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Approaches for Planning and Implementing Sustainable Energy Growth in a Complex World

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APPROACHES FOR PLANNING AND IMPLEMENTING SUSTAINABLE ENERGY GROWTH IN A COMPLEX WORLD

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ABSTRACT

Efforts to promote significant market penetration of renewable energy have come to incorporate elements of complexity thinking; this includes looking at the energy sector as a system of systems, and including sociopolitical factors in these systems rather than focusing only on technical systems. These approaches are necessary, but not sufficient, and past strategies toward formulating roadmaps to high renewables penetration depend on unlikely scenarios. Fuels and electric power are commodities, and most people are satisfied when these commodities are readily available at a reasonable price. History suggests that this situation will likely change only in response to a major crisis such as a climate disaster, an energy shortage driven by growing demand, or a supply interruption caused by war. Obviously there is no firm way to predict a crisis, but drivers can be suggested for many types of crises: global population growth, pollution of all types, resource imbalances, etc.

A new approach is needed that builds awareness of knowable drivers to prepare for and capitalize on knowable events, and to build resilience and foresight for responding to unknowable future crises and opportunities. This paper will build on current thinking related to sustainable development, energy forecasting, and complexity theory and show how past roadmapping methodologies fall short. While proposing ways of thinking about our responses to global changes, we consider how we can create and discover the pathways through those unpredictable changes toward high global renewables penetration.

1. INTRODUCTION

The subject of sustainable energy development has been widely discussed and debated in recent years. However, despite widespread interest, progress toward this goal has been limited. The following discussion will attempt to identify some of the barriers to progress, and will attempt to recommend improved approaches, based on current theories about large-scale systems.

2. THE SITUATION AS IT IS—WHAT'S BEEN TRIED AND WHAT DOESN'T WORK

There is a significant level of support for altering the energy supply and demand status quo. This support comes from a variety of viewpoints, including reduction of carbon emissions, concerns about peak oil and the growing global demand for oil, and addressing the national security concerns of nations that depend on other nations for much of their oil supply. Proponents of these various viewpoints may disagree about specific approaches, but it is still reasonable to project that these collective concerns will drive changes to the global energy economy in the coming decades. The challenges are to plan, estimate, and project the exact trajectory of these changes and the ultimate outcomes.

Leaders from various stakeholder organizations want to have some level of comfort about the expected outcomes from policy or investment decisions to be able to constructively promote change. Achieving such a comfort level will require appropriate tools and techniques, and it will be argued in the following sections that current tools and techniques do not fully meet the needs. The vision promoted here will be to better understand our complex world, and to develop new ways of thinking that can, as much as possible, envision and influence the future of global energy.

Major energy sources have evolved over the past two centuries, from wood to coal to oil and gas to nuclear and renewables. A discussion of this history is beyond the scope of this paper, but the drivers for this historical development have been a mix of resource availability, technological developments, investment decisions, and public policy decisions. The actual pathways that developed were not driven by overarching goals such as those described in the current vision. There generally was no designed approach to the development of the various systems, and development occurred at an evolutionary rather than a transformational rate of speed (1). The history of the U.S. energy sector is therefore not a good model for developing a roadmap for our energy future.

The current global energy supply is dominated by fossil fuels. Their major sources are not uniformly distributed, but rather are concentrated in a few countries; see Figure 1. This uneven distribution has significant geopolitical impacts, affecting commerce, international relations, and even armed conflicts.

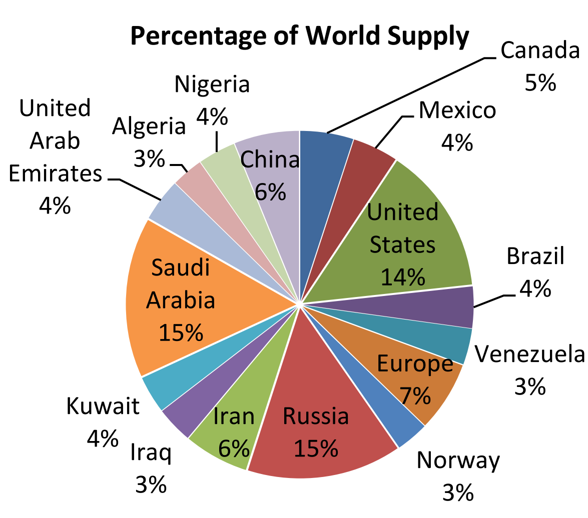

Fig. 1: Major Oil-Producing Countries (2)

The sheer size and dominance of the fossil fuel industry constitute a major impediment to a large-scale shift to more sustainable energy sources. A discussion of industry details would need to be extensive, but for the purposes of this paper one way to highlight its magnitude is to consider its impact on U.S. foreign and military policy. After the fall of the Soviet Union, the United States had no reason, from a global perspective, to continue its military focus on the Persian Gulf. However, this region remained critical because of its significant oil production, and U.S. policy remained focused on protecting oil supplies as a critical principle (3). Another way to highlight the influence of the fossil fuel industry is to look at U.S. government subsidies; a 2009 study estimated that over a recent seven-year period the fossil subsidies totaled $72 billion; the renewable subsidies totaled $29 billion. In addition, nearly $17 billion of the renewables total went to corn ethanol, which is a renewable source but one that does not contribute to an infrastructure change toward more sustainable electric vehicles (4).

The bottom line on the current energy system structure is that the system is enormous, and thus hard to change, and it has evolved to its present configuration in an uncontrolled manner. This reality suggests that traditional methodologies for planning and promoting change are unlikely to be successful; new ideas are required.

3. THE IMPOSSIBILITY OF PREDICTING HOW IT WILL OCCUR

There are well-established methods for predicting the future of energy supply and demand. Typical methodologies are based on trend analysis and assumptions that are based on historical patterns. In the United States, the key organization for energy data collection and forecasting is the Energy Information Administration (EIA). The current EIA projection for electricity generation through 2035 provides a good example of an energy forecast; see Figure 2. Note that in this forecast the mix of energy sources for electricity is not significantly different from the mix today.

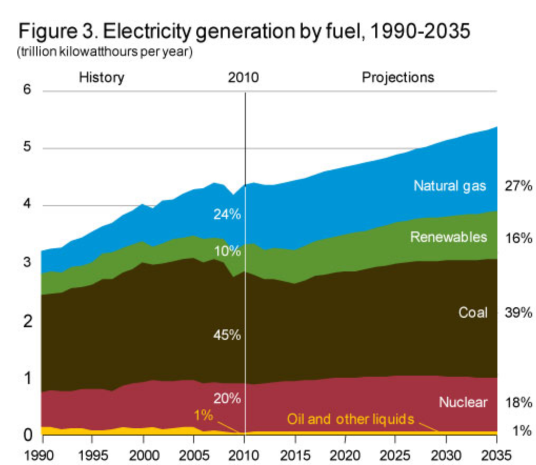

Fig.2. EIA Electricity Generation Forecast (5)

Several issues influence the advancement of sustainable energy growth, which in turn severely limit the ability to plan for this growth. The first and foremost issue is the notion of planning for anything on a global scale; this has not been done before, and the feasibility of actually doing it is highly questionable. The second issue is the lessons from energy development history, as described above; multiple, sometimes disconnected drivers will dictate the developmental pathways and ultimate outcomes. Finally, there is the issue of the complexity of the global energy system; this issue requires further discussion.

The science of complex systems is relatively new, having developed over the past few decades. This body of knowledge is multifaceted, and not all aspects are applicable here, but fairly recent developments provide useful information about understanding the nature of the global energy mega-system. Complex systems are defined as containing all of the following: diversity, connection, interdependence, and adaptation (6). There are many properties of complex systems, but perhaps the most interesting is that they have emergent properties. In the energy mega-system, which meets all the requirements for a complex system, properties emerge that cannot necessarily be predicted by studying the underlying components. A positive result of this phenomenon is that the system becomes very robust, which means that consumers will largely continue to have reliable energy supplies in spite of unpredictable negative events. However, when attempting to fundamentally change the system, as is the case when driving a change from fossil to renewable energy, the robustness of the current system will tend to reinforce the status quo, so any changes will be resisted.

Another macro-level feature of the present global environment is that, according to some authors, we are at a point of significant change at the global level. One argument is that we are entering yet another "age," chronologically following the agricultural, industrial, and information ages. The three overarching characteristics of this age are accelerating electronic connectedness, global economics leading to global culture and politics, and increasing individual choices and control that will decrease the power of institutions and organizations (7). Another argument is that we are entering a revolutionary age unlike anything that has been seen in the past few hundred years. The driver for this revolution is an increasing number of players, interconnectedness, and the speed of information transmission. The result of this new reality is the development of nonlinear systems (sandpiles) that represent energy that is ready to avalanche, which in turn can produce great change that is unpredictable because it is organic rather than mechanistic (8). The characteristics noted here, based on analysis of current global realities, match up well with those of complex systems.

The key point of visualizing the global energy mega-system in complex systems terms is to frame any discussion of changing this system within the associated realities. A new framework for change is needed—one that is based on working with uncertainty rather than relying on traditional reductionist thinking.

4. AN APPROACH TO GUIDE OUR PATH—IN LIEU OF A ROADMAP

Sustainable energy growth can be justified on the basis of various drivers; three that are commonly cited in support of renewable energy are the environment (carbon concerns and/or pollutants), national security, and energy security. However, energy is a commodity, and as such changes to how energy is produced are not necessarily important to the typical consumer. To raise the level of importance in the public's perception, it is necessary to frame sustainability as a value proposition.

Actually creating a sustainable environment is more of a sociopolitical activity than a technical one, and the technical community has responded to this reality by creating many "scenario analyses" that are intended for consumption by policymakers. The shortcoming of these analyses is that they attempt to visualize one or more possible future states, but they sometimes gloss over the many difficult steps needed to get to the end state. Detailing those steps is a function of traditional roadmapping.

4.1 Roadmapping

Roadmapping is a method for strategically charting technological development toward a desired end state. There are various references for this process, but for sustainable energy development, which will be largely a commercial activity, a reasonable reference is the International Technology Roadmap for Semiconductors; this activity is managed by an international consortium of chip manufacturers. The process develops improvement targets for parameters such as cost, throughput, power consumption, and physical size. Targets are developed under the assumption of continued scaling of electronics; underlying this is the assumed validity of Moore's Law, which predicts that the number of components per chip doubles roughly every 24 months (9). Referring back to the definition of complex systems, the semiconductor industry does not seem to meet all the requirements, and an examination of the roadmapping methodology reveals traditional reduction of technical elements into building blocks that can be individually improved.

4.2 Decision-Making

Closely related to roadmapping is decision-making. Traditional decision-making does not take into account the behavior of other interested actors, and it focuses on a single outcome rather than on system properties. This process focuses on command and control optimization, rather than on understanding the systems within which one must work (6).

Alternatives must be proposed to replace traditional processes and to establish the value proposition for sustainable energy. As a first step, a general concept is that a way to drive change in a system is to expose it to an environment in such a way that interactions with the environment drive the system in the desired direction (10). With regard to energy system changes at a smaller scale, there are well-established public policy mechanisms that can be used to create an environment that promotes movement toward a desired end state. However, these smaller scale changes deal with linear, noncomplex systems, and are not likely to be effective with larger issues; thus, a new approach for changing the environment is needed.

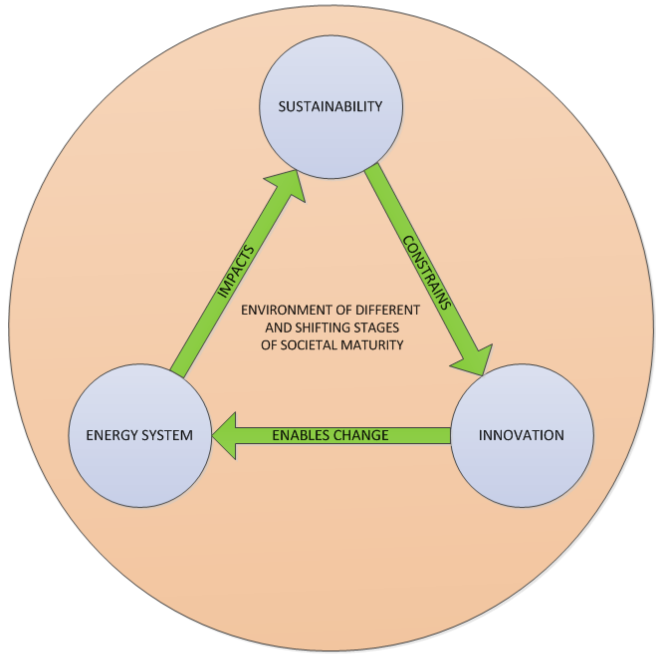

Fig. 3. The Environment of Complex Change

4.3 Innovation

Innovation has the potential to change the environment, which in turn can push desired change. In a consumer product setting where innovation provides new capabilities, the changes can be transformative; the obvious example in recent decades is with personal computers and other consumer electronics, which have literally changed the world in countless ways. The question now becomes how to address the needed steps in a nonlinear, complex environment. As a starting point, examining the relationships between sustainability, the energy system (at various levels), and innovation is helpful. Figure 3 illustrates these relationships.

Sustainability constrains innovation because it limits what is acceptable; for example, burning certain hazardous wastes might be the most efficient method for destroying them, but the release of byproducts to the environment could be unacceptable. Innovation enables change by providing new technologies and methods for generating energy or reducing energy waste. The energy system impacts sustainability because utility-scale energy production is a large industrial process (even renewable energy production), and such large processes inevitably have some environmental impacts. All of these elements operate within an overarching framework of societal maturity. Of the three connecting linkages, only innovation drives improvement; the others constrain or impact. Thus, it is worthwhile to explore how to leverage innovation.

Innovation is typically associated with technological advancement, but in this instance it is appropriate to define innovation more broadly. Referring again to the concepts of an energy mega-system and the environment that surrounds it, there is a need for extensive innovation in the nontechnical elements if there is to be any hope of seriously changing the status quo. The scenario analyses referenced above typically contain many caveats about these nontechnical factors, and because the nontechnical factors often cannot be reduced into easily addressed elements, the focus on innovative solutions often stays on the technical elements that can be defined and addressed.

An example of a proposed nontechnical innovation is the concept of regional innovation investment boards that would support demonstration projects and early adoption programs for alternative energy. These boards would be chartered by a federal agency, funded through electricity surcharges, and be structured to deal with the unique issues of each region rather than taking a uniform national approach. The goal of setting up such boards would be to deal with the middle activities between initial technology development and large-scale deployment; this middle area is often referred to as the "valley of death" (11).

The analyses show that many such innovative ideas will need to be proposed and implemented to change the status quo. However, each action will be resisted, for the reasons noted above. History suggests that, at the macro scale, this situation will likely change only in response to a major crisis such as a climate disaster, an energy shortage driven by growing demand, or a supply interruption caused by war. However, this is certainly not a preferable way to move forward, so a mechanism is needed to enable major changes without a driving crisis.

4.4 Knowable Drivers

A new approach is needed that builds awareness of knowable drivers to prepare for and capitalize on knowable events, and that builds resilience and foresight for responding to unknowable future crises and opportunities. These knowable drivers include global population growth, pollution of all types, and resource imbalances. These must operate within an environment of growing societal maturity. It can be argued that as a global society has developed in areas such as commerce and academics, the structures of governments and the viewpoints held by other key decision-makers and the constituents they represent remain in the narrow and myopic realms that developed in an earlier and far different time. Only by developing viewpoints that are inclusive of societal goals at some level—even if they are not initially global—can awareness of drivers be leveraged into actions that shape the future.

Unfortunately, there are no instant solutions to the challenges posed by societal maturity. Change will likely be a slow process, perhaps accelerated only by some crisis. However, the development of tools designed to deal with change in the new, complex global environment may help spur the emergence of resourceful viewpoints and societal structures.

5. EXPLORING OUR ANALYTICAL TOOL KIT

Understanding the approaches used in the past to analyze these issues—and their strengths and limitations—may help us identify useful tools for responding to the emerging needs of the energy system. We group these approaches into four broad categories: linear causality, circular causality, complexity, and reflexivity (10).

5.1 Linear Causality

As noted earlier, linear roadmapping, forecasting, and many decision-making approaches fall short in analyzing the complex global energy system. Linear analytical tools identify short-term implications of policy or investment decisions. In stable situations, relatively bounded in space or time, they can also be useful for extrapolating longer term forecasts from past trends. When the territory stays the same, roadmaps based on prior experience can be useful predictive tools.

Linear analyses of energy systems provide straightforward explanations that are easily quantified, explained, and grasped. However, the clarity of explanations can blind decision-makers to other equally defensible descriptions of system effects. Simple analyses disregard the effects of other key drivers, longer term system feedback loops, and interactions with other systems. Outside the implicit boundaries of a linear model, for example, could be an analysis of the economic benefits of a coal power generation plan—its effects could be equally provable as a driver of ecological degradation or of cultural disruption.

5.2 Circular Causality

Although linear models effectively predict short-term effects, in the real world, there is always a long term. More sophisticated models, including circular causality, add in feedback loops and self-reinforcing cycles to account for longer term interactions. Tools such as system dynamics modeling provide insight into longer term, more widely distributed impacts of policy or investment decisions. These help decision-makers understand linkages between remotely related system elements. Circular models can, for example, consider a power plant's further influence on economic development, population growth, and increased power demand.

As circular models expand, their discrete predictive capability declines, frustrating decision-makers who seek definitive answers. These models are most useful for understanding essentially closed systems with limited numbers of known players, systems where major system drivers are controllable from within the system, and systems whose dynamics are not impacted from outside their boundaries. Even when analyzing more open, less predictable systems, decision-makers gain some level of comfort and guidance from the insights provided by these tools.

When adding in the complications of circular causality and feedback loops, the increasingly complex interactions between multiple system elements can render analysis of key drivers, at best, situationally dependent and, at worst, misleading. Trying to predict the effect of a particular action using circular analysis delivers first hopefulness, as the more sophisticated analysis yields new insights and a sense that a decision's effects can be predicted. Ultimately, however, that hopefulness turns to frustration as unanticipated longer term implications and the model's shortcomings become apparent.

5.3 Complexity

The relatively new area of complex systems theory holds promise for helping decision-makers develop new viewpoints. It enables simulation of interacting systems and provides useful descriptions of emergent system properties, competition between systems, and characteristics of highly interrelated systems. These models provide insight into self-organization, the emergence of new variety, and natural selection within a system.

Complexity shifts the focus from transactions to relationships and shows how relationships between agents and with system structure influence system outcomes. Understanding the effect of system structure on system behavior provides important insights into the effects of policy or regulation.

Complexity theory provides insights into globally interconnected energy systems and highlights the limitations of models to discretely predict impacts. This essential uncertainty is counterbalanced by the richness of insight into the dynamics of changes and the impacts of policy, regulation, and sustainability constraints. This assures decision-makers that the most foreseeable impacts have been considered, even if their exact effects cannot be predicted.

5.4 Reflexivity

The newest tools come from the field of reflexivity theory, which considers the unique characteristics of systems with thinking participants. Reflexivity draws distinctions between human systems and natural systems. Two key elements of human systems are fallibility and reflexivity. Fallibility describes the partial or distorted world views of any participants in a system. Reflexivity describes how these distorted views can influence the situation to which they relate, as distorted views lead to inappropriate actions. Reflexivity describes the feedback loops in which participants' views influence the course of events, and the course of events influences the participants' views as a continuous and circular feedback loop. (12)

Reflexivity offers a vantage point for rethinking and developing new viewpoints that are more in sync with changing global energy systems. As it seeks to include decision-makers within the system model, it integrates the roles of decision-makers as model constructors and system participants, as well as observers. It acknowledges that each model is a reflection of the modelers' thinking or the decision-makers' viewpoints and reflexive of their positions within the modeled system. Reflexivity extends the full circular effects of other models by considering how the perspectives, beliefs, assumptions, and actions of decision-makers are affected by system constraints and how they, in turn, affect system outcomes.

Reflexivity describes the emergence of innovation as pivot points for nonlinear system shifts. Innovation in energy systems emerges in response to—and is limited by—constraints. Reflexive, resilient entities in the system innovate and adapt to protect self-interests and to exploit emergent opportunities in the system. As entities innovate, they shift the dynamics of the embedded subsystems, resulting in ripple or cascading nonlinear system changes—those unpredictable sandpile avalanches.

Although not yet fully explored, reflexivity provides tools for describing the effects of entrenched system agents employing defensive strategies to protect market positions, building alliances to erect barriers to entry, or attack or swallow more resilient, adaptive, and innovative entities. Reflexivity enables not just the understanding of how systems adapt and change, but also how decision-makers, working within the system with real-time feedback, might adapt to influence the system toward desired ends.

The reflexive perspective may enable decision-makers to see how the assumptions behind their models may limit their resilience. It can help them rethink their models to integrate emerging patterns and more agilely adapt to changes. Applied reflexively, tools such as iterated scenario planning use the construction of planning scenarios to explore potential new drivers of change and to develop portraits of decision-makers' thinking. Iterated scenario planning integrates real-time experience with the changing environment to developing more agile responsiveness and resilience.

Other reflexive tools that extend perspectives and develop adaptive capabilities include open system and dialogic methods such as appreciative inquiry. They enable entities and decision-makers from across systems to exchange key information about the nature of the system, facilitate self-organization of innovation networks and encourage development of higher order system goals of sustainability and energy security.

Reflexivity acknowledges that, in systems such as the global energy system, decision-makers are never disinterested observers and their learning always changes the system and its outcomes. It accepts the inability to discretely predict but builds on the human ability to grow, adapt, and innovate toward a new future.

CONCLUSION

Building on the broad agreement of the need to move toward more sustainable energy systems, leaders and decision-makers will continue to request more sophisticated theories, models, and tools to guide their plans. Although decision-makers want comfort and predictability, in a changing world, they most need the perspectives, skills, and tools for gaining insight into the dynamics of shifting systems. New tools enable them to explore complex interactions of possible scenarios and to acknowledge that risk is a feature of the world. This cultivates rapid awareness and quick reaction time to unpredictable events.

In the complex and shifting world of global energy systems, modelers' and planners' roles must shift from attempting to predict the unpredictable to helping decision-makers cope successfully with the uncertainties of a globally interconnected world. Planning and modeling become even more important tools for building resilience and agility to adapt to emerging challenges and seize opportunities within emerging global energy systems.

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