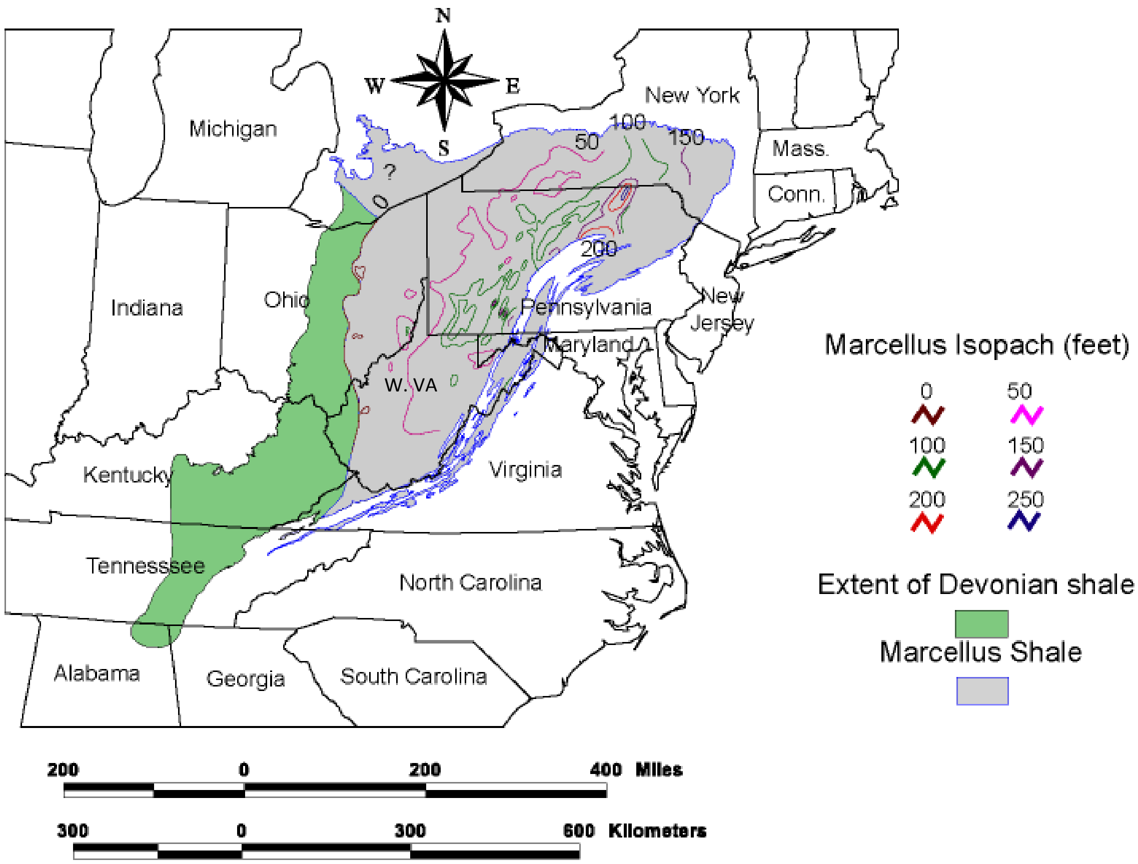
Energy Transitions: A Systems Approach Including Marcellus Shale Gas Development



A Report of a Study Group Sponsored by The Atkinson Center for a Sustainable Future Cornell University

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Executive Summary

In the 21st century new sources of energy will be needed across the globe, as easily available fossil fuels are exhausted, as we try to minimize the adverse environmental and other costs of fossil fuel extraction, and as we move towards fully sustainable energy sources. New sources of energy will both enable and *require* major transformations in the communities in which they are developed. Many of these energy sources will be alternative, renewable sources, but at least in the short term many may be new ways of extracting and using hydrocarbons such as natural gas. Whereas an overall goal for the century is to achieve a sustainable system of energy sources globally, some very strong short-term drivers of energy transitions reflect rising concerns over energy security and economic growth. As an example, these will undoubtedly lead to increased use of unconventional gas resources as a result of declining supplies of conventional resources, local and regional economic pressures, and, more broadly, the geopolitics of energy. Consequently, some regional and national energy transitions initially will likely only be bridges toward full sustainability.

Given energy's critical role in the economy, our way of life, jobs, the global power balance, the balance of trade, and the environment, we must learn how to manage many different energy transitions wisely and effectively. Many faculty, staff, and students at Cornell University have begun studying aspects of these upcoming transitions. In this document we present the results of one group project involving more than a dozen faculty and staff from a wide range of disciplines at Cornell University. We studied the overall problem of energy transitions taking a systems view, and including environmental, regulatory, social, economic, business, and job implications of upcoming transitions and necessary decisions. This approach is different than many other studies that focus on parts of energy source impacts in isolation from some of their interactions with a range of environmental, economic, and societal issues. Such work has led to poor energy decisions in the past, such as corn-grain based ethanol. As a particular case study of energy transitions we focused on the case of unconventional natural gas recovery from the Marcellus shale

In addition to the specific questions identified for the case of Marcellus shale gas in New York, we have identified the key *overall* energy transition questions that include:

1. For various energy sources what will be the life-cycle impacts and cost structures, including the activities of capital availability, exploration, construction, production, operations, and infrastructure management, as well as eventual end of use and reclamation of the system components?

2. What will be the life cycle, environmental, social equity, and job implications of energy source development in a community or region? How do these differ from the perceptions of different affected publics?

3. What are the essential and critical operations of the regional economy, associated activities, policies and regulation that must be included in a comprehensive integrated assessment of the impacts of an energy source? What is the relative costs/risk/benefit analysis of extraction or operations in a region *vs.* alternative sources of energy in other regions?

4. How are many of the above questions are affected by inter- (and intra-) state and nation variations in policies, regulations and the background socio-economic conditions found therein?

To answer these questions and more effectively engage the public and policymakers, we are continuing to develop further information and models that will guide decision making.

INTRODUCTION

Widespread transitions of energy systems are inevitable over the span of the next 100 years as consequences of global demand for increased energy consumption, depletion of finite natural resources, concerns about the environmental impacts of fossil fuels at local to global scales, and technological advances. Yet transitions of energy systems are among the most complex issues facing communities, nations, and the world. Such transitions encompass physical, engineering, and social transitions. How we manage these transitions will determine the quality of life of future generations.

Therefore, we began a series of wide-ranging interdisciplinary research projects, based on principles of complex adaptive systems, to increase collective understanding of the connections among the underlying energy technologies and key social, economic, and environmental phenomena. Such understanding will support a broad range of decisions, spanning business investments, community planning, environmental management and mitigation, and the development of effective regulatory programs and tax policies. Cornell University is ideally positioned to be a leader for this kind of study because of its outstanding strengths in both the relevant disciplinary areas and in the existence of an atmosphere conducive to cross disciplinary and systems research with real-world applications. As New York State's Land Grant University with a Cooperative Extension system that links research activities to the public, Cornell can and should assist the state's population to integrate the new energy system knowledge into their decisions and actions.

We have been pursuing the development of this understanding of complex energy transitions through the mechanism of a current real-world case study focused on the recovery of natural gas from the Marcellus Shale. Our case study and more general investigations focus on the systems and their whole life cycles, as well as on key components of the systems. The system components include geological, hydrological, industrial, infrastructural, social, political, and fiscal aspects to which the system behavior is particularly sensitive. Investigation of these interdependent system components will eventually be facilitated in part by development and implementation of a set of complementary spatial dynamic systems models and supporting visualization tools and decision- and planning-support capabilities. The ultimate goal of the proposed research is to facilitate the achievement of energy transitions while supporting those individuals and groups who will make the important decisions through political processes. Thus the knowledge gained through our research must be transformed into actionable public understanding of the relevant findings. To that end, we are simultaneously investigating best practices for promoting public understanding of the relevant findings and for involving stakeholders in policy discussions.

More specifically, we are investigating the interactions among natural variability in the energy resource, natural variability of environmental sensitivity, technology, evolving economic relationships, community understanding of consequences, society's decisions, and outcomes. This suite of key components interacts in the Marcellus shale gas development system and these components would also be components of all other major energy transitions. Many people in Cornell's research community are working on gathering or developing knowledge of these components in the Marcellus system.

Cornell University's commitments to research, education, and engagement, embodied in its Land Grant Mission, are all central facets in the envisioned systems study of the case of the Marcellus shale gas regional energy transformation.

SYSTEMS VIEW OF ENERGY SOURCES

There are many possible sources of energy, whose uses are affected by considerations of economics, the environment and community interests (Fig. 1). All the possible sources have some economic and environmental effects, risks, and benefits. An overall goal for the century is to achieve a more sustainable system of energy sources globally. But because depletion of resources and global politics play very important roles in the current energy system, some regional and national energy transitions will occur with lesser consideration for sustainable outcomes. Communities need to make informed decisions about global and regional energy sources and technologies, either for the short or long term. These decisions will need to maximize benefits and minimize risks in the region but also be consistent with global objectives. Quantitative characterization of interactions among the economics, environment and community interests is needed. Such information will then help the public and decision makers decide on whether and how to proceed based on better information on likely outcomes for the regional and global environment, economics, types and stability of jobs, risks, etc.

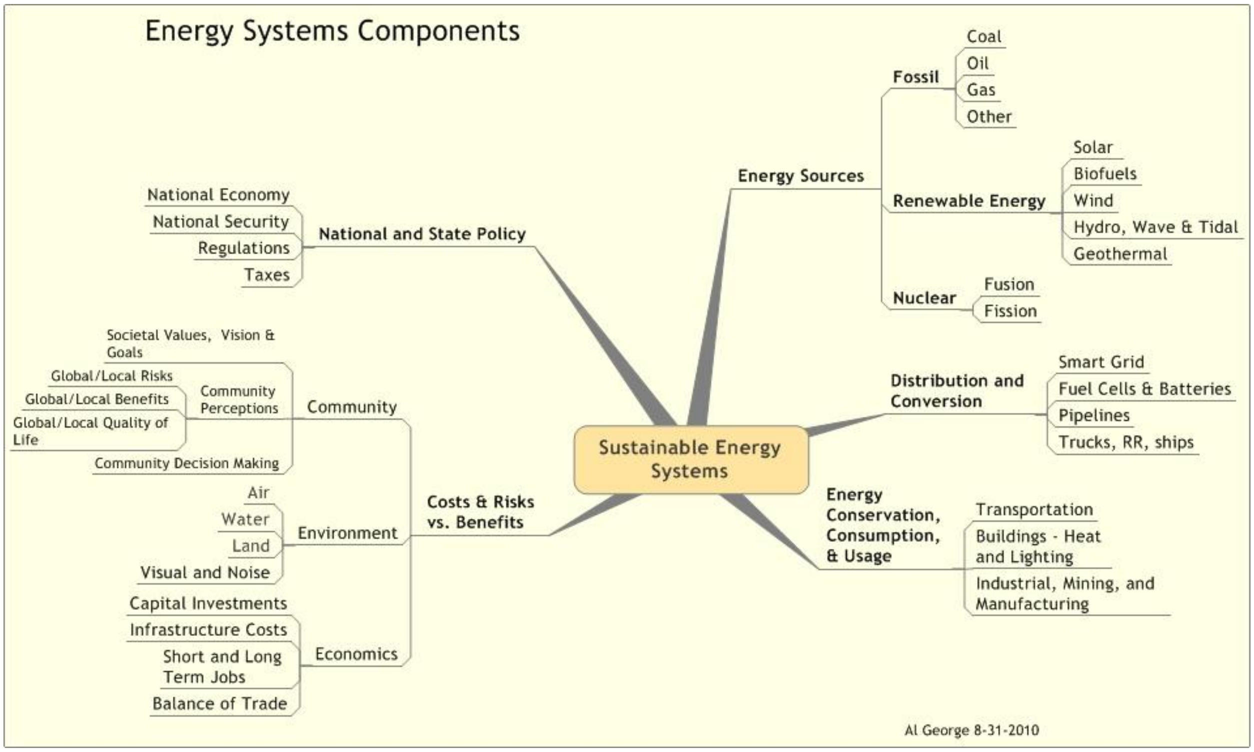


Figure 1. Numerous interacting components of any energy system each contributes attributes to the whole, and interacts with other components. The objective of 21st century energy transition is to achieve sustainable energy supplies, at scales ranging from local to global.

While these goals are simple to state, there is currently no means by which to rigorously explore the probable system-wide outcomes of changes to components of the system. The public needs the ability to foresee consequences of a range of scenarios, but multi-disciplinary and interdisciplinary research is needed before relevant decision-support tools can be made available.

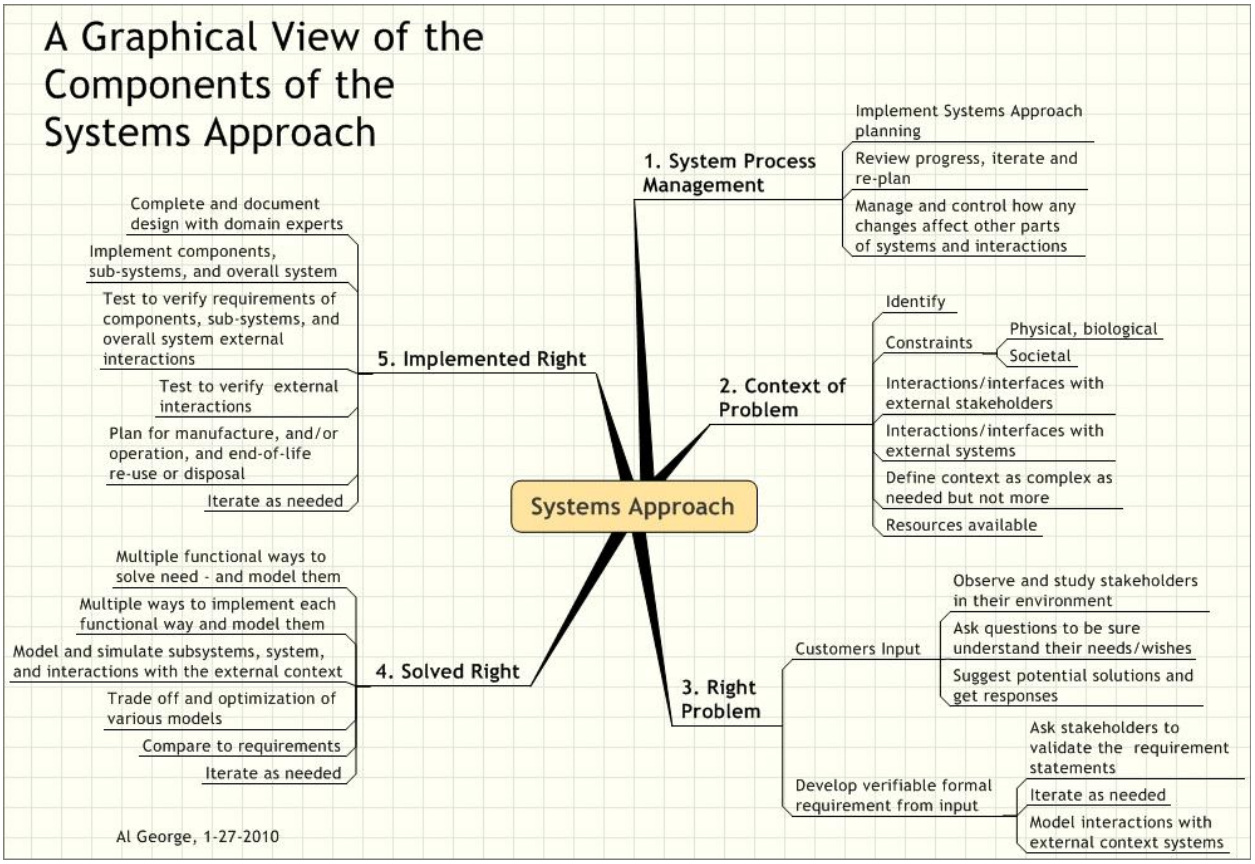
A life-cycle systems approach is essential to understand how to devise systems whose outcomes will be judged successful by stakeholders. Such an approach is structured to begin by carefully defining the problem, systems boundaries, desired outcomes, requirements, and constraints. The systems approach then devises multiple possible solutions, models and optimizes them, and compares the results to the requirements. Figure 2 illustrates five sequential steps in this approach.

Our approach proceeds in four parts, as does this white paper:

1. A definition of the research problem and an assessment of its importance in relation to the general problem of transitions to more sustainable energy.
2. Characterization of natural gas drilling and production in the Marcellus shale case to achieve improved understanding of the range of parameters that could be anticipated in a particular region. These aspects include a) geologic setting, b) drilling and stimulation technology, c) water issues, d) social and economic issues, and e) regulatory and governmental policy issues.
3. Development of a strategy for constructing a framework to support the research proposed.

4. Methods for dissemination of research findings, engagement, and outreach.

Figure 2. A graphical view of the components of the Systems Approach.



1. PROBLEM DEFINITION AND IMPORTANCE

The nation anticipates an all encompassing transition in energy sources during the 21st century, motivated by the issues of fossil fuels depletion, effects on climate of GHG emissions from the use of fossil fuels, persistent concerns about environmental health and safety of various fossil fuel development operations, balance of trade, and national security. Recent missteps with potential sources of energy—such as corn-grain based ethanol, gasoline additives (MTBE), and coal methanol—and their utilization provide examples of the actual complexity of the system issues. Managing these coming energy transitions to best effect is a daunting task.

To minimize turmoil across our economy and society, we will have to develop a range of mechanisms to advance key technologies and successfully usher them into implementation. The challenge will be to identify which technologies also have the potential to strike the best balance between economic and environmental concerns at a large scale, while at a more granular level promote equity across society in the benefits generated and the life-cycle costs that must be incurred to bring the energy transition to fruition. In other words, the transitions must be looked at as interdependent complex system transformations rather than as a series of weakly connected technological, economic, and environmental activities. The key mechanisms society has at its disposal to guide these transitions are education of the electorate and policy makers, investment (both public and private) in alternative infrastructure systems, regulation, and financial inducements (taxes and tax incentives).

Decision-making by numerous stakeholders will play a critical role in various energy transitions. Those decisions will focus on distinctly different spatial scales, from national to regional to local, and time scales from years to centuries. Today, the current frame for community decision-making (Figure 3a) often focuses both too narrowly and too myopically on short-term regulatory and tax policies. If today's decisions are made without a clear understanding of how, through systems interactions, those decisions will translate into long-term impacts on the economic well-being of the full range of stakeholders, on the environment, and on the social fabric of society, each at a range of scales, unintended, and with dire consequences that could ensue.

Debate tends strongly to polarization around the choices of energy sources and technologies. Yet the decisions are not well informed about the systems aspects of the energy choices, including the necessity to choose *some* new energy sources, the economic consequences of the choices, and the *comparative* risks of each choice. Decisions will result in trade-offs, but the trade-offs are not currently clearly visible. A significant part of current heated disagreement about energy transition decisions results from the lack of sufficient means to assess the multi-faceted life-cycle costs and benefits in these complex, dynamic systems which couple multiple natural and human phenomena.

We are undertaking research that will enable adoption of a broader decision and discussion frame (Figure 3b). Our research integrates a range of disciplines into an interdisciplinary understanding of how to optimize interconnected decisions, while leaving the definition of "optimum" to the community. Among the research products will be new tools with which to assess the system-wide outcomes. Use of these tools by communities to inform considerations of regulatory and tax policies will support an energy transition that is effective in the long run.

We propose to hone this approach using a single regional energy transition that is underway, specifically the production of natural gas from shale. To ascertain the comparative risks and benefits of shale gas versus other energy source and technology options will ultimately require parallel system studies of those other choices. Nevertheless, to avoid years of delay, the current study will rely on the best available information about other energy sources and technologies without waiting for completion by other groups of up-to-date system studies of all of the alternatives.

Overcoming the current limited decision focus requires that the research include *innovations in systems analysis*. The goals of the new tools and models will be stated in terms of objectives at a level higher than they are presently, for example as environmental quality, social and economic well-being of a range of stakeholders, and equitability in the distribution of a full range of both the benefits and the costs (economic, environmental, and social) of the transition. This reframing of the discussion will help foster regulatory and tax policy transparency, and will promote a widespread understanding of goals to be achieved by their adoption.

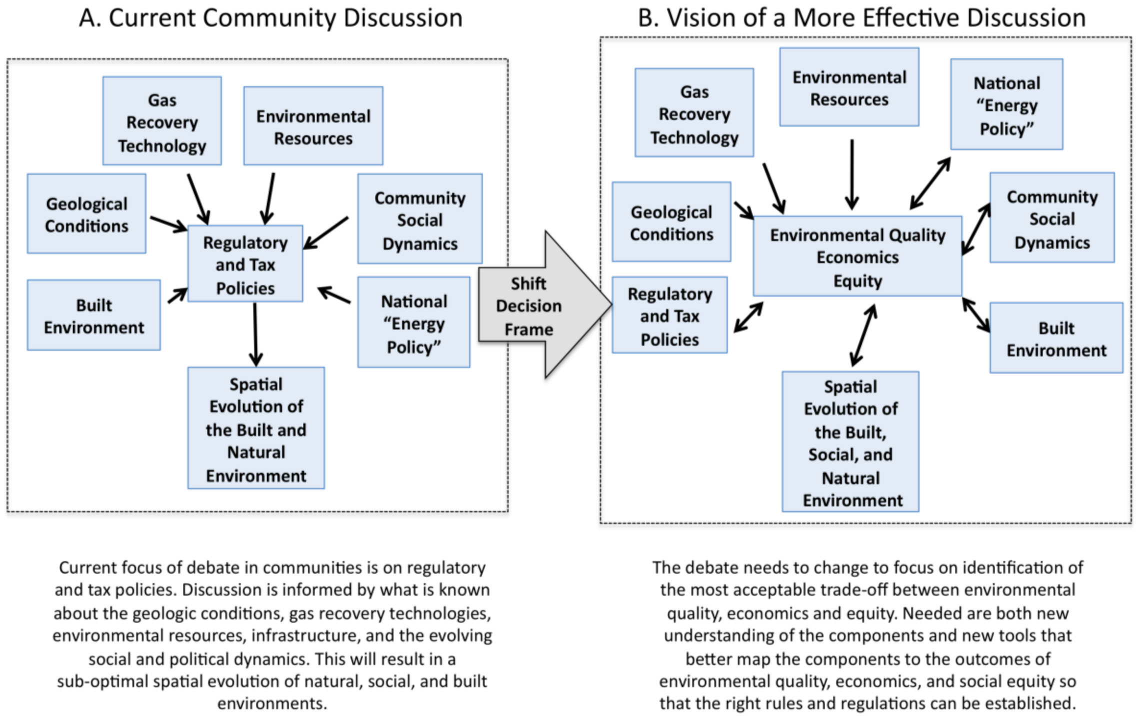


Figure 3. (a) Traditional, and (b) Proposed new framework of decisions about energy transitions.

We are pursuing the development of such frameworks through a real-world case study focused on the recovery of gas from the Marcellus Shale. In numerous parts of the U.S., exploitation of natural gas from shales emerged from higher fuel prices and improved technologies to become a fast-advancing industrial phenomenon moving into regions that had not previously seen similar scales of energy production. In West Virginia, Pennsylvania and New York State, production activity from the Marcellus Shale either began in the last two years or may shortly commence in high volume, even as the appropriateness of statutory controls of the environmental impacts of this activity are under debate. Not only the environmental impacts of drilling are uncertain, but also the extent and nature of potential socio-economic risks and outcomes are unclear. Put in the context of the benefits and risks of other energy source and technology options, it may be the case that exploration for and extraction of natural gas from the Marcellus Shale are, or are not, important activities to pursue as part of a strategy to transition to a sustainable *regional* energy system. We envision it, however, as emblematic of a larger suite of examples, most of which involve reducing the impact of fossil fuel-based energy production and substitution of renewable energy resources. By studying natural gas recovery and use, environmental impacts, and community impacts we hope to gain important insights into the larger class of problems inherent in managing other transitions to more sustainable lifestyles.

We believe that the development of such an overall framework requires the advancement of knowledge in a range of areas as well as advancement of the capability to integrate much of that knowledge together into systems-level models. There are two key goals of the research activity:

1. Develop the ability to map key decisions into long-term life-cycle impacts like environmental quality and the distribution of economic benefits and costs
2. Seek an understanding of how different elements of the system come together to generate emergent system behavior. Such understanding would make it easier to identify what additional information is needed to improve our ability to predict the outcomes of key decisions.

Cornell University is ideally positioned for this research. Cornell's research in the component parts and in systems analysis is broad and very strong. Cornell's status as a land grant university positions it well to contribute to resolving these issues. Cornell University has an atmosphere conducive to cross-disciplinary and systems research with real-world applications.

We now proceed to a description of some of the key issues that must be explored in order to develop a systems level perspective on the development of the Marcellus Shale.

2. KEY ISSUES TO BE EXPLORED

The development of the Marcellus Shale gas recovery system is impacted by a range of issues, which can be broadly categorized in three areas:

1. Those natural and technical issues associated with the recovery of the gas from the shale and its environmental impact,
2. Those associated with the community acceptance and regulatory environment, and
3. Those associated with international energy markets and the financial markets that govern investment and exploitation of opportunities associated with the development of the shale in relation to other sources of energy.

Clearly there are interdependencies between these three broad categories of issues, and understanding their inter-relationships is critical to effective decision support. Below we highlight the systems aspects of each category, and in an appendix we provide information about more disciplinary issues in those categories.

The three sets of issues will be major factors determining the extent of the development of the Marcellus shale, or any new local energy source such as wind or biomass. Also these features affect the character and risk to the community posed by the development. The decisions by communities, landowners and gas development companies as to whether or not to proceed, and how, are affected by a range of details: by projections of natural resource recovery from specific locations, by policies (concerning well pad size, location, spacing, and numbers of bores), by local, regional and state taxes, by environmental regulations and their enforcement, by liability laws, by the types and amount of required disclosure of information, by identifying the corresponding risks that influence energy prices, and ultimately by our operative understanding of how to proceed with the phasing in and out of infrastructure systems for progressively more sustainable energy production and distribution. The cumulative impacts of the numerous life-cycle costs and benefits are important to nearly all the stakeholders, but are hard to capture other than through coupling of the components in a system-wide model.

Natural and technical issues

Uncertainty on Gas Recovery Potential

Like any mineral resource that is extracted and recovered from underground, there is inherent uncertainty both in the total amount of a particular resource present as well as in the amount that can be extracted. The former is often referred to the *resource base*; the latter is referred to as the *reserve or recoverable resource*, and is a function of both technical issues and the magnitude of economic investment made to extract the resource. Estimates of the resource base and the recoverable resource are subject to large uncertainties, with the result that there can be orders of magnitude variation in estimates of both resource base and reserves. The Marcellus gas resource fits this pattern: for the resource base, estimates vary from 2 TCF (2002 USGS Assessment of Undiscovered Oil and Gas Resources of the Appalachian Basin Province) to almost 900 TCF. There is an equally wide range in estimates of what percent might be technically and economically recoverable resource (Engelder 2008[1]). Even for a single group like the U.S. Geological Survey, the range of estimates can be large because knowledge evolves through time (compare Soeder and Kappel 2009[2] to earlier work). As production proceeds in a particular field or local region, the uncertainties will naturally decline but often these improved estimates are closely guarded by the developer and not publically available. Nevertheless, a quantitative picture of anticipated ranges with appropriate probability ranges for the recoverable gas resource needs to be a part of any systems assessment.

Geology and Drilling

Though it is well known that the Marcellus Formation varies geologically across its geographical range, and although we have a general knowledge of the geologic history of the basin, we have very few data publicly available on the temporal-spatial variation of quantities such as organic matter and natural gas concentrations, rheological properties, permeability, formation water chemistry, and naturally occurring radioactive materials (NORMs). Acquisition of the data for these properties is considered a high priority for both basic understanding of the opportunities and risks of Marcellus shale gas drilling and for accurate modeling of gas drilling systems. Areas of needed geological research are the potential for induced seismicity and the induced migration of natural gas at a distance from the boreholes. Background information must be collected to characterize the natural micro-seismicity and pre-drilling gas migration to the surface, and their spatial variability. In addition, monitoring is needed to measure the impact of hydrofracturing on micro-seismicity and gas migration.

Water Withdrawals and Quality

Exploiting gas in the Marcellus Shale using horizontal hydrofracturing requires the withdrawal of water from nearby surface waters and possibly groundwater. The Susquehanna River Basin Commission (SRBC) estimates that the cumulative consumptive use of water in the Susquehanna River Basin for shale gas well hydrofracturing could be 28 mgd, which is only about 5% of current total daily consumptive use in the basin. The SRBC has since indicated that this value may

[1] Engelder, T., 2009, Marcellus, 2008: Report card on the breakout year for gas production in the Appalachian Basin: Fort Worth Basin Oil and Gas Magazine, August 2009, p. 19-22.

[2] Soeder, D. J., and Kappel, W. M., 2009, Water resources and natural gas production from the Marcellus Shale, USGS Fact Sheet 2009-3032.

be too high, as they assumed no reuse of flowback water for hydrofracturing, but reuse is now occurring in Pennsylvania. This evaluation suggests that the annually available basin wide surface water resources are sufficient to support likely rates of gas drilling in the Marcellus. However, regulations are needed to mitigate environmental and drinking water supply impacts of cumulative water withdrawals during specific times and within specific stream systems.

Regulations governing water basins are not uniform in New York State or Pennsylvania. It is likely that this array of regulatory structures will differentially impact the development of gas well drilling in these different regions. The proposed systems framework could be used to explore the water resources impact of the different regulatory structures (including pass-by flow requirements) in the different basins in which Marcellus drilling may occur, as well as the impacts on intensity and progression of drilling.

The locations where water will be collected to supply the drilling operation need to be carefully considered. Conditions to take into consideration include the sufficiency of natural stream flow, the spatially heterogeneous natural environmental needs and the community water resource needs. Also important are the consequences of the alternative sources for highway infrastructure and water transportation costs to the gas producer. A systems model should be used to evaluate tradeoffs in costs, road disturbances, and ecosystems services between locating water withdrawals in a central versus more distributed manner, and between piping versus trucking water to drill sites.

Water quality issues of two types pertain to gas drilling in the Marcellus Shale. First, there is the possibility of surface discharge and environmental effects of drilling and fracturing chemicals and flowback water. Storm water runoff from disturbed surfaces such as the well pads, access roads, and gas connector lines could also impact surface water quality. In addition to water pollution via the land surface, gas drilling may also impact groundwater quality from below ground due to improper casing and/or gas migration. The model we are developing could be used to evaluate a number of scenarios to assess the impact of gas drilling on water quality.

Comparative Environmental Impacts of Shale Gas Relative to Other Energy Sources

One of the motivations for undertaking transitions of the energy system is to mitigate ongoing global climate change. Yet the relative greenhouse gas emissions of transitioning to rely heavily on shale gas rather than remaining dependent on coal or instead converting to an unrelated energy source are unclear. Although the greenhouse gas emissions caused by combustion of the fossil fuel are well documented, the life-cycle emissions of the work of finding, producing, and distributing the fossil fuels are not. In total, the greenhouse gas benefits or costs of Marcellus shale gas production are highly uncertain. The development of a life-cycle emissions assessment for shale gas development must be completed and compared to the life-cycle emissions associated with coal use, various biomass energy technologies, and other plausible alternative energy raw materials and technologies.

Natural and Managed Land Uses

Landscape impacts of drilling may include natural systems (hillslope runoff and gullying, ecosystem services, ecosystem fragmentation) as well as local and regional landscapes managed for economic gain. Rural economies are particularly dependent on the maintenance of high quality land resources, which support agriculture, forestry, and tourism. Tourism, in turn, includes hunting and fishing and depends on scenic esthetics. While individual landowners may focus on the potential impacts of a single well pad, a community concern is for the cumulative impact of the set of well pads over the lifespan of the Marcellus gas play. The spatial density of the well pads, the timeframe over which well pad construction and maintenance occurs, and the amount of land impacted to construct connector lines and access roads all influence the amount of land disturbed and the fragmentation of the landscape. These in turn impact storm water runoff, erosion, invasive species, and wildlife habitats. Access roads, well pads, and collector pipelines are also factors that come into play after the well fields have been developed, since access and rights of way must be maintained. Using the proposed systems modeling framework, we are exploring the cumulative impacts of various gas development scenarios and regulatory structures on the landscape impacts.

Drilling and Production Technologies and Infrastructure

There is sufficient evidence that some incidents of environmental damages have resulted from shale gas development, and that there are some inherent risks and uncertainties connected to the drilling, fracturing and production methods. Effort is needed to sort through the anecdotal information to make a clear distinction between occasional problems associated with improper engineering practice and problems that are systemic technical issues. For example, leakage behind steel casing as a result of poor cementing practice has led to gas migration into homes as well as water aquifer contamination by fracturing fluids that have migrated under pressure from much deeper shale deposits. This kind of damage is avoidable and quite different than the potential risk of contamination caused by reservoir or fracturing fluids that may migrate sufficiently upward to reach drinking water aquifers, enabled by preferential flow along vertical fractures that have been created and have propagated upwards by the gas stimulation procedures. Surface management of well site materials also poses risks of contamination of soils and surface waters, some of which is avoidable through compliance with appropriate regulations regarding containment and treatment of flow-back fracturing fluids and co-produced water during gas production. Identification of the issues that can be effectively managed by on-site practices that can be monitored, as distinct from those issues that are naturally or technologically beyond reliable management, will inform decisions about locations to exclude from shale gas development as well as about the oversight of drilling and fracturing operations and penalties.

Transportation Infrastructure

As in the case of all exploitation of natural resources, a transportation infrastructure is vital. Highway network properties influence the decisions of operating companies, the physical roadways that will be impacted by heavy vehicle traffic. Also, the communities who live along and travel over the highways will be impacted in new ways by traffic and maintenance. For example, with hydrofracturing, hundreds of truck trips between the source of the water and a given well site may be required to have sufficient water available on site. Impacts on transportation networks also affect commerce and supply chains of other industries operating in the region.

Monitoring Strategies

A major issue related to managing impacts of horizontal drilling in the Marcellus Shale is monitoring of well site work, pipelines, and transportation networks. To date the list of attributes and locations now considered important to monitor is long (e.g., water withdrawals including its timing; surface conditions at well pad and access roads inclusive of spills, erosion, and compliance with accepted stormwater pollution prevention plans; aquifer quality within and surrounding well fields; traffic on public roads; traffic at water withdrawal sites; maintenance of pass-by flows in streams). Yet the list is likely to grow even longer because additional attributes will be deemed important to monitor as shale development and knowledge progress. The NYS Department of Environmental Conservation (NYS DEC) has responsibility for these activities, but does not currently have the capacity to monitor effectively. As part of our research, we are evaluating the need for monitoring, recommend monitoring plan(s), quantify resources needed for the monitoring, and evaluate the role of enforcement in maintaining compliance with rules and permit conditions over long periods of time. A database of monitoring results can be built for use by NYS DEC and as input to system models, which could thereafter be maintained by NYS DEC.

<u>Community Acceptance, Education, and Regulatory Environment</u>

Concerns, Opportunities, and Decisions

The on-going large-scale re-orientation of the nation's energy supply will have dramatic implications for the sustainability of rural communities and small- and medium-size cities in the Northeast and in the nation as a whole. Emerging energy development opportunities are potentially attractive both as a stimulus for local economies and to provide alternative sustainable energy.

However, it is not well understood what system-wide effects will result from these partial or complete energy transformations, individually and cumulatively. This uncertainty is dramatically increased when we consider the full range of energy source scenarios needed to achieve sustainability, a range that includes both short-term transitional energy sources and long-term energy sources. As a consequence, there are no complete answers about the impacts on the sustainability of their communities for stakeholders facing the effects of exploration, exploitation, and transport of intermediate (natural gas) and "green" energy projects. For the communities, sustainability encompasses economic, environmental, and social qualities. Positive and negative impacts of importance to communities include local ecological systems, land use, types of jobs created, economic inequality (including effects on property values), the quality of natural amenities, stresses on municipal services, and economic growth. The difficulty of projecting short- and long-term system effects is increased by the tempo of a natural resource exploitation pattern, which often leads to a "boom/bust" cycle of economic investment (see appendix).

The impacts on the workforce as well as on small business are complex and need to be looked at in terms of the various phases of natural gas development. We are interested in a focus on the Marcellus Shale as a way of building the capacity of local governments to address future energy development scenarios and to optimize economic development benefits. Planning, understanding the issues, and foresight can help to mitigate negative impacts. Further, there are advantages to collaboration among communities and municipalities at a regional level.

We intend that the systems modeling framework we develop serve not only as a device for conducting sophisticated thought experiments, but also as a planning tool which community representatives can use to envision the potential consequences of any chosen course of action. It is important for decision makers to understand from a systems view that opportunities and life-cycle costs depend in part on locally varying attributes of the earth, environment, and public opinion. Consequently, the potential rates of gas development, environmental impacts, and revenues (among other factors) will vary between communities. Understanding why these factors vary and what to expect will help officials make decisions that are most appropriate for their local communities. It is also important for local government leaders to understand basic systemic interrelationships within the Marcellus Shale gas production (or any other energy) system. In practical terms this means that any given decision (e.g., which energy resources to develop or not to develop; when and where to encourage development) will result in a string of causal economic and societal relationships that can be anticipated and assumed for planning purposes.

Whereas the distant future will hold judgments of the degree of success of the energy transitions achieved by the nation, region, and communities in this century, the decisions about policies and regulations are made on a very short-term basis, often related to the 2- to 6- year election cycle of community leaders. Decisions are made based on the perceived short-term risk profiles associated with any action or inaction, and are carried forward through behavior incentives, such as zoning, regulation of transportation and waste water, taxation and fees. If all goes well, the short-term decisions result in short-term enhanced wealth and social equity, new business and employment opportunities that are adapted to the new energy source(s), and mitigation of negative impacts that are consequences of the transition. But we need to ask whether the decisions move the region toward the simplest, least disruptive, optimal series of energy transitions, leading to achievement of a sufficient global energy supply, a sustainable economy, and social equity. A key facet of our study is to provide means for a community to identify the potential impacts over longer time spans of their short-term decisions and, in turn, the longer-term transition path that results from those decisions (Figure 3). Typically, the community decisions are only evaluated once, at the time an initial permit is awarded. Nevertheless, a newer and more robust system of performance review may be needed in order to make new energy resources work within the overall energy system.

A major question is whether long-term life-cycle social and economic benefits at the community level can be captured from the short-term expenditures that are part of the gas development process, rather than only the short-lived boom-town phenomenon. If long-term community opportunities can be foreseen, infrastructural and educational gains made in the short term may contribute to more sustainable long-term economic development. Business development and workforce development programs are critical to developing economic capacity in the communities where drilling occurs. Identification of opportunities requires systems-wide analyses. We are working to develop such analyses in collaboration with stakeholders and through modeling. A key goal is to illuminate to communities feasible long-term opportunities and strategies, and then to inform and assist them in crafting community-benefits agreements with the drilling companies to aid long-term development goals.

Education

Conveying to the public an understanding of the properties of complex adaptive systems is of vital importance. The progressive learning by all stakeholders will itself influence the development of the shale gas and other energy transitions. At present much debate is polarized between "not-in-my-back-yard but I want lots of cheap energy" and assurances that "everything will be fine if we trust the energy developers." Public education is needed to achieve the inevitable energy transitions in acceptable and sustainable manners.

Neither the public education system nor the media offer good models for educating our communities broadly about energy needs and choices or about complex system behavior. Yet individuals experience similarly dynamic, coupled systems in their own lives. Thus, if they are provided digestible information and tools they are quite capable of grasping the basics of the energy transitions trade-off decisions and the choices they will entail. Various stakeholders will use different styles of decision making, and their needs for information will differ. We need to explore pedagogical approaches that enable widespread appreciation of the choices to be made, the long-term and short-term costs and benefits at stake, and the value of information-based decisions.

Regulatory Frameworks

Assessments of current policies and the regulatory environment should embody a systems view. Evaluation is needed of various kinds of enabling legislation for permitting, water withdrawal controls, monitoring and other purposes. For example, various bills might be set forth to allow staff to be hired and a permitting and enforcement processes to be developed for the DEC or other agencies. But a systems analysis is needed to project how the details of plausible alternative regulations and monitoring would impact the efficiency and the effectiveness with which their objectives are achieved. Given the systems modeling framework and database of existing monitored data that we are developing, stakeholders could better foresee their needs and develop recommendations for comprehensive monitoring policies at multiple government levels.

<u>Economics</u>

Financial Issues and Opportunities

Energy systems are among the most complex and capital-intensive industries in the world. The fact that they are not optional (i.e. no industrialized western economy can substitute for competitively priced, on-demand supplies of electricity, natural gas and transportation fuels) makes the stability, access and operations of the energy system critical. This characteristic underlies much of the regulatory and policy oversight of the industry and the infrastructure that underpins it. As a consequence, access to capital and the special financing instruments that serve energy companies and dispatch or service agencies is a fundamental concern for long-term viability of the system.

Through most of the past century, energy-supply infrastructure and regulatory systems have favored a hydrocarbon-based fuel supply (coal and natural gas) through most of the United States, enabled by an extensive high voltage AC transmission system. Recent changes in emissions rules affecting coal in particular and declining reserves of traditional natural gas supplies have prompted industry research and development of unconventional gas supplies to augment and eventually replace existing resources. Advances in technology and horizontal drilling techniques have made these resources cost effective, and when viewed spatially, broadly accessible throughout North America.

Forecasts for available reserves of unconventional or tight gas or associated resources such as coal bed methane suggest very competitively priced supplies over a very long time, perhaps in excess of 50 years at the equivalent price of $4.50 (US) per Gigajoule. This iconic example or scenario, if true, has profound implications for other fossil resources such as coal as well as more environmentally benign resources such as hydropower or wind, solar and tidal resources. It is conceivable that price levels such as this, combined with the attractive dispatch characteristics of natural gas turbines, might impact the long-term viability and attractiveness of nuclear facilities as well.

How this transitional resource and the technology necessary to deploy it would be financed is a critical question for policy-makers and regulators in the energy industry. Issues such as

- Energy price impacts on investments for natural gas, competitive fossil fuels, and alternative energy must be examined in a manner that allows confident expectations of changes and competition between technologies
- Effects on the installed capital base of energy extraction, conversion, transmission and even storage facilities must be taken into account

In addition, the estimation, control, and pricing of carbon emissions associated with power system operation must be taken into account in the regulatory and environmental permit system.

The economic analysis must be broader and longer term than is common practice, to consider intergenerational criteria of a sustainable economy and a sustainable energy system. For a systems analysis, it will be vital to a treatment of life cycle costs to consider the costs of retiring the shale gas infrastructure when alternative energy technologies become mature.

Regional and Local Economic Opportunities Associated with the Development of the Shale

Natural gas drilling and development of associated infrastructure systems for processing and distribution of gas are being undertaken at great cost because of the great economic benefits. Attractive economic benefits are anticipated by a range of stakeholders, from the international gas industry, which stands to reap large profits, to land owners, who stand to receive large rents on their properties and to state and local governments that stand to garner large tax revenues. But expansion of the natural gas industry—or any other energy resource development industry—will exert many other strong influences (and multiples of such influences, or *multiplier effects*) on the regional economy through backwards and forwards economic linkages to industries that supply goods and services to the gas industry or purchase the same from the industry. Not all of these effects will be positive, as some industries and their workforces will be displaced, or the prices of inputs in different markets will be bid up through increased demand. There are growing concerns that such effects may induce what economists term a ‘resource curse’ effect. Studies comparing counties that have relied on gas extraction for economic growth to similar counties that did not have found that gas-reliant counties, over the long term, have had (1) less economic diversity and resilience, (2) lower levels of education in the workforce, (3) a greater gap between high and low income households, (4) a growing wage disparity between energy-related workers and all other workers, (5) less ability to attract investment and retirement dollars, and (6) economies that grew more slowly. The vagaries of international markets for energy sources will also play a role in regional markets.

Moreover, the economic costs of externalities of the activities related to extraction need to be reckoned. Through their inclusion in a systems model, we will illustrate their allocation over time and space to communities that will bear the costs or that must put in place measures to assess and recoup fair values of assessments of such impacts.

To study these potential economic and related effects, we plan to develop as part of the overall systems modeling framework a *dynamic spatial computable general equilibrium model* of the regional economy. This model will explicitly account for the strategic behaviors of different types of actors, underlying and interdependent infrastructure systems, all essential markets (local, domestic, and international) of all critical goods and services (including labor), the interaction of such markets, the movement over space of key commodities through transportation or other infrastructure networks, and related emissions of EPA so-called 'criteria pollutants.' (Much of this model is already under development in a US EPA STAR funded project involving four departments and three colleges at Cornell.) The model will lend itself to implementation in simulation experiments of policies and plans representing alternative approaches to managing changes over the short-run and longer decision-making horizons. The solutions to the model will be presented in visualizations employing 3-D GIS tools that can highlight the sensitivity of outcomes in space and time to changes in assumptions.

3. PROPOSED RESEARCH FRAMEWORK AND MODELING NEEDS

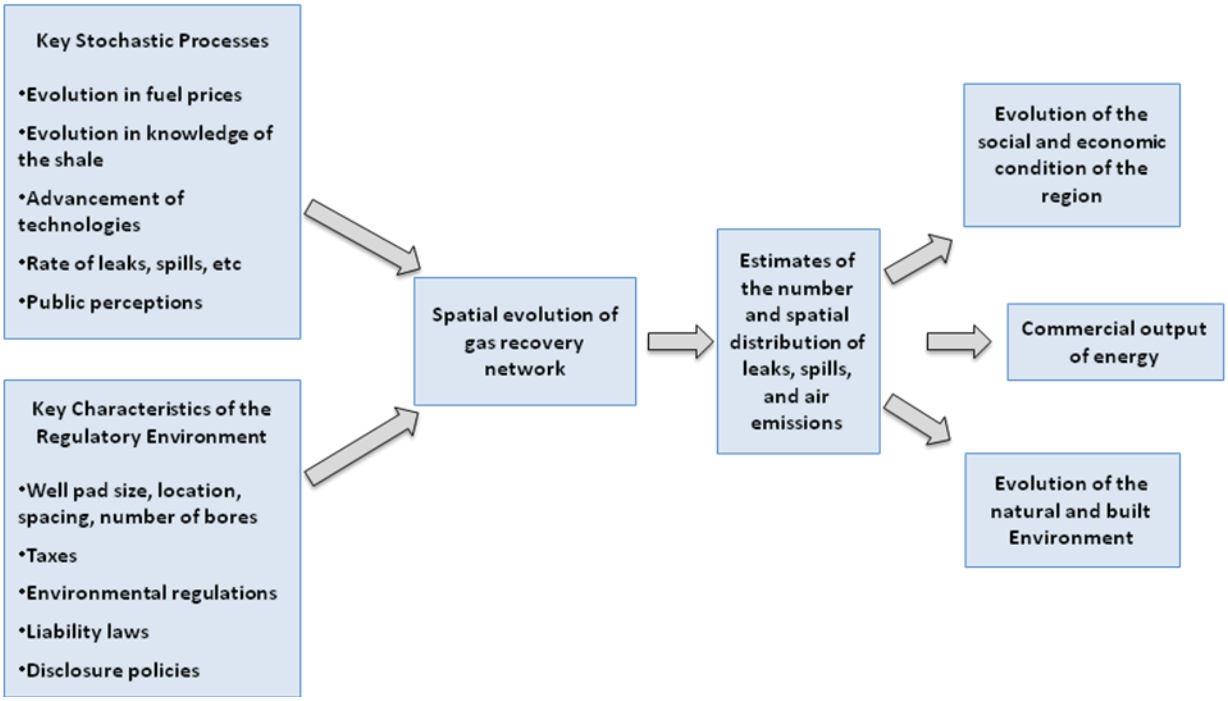
Developing an effective framework to support decision making in the development of the Marcellus Shale and other energy transitions is a critical but challenging activity. The components of energy development and its consequences interact, and the system ignores traditional disciplinary boundaries. We need a variety of formats for interactions of knowledge and experts from different disciplines. Some of the requisite interdisciplinary research has already been accomplished at Cornell, partly as a result of the present and past initiatives.

One of the ways to codify and enable an effective systems view is to develop models of the system and its dynamics. Using such models, one can demonstrate and study the systems interaction effects of various inputs, actions, and policies. Ideally the models should be clear in their assumptions and based strongly on disciplinary knowledge of inputs and on algorithms that simulate interactions. The models will be developed in stages, beginning with simple concepts and incrementally integrating more complexity and more connectivity with each other.

Developing a computationally effective modeling framework is critical for two reasons. First, and obviously, if they are well constructed, simulation models can be used to understand what actions lead to better outcomes in a particular case. In complicated systems like the Marcellus Shale, outcomes are often very hard to determine without sophisticated analytical tools, both because there are many inputs and because the inputs are dynamically coupled to one another. Second, and perhaps more important in this application area, a modeling tool can be used to clarify how our understanding of different aspects of the system either fit or do not fit together, and how well the results fit reality. In turn this critical examination of existing knowledge highlights where additional insight is needed. For example, the spatially varying characteristics of the geology in itself will have differing impacts on the relative economic viability of the development of the shale in different areas. Independently, the spatial distribution of community resources (e.g., land use values, landowner organizational capacity) across the shale and of attitudes about the role of government also will have a significant impact on the regulatory and tax structure that are enacted. Simultaneously, our knowledge base about the shale technology, the risks, and the alternative energy sources is evolving. In a computational environment that facilitates the integration of these diverse types of issues over a range of time scales, the inter-related impacts of many types of variables can become apparent.

Figure 4 illustrates the core idea behind this type of modeling framework. Many important elements that impact the shale gas outcomes cannot be known with certainty. Therefore, an important role of the development of these models is to consider the inherent uncertainty in important input parameters, such as the evolution in fuel prices, our knowledge of the shale and how its characteristics vary spatially, how hydrofracturing technology will evolve, etc.

Figure 4. Ultimate structure of the modeling framework. A set of models of the components of the overall system to be developed in stages, beginning with simple concepts and incrementally integrating more complexity and with more connectivity to each other.



Integrative models like this must be capable of predicting the spatial and temporal development of the supply network of drill pads and vertical and horizontal bore holes over a region on the scale of the entire Marcellus Shale, and then illuminating the social outcomes. If they will eventually be used to illustrate alternative socially beneficial development pattern, the models should take into account the impacts on the behavior of the system of varying regulations among states, river basins, and other sub-regions, as well as varying motivations of the public regarding infrastructure development.

Simulated patterns of spatial and temporal development will underlie steps that identify and quantify a range of environmental, social and economic impacts. Taking into account the system dynamics, both positive and negative economic and environmental consequences of different spatial and temporal development scenarios will be probed. The systems modeling framework also supports a range of risk-based analyses that explore issues like the cumulative impacts of aquifer disturbance, seal and casing leaks related to pollution of aquifers, spills or other releases of hydrofracturing fluids or their ingredients, and air emissions from well pad equipment and the related transportation. The models should also enable visualization of the footprint on the natural landscape created by the industrial processes.

In order to simulate the long-term behavior of the system, we expect to focus on behavior of the models across temporal scales of 5 years, 20 years (the interval of maximum rate of drill site development), and 50 years (the total interval over which most gas production is likely to take place). We will be able to use Marcellus Shale drilling in Pennsylvania and West Virginia, which has been occurring for about two years, to calibrate short-term behavior of components and of the full model system.

As mentioned above, the component models of the overall systems framework will be developed in stages, beginning with simple concepts and incrementally integrating more complexity and with more connectivity to each other. As examples of early simplifications, we expect to treat the gas companies as a single entity with an 'average' profile for costs and technological development. We would also simplify the variables influencing the gas company's decisions by assuming stochastic variability in energy prices, geological characteristics, and drilling technologies. These assumptions are likely to yield a multi-stage stochastic program. At advanced stages, we will probe alternative regulatory structures, the competitive strategic interactions between the drilling companies and landowners (or their coalitions), and cumulative impacts. These advanced stages will require the integration of key ideas from computational game theory for which each agent optimizes their actions over time based on an expanding knowledge base. Users of the advanced stage modeling framework will be able to explore scenarios to identify decision strategies that might maximize the benefits to sets of stakeholders or the whole system. It is hoped that this decision and planning support will ease the burden on the user and point them to the structure of policies that are likely to be quite useful. The model framework will also enable much faster development of models of other future alternative energy systems.

4. DISSEMINATION AND OUTREACH

Effectively explaining the nature and results of the project is essential to achieve our objective: the adoption of systems understanding, systems reasoning and the use of modeling results for guidance by relevant stakeholder communities. For credibility, it is essential that we rely on data and models that can be shared freely and that we are clear about the assumptions and uncertainty measures used for model construction and application. Our objective of assisting stakeholders to make wise decisions can best be achieved if the stakeholders can explore the outcomes of alternative decisions through our work and decision-support tools, but they will only do so if we make the results accessible.

Communication products will include models of the systems interactions, with which to foresee what are sometimes non-intuitive emergent properties of such a system. In order to help explain such technical topics, we plan to construct several very simple heuristic models with game-like dynamic graphical output that can be used to help stakeholder audiences understand how these models work. Furthermore, it is essential to develop high quality user-friendly graphics depicting the interactions and results for the full model. For example, it is important for communication that there be GIS-based visualization of the impacts created by a scenario or of the inputs to a full system model. These will be developed and evolve throughout the project.

Decision makers will ultimately have access to the various models, to experiment with parameters—and the sensitivity of solutions to parameter values—to better understand Marcellus drilling in their own communities. These individuals will need training on interpretation of the model results, and how to use the models for real-world application.

Cornell's academic strengths are enhanced greatly by Cornell Cooperative Extension (CCE) whose mission is to help New Yorkers improve their lives and communities. CCE acts to provide context and information and empower those individuals and communities so that all realize greater prosperity, self-sufficiency, and sustainability. CCE serves as an educational resource to citizen groups who wish to become better informed on complex issues.

CCE is already responding to a variety of stakeholders who seek a scientific, economic, and environmental understanding of the issues associated with Marcellus Shale natural gas exploration and drilling. These Marcellus Shale stakeholders who have sought CCE assistance include municipal bodies, community task forces, landowner coalitions, workforce and economic development networks, and environmental advocacy groups. There is a tremendous research and engagement opportunity as communities struggle with energy issues and look to a complex and unclear future. Municipalities and individuals are taking a closer look at energy conservation and renewable energy and are seeking guidance on how to bridge to a future that will have less reliance on fossil fuels and a reduced carbon footprint.

Likewise, the Paleontological Research Institution (PRI), an independent but Cornell-affiliated body, is a partner in dissemination and outreach. PRI has undertaken a major effort to develop and deliver materials for informal education regarding the natural gas resource and the environmental risks of shale gas development. PRI develops materials for audiences of all ages and backgrounds, including materials for use by K-12 teachers, and it reaches venues widely across the region.

The Marcellus Shale "discussion" has led to a broader dialogue about our collective energy needs, uses and sources. The "discussion" engages a much larger, more diverse, and more polarized regional constituency than had previously paid attention to energy issues. This attention provides unique advantages to educators and those working to create policy for future sustainable communities, as people are paying attention. The attention is also a challenge, because polarized participants tend to view information only for its strategic usefulness to their pre-existing positions rather than to inform themselves.

Results of the project will be made available in a wide variety of contexts, including (but not necessarily limited to) printed and website resources for decision makers and the general public, and presentations by project team personnel. Complementary materials will ultimately be adapted for teacher professional development for secondary school teachers and college faculty who integrate Marcellus Shale drilling issues (or energy transition issues in general) into their curricula. Cornell and PRI can and should be the leaders in the dissemination of the results of these studies.

GENERAL ENERY TRANSITIONS CONCLUSIONS

The key *overall* energy transition questions include:

1. For various energy sources what will be the life-cycle impacts and cost structures, including the activities of capital availability, exploration, construction, production, operations,

and infrastructure management, as well as eventual end of use and reclamation of the system components?

2. What information is there about baseline environmental, wildlife, land use, and community infrastructure quality; what are the expected changes and how will they be regulated, monitored, and controlled and at what costs, paid by whom?

3. What will be the life cycle, social equity, and job implications of energy source development in a community or region? How do these differ from the perceptions of different affected publics?

4. What are the essential and critical operations of the regional economy and associated activities that must be included in a comprehensive integrated assessment of the impacts of an energy source? What is the relative costs/risk/benefit analysis of extraction or operations in a region *vs.* alternative sources of energy in other regions?

5. How do global energy markets and regulation or subsidies influence operating company strategies and decisions about energy extraction choices and the pace and scale at which extraction takes place? How are tax revenues of various jurisdictions affected?

6. What pedagogical approaches and activities are best suited to impart an appreciation of these and kindred problems to a range of audiences, from state, local and national officials to K-16?

7. How are many of the above questions affected by inter (and intra) state and nation variations in policies, regulations and the background socio-economic conditions found therein?

A CALL TO ACTION

We conclude that there is an urgent need for research that will develop a systems approach to studying energy transitions. In addition to our launching formal studies of the Marcellus shale gas development system, as outlined above, we are committed to enhance broad understanding of the challenges of energy transitions. In particular, we propose the following:

- Engage more Cornell and other university and faculty, staff, and students in research and education pertaining to energy transformations
- Encourage dialogue about public issues.
- Continue to work with Penn State University, West Virginia University, and other universities on Marcellus and energy transitions issues.
- Continue working with a pilot communities to develop protocols and tools for building local governmental capacity to manage the shale gas transition

- Maintain an open dialogue with the range of energy constituents (researchers, educators, consumers, industry, local officials, environmental groups, etc.)
- Support the ongoing Land Grant natural gas education, engagement, and outreach initiatives

But a systems-wide study must rest upon knowledge of many components of the system, for which research is also needed. We strongly encourage researchers to engage in a broad range of investigations. Whereas the focus in this White Paper has been largely on the research needed for understanding of the system, the following is a list of questions about components in the Marcellus shale gas system for which answers need to be developed:

1. What key information/decision making systems are or should be used by people and organizations involved in energy choice decisions? How does their capability to absorb and need for different types of information influence their abilities to make decisions leading to short and long term benefits to individuals, communities and regions?

2. What information, models, data, and levels of complexity would help decision makers and the public make good choices? How do the above differ between decision makers and the general public? How do uncertainties and probabilistic effects in the models, their inputs, and available data affect the usefulness of the results? What are the choke points and nonlinearities in the existing systems; are threshold effects important, especially in consideration of cumulative impacts, or are linear assumptions adequate?

3. In regions being developed for natural gas, what were the relevant baseline water properties? What are the water withdrawal requirements? What are documented, statistically valid, relevant changes associated with drilling, spills, hydrofracturing, and post fracturing flow back water?
4. What are the probability and evidence for short-term and long-term well-casing failure or of cracks from hydrofracturing regions in the shales travelling vertically into water aquifers, or other near surface formations? What are the factors affecting these probabilities? What would be the distributions, concentrations, and health and environmental consequences under various plausible scenarios?

5. Can all flowback fracking fluids and water coming out with gas be processed and treated to both recover the methane and treat the water to concentrate and remove certain components in a separate phase (as a solid or concentrated sludge) so that the water can be recycled, reused or discharged as is being done partially by some drilling companies? What are the energy/cost requirements of doing so?

6. In regions being developed for natural gas what are the baseline natural methane emissions? What research should be conducted about the quantitative magnitude of these baseline cases and those from gas and coal extraction? To what extent could available technologies or more stringent regulations reduce the emissions in gas drilling below current practice and at what cost?

7. How variable and uncertain are the geologic properties that govern the potential for natural gas production, its risks, and the environmental impacts?
    a. What has been learned about the distribution of recoverable gas throughout the shale? Is the economically recoverable gas likely to be concentrated in small sub-areas (sweet spots), or distributed fairly evenly throughout the entire Marcellus region? What are we learning about Marcellus shale gas well-decline curves?
    b. What is the statistical evidence about radioactivity or other toxic components in the ground-up stone resulting from drilling? What are the implications and how are these components isolated and disposed of?

8. What is the status of alternative shale fracturing methods?
   a. What are the most likely changes in the technology of drilling – what alternatives to slickwater hydrofracturing, such as fracturing with propane, are feasible, with what advantages/disadvantages?

   b. Which chemicals are used that have good functional substitutes, which don't?

9. What will be the life-cycle impacts and cost structures, including the activities of exploration, production, and infrastructure management, as well as eventual end of use and reclamation?

10. What information is there about baseline air quality and degradation from drilling rig and trucking operations?

11. What are the damages to roads from increasing the volume and changing the nature of drilling characteristics? Can the costs for road damages be recovered by local or state government regulations/policies?

12. What are the wildlife, habitat migration, and land use implications for natural gas drilling and production vs. other energy supply options?

13. What are the essential and critical operations of the regional economy and associated activities that must be included in a comprehensive integrated assessment of the impacts of natural gas drilling? What is the relative costs/risk/benefit analysis of drilling in NY *vs.* alternative sources of energy in NY or elsewhere?

14. What would it cost to monitor all drilling wells effectively?

15. To what extent—and for what variables—can citizen monitoring supplement governmental or industry monitoring efforts?

16. To what extent will the shale gas supplies be plentiful at low prices, and thereby reduce incentives for investment and consumption of renewable energy?

17. What is the long term break even price of natural gas drilling here. . . after short term considerations like "held by production" incentives, joint venture conditions, futures market influences, and subsidies have been taken into account**?** How do these prices compare with oil, geothermal, solar, wind, biomass, etc. including the same considerations? Effectively this is equivalent to providing a supply curve for a specific shale gas region and comparing it to alternative options.

18. What are the pros/cons with the "held by production" rules which give incentives to drill quickly? If drilling were "rationalized" across larger management units, would there be economic/environmental/technical benefits?
    a. What technical considerations come into play, especially regarding decline curves and ultimate recovery, for "starting and stopping" gas flow from a Marcellus well, e.g., in response to market or regulatory conditions?

19. How do global energy markets influence operating company strategies and decisions about energy extraction choices and the pace and scale at which extraction takes place?

20. What is the full set of fiscal impacts:
    a. Costs and benefits that are likely to affect each different taxing jurisdiction and service unit?

b. Fiscal effects of a state or local severance tax?
c. Property price impacts (including agricultural land) and assessment impacts of gas leasing, gas drilling. . . for properties including wells, leases, lands and buildings proximate to wells, leases, supply corridors, pipelines, etc. ?

21. What will be the life cycle, social equity, and job implications of shale gas development in a community or region? How do these differ from the perceptions of different affected publics?
22. What pedagogical approaches and activities are best suited to impart an appreciation of this and kindred problems to a range of audiences, from state and local officials to K-16?
23. How are many of the above questions affected by inter (and intra) state variations in policies, regulations that govern shale gas development and the background socio-economic conditions found therein?

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Appendix A

The energy "system" is broadly interlinked, but in general can be thought of as comprised of two major sectors: transportation fuels and processing (generally petrochemical today), and the electricity sector. The electricity sector is generally served by a combination of generating sources based in coal, natural gas and renewable energy resources such as hydropower and to a lesser extent by geothermal, wind and solar energy. When unconstrained by environmental rules and compliance, the electric industry is broadly organized around generation either close to load (demand) or in proximity to high capacity bulk transmission systems.

Natural and Technical Issues to be Explored

Geology and Drilling Technology: Data for temporal-spatial variation of organic matter, natural gas concentrations, rheological properties, formation water chemistry, and NORMs are sought.

Experiences in Pennsylvania reveal that the outcomes of hydrofracturing on permeability and the productivity of individual wells vary over short distances. Similarly, the concentrations of NORMS vary by orders of magnitude among wells. Until the causes for these variations are well understood, it will be difficult to adopt optimal plans for well field development and waste management.

Data on organic matter content can be inferred from well logs archived by the state geological surveys, and Total Organic Carbon of well cuttings is being compiled by other academic and state agency research groups. Some of the data may be available from industry representatives already in the process of drilling. If the data are not highly spatially heterogeneous, stratigraphic and paleoceanographic models may help predict the distribution of rock properties where empirical data are sparse.

The potential for induced seismicity exists wherever fluids are pumped deeply into rock. Observational studies are needed to develop the knowledge necessary to predict the degree and distribution of induced seismicity and therefore to communicate the risks to the nearby communities, design well fields and hydrofracturing to mitigate the risk, and develop liability plans and insurance practices. The observational studies must include both characterization of the pre-drilling natural micro-seismicity, and monitoring of some active hydrofracturing sites. Monitoring is needed not only in the immediate surroundings of the test well fields, but also beyond the zone of intentional fracturing to learn the distance over which pressure changes cause microfractures. Monitored results should be compared to the operator's predictions of the seismic energy that would be released by the planned fractures. In general, we need to learn whether pre-existing fracture properties pre-condition certain locations to greater likelihood of induced seismicity during development and production.

Water: Withdrawals and Quality

The withdrawal of water from natural water sources for use in hydrofracturing is governed by a variety of interstate commissions and state agencies. Within the part of New York State with rocks suitable for shale gas extraction, there are four different water resource governance structures. The Susquehanna River Basin Commission (SRBC) has implemented changes in its permitting process to address water withdrawals for hydrofracturing while requiring maintenance of minimum levels of pass-by flow to maintain adequate stream ecosystem services. The Delaware

River Basin Commission (DRBC) has the authority to implement comparable regulations in the Delaware Basin. No similar regulatory or permitting structure exists in the currently unregulated Great Lakes and Hudson-Mohawk River Basins and the Adirondack region of northern NYS. The New York City (NYC) Watershed has received an exemption from the Generic Environmental Impact Statement (GEIS) and the Supplemental Generic Environmental Impact Statement (SGEIS), as the NYS Department of Environmental Conservation (DEC) is requiring that an environmental impact statement be produced for each horizontal extraction well drilled in that watershed area.

The possible environmental impacts of discharges of fracturing fluids and flowback water will vary from place to place, as well as through the time span of development and production. The chemical properties of both the injected fluids and the natural formation water will vary among well field locations. In the absence of a database for the formation water composition and for the rheology of the rocks, which influences the hydrofracturing design, the flowback chemistry is currently very difficult to predict. The water management practice of use of storage ponds near drilling sites can pose risks of overflow due to accidents or heavy rain. At some time in the future, the storage pond and drill site construction areas must be reclaimed.

Community Acceptance, Engagement, and Regulatory Environment

Community Concerns, Opportunities, and Decisions

A review of the social and economic impacts of the drilling process shows that there are a wide range of immediate impacts that require analysis if communities are to be prepared to respond, including roads conditions, traffic, schools, police, public health, and fire and emergency services. Experiences to date reveal that two factors influence how a community's quality of life will be affected by these challenges. They are revenue streams to address the impacts, and governmental capacity.

The Boom-Bust character of the drilling activity requires its own consideration. The social and economic impacts of natural gas drilling are rooted in its short-term character (development phase) and the fact that communities with incomplete information might make what become long-term decisions based on short-term impacts (or vice-versa). Social and economic impacts occur over the pre-production, production and reclamation phases of the natural gas drilling process. As in any large-scale transition, there will be disruptions and most likely there will be both winners and losers in each community.

In the case of shale gas, industry goals are to minimize investment and maximize financial gain. Often sub-contractors are used for various stages of the work, and their motivations are usually very short term: accomplish the work quickly and move on. The workforce is likely to be composed of skilled labor from outside the communities. Communities experience many negative impacts before they have the revenue or the government capacity to address them.

The attitudes of the public toward the opportunities and costs vary from community to community. As one of many examples, some communities are motivated to encourage the creation of road infrastructure and to be the water supply points, while other communities are not.

While money flows into some communities, it is unclear how much is actually expended in the affected communities. It is also unclear whether natural gas drilling can contribute to building the economy and government capacity in those communities where drilling occurs.

Just as important but even less studied are the longer-term impacts of natural gas drilling operations for community economic and environmental sustainability. The long-term impacts will be a direct consequence of the number of drilling rigs in an area and the time frame within which drilling occurs. One major unanswered question is the cumulative impact of the drilling relative to the number of rigs working in an area.

Regulatory Frameworks

Regulations need to be developed for the effective mitigation of many aspects of shale gas development. At a minimum, these include regulation of the cumulative impacts of water withdrawals in the currently unregulated basins, as well as for effective monitoring of flowback and run-off, aquifer disturbance, air pollution, well casing quality, anti-blowback technology, etc. For example, New York State is considering the NYS Bill A8806 relating to the implementation of water withdrawal permits to support water delivery.

<u>Financial and Related Issues and Opportunities</u>

The estimation, control and pricing of carbon emissions associated with power system operation encompass several areas of interest and impact:

- Structure of carbon control mechanisms ranging from carbon taxes to cap-and-trade and physical capture systems will impose costs and a high degree of uncertainty in operations and costs on the industry in the future.
- The geo-political implications of policies for oil and gas recovery and processing will influence price, financing demands and the cost of capital. This will be more pronounced when questions of national sovereignty, security and energy independence are taken into account.
- General national economic welfare, and its impact on energy consumption;
- Evolving knowledge of carbon emissions from various energy sources and of predictions of global change as a function of carbon emissions.

Other issues include the appropriate risk evaluation during hearings, as well as monitoring and enforcement following project approvals. This implies a reevaluation of the system that apportions the costs of compliance and the level of those costs on an ongoing basis as energy development commences. Included here are issues which might see developers bearing the cost of needed governmental services and infrastructure such as monitoring, emergency services, roads, etc.

Expanding the base of capital facilities used in the energy industry as well as maintaining and upgrading existing facilities is critical to reliable operations and maintenance of energy supplies. Financial resources necessary to meet this objective are competitive by nature and reflect market perceptions of risk and uncertainty. Once thought of as the safest of investments (often referred to as blue-chip), uncertainty in regulatory institutions, processes and rules, supply availability and price volatility have increased the perception of uncertainty and corresponding estimates of risk. Research using the model of the Marcellus Shale development can not only help define these risk and uncertainty characteristics, but provide the structure for systematically pricing or providing risk equivalency with other investments that will benefit market perception of this emerging industry.

Systems Modeling

Other ongoing research projects apply systems modeling tools to analyze complex land-use planning issues. See http://plone.rehearsal.uiuc.edu/leam/ for an illustrative example.

Dissemination and Outreach

As communities struggle with energy issues and look to a complex and unclear future, there is a tremendous education opportunity. Municipalities and individuals are taking a closer look at energy conservation and renewable energy and are seeking guidance for bridging to a future that will have less reliance on fossil fuels and a reduced carbon footprint. Cornell Cooperative Extension (CCE) can work with the local stakeholders to build their capacity for assessing different energy development scenario.

Communities are motivated to understand the available information on drilling in the Marcellus Shale in order to make informed decisions. CCE resources and Paleontological Research Institution (PRI) programming provide targeted education, training, and support to participants on resource science, technology, and regulatory topics. Both CCE and PRI are working to increase energy literacy in regional communities.

A vital part of dissemination and outreach involves fostering communication among municipalities and individuals to support energy transitions at local and regional levels. Negative impacts are more likely minimized and positive aspects realized when all concerned parties are proactively engaged in education and dialogue and prepared to anticipate, shape, and respond to changes. CCE with faculty partners can assist municipalities as they interface with regional, state and federal agencies and organizations. CCE educator roles may include helping community members synthesize knowledge from various sources, researching prospective partners, interpreting research, and acting as intermediaries.