Climate Change.* 71: 175-201.

American Wind Energy Association (AWEA). 2008. "U.S. Wind Energy Projects." Accessed 2010 at http://www.awea.org/projects/.

Andrews WJ, NI Osborn, and RR Luckey. 1999. "Rapid Recharge of Parts of the High Plains Aquifer Indicated by a Reconnaissance Study in Oklahoma." *U.S. Geological Survey Fact Sheet 137-00*. http://www.owrb.ok.gov/studies/reports/reports_pdf/high_plains_2.pdf.

Angel J and K Kunkel. 2010. "The Response of Great Lakes Water Levels to Future Climate Scenarios with an Emphasis on Lake Michigan-Huron." *Journal of Great Lakes Research*, 36(2): 51-58. DOI: 10.1016/j.jglr.2009.09.006.

Baker Institute. 2008. *Biomass to Chemicals and Fuels: Science, Technology and Public Policy Conference Report, January 2008*. James A. Baker Institute for Public Policy, Houston, Texas

Belzer D, M Scott, and R Sands. 1996. "Climate Change Impacts on U.S. Commercial Building Energy Consumption: An Analysis using Sample Survey Data." *Energy Sources Part A: Recovery, Utilization, and Environmental Effects* 18(2): 177-201.

Brown M, M Levine, W Short, and J Koomey. 2001. "Scenarios for a Clean Energy Future." *Energy Policy* 29(14): 1179-1196. DOI: 10.1016/S0301-4215(01)00066-0.

Brown LR. 2006. *Plan B 2.0: Rescuing a Planet under Stress and a Civilization in Trouble*. W.W. Norton and Company, New York, New York.

Burkart M, D James, M Liebman, E van Ouwerkerk. 2006. "Integrating Principles of Nitrogen Dynamics in a Method to Estimate Leachable Nitrogen under Agricultural Systems." *Water Science Technology* 53: 289–301.

Cantrell KB, TF Ducey, KS Ro, PG Hunt. 2008. "Livestock Waste-to-Bioenergy Generation Opportunities." *Bioresource Technology*. 99(17): 7941–7953.

Cartalis C, A Synodinou, M Proedrou, A Tsangrassoulis, and M Santamouris. 2001. "Modifications in Energy Demand in Urban Areas as a Result of Climate Changes: An Assessment for the Southeast Mediterranean Region." *Energy Conversion Management.* 42(14): 1647-1656.

Chen C, R Wiser, A Mills, and M Bolinger. 2009. "Weighing the Costs and Benefits of State Renewables Portfolio Standards in the United States: A Comparative Analysis of State-Level Policy Impact Projections." *Renewable and Sustainable Energy Reviews* 13(3): 552-566. DOI: 10.1016/j.rser.2008.01.005.

Cherkauer, K, and T Sinha. 2010. "Hydrologic Impacts of Projected Future Climate Change in the Lake Michigan Region."*Journal of Great Lakes Research*, 36(2): 33-50, DOI: 10.1016/j.jglr.2009.11.012.

Chesapeake Bay Commission. 2007. *Biofuels and the Bay: Getting It Right to Benefit Farms, Forests and the Chesapeake*. Annapolis, Maryland.

Chiu Yi-Wen, Walseth, Brian, Suh, Sangwon, 2009. "Water Embodied in Bioethanol in the United States. *Environmental Science and Technology* 43(8): 2688–2692, DOI: 10.1021/es8031067 (policy analysis).

Cohen SJ. 1986. "Impacts of CO_2-Induced Climatic Change on Water Resources in the Great Lakes Basin." *Climatic Change* 8(2): 135-153.

Colombo A, D Etkin, B Karney. 1999. "Climatic Variability and the Frequency of Extreme Temperature Events for Nine Sites Across Canada." *Journal of Climate.* 12(8): 2490-2502.

Commission for Environmental Cooperation (CEC). 1997. *Ecological Regions of North America. Montreal, Quebec, Canada: Commission for Environmental Cooperation.* Accessed June 11, 2008 at http://www.epa.gov/wed/pages/ecoregions.htm.

Croley T and M Lewis. 2006. "Warmer and Drier Climates that Make Terminal Great Lakes."*Journal of Great Lakes Research*, 32(4): 852-869. DOI: 10.3394/0380-1330(2006)32[852:WADCTM]2.0.CO;2.

Davidson CL, JJ Dooley, and RT Dahowski. 2009. "Assessing the Impacts of Future Demand for Saline Groundwater on Commercial Deployment of CCS in the United States." In *Energy Procedia: 9th International Conference on Greenhouse Gas Contorol Technologies (GHGT9)* 1(1): 1949-1956. Elsevier, London, United Kingdom. DOI:10.1016/j.egypro.2009.01.254.

De La Torre Ugarte DG, MW Walsh, H Shapouri, and SP Slinsky. 2003. The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture. U.S. Department of Agriculture, Agricultural Economic Report No. 816. Available at http://www.usda.gov/oce/oepnu/AER816Bi.pdf.

Denholm P. 2006. "Improving the Technical, Environmental and Social Performance of Wind Energy Systems Using Biomass-Based Energy Storage." *Renewable Energy* 31(9): 1355-1370. DOI: 10.1016/j.renene.2005.07.001.

Dziegielewski B and FJ Chowdhury. 2008. *Regional water demand scenarios for northeastern Illinois: 2005-2050.* Project Completion Report prepared for the Chicago Metropolitan Agency for Planning (CMAP) through the Southern Illinois University, Carbondale, Illinois. Available at http://www.cmap.illinois.gov/watersupply/default.aspx.

Dominguez-Faus R, S Powers, J Burken, and P Alvarez. 2009. "The Water Footprint of Biofuels: A Drink or Drive Issue?" *Environmental Science & Technology* 43(9): 3005-3010.

Donner SD, CJ Kucharik. 2008. "Corn-Based Ethanol Production Compromises Goal of Reducing Nitrogen Export by the Mississippi River." *Proceedings of the National Academy of Science of the United States of America* 105(11): 4513–4518.

Donner SD, CJ Kucharik, JA Foley. 2004. "Impact of Changing Land Use Practices on Nitrate Export by The Mississippi River." *Global Biogeochemical Cycles* 18(1): GB1028.

Dooley JJ, RT Dahowski, CL Davidson, MA Wise, N Gupta, SH Kim, and EL Malone. 2006. "Carbon Dioxide Capture and Geologic Storage: A Core Element of a Global Energy Technology Strategy to Address Climate Change." Battelle Memorial Institute.

Energy Information Administration (EIA). 2006. *Energy Demands on Water Resources; Report to Congress on the Interdependency of Energy and Water*. U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA). 2010. "State Energy Profiles: Kentucky." Accessed August 9, 2010 at http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=KY.

Eaves J and S Eaves. 2007. "Renewable Corn-Ethanol and Energy Security." *Energy Policy* 35(11): 5958–5963.

Environmental Protection Agency (EPA). 2001. "Mississippi River/Gulf of Mexico Watershed Nutrient Task Force." *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*. Washington, DC. Available at www.epa.gov/msbasin/pdf/actionplan2001.pdf.

Environmental Protection Agency (EPA). 2008. *Hypoxia in the Northern Gulf of Mexico*. EPA-SAB-08-003, U.S. Environmental Protection Agency, Washington, DC.

Food and Agricultural Organization (FAO). 2008a. *The State of Food and Agriculture 2008. Biofuels: Prospects, risks and opportunities*. Food and Agricultural Organization of the United Nations, Rome, Italy.

Food and Agricultural Organization (FAO). 2008b. *Major Food and Agricultural Commodities and Producers: Countries by Commodity.* Available at http://www.fao.org/es/ess/top/commodity.html?lang=en&item=156&year=2005.

Fargione J, J Hill, D Tilman, S Polasky and P Hawthorne. 2008. "Land Clearing and the Biofuel Carbon Debt." *Science* 319: 235–238.

Flaspohler DJ, RE Froese, and CR Webster. 2008. "Bioenergy, Biomass and Biodiversity." In: *Renewable Energy from Forest Resources in the United States*. London: Taylor & Francis133–62.

Froese R, D Shonnard, C Miller, K Koers, and D Johnson. 2010. "An Evaluation of Greenhouse Gas Mitigation Options for Coal-fired Power Plants in the U.S. Great Lakes States." *Biomass and Bioenergy* 34(3): 251-262. DOI: 10.1016/j.biombioe.2009.10.013.

Galloway JN, JD Aber, JW Erisman, SP Seitzinger, RW Howarth, EB Cowling, and BJ Cosby. 2003. “The Nitrogen Cascade.” *BioScience* 53(4): 341–356.

Gaumnitz L, T Asplund, and M Matthews. 2004. “A Growing Thirst for Groundwater.” *Wisconsin Natural Resources Magazine,* June 2004.

Goolsby DA, WA Battaglin, BT Aulenbach, and RP Hooper. 2000. “Nitrogen Flux and Sources in the Mississippi River Basin.” *Science of the Total Environment* 248(2-3): 75–86.

Hartmann H. 1990. “Climate Change Impacts on Laurentian Great Lakes Levels.” *Climate Change.* 17(1): 49-67.

Hayhoe K, M Robson, J Rogula, M Auffhammer, N Miller, J VanDorn, and D Wuebbles. 2010. “An Integrated Framework for Quantifying and Valuing Climate Change Impacts on Urban Energy and Infrastructure: A Chicago Case Study.”*Journal of Great Lakes Research* 36(2):94-105. DOI: 10.1016/j.jglr.2010.03.011.

Henley A and J Peirson. 1998. “Residential Energy Demand and the Interaction of Price and Temperature: British Experimental Evidence.” *Energy Economics* 20(2): 157-171.

Huntington T. 2006. “Evidence for Intensification of the Global Water Cycle: Review and Synthesis.” *Journal of Hydrology* 319: 83-95.

Hutson SS. NL Barber, JF Kenny, KS Linsey, DS Lumia, and MA Maupin. 2004. *Estimated Use of Water in the United States 2000*, U.S. Geological Survey, Reston, Virginia.

Injerd D. 1998. “Impacts and Risks of Climate Change and Variability: Stakeholder Perspectives in Adapting to Climate Change and Variability in the Great Lakes – St. Lawrence Basin.” In *Environmental Adaptation, Adapting to Climate Change and Variability in the Great Lakes-St. Lawrence Basin--Proceedings of a Binational Symposium*, Toronto, Ontario May 13-15, 1997.

Izaurralde C, N Rosenberg, R Brown, and A Thomson. 2003. “Integrated Assessment of Hadley Center (Hadcm2) Climate-Change Impacts on Agricultural Productivity and Irrigation Water Supply in the Conterminous United States: Part II. Regional Agricultural Production in 2030 And 2095.” *Agricultural and Forest Meteorology* 117(1-2): 97-122. DOI: 10.1016/S0168-1923(03)00024-8.

Jiusto S. 2008. “An Indicator Framework for Assessing U.S. State Carbon Emissions Reduction Efforts (With Baseline Trends From 1990 To 2001).” *Energy Policy* 36(6): 2234-2252. DOI: 10.1016/j.enpol.2008.02.034.

Johannes C. 2008. *Renewable Energy Background and Outlook for Nebraska Electricity Consumers Report: A Reference Document on Renewable Energy Resources in Nebraska.* Nebraska Power Association, December 28, 2007. Accessed August 9, 2010 at http://www.nepower.org/.

Kangas RS and TJ Brown. 2007. “Characteristics of U.S. Drought and Pluvials from a High-Resolution Spatial Dataset.” *International Journal of Climatology* 27(10): 1303–1325.

Karl TR, GA Meehl, CD Miller, SJ Hassol, AM Waple, and WL Murray. 2008. *Weather and Climate Extremes in a Changing Climate*. U.S. Climate Change Science Program, Washington, DC. Available at www.climatescience.gov.

Karp A and I Shield. 2008. "Bioenergy from Plants and the Sustainable Yield Challenge." *New Phytologist* 179(1): 15–32.

Khanna M, B Dhungana, and J Clifton-Brown. 2008. "Costs of Producing Miscanthus and Switchgrass for Bioenergy in Illinois." *Biomass and Bioenergy* 32(6): 482-493. DOI: 10.1016/j.biombioe.2007.11.003

King C, M Webber, and I Duncan. 2010. "The Water Needs for LDV Transportation in the United States." *Energy Policy* 38(2):1157-1167. DOI: 10.1016/j.enpol.2009.11.004.

Klinenberg E. 2002. *Heat Wave: A Social Autopsy of Disaster in Chicago*. University of Chicago Press, Chicago, Illinois.

Kling G, K Hayhoe, L Johnson, J Magnuson, S Poasky, S Robinson, B Shuter, M Wander, D Wuebbles, and D Zak. 2003. "Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystem." *UCS Publications*, Cambridge, Massachusetts.

Kosnik L. 2008. "The Potential of Water Power in the Fight Against Global Warming in the U.S." *Energy Policy* 36(9): 3252-3265. DOI: 10.1016/j.enpol.2008.05.009.

Lal R. 2006. "Soil and Environmental Implications of Using Crop Residues as Biofuel Feedstock." *International Sugar Journal* 108(1287): 161–167.

Lenters J. 2001. "Long-term Trends in the Seasonal Cycle of Great Lakes Water Levels." *Journal of Great Lakes Research* 27(3): 342-353. DOI: 10.1016/S0380-1330(01)70650-8.

Lenters J, T Kratz, and C Bowser. 2005. "Effects of Climate Variability on Lake Evaporation: Results from a Long-Term Energy Budget Study of Sparkling Lake, Northern Wisconsin (U.S.A.)." *Journal of Hydrology* 308(1-4):168-195. DOI: 10.1016/j.jhydrol.2004.10.028.

Lofgren B, F Quinn, A Clites, R Assel, A Eberhardt, and C Luukkonen. 2002. "Evaluation of Potential Impacts on Great Lakes Water Resources Based on Climate Scenarios of Two GCMs." *Journal of Great Lakes Research* 28(4):537-554. DOI: 10.1016/S0380-1330(02)70604-7.

Louisiana Universities Marine Consortium (LUMCON). 2008. "'Dead Zone' Again Rivals Record Size." *LUMCON News* July 28, 2008.

Matzinger A, Z Spirkovski, S Patceva, and A Wuest. 2006. "Sensitivity of Ancient Lake Ohrid to Local Anthropogenic Impacts and Global Warming."*Journal of Great Lakes Research*, 32(1): 158-179. DOI: 10.3394/0380-1330(2006)32[158:SOALOT]2.0.CO;2.

Maupin MA and NL Barber. 2005. "Estimated Withdrawals from Principal Aquifers in the United States, 2000." *U.S. Geological Survey Circular* 1279, U.S. Geological Survey, Reston, Virginia.

Mcguire VL. 2007. *Ground Water Depletion in the High Plains Aquifer*. Fact Sheet 2007-3029, U.S. Geological Survey: Reston, Virginia.

McLaughlin SB, Wimmer R. 1999. "Calcium Physiology and Terrestrial Ecosystem Processes." *New Phytologist* 142: 373–417.

Meehl GA et al. 2007. "Global Climate Projections." In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, New York.

Mendelsohn R and J Neumann. 1999. "The Impacts of Climate Change on the U.S. Economy." *Cambridge University Press*, Cambridge, United Kingdom.

Milbrandt A. 2005. *A Geographic Perspective on the Current Biomass Resource Availability in the United States.* NREL/TP-560-39181, December 2005, Golden, Colorado.

National Agricultural Statistics Service (NASS). 2008. "Data on U.S. and All States Data – Crops." *U.S. Department of Agriculture*, Accessed February 12, 2008 at http://www.nass.usda.govs.

National Agricultural Statistical Services (NASS). 2010. *"Corn Grain Quick Stats*." U.S. Department of Agriculture: Washington, DC. Available at www.nass.usda.gov/Statistics_by_Subject/index.asp.

National Energy Technology Laboratory (NETL). 2007. "Carbon Sequestration Atlas of the United States and Canada." U.S. Department of Energy, Office of Fossil Energy, Washington, DC.

National Electric Transmission Congestion Study. 2009. United States Department of Energy, Washington, D.C. Available at www.congestion09.anl.gov/documents/docs/Congestion_Study_2009.pdf.

National Transmission Grid Study. 2002. United States Department of Energy, Washington, D.C.

NE-DNR, 2005. Fact Sheet Questions and Answers: Conservation Reserve Enhancement Program Nebraska Platte-Republican Resources Area." United States Department of Agriculture, Farm Service Agency. Accessed September 26, 2008 at http://www.cnppid.com/CREP_Rules.htm.

NE-FSA, 2007. Fact Sheet – Nebraska Central Basins Conservation Reserve Enhancement Program (CREP). United States Department of Agriculture, Farm Service Agency. Nebraska Farm Service Agency, Lincoln, Nebraska. <http://www.fsa.usda.gov/Internet/FSA_File/fsnecrep032307.pdf> (accessed 26.09.08).

Negri DH, NR Gollehon, and MP Aillery. 2005. "The Effects of Climatic Variability on U.S. Irrigation Adoption." *Climatic Change* 69: 299–323

New York State Energy Research and Development Authority (NYSERDA). 2009. "The New York Renewable Portfolio Standard: A Clean, Green Tomorrow Starts Today." Accessed August 9, 2010 at http://www.nyserda.org/rps/index.asp.

NRC 2007. *Water Implications of Biofuels Production in the United States. Committee on Water Implications of Biofuels Production in the United States.* Water Science and Technology Board, Division on Earth and Life Studies, The National Academies Press, Washington, DC. Available at http://www.nap.edu/catalog/12039.html.

National Research Council (NRC), 2008. Potential Impacts of Climate Change on U.S. Transportation. *Transportation Research Board Special Report 290*, Transportation Research Board, Washington, DC.

Ohler A and K Radusewicz. 2010. "Indirect Impacts in Illinois from a Renewable Portfolio Standard." *The Electricity Journal*. DOI: 10.1016/j.tej.2010.07.003.

Parrish DJ and JH Fike. 2005. "The Biology and Agronomy of Switchgrass for Biofuels." *Critical Reviews in Plant Sciences* 24(5-6): 423–459.

Pavelis GA. 1987. "Farm Drainage in the U.S. – History, Status and Prospects." *U.S. Department of Agriculture Economic Research Service Miscellaneous Publication No. 1455*.

Payne W. 2010. "Are Biofuels Antithetic to Long-Term Sustainability of Soil and Water Resources?" *Advances in Agronomy*, *Academic Press* 105: 1-46. DOI: 10.1016/S0065-2113(10)05001-7.

Pew Center on Global Climate Change. 2009. "Renewable and Alternative Energy Portfolio Standards." Accessed August 9, 2010 at http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm.

Polich R. 2007. "A Study of Economic Impacts from the Implementation of a Renewable Portfolio Standard and an Energy Efficiency Program in Michigan." *NextEnergy Center.* Detroit, Michigan: Available at: http://www.michigan.gov/documents/gov/Michigan_RPS_EE_Final_Report_193775_7.pdf.

Powers SE. 2007. Nutrient Loads to Surface Water from Row Crop Production. *International Journal of Life Cycle Assessment* 12(6): 399–407.

Powers SE, LA Ascough, and RG Nelson. 2008. Soil and Water Quality Implications Associated With Corn Stover Removal and Herbaceous Energy Crop Production in Iowa; In *Proceedings of the 2008 Annual International Meeting of the American Society of Agricultural and Biological Engineers*, Providence Rhode Island, Paper Number 083916.

Rabalais NN. 2002. "Nitrogen in Aquatic Ecosystems." *Ambio* 31(2): 102–112.

Rabalais NN, RE Turner, BK Sen Gupta, DF Boesch, P Chapman, and MC Murrell. 2007. "Hypoxia in the Northern Gulf of Mexico: Does the Science Support the Plan to Reduce, Mitigate, and Control Hypoxia?" *Estuaries and Coasts* 30(5): 753–772.

Reijnders L. 2006. Conditions for the sustainability of biomass based fuel use. *Energy Policy* 34: 863–876.

Rosenthal D, H Gruenspecht, and E Moran. 1995. "Effects of global warming on energy use for space heathing and cooling in the United States." *Energy Journal* 16(2): 77-96.

Roth RR. 1976. "Spatial heterogeneity and bird species diversity." *Ecology* 57: 773–82.

Ruth M and A Lin. 2006. "Regional Energy Demand and Adaptations to Climate Change: Methodology and Application to the State of Maryland." *Energy Policy* 34: 2820-2833.

Sailor D. 2001. "Relating Residential and Commercial Sector Electricity Loads to Climate-Evaluating State Level Sensitivites and Vulnerabilities." *Energy* 26(7): 645-657.

ScienceDaily. 2009. "Bioenergy Makes Heavy Demands on Scarce Water Supplies." Available at http://www.sciencedaily.com/releases/2009/06/090603091737.htm.

Siemann E. 1998. "Experimental Tests of Effects of Plant Productivity and Diversity on Grassland Arthropod Diversity." *Ecology* 79(6): 2057–2070.

Simpkins WW, MR Burkart, MF Helmke, TN, Twedt, DE James, RJ Jaquis, and KJ Cole. 2002. "Potential Impact of Earthen Waste Storage Structures on Water Resources in Iowa." *Journal of the American Water Resources Association* 38(3): 759–771.

Simpson TW, AN Sharpley, RW Howarth, HW Paerl, and KR Mankin. 2008. "The New Gold Rush: Fueling Ethanol Production While Protecting Water Quality." *Journal of Environmental Quality* 37: 318–324.

Singh Prasad SA, N Jain, and HC Joshi. 2007. "Ethanol Production from Sweet Sorghum Syrup for Utilization as Automotive Fuel in India." *Energy Fuels* 21: 2415–2420.

Slingo JM, AJ Challinor, BJ Hoskins, and TR Wheeler. 2005. "Introduction: Food Crops in a Changing Climate." Philosophical Transactions of the Royal Society B: Biological Sciences 360(1463): 1983–1989.

Sovacool B. 2009. "Rejecting Renewables: The Socio-Technical Impediments to Renewable Electricity in the United States." *Energy Policy* 37(11): 4500-4513. DOI: 10.1016/j.enpol.2009.05.073.

Stone K, P Hunt, K Cantrell, and KS Ro. 2010. "The Potential Impacts of Biomass Feedstock Production on Water Resource Availability." *Bioresource Technology* 101(6): 2014-2025. DOI: 10.1016/j.biortech.2009.10.037.

Tomer M and K Schilling. 2009. "A Simple Approach to Distinguish Land-Use and Climate-Change Effects on Watershed Hydrology." *Journal of Hydrology* 376(1-2): 24-33. DOI: 10.1016/j.jhydrol.2009.07.029.

Twomey KM, AS Stillwell, and ME Webber. 2009. "The Water Quality and Energy Impacts of Biofuels." In: *Proceedings of the ASME Third International Conference on Energy Sustainability*.

Valor E, V Meneu, and V Caselles. 2001. "Daily Air Temperature and Electricty Load in Spain." *Journal of Applied Meteorology* 40: 1413-1421.

Vries B, D Vuuren, and M Hoogwijk. 2007. "Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach." *Energy Policy* 35(4): 2590-2610. DOI: 10.1016/j.enpol.2006.09.002.

Wilbanks TJ, P Romero Lankao, M Bao, F Berkhout, S Cairncross, JP Ceron, M Kapshe, R Muir-Wood and R Zapata-Marti. 2007. "Industry, settlement and society." In Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change – Chapter 7, Cambridge University Press, Cambridge, United Kingdom 357-390.

Wuebbles D and K Hayhoe. 2004. "Climate Change Projections for the United States Midwest." *Mitigation and Adaptation Strategies for Global Change* 9(4): 335-363.

Wuebbles D, K Hayhoe, and J Parzen. 2010. "Introduction: Assessing the Effects of Climate Change on Chicago and the Great Lakes."*Journal of Great Lakes Research* 36(s2): 1-6. DOI: 10.1016/j.jglr.2009.09.009.

USDA-NASS. 2004. *Farm and Ranch Irrigation Survey (2003), Volume 3, Special Studies Part 1, AC-02-SS-1, of the 2002 Census of Agriculture.* AC-02-SS-1, U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, DC. Available at http://www.agcensus.usda.gov/Publications/2002/FRIS/fris03.pdf.

USDA. 2008. *Acreage Report*. National Agriculture Statistics Service, U.S. Department of Agriculture: Washington, DC, June 2008; p 41.

U.S. Geological Survey. 2008. *Hypoxia in the Gulf of Mexico Studies*. Reston, Virginia. Available at http://toxics.usgs.gov/hypoxia/.

U.S.-Water News Online, 2005. Accessed October 9, 2008 at http://www.uswaternews.com/archives/arcsupply/5nebrfarm4.html.

Distribution

No. of
Copies

No. of
Copies

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov