Wind Turbine (R)evolution: A Study of Technological, Organizational, and Institutional Change, 1980–2003

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ABSTRACT

Forty years ago, a wind power industry did not exist. Today, it not only exists but it flourishes. This development is surprising because it has involved the spread of a radical new technology through a sector that is historically both very risk averse and characterized by high barriers to entry. This thesis tries to explain the success of wind power by examining existing historical studies, quantitative data sources, and a set of original interviews with key industry participants. It uses ideas from two sociological subfields—Social Construction of Technology and New Institutionalism—to go beyond simple ideas of technological or economic determinism. It looks at how the success of wind power involved the co-evolution of physical technologies that are believed to work, and new organizational arrangements that are perceived to be beneficial. The development and use of windmill technology was not simply the direct result of technical breakthroughs or industry deregulation but was caused by the interaction of these factors with changes in industry organization, resulting in the development of a new organizational field in which a particular kind of wind generator makes sense. The thesis also looks at how the perceptions of the stability of this technology/field combination feed back into the institutional setting and hence push future development in a particular direction.

INTRODUCTION

This research takes a single case—the wind power industry—and explores both its technological and organizational development within the context of the electricity industry. The central task is to explain the success of this new industry by combining the insights from the Social Construction of Technology and New Institutionalism in order to get beyond simple technical or economic explanations. Technologies are not just socially constructed through complex processes of negotiation between various interest groups in the early phases of development; in fact *technology is never stable*. The social groups which negotiate the construction of a "working" technology are themselves constructed and changing, such that the perception of stability itself is defined by the nature of the institutional context at any given time. Thus in order to explain the processes of industry *and* technology formation and success, snapshots and cross-sections simply will not do. Understanding the dynamic nature of technologies and organizations in the broader context of social, economic, political, and cultural changes over time is essential for understanding economic and organizational behavior. Examining in detail the case of wind power demonstrates this claim.

The case of wind power was chosen because it provides a unique opportunity to combine technological and organizational sociology, as neither paradigm alone provides a satisfactory explanation for this industry's success. Furthermore, energy issues present tremendous moral, social, economic, political, and environmental challenges for contemporary society. The dependence of the United States on fossil fuels such as coal and oil when there seem to be alternatives that make so much more sense from a social and environmental—and even economic—standpoint is, to say the least, concerning. Understanding how and why society has become locked into ways of behaving that are far from the most efficient or healthy courses of action for the long term is essential for creating a better world in the future. Because this issue involves at its core technologies, and because these technologies are embedded and used by actors in complex organizational networks and institutions, both of these broad aspects need to be examined simultaneously. Understanding in detail how current possible choices of action are introduced and how they become accepted by a particular set of organizations once they become a reality is, therefore, essential.

The modern energy sector is frequently engaged by political scientists and economists but rarely by sociologists.[1] This fact is somewhat surprising given that so much recent

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[1] There are several notable exceptions here. Organizational sociologists have begun to address aspects of the electric power industry in the last several years, focusing on changes in institutional environment and

sociological work has been aimed at understanding economic behavior and the structures of markets, political processes, and cultural change. However, a significant body of sociological work has confronted general issues relating to technological change and organizational dynamics. Research on technological change in particular takes a multidisciplinary stance, positing that the economic, the social, the political, and the technical are all intimately connected. In order to understand technological change one must also understand the context in which this change takes place. Research on organizations and institutions has thus been successful at providing some insights into the ways that these contexts influence economic decision-making and how such choices are shaped by a milieu of non-economic factors, as well as how all of these factors then interact to form complex systems which help guide organizational behavior. These two areas of research offer many analytical and methodological tools for understanding wind power in particular.

Perhaps the apparent avoidance of the electric power industry by organizational sociologists stems in part from the uniqueness of the product: with electricity, demand must exactly equal supply at all times. The energy flowing into the lights of the room in which the reader now sits is being generated at that moment and flows instantaneously through thousands of miles of cables from the power plant to the light bulb. When the consumer flips the switch, it is expected—and demanded—that power be provided *at that moment*, without delay. The physical structures involved in accomplishing this feat are tremendous, and the organizational components are perhaps even more astounding. But the majority of social scientific work on this sector cannot get away from notions of efficiency and cost—as conceptualized in classical economics—as immutable independent variables. As the field of economic sociology has revealed, even these concepts are socially constructed and influenced by institutional environments. The electric power industry is thus an appropriate field of study for sociology as well as for economics.

While the physical nature of the product provided by the power industry is unique, so too is the political and social environment surrounding it. Because this product is so essential to modern life, the range of stakeholders is extremely broad. All persons and organizations have a stake in the way that electricity is provided and produced. It thus becomes extremely difficult to analytically bind the subject of study and to focus on only a single aspect of the industry; one cannot explain choices of technologies by deferring to cost alone, as policy and culture influence both the perceptions of cost and the nature of the environment in which costs are calculated. Similarly, one cannot explain such choices by deferring to policy or culture alone, as technology

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the emergence of new fields. Both Russo's work (2001) and the work of Sine, Haveman, and Tolbert (2002) focus on the formation of the independent power production industry in the context of policy and regulatory changes affecting the entire power industry starting in the late 1970s.

and organizational relationships *are distinct from such factors but are intertwined with them* as well. In order to understand more completely how organizations and technology interact to shape economic behavior relating to a particular type of product, the changing nature of the meanings assigned to such constructs and the perceptions of viable courses of action is examined in detail.

This thesis makes such an examination by focusing on the formal rearrangement of organizational actors within an organizational field as a result of federal and state policies. Starting in 1978, a system of competition in wholesale generation was slowly introduced into an organizational field with an established natural monopoly structure. As a result, two organizational forms (utility and nonutility) have come to coexist in an organizational field historically dominated by one. Throughout this thesis, these two organizational forms are conceptualized as belonging to separate organizational fields. Electric utilities, constituting the established electricity industry, belong to FIELD 1. Nonutility independent power producers (IPPs) belong to FIELD 2, which was created by a political action. Understanding its evolution and relationship to FIELD 1 is a central concern of this thesis, as this organizational change has been coupled with changes in the types of technologies used to produce power as well. New renewable technologies including solar, biomass, geothermal, and wind have increasingly been pursued as alternatives to the more traditional types of fossil fuels and even older renewables such as hydropower. This thesis argues that these two changes, while it is perhaps possible to separate them conceptually and analytically, are in reality interdependent and co-evolving constructs that simultaneously affect each other. Focusing on both a new technology (wind power) and a new organizational form (nonutility IPPs) within the context of broader industry-wide changes affecting the cognition of organizational actors, the potential courses of action and technologies available to them, and the relationships between them demonstrates this claim

The structure of this thesis is as follows. Chapter One provides the theoretical frameworks of the two subfields of sociological research most heavily drawn from. The first section of Chapter One introduces the Social Construction of Technology (SCOT) by highlighting the work of Wiebe Bijker, a prominent researcher in the field. Research in this vein posits that technology evolution is not a simple linear process; the prevalence of a given technology cannot be explained simply by the fact that it "works." Instead, what it means to have a "working" technology is a social construction built by various relevant social groups (RSGs) with different definitions and meanings of what a given technology should look like. The second section of Chapter One then provides the conceptual foundations of New Institutional sociology, a body of research which began by trying to explain the startling homogeneity of organizational forms by addressing the context in which economic behavior takes place. It later incorporated organizational innovation and heterogeneity. Central to work in this field is the notion that economic and organizational behavior—like technologies—cannot be explained functionally. In other words, the prevalence of some organizational forms rather than others is best explained by addressing the relationships between actors as they strive for legitimacy within existing systems and institutional frameworks. Although Chapter One combines the conceptual insights from each theoretical subfield, it draws the most from the methods of SCOT. Chapter One ends with a summary of the methodology used in this current thesis, as well as some of its strengths and weaknesses.

Chapter Two examines the physical technology of the modern windmill and the processes of its development within industry research and development (R&D) firms and field testing settings. In the SCOT tradition, this chapter highlights the fact that the perceptions of a "working" modern wind turbine are socially constructed, and that these constructs actually influence the physical design of the machine. Understanding the nature of the relationships between organizational actors—or RSGs—is then essential for explaining the evolution of wind technology. Chapter Three, by contrast, focuses on how the RSGs involved in wind technology have themselves been constructed. In the tradition of New Institutional sociology it looks at how major public policies have altered the institutional setting of R&D, caused industry-wide restructuring, and changed the roles and perceptions of the participants in relation to each other. Chapter Four concludes the analysis by considering some significant barriers that appear to be major problems for participants in terms of the future success of the industry. It shows how the causal processes discussed in Chapters Two and Three come together, highlighting the ways that technological change, organizational form, cognition, and policy interact with one another. While each of these chapters are separated analytically as a way of presenting the data, these distinctions do not definitively exist in reality; in fact this is the central argument of this thesis. Technology and organizational forms co-evolve and cannot really be separated from each other.

As a final comment before all of this gets underway, it seems appropriate to note who this current research is intended for. This study crosses several disciplinary boundaries even though it is most firmly rooted in sociology. This study—while it engages policy issues throughout and views policies as essential explanatory variables—is not a policy study *per se* and does not take a stance about the appropriate or ideal direction of future policies. It offers few recommendations for practical action. In other words, this study is first and foremost a *descriptive* endeavor in the sociological and historical traditions intended to inform sociological theories, not a *prescriptive* endeavor intended to shape future policy choices. This being said, the participants themselves, many of whom are directly and indirectly involved in the policy process, are also an audience for this current work and many of them will receive copies of it upon its completion. As a result, this study will become a part of the ongoing dialogue between *all* of the various types of organizational actors—including academia.

CHAPTER ONE – Literature Review and Methods

Two major threads in sociological research attempt to grapple with the complex interplay between groups and the objects that these groups use: Social Construction of Technology and New Institutionalism. While these seem rarely to connect in the literature, both take an integrated, holistic approach to problems of organization and change. In fact, the lack of discourse between them is surprising considering their many similarities. Both recognize the importance of social, political, economic, cultural, and technological factors in their analyses. Both also understand that the level of analysis is an essential variable. Perhaps most importantly, both realize that an adequate understanding of the behavior of social actors, of the emergence and change of organizations over time, and of the invention, alteration, and adoption of technologies by organizations must take into account existing institutional structures in order to explain outcomes. In other words, context matters, and it matters in many very specific ways.

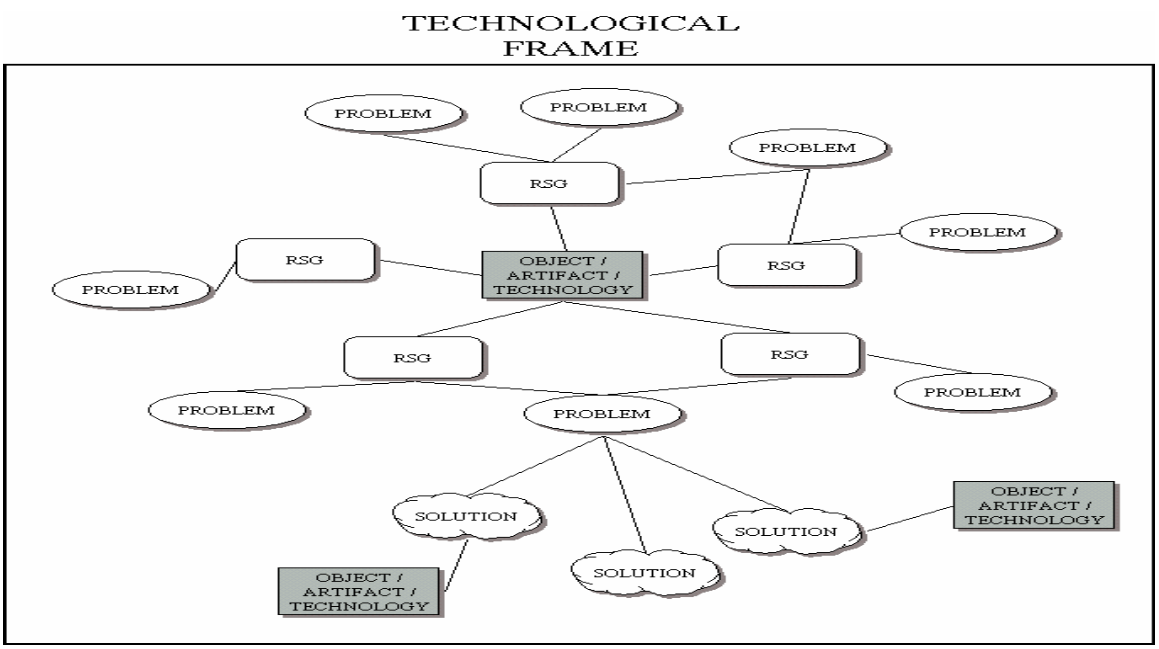
The wind power industry provides an opportunity to integrate these two fields around a single, complex case. As will become quite clear throughout this paper, questions about why certain organizations act in particular ways when confronted with specific technologies are intimately tied up with social, political, cultural, normative, legal, economic, and technical explanations. At the same time however, specific technologies themselves are not stable entities but are constantly being revised, adapted, and altered as the social, political, cultural, normative, legal, and economic contexts change around them *and in response to them*. This chapter focuses on two main topics: 1) how new technologies and new organizational forms and relations emerge and change in the context of existing organizational structures and environments, and 2) how these developments feedback into the environment to further alter the contextual landscape of future activity. This chapter thus is simultaneously a review of the relevant literatures and an attempt to integrate these literatures into a coherent conceptual framework to help guide the current research on the wind power industry.

The Social Construction of Technology (SCOT)

Sociological studies of technology borrow much of their theoretical insights from social constructivism. Perhaps the defining characteristic of such studies is, not surprisingly, a claim that objects and practices are shaped by social forces and not only internal or economic factors. Many taken for granted objects—and even abstract concepts like reality—are constructed and maintained through ritual social interactions structured by social institutions (Berger and Luckman, 1966). This notion has helped direct research into more specialized areas, most notably that of scientific knowledge. Long held to be immutable, "objective," and "true," even scientific knowledge, it is argued, is significantly influenced by the formal and informal institutional relationships among scientists and between science and other institutions (Latour and Woolgar, 1979, Latour, 1987; Collins, 1992).

Similarly influenced by the constructivist paradigm have been researchers interested in the processes of technological change. Social Construction of Technology (SCOT) emerged in the 1970s as a pointed reaction to models of technological change that placed the locus of innovation in the individual genius and which explained the success or failure of a technology by its performance. Bijker's (1995) work on the social construction of individual technical artifacts is exemplary of the SCOT approach, which posits that technologies result from the social shaping processes of actors within networks. Figure 1 is a diagram of this conception of technology and its embeddedness in social networks. The development of a technology is not a linear process, and the "working" and "not working" of

Figure 1: Network of Factors That Influence Technological Outcomes



an artifact is not enough to explain its success or failure. Rather, these are meanings assigned to artifacts by relevant actors. The SCOT approach tries to be more symmetrical in its analyses by accounting for failed technologies as well as successes, something that linear models of development and progress leave by the wayside. As Bijker states, both the "nuts and bolts" of technologies *and* the larger social context in which they develop are essential for any complete analysis (1995: 10).

Bijker (1995) offers an interesting heuristic methodology for understanding how new technologies emerge, how they change over time, and how they stabilize into solid, uncontested forms. This methodology contains five parts, the first of which is identifying what he calls the *relevant social group* (RSG). These groups are defined by the participants themselves using a technique often called "snowballing." This technique is adapted from the sociology of scientific knowledge where the analyst defines a core set of actors through interviews whereby actors themselves generate a list of centrally located participants.[1] By doing so, the analyst hopes to avoid making any *a priori* choices about who is relevant and who is not. It is only by trying to understand the problems and solutions as they are presented by RSGs in times of disturbance that the analyst will ever understand the fluid nature of artifacts.

The second analytical tool, *interpretive flexibility,* is meant to capture the notion that it is not only that different RSGs see the same objects differently, but that the meanings they assign these objects actually constitute the objects themselves (Bijker, 1995: 77). This notion of *interpretive flexibility*, that actors see and value things differently, reveals that the development of artifacts and innovations are not innate to these objects but take shape through a social process of competing definitions. While thinking along these lines has long been taken for granted, for example in political conceptions of agenda setting and the production of culture, its application to technological innovations allows for a very different model of technological change than classical histories of technology employ.

Analogous to the Kuhnian paradigm[2] and to Giddens's (1984) structuration concept, Bijker's third analytical tool, the *technological frame*, provides a setting for the activities of the relevant actors (192). The *technological frame* is built up by the inclusion of new RSGs and is constituted by key problems, problem solving strategies, current theories, tacit knowledge, testing procedures, user's practices, and exemplary artifacts, among other things. As new groups enter into this system, they bring with them new definitions, new perspectives, and new problems. This interaction simultaneously enables and constrains the behavior of actors. Bijker thus conceptualizes the *technological frame* a sort of hinge between RSGs and artifacts.

The catalyst for change is embodied in the fourth analytical tool: *degrees of inclusion*. It emerges from the following question and observation: if a *technological frame* structures the interactions among members of social groups and between social groups, what happens when

[1] Bijker specifically draws on the work of Collins (1981) for his methodology concerning the "core set."
[2] One major distinction between Bijker's *technological frame* and Kuhn's paradigm is that the *technological frame* allows for a more heterogeneous conception in which all RSGs, not only engineers (or scientists), actively participate in the shaping of outcomes.

an individual is a member of more than one group? Bijker's answer is that these differing *degrees of inclusion* help to construct the *technological frame* itself as well as account for the process of creation and change. Invention is not the result of individual genius operating in isolation; it is the result of applying new ways of thinking to old questions or problems. Part of the process of technological change and invention is this notion that actors often span multiple RSGs at once, and in doing so they facilitate the spread of new problems, solutions, and meanings, thus broadening the *technological frame* and creating catalysts for change.

Work in the SCOT framework understands the emergence of new technologies as the result of actors shifting from one frame to another and providing new insights into old problems. The "working" or "not working" of a technology is a social construct. A technology "works" when all RSGs agree on a definition and when all of the competing meanings converge on a single design. Using this framework, a wide range of studies have explored the development of specific technologies and more complex technical systems, ranging from steel (Misa, 1992) to modern aircrafts and military missile accuracy (MacKenzie, 1996), and from clinical budgeting practices (Ashmore, Mulkay, and Pinch, 1989) to national systems of electrification (Hughes, 1983). In most of these cases, the resultant product is not viewed as the most "efficient" or "best" model. Instead, these studies highlight how the very concepts of "efficiency" and "best" are constructed and negotiated by *all actors* embedded in complex systems of social interaction.

The SCOT model is a powerful analytical tool for understanding the factors involved in shaping the designs of specific physical technologies. It is also a powerful methodological tool, as it provides a framework for conceptualizing interest groups and a way of analyzing these interests and exploring their various influences. However, this does not mean that the SCOT model is complete or that it offers an entire explanation of technology evolution. As described above, SCOT posits that a stable design is the result of the cessation of the different views of RSGs. But what happens if the actors are never able to agree on a meaning because the context in which they are embedded continually changes, subsequently changing their visions and the meanings they assign to the objects? In other words, how do we understand a technology if the meanings assigned to it by a given RSG constantly change and are re-negotiated as a result of larger macro-institutional developments? How is technical stability to be conceptualized in such a situation? SCOT does not provide answers to these questions and is thus partially inadequate at revealing the dynamic nature of technical change and development when the institutional and organizational roles of the various RSGs also change.

In light of this, the SCOT model cannot fully explain why and how wind power technology has become a prevalent alternative in the electricity industry. Applying the SCOT model and using its analytical insights would help us understand how different groups and their different interests and desires served to mold the design of windmills so as to achieve a resultant "stable" design accepted by all the relevant actors. As discussed in the next chapter, however, stability itself is not an absolute but is a cognitive construction that itself changes. The stability of a technology does not always coincide with perceptions of stability. Furthermore, SCOT does not tell us anything about where relevant social groups come from and why they value objects differently. Thus if we want to understand the processes by which technologies emerge, develop, and become accepted, we also need to know something about the larger environment that shapes and influences the very organizations that are involved in technical development. This is why the sociology of organizations embodied in New Institutionalism is essential, for New Institutionalism focuses on how economic and social organization are—like technologies—not functional givens but social constructions built up by repeated interactions between actors embedded in networks. What is more, New Institutionalism argues that organizational behavior is best understood by being placed in an institutional environment. It is to these theoretical and analytical insights that this chapter now turns.

New Institutionalism and the Social Construction of Organizations

A summary of all the research that has been done on "institutions" is far beyond the scope of this paper and has been engaged elsewhere (Powell and DiMaggio, 1991; Scott, 1995). What primarily concerns the current research is, more than anything, the fundamental principles behind New Institutional sociology. These fundamental organizational principles are important in part because they offer an integrated, multidisciplinary, and explanatorily powerful set of concepts for the ways that institutions and organizations interact, and in part because these principles have informed a wealth of other research focusing on specific organizational mechanisms. However, before the branches of sociology that stem from the New Institutional trunk can be presented in more detail, the fundamentals of New Institutional thought need to be highlighted and explained.

Even before these fundamentals, some definitions and clarification of terms are in order. To use Scott's (1995) definition of institutions,

> [They] consist of cognitive, normative, and regulative structures and activities that provide stability and meaning to social behavior. Institutions are transported by various carriers—cultures, structures, and routines—and they operate at multiple levels of jurisdiction. (33)

Institutions refer to the formal and informal rules that govern the behavior of actors. An *actor* can be an individual person, a firm, a group of firms, a political party, or an entire nation, depending on the level of analysis. The key feature of an *actor* is that it be an entity capable of behaving and making decisions as a coherent whole.[3] *Outcomes* refer to the formal and informal ways of organizing and to the physical composition of technical systems. An *outcome* is the result of a decision made by an *actor* embedded in a framework provided by *institutions*.

New Institutionalism rejects the premise that specific organizational outcomes are the sole result of internal characteristics of those organizations, of the populations they help constitute, or of reductionist economic factors. Just like technologies, organizational outcomes do not spring forth as rational solutions to problems of control and competition; rather, they are shaped by the "taken-for-granted" frames of appropriate action that are constructed by the institutions within which organizations are embedded (DiMaggio and Powell, 1983; Granovetter, 1985).[4] Perhaps most importantly, actors seek legitimacy by attempting to align themselves with cognitive, normative, and regulative forces which existing institutions help to structure (Scott 1995: 45). In the New Institutional paradigm, the cognitive is an essential factor, not because actors behave according to objective rational interests but because "the means by which interests are determined and pursued" are defined by institutional frameworks (Scott, 1987: 508). In order to understand why groups are organized as they are, the ways that actors perceive the context of their actions must be considered. While the linking of internal perceptions and external environments is not a new concept, New Institutional theory stresses that central to these internal perceptions are normative, cognitive, and regulative pressures which are distinct from—*and indeed help constitute*—what is considered rational, appropriate action at a given time.

Focusing on the organizational field,[5] DiMaggio and Powell (1983) identify three mechanisms driving the convergence of organizational forms around a dominant model. Instead of asking why there are different types of organizational forms, the authors ask "why there is

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[3] School teachers, for example, as individual persons are not considered an organizational actor unless they are joined together in a professional association that represents their collective interests as a single entity. While alone they may each be actors within the organization of the school, it is only as a formalized, collective body that they are considered an organizational actor. The definition thus depends on the level of analysis, but it also spans multiple levels.

[4] This is not to say that actors are not able to act "rationally;" it is simply a recognition that what it means to act "rationally" is not independent of the systems of meanings that institutions provide. The very notion of "rational economic behavior," for example, is a social construct influenced by the structures of markets and systems of exchange; it is not a "natural" phenomena but a socially constructed one.

[5] An *organizational field* is defined as "those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar products or services" (DiMaggio and Powell, 1983: 148). This definition is meant to create a unit of analysis that includes all relevant actors, not just formal networks and competitors. It is analogous to the Bijker's *technical frame*.

such startling homogeneity of organizational forms and practices (148)?" Coercive, mimetic, and normative forces drive this process of isomorphism. These forces play themselves out in political influence, in standard responses to uncertainty, and in professionalization, respectively. In the most simple terms, actors within an organizational field tend to resemble each other because they seek legitimacy, and in trying to achieve this end, they are susceptible to political influence, to the activities of the other actors they interact with and depend on for survival, and to the specific training and problem solving strategies embodied in specialized schools of thought that traverse industry and field boundaries. Just as with technologies wherein the forces exerted by different groups shape the resultant design, so too do organizations tend to converge around a dominant model because these three forces influence the behavior of individual actors within the field. Also similar to technology, this convergence around a dominant model constrains the activity of actors, thereby limiting options for future behavior.

One shortcoming of this conception of isomorphism is that it does not adequately explain the emergence of new forms. If coercive, mimetic, and normative forces constrain and direct activity toward a single form, how then does change occur? How are new models generated? Research aimed at trying to explain the emergence of new forms has been categorized into three central theoretical camps, with little consensus taking shape among them (Romanelli, 1991). The first camp posits that new forms emerge from random events arising out of everyday activity. This camp focuses on the internal characteristic traits of organizations and how these traits or characteristics limit an organization's perception about appropriate and acceptable actions when confronted with random events in the environment. Romanelli terms such studies as adhering to a form of "organizational genetics." For example, organizations are said to possess certain "genes" that express these characteristic traits and are copied by other organizations, such as routines that can be defined by formal and informal rules of behavior (McKelvey, 1982; Nelson and Winter, 1982). Organizations with routines that are better able to cope with specific environmental conditions thrive while less capable organizations will not (Nelson and Winter, 1982). It is important, Romanelli points out, that "the nature of these realized variations is random" (86). Thus changes in the environment do not dictate subsequent changes in organizational form, although they do exert the impetus for adaptation and "gene" transfer. While this conception of organizational evolution is appealing because it offers a fairly comprehensive conceptual apparatus, identifying these "genes" proves to be a very difficult a task in practice (Romanelli, 1991: 87).

The second camp posits that the emergence of new forms is dependent upon the environment in which actors are situated. Certain environments are conducive to specific types of forms, and changes in the environmental context in which actors are located will drive a subsequent change in form. Born out of the work of Shumpeter (1939, 1950) on business cycles and capitalism, population ecology studies such as Hannan and Freeman's (1987) work focuses on the interdependent relationships of existing organizations (Romanelli, 1991: 89). Tushman and Anderson (1986), as another example, showed that competency-enhancing innovations produced by new actors will be readily adopted by existing organizations (Romanelli, 1991: 90). Other work in this vein has highlighted the importance of environmental changes for resultant organizational forms and the extent of variations in these forms. Selznick (1949) has demonstrated how political ideologies influenced the formation of the Tennessee Valley Authority by "imprinting" certain types of administrative procedures that continued to be part of the organization's operations, thereby reducing overall variation. Fligstein (1990) has also shown how a specific legislative act aimed at preventing certain types of mergers ended up unintentionally spurring mergers of a totally different type, thereby increasing variation (Romanelli, 1991: 90–92).

The third camp posits that new forms emerge from the embeddedness of social-organizational interactions and their collective pursuit of new systems of organization. Independent entrepreneurs perceive a potential to create a new organization, and in the process of seeking out resources, interdependencies among similarly independent actors are established. These interdependencies lead to the sharing of information in an attempt to establish legitimacy and isolate the new form from competitors. Over time, networks between actors who compete and those who cooperate are formed, thus creating an industry which is defined by particular relationships to an innovative technology (Van de Ven and Garud, 1989). This view combines the internal and the external to explain organizational activity.[6] Perhaps most importantly, it focuses on the ways that all organizational forms revolve in one way or another around specific products, services, or technologies, be they ancient practices or brand-new innovations.

These various literatures all explain the development of organizations without relying on notions of absolute, objective efficiency. Instead they highlight the importance of the pressures exerted by regulations and cultural norms as well as the differences in these institutional forces and their variations depending on the type of product around which organizational activity is structured. Different products require different types of organizational forms to achieve legitimacy, and seeking this legitimacy drives isomorphism such that new forms tend to resemble those that already exist. What is more, the structure of organizations also affects innovation and change. As organizations provide the frames of meaning that are used to interpret environmental

[6] The Minnesota Innovation Research Program (MIRP) began in 1983 and is been aimed at "tracking the diverse set of innovations over time as they develop in their natural field settings" (Van De Ven, Angle, and Poole, 1989). This research program generated quite a substantial body of work which is compiled in an edited volume by the above authors published by Ballinger in 1989. Interested readers are referred to this volume for more information, as a complete summary of the findings of this program is not feasible in this current paper.

pressures as they are exerted on the organization itself, they also provide the context for inter-organizational interaction. These theoretical insights open the doors for a whole slew of case studies aimed at identifying both the distinctive features of specific industries and their emergence. These studies also touch on the mechanisms driving and constraining institutional, organizational, and technological change.

While it would be difficult—perhaps even impossible—to place all of the findings from researchers dealing with institutions, innovations, and organizations into neat and orderly categories, this does not mean that their findings are necessarily incompatible with each other. This inability to neatly summarize the findings of existing research stems in part from the fact that many researchers examining similar phenomena approach their topics from completely different theoretical stances with little discursive overlap. To complicate things further, even researchers engaging similar theoretical issues pursue the cases at different levels of analysis, and more importantly, at different phases of change and development. In some cases, for example, federal regulation seems to be the main force spurring variations in organizational behavior in early railroad foundings (Dobbin and Dowd, 1997) and in the independent power industry that emerged in the 1980s in the United States (Russo 2001; Sine, Haveman, and Tolbert, forthcoming). In both these cases, regulation was important because it directly altered the competitive environment of these organizations. This shift in the legal and political environment forced organizations to adapt. But what looks like a straightforward answer is in fact quite complicated, as this regulatory shift also caused a change in the normative environment and perceptions of legitimacy. In light of this, did organizations change because of coercive or normative forces? Explanations become hopelessly tangled, as the “three pillars” of institutionalism (normative, cultural, regulative) seem all to play simultaneous roles in driving change. What is more, their influence may vary depending on the phase of industry development, and it is unclear if the same processes are at work during the emergence of a completely new industry and during the adoption of a new practice among existing organizations.

It is clear that institutional forces play a significant role in the process of industry emergence, market creation, and technological change, although the specific circumstances in which they each function still remains an open debate. This may be because while the “three pillars” are analytically distinguished by researchers, they may in reality be extremely difficult to tease apart. Thus while politics is important for the shaping of markets and therefore structuring economic activity (Fligstein, 1990, 1996), how can we determine if the “political” is a coercive or a normative pressure? In other words, the harder we look for *the* mechanism driving organizational change, the more we see that change results from different but interrelated mechanisms functioning at different times in the innovation process, at different levels of analysis, and in different contexts. What is more, applying the conception of technical change from the SCOT model to organizational innovation is suggestive, for perhaps organizations, like technologies, are shaped into coherent and stable forms through ongoing interactions between participants. The nature of the ties between organizational actors is thus important for transferring meaning and normative, cultural, and regulative pressures from one organization to another.

Despite the obvious similarities between SCOT and New Institutionalism, few existing studies incorporate the insights of both. Most New Institutional studies tend to abandon “internal” characteristics as important for explaining organizational outcomes, and just as SCOT treats RSGs as black boxes, New Institutionalism assumes that technology itself can be treated as an independent variable. When technology is engaged in the New Institutional framework, it assumes that objects are stable and are simply adopted by organizational actors. Such diffusion studies fail to recognize that objects and practices change as they spread and are adopted by new organizations in different institutional locations. As this thesis argues, content and context cannot be separated quite so easily. This is not to say that they are one and the same thing; in fact both SCOT and New Institutionalism explicitly reject this. What it does mean, however, is that one cannot assume that organizational outcomes are structured around stable physical artifacts and technical systems. Instead, these artifacts and systems are shaped by existing organizational forms and relationships within fields, and they also feedback into these systems to shape organizational forms. In other words, SCOT and New Institutionalism need to be combined, as technology and organization co-evolve within changing institutional frameworks.

Conclusions: Combining Two Constructivist Literatures

The two main literatures discussed in this chapter are intimately connected in their conceptualizations of the forces that shape organizational behavior even though they remain theoretically and discursively disconnected. SCOT and New Institutionalism refuse to take as explanations for behavior single variables associated with internal organizational characteristics. SCOT studies focus on specific technologies and seek to discover the multiple frames of meaning that different RSGs project onto artifacts in order to shape and change them to suit their desires. But because most technologies involve interactions between RSGs from different *technical frames* with different *degrees of inclusion*, emergent designs always embody a compromise. Similarly, New Institutional studies focus on the ways that specific forms of organization become dominant and on how new forms emerge to challenge this dominant model. The focus here is on institutional forces—mainly normative, cognitive, and regulatory—which provide models for economic behavior and shape organizational frames embodied in different organizational fields. While each certainly acknowledges that some internal characteristics are important, the focus is on contexts created by macro-institutional forces and the organizational and technical decisions made by actors embedded in these contexts.

Both literatures emphasize the importance of the cognitive for explaining outcomes. In SCOT, technology is shaped by different cognitive perceptions of what an artifact should like and of what the problems associated with existing artifacts are. In New Institutionalism, organizational form is shaped by different cognitive perceptions of what appropriate courses of action are in a particular institutional environment. Likewise, one cannot assume that the meanings assigned to technologies are stable either, as the cognitive frames influencing the shape of artifacts also change with institutional context. When these theories are combined, technology and organization can no longer be treated as independent from each other. Instead, *technology and organization must be treated as interdependent aspects of the same institutional system*. New Institutionalism must recognize technologies as social constructs that are distinct from but connected to normative, regulative, and legal factors. Similarly, SCOT must recognize organizations as social constructs that frame and give meaning to the problems and solutions that shape technologies. As a result, research dealing with industry emergence and change must take into account the systems of feedback between technology and organization.

SCOT and New Institutional studies both recognize that new organizational and technological arrangements significantly affect the activity of existing actors as well as new entrants by altering fundamental distributions of power, resources, and legitimacy. In trying to understand the emergence of a new industry using a specific technology, each theoretical paradigm proposes a complete explanation. On the one hand, SCOT posits that the process by which a specific technology comes into being and takes a solid form involves a complex interplay of social networks, of conflicting institutions, of malleable norms, and of competitions between groups. Technologies thus are indirectly shaped by stable institutional forces acting through relevant social groups. This model conceptualizes adoption as a phase of technological development when all the relevant groups come to agree upon definitions and meanings. On the other hand, New Institutionalism posits that innovation results from specific types of institutional and organizational arrangements that serve to establish legitimate practices. A practice or technology is stable and is adopted or not adopted because it serves a purpose in the actor's quest for legitimacy; decisions are made based on cognitive perceptions of appropriate activity.

As the case of wind power will make clear, these paradigms need to be combined in order to construct a complete picture of industry emergence and success. The success of wind power involves the simultaneous development of perceptions concerning technologies *and* organizational arrangements. A study solely in the SCOT vein would examine the shapes and sizes of windmills and their changes and transformations until a design was achieved that satisfied the needs of all the actors. But identifying these needs—how they came to be and what they exist in relation to—is of central concern and is not a simple task. Furthermore, to explain behavior based on some set of internal *needs* reverts to a sort of functionalism that both SCOT and New Institutionalism strive to escape from. SCOT assumes that these needs are stable, something that New Institutionalism rejects. But New institutionalism treats technology as stable, something that SCOT rejects. A study solely in the New Institutional vein would examine the types of relationships between organizations and the legal, normative, and regulative institutional environment. In light of this, the current research blends together these conceptual frameworks in order to clarify each of them and provide a richer, fuller account of industry emergence and success.

Methods

The methods employed in the current research combine analyses of existing historical studies, quantitative data sources, and original interviews with key participants in the wind power industry. Almost all of the extensive existing historical studies on this topic pull from a multiplicity of sources ranging from newspaper and trade publications to technical specifications for specific windmill designs, and from policy memos and legislative acts to interviews with participants involved in various aspects of the industry. This study uses insights and findings from many of these sources to provide the context for the development of the wind industry as well as many of the problems and barriers confronting the industry. In fact, largely because these studies are all of such high caliber, the current research is aimed not at verifying and contesting previous findings but instead at expanding upon them to clarify details. Furthermore, because the majority of these studies were completed in the mid 1990s, the current research seeks to explore more recent developments taking place at the end of the 1990s up through the first two years of the new century.

Following in the footsteps of Gipe (1995), Serchuk (1995), Righter (1996), Asmus (2001), and Sawin (2001), original interviews were conducted with key participants in order to understand recent developments and gain perspective on historical events. Most of these participants were identified indirectly by using a publicly available data set called the Renewable Electric Plant Information System (REPIS) compiled by the National Renewable Energy Laboratories (NREL). This database contains information about all of the organizations and firms that currently own or operate wind facilities in the United States. These include traditional vertically integrated and regulated utilities, public and cooperative utilities, nonutility Independent Power Producers, and individual owners using small scale technologies. After identifying the main firms using wind power in the United States, persons at those firms with an extensive history in the wind industry (who had preferably been with the company for a number of years) and who were directly involved with organizational decision making were located using company websites. These persons then received a letter of introduction and a request for an hour-long, tape recorded interview over the phone or in person (see Appendix II for sample). The majority of letters were printed on Reed College Department of Sociology stationary and mailed directly to the potential interviewee. Several letters were also sent via email.

Because previous studies noted the interdependencies between power producers and a number of other actors in the industry, requests for interviews were also made to persons associated with federal research and development programs and agencies, industry and trade associations, consultants, and state and regional policy making. These persons were identified through web site searches of organizations already identified as influential from previous research. In some cases, the initial letter was forwarded within the receiving organization to an individual identified as more able to speak on the current topic or with more experience. Additionally, some participants gave references to other individuals not on the original list who they felt were qualified or who could offer special insights. In these cases, these references were contacted and almost all resulted in an interview. A total of sixty letters of request were sent out; of those sixty, twenty-five responded, leading to nineteen interviews, nine of which were conducted in person and ten of which were conducted over the telephone (see Apendix I for list of interviews). Table 1 shows the breakdown of the distribution of interviews by category. Investor Owned Utilities and consultants make-up the two largest groups, while municipal utilities and trade associations

Table 1: Distribution of Interviews

Category	Number of Interviews Conducted
Investor Owned Utility	4
Independent Power Producer	4
Municipal Utility	1
Federal Research Agency	2
State / Regional Policy	2
Industry / Trade Association	1
Consulting / Academia	5

make-up the smallest. All but four of the interviews were tape recorded and transcribed with the consent of the participants.

The interview format could be characterized as a semi-structured, informal conversation. Three participants did not receive the initial letter and were not recorded.[7] All other interviews began with a request for permission to record followed by a brief elaboration of the purpose and extent of the research and the confidentiality of the material revealed. Because each interviewee was from a different part of the industry with a different history, questions were tailored to each interview. Topically, the interviews tended to focus on the current status of the wind industry or on more recent history since the mid 1990s. At the end of each interview, participants were given the opportunity to ask questions, and permission to use direct quotes was requested. A final letter of closure and gratitude was sent on department stationary to each participant, along with contact information (see Appendix II for sample).

It should be noted that even though the interviews spanned many different organizations in the wind power industry, they did not encompass them all. Unfortunately, no interviews were conducted with turbine manufacturers or with the American Wind Power Association due to a lack of response from these organizations. However, several interviewees offered a perspective on turbine development and numerous participants had extensive involvement with turbine manufacturers. Furthermore, multiple existing studies contain interview data from these sources, and this material helped inform the current research. While the lack of inclusion of this group is perhaps regrettable, it simply means that future research should include this group to examine if such inclusion significantly alters the story constructed in the chapters that follow.

Before delving into the specifics of the construction of wind-power technologies and organizations, however, a general note about the analytical method used in the remainder of this thesis is in order. An important thread that runs through each of the following chapters to tie together the argument is a focus on two different organizational fields and the changing nature of their relationships over time. The first field, called FIELD 1, is constituted by the established electric power industry. It includes a system of legally structured relationships between organizational actors as well as a system of technologies that these organizations are used to using. This organizational field, and its technical frame, are dominated by regulated electric utilities. The second field, called FIELD 2, is constituted by a new class of nonutility independent power producers (IPPs) with a fundamentally different set of legally structured relationships and a different technical frame. Using the field as a guiding framework for the following analysis helps demonstrate the claim that technology and organization must both be considered in order to explain industry emergence and success.

[7] These interviews were conducted on a very informal basis. Participants were aware of the goals of the interview and gave permission to be identified.

CHAPTER TWO – Constructing Technology: Wind Turbine (R)evolution

It is difficult to tell the history of a technology without reverting to a simple chronological listing of events and developments. After all, technology does change as time moves forward. But as SCOT points out, it is a mistake to tell the history of technology from a purely functional point of view or to assume that "progress" is a universal, easily measured characteristic. Instead, understanding technology—the way it comes into being and changes form—requires an awareness of the context in which it develops. But more than that, it requires an awareness of the cognitions of those directly and indirectly involved in shaping the technology itself. In the case of wind power, these contexts can best be understood as levels of analysis that are distinct from each other but are all interrelated. Technology is embedded in many types of organizations, industries, and institutions, each functioning at different levels. An analysis of wind power must look at how the physical technology was shaped by the individual and collective goals of the organizations developing it.

Chapter One argued that it is difficult to separate technology, organizational form, and policy from each other. The three are interconnected. But for the purposes of this analysis, the three are separated analytically in order to lend clarity to the data and findings. This chapter's focus is mainly on the physical technology, but in fact aspects of organizations and policy both creep in as part of the story. Indeed, this is the whole point of this thesis: technology, organizations, and policy all affect each other. This chapter begins with a brief overview of FIELD 1, the electric power industry and its historical context. This overview is meant to provide the essential backdrop against which FIELD 2 (nonutility independent power producers) developed and into which it subsequently was accepted. While this chapter mainly addresses technology, this first section includes material related to policy and organization as well, for the emergence of wind power must be viewed in the context of the existing organizational and technical structures that constitute the electric power industry more generally. The formation and maturation of the wind power industry involved the acceptance of particular types of technologies and the construction of an infrastructure to support them. Actors in both FIELD 1 and FIELD 2 were interested in wind power technology. In order to illustrate the differing conceptions of this technology by field, the nature of the research and development environment and the demands and pressures exerted by RSGs are explored in depth. In general, then, this chapter follows wind turbine technology from its infancy to its adolescence, highlighting the ways that the actors in different fields have changed their cognitive perceptions of the technology as "working" or "not working" in different ways at different phases of industry formation and maturity.

Overview of the United States Electricity Industry

The modern electric power industry—FIELD 1—has not always looked like it does at present. In general, the historical structure of the industry can be separated into three phases: 1880–1935, 1935–1978, and 1978–present. These phases largely correspond to specific types of policy environments affecting the nature of the relationships between actors as well as the types of technologies used by them. The first period was characterized by a fair amount of variation in both the types of technologies used and the structure of the organizations using them. During this first phase, both distributed and centrally produced power were used by a multiplicity of actors. By the mid 1930s, most urban residents received their power from regulated monopoly utilities using centrally generated power technologies and fuels, such as coal fired plants (Granovetter and McGuire, 1998). During the second phase, this model of central power dominated the electricity landscape, although there was some limited diversification of fuel types. Specifically, hydropower became a large part of the nation's electricity mix during the Second World War, and nuclear power entered the scene briefly during the 1960s and 1970s. While a few parts of the country still used distributed power technologies, this second phase largely involved the expansion of the central power grid to almost all parts of the nation and the increasing dependence on fossil fuels for generating electricity.

In 1978, five years after the OPEC oil embargo, a system of limited competition was introduced into the wholesale generation market as a result of the Public Utilities Regulatory Policy Act (PURPA), which marks the beginning of the third phase. One major consequence of this federal legislation was that it created a new organizational field—FIELD 2—as a legal entity focused on a specific technological mission: develop new renewable energy sources. It had become clear that electric utilities would not take on this task because of their historical risk and innovation aversion. FIELD 1 tended to stay with established and proven technologies and not develop new, cleaner methods for producing power. In part, this aversion to innovation was due to the regulatory structure of the industry, as it provided no internal incentives for electric utilities to innovate or increase the efficiency of their generation techniques. The calculated rate of return for regulated utilities does not include research and development or investment in new technologies. If

> . . . a utility makes a substantial investment into a new technology . . . [and] the technology fails to meet expected performance standards, operating costs will

> increase but rate setting commissions may delay or completely disallow a pass-through to the customers. . . . On the other hand, if the technology performs as well or better than expected, operating costs may decrease, but rate-setting policy would typically pass most of the benefit to the ratepayer and not the stockholder whose money was at risk. This situation reinforces risk aversion and is not conducive to experiments with new technology at investor expense. (March, Dlott, Korn, Magio, McArthur, and Vachon, 1982)

This drove the industry toward conservative courses of action. While PURPA did open up the wholesale generation market, it did not transform the nation's power supply overnight.

Since 1978, wholesale power generation has become increasingly divided between these two organizational fields—the older model of the regulated electric utility and the newer model of the unregulated nonutility independent power producer (IPP)—called FIELD 1 and FIELD 2 in this analysis, respectively. To use the definitions of the U.S. Department of Energy, an electric utility is,

> [a] corporation, person, agency, authority, or other legal entity instrumentality aligned with distribution facilities for delivery of electric energy for use primarily by the public. Included are investor-owned electric utilities, municipal and State utilities, Federal electric utilities, and rural electric cooperatives.[1]

A nonutility IPP, on the other hand, is,

> [a] corporation, person, agency, authority, or other legal entity or instrumentality that owns or operates facilities for electric generation and is not an electric utility. Nonutility power producers include qualifying cogenerators, qualifying small power producers, and other nonutility generators (including independent power producers).[2]

Figure 2 shows the percentage of the industry occupied by type of power provider in 1999 and Figure 3 shows the breakdown of fuel usage by these two types of organizational

[1] This definition was accessed from the online EIA glossary on April 9, 2003 at http://www.eia.doe.gov/glossary/glossary_e.htm#el_utility.
[2] This definition was accessed from the online EIA glossary on April 9, 2003 at http://www.eia.doe.gov/glossary/glossary_n.htm.

Figure 2: Share of Total Industry Capability by Industry Sector and Ownership, 1999

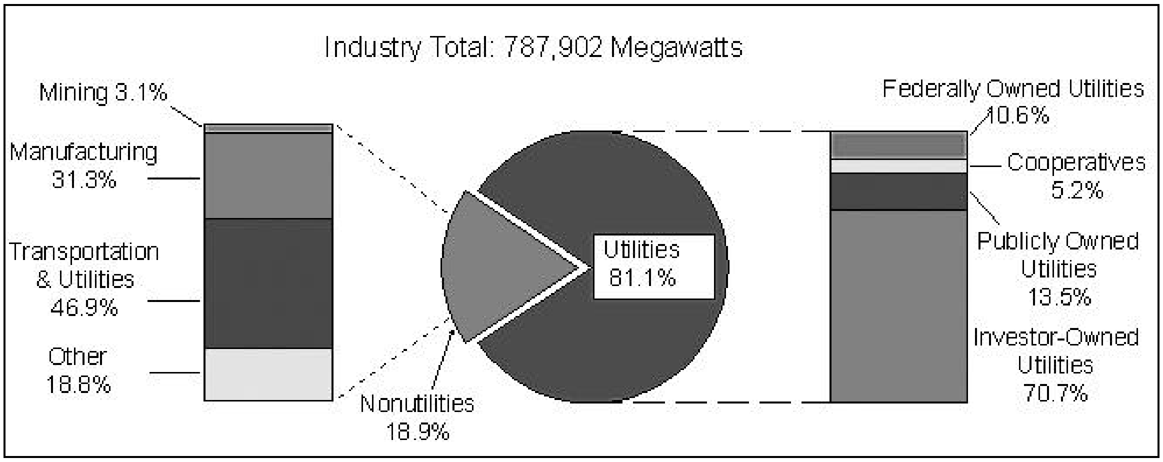
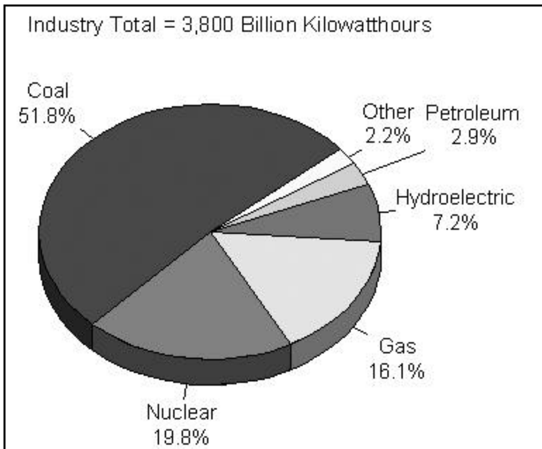


Figure 3: Shares of Net Generation by Energy Source and Industry Sector, 2000



Energy Source	Share (Percent)	
	Utility	Nonutility
Coal	86.2	13.8
Petroleum	66.3	33.7
Gas	47.5	52.5
Nuclear	93.6	6.4
Hydro	90.9	9.1
Other	2.7	97.3

Notes: •Utility total = 3,015 billion kilowatthours and nonutility total = 785 billion kilowatthours. •Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report," and Form EIA-900, "Monthly Nonutility Power Plant Report."

Source: This graph is publicly available on the Energy Information Administration website. It was accessed on April 9, 2003 from http://www.eia.doe.gov/cneaf/electricity/epav1/fig5.html.

forms in 2000. While the 1978 legislation was intended to promote cogeneration facilities,[3] one unintended consequence was that it allowed entrepreneurs interested in new renewable technologies[4] to try and break into the market. The central story engaged in this thesis focuses on how this new organizational field (populated by IPPs) co-evolved with a specific type of innovative technology (the modern wind generator) and became established alongside the old organizational field (electric utilities).

Figure 4 shows the cumulative wind capacity in the United States starting in 1980.

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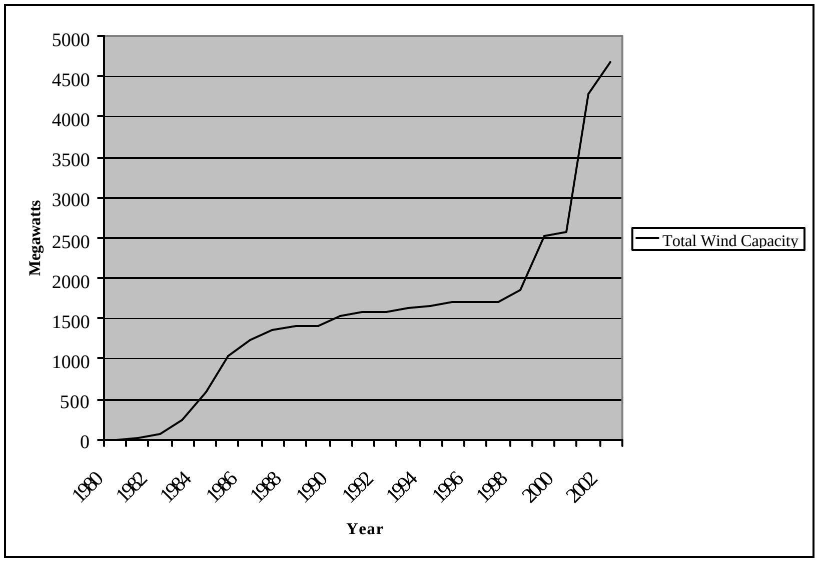
[3] Cogeneration facilities use excess heat and energy from industrial processes to generate power, often for on-site use.
[4] New Renewable technologies most often refer to solar, biomass, geothermal, tidal, and wind.

Figure 4: Total U.S. Installed Wind Capacity, 1980–2002



Source: The data for this figure is publicly available from The American Wind Energy Association. It was accessed on April 12, 2003 at http://www.awea.org/faq/instcap.html.

It is important to note that 5000 MW of power produced from wind turbines in 2001 is still a miniscule portion of all the electricity produced in the United States in a year. Wind power occupies a small portion of the "other" category in Figure 3, which itself only constituted 2.2 percent of the nation's electricity in 2000. However, the general sentiment in the industry today is that wind power is the fastest growing new renewable technology on the market and that it is being pursued even by electric utilities. In 1980, wind power was all but nonexistent in the world of large electric utilities, and by 2003 it has become a flourishing industry using a "proven" technology. To say that wind technology seems to have become accepted simply because it became a "proven" technology is not an adequate or complete explanation. Similarly, to say that nonutility IPPs using wind technology broke into the electric power industry because they are "best suited" to provide electric power is just as inadequate and incomplete. As SCOT and New Institutionalism argue, technologies and organizations do not "prove" themselves by "working better;" instead these cognitive perceptions themselves are social constructs that can be observed, studied, and explained. The development of wind power has thus involved the simultaneous co-evolution of wind technology and a particular type of organizational form within a new organizational field.

Early Wind Power

Before the late 1970s, a wind power industry—constituted by a formalized group of consumers and producers participating in stable economic relationships—did not exist. FIELD

2 as presented in this analysis did not yet exist. From the turn of the century until the advent of the Rural Electrification Administration (REA) in 1936, most rural parts of the country were not connected to a central electric grid. The REA was formed in part because it was believed that these rural areas should "modernize" and receive the benefits of central power. Electric utilities during that time often would not provide services to these parts of the country because these areas had such a small customer base and low energy demands that it was not worthwhile to build a line servicing them. In an attempt to rectify this situation, the REA provided funding to help start municipal and cooperative utilities in these areas and it also subsidized power lines.

Before the REA, many businesses manufacturing small scale wind turbines for rural home and farm use off the utility grid did quite well. The lack of utility interest in servicing isolated rural areas ensured an adequate market for these few windmill manufacturing companies, and although there was little cooperation and organization among them, there was significant competition among companies championing their own unique designs. But the advent of the REA brought about strong normative pressures for farmers to connect themselves to the expanding national transmission system even though many of them already owned turbines that generated more power than they could use. What had been a relatively successful (though informal) wind industry in the beginning part of the century collapsed as the nation became tied together with large transmission systems providing centrally generated power (Righter, 1996: 60–130).

The relevant social groups (RSGs) in the first half of the century involved with wind were thus primarily a few windmill manufacturers and many of the nation's rural farmers. The federal government and the large monopoly utilities were not involved at all in the shaping of these windmills, as neither had much interest in small scale power production, especially in areas outside of traditional service territories. Furthermore, the technology that was needed to keep the windmills operating reliably was relatively simple, required little maintenance, and did not need the expertise of large industrial firms.[5] But the lack of any formal standards or industrial organization spurred each business to distinguish itself from its competitors by offering something unique. This was coupled with a general aura of experimentation with tower height and blade arrangement, as little was known about the details of actually generating electricity using an intermittent power source such as the wind.

The multiplicity of early designs reflected the lack of formal institutional arrangements between manufacturers, and consequently no universally accepted standards emerged. The

[5] Righter (1996) comments that the windmills made during this time were so reliable that the manufacturers began to run out of clients, as the windmills almost never broke down and the market became saturated. In fact, as the interest in windmills resurfaced in the 1960s, many inventors and tinkers were able to look at these earlier designs for guidance, as they often still stood on many rural farms and even worked with some basic maintenance some 40 years later.

lack of a dominant design was also a consequence of the removal of an end user market, as centrally located power plants distributing power through large voltage transmission systems came to dominate the energy landscape after the 1930s. However, even though the specific windmill designs were diverse in their component arrangements, the size of the windmills was influenced by the perceived market for the product (i.e. small farms with low electricity requirements). Gigantic windmills serving entire cities were not pursued as a viable option because the end customers for such power were already being served by utilities with monopoly control of the market using a different set of technologies. In other words, actors in FIELD 1 were successful at promoting their definition of the technical frame. Thus early wind technology was shaped by the existing (or nonexistent) institutional arrangements, which included (or excluded) wind power as a possible form of power production.

When the OPEC oil embargo of 1973 caused sharp increases in the price of oil, the nation began to reconsider its dependence on fossil fuels for electricity. Starting in the early 1970s, the federal government began research on new renewable technologies such as solar and wind. But with wind, for example, the only turbines that existed were for small scale use and could not provide anywhere near as much power as electric utilities and the public demanded. In this sense, a “working” wind turbine for utility scale applications did not exist in 1973. This external shock to the system redefined what a “working” wind turbine meant, as well as what was an appropriate technology for FIELD 1 to pursue. Such a technology had to be large enough to provide significant output to electric utilities but also cheap enough to compete with all of the entrenched technologies that the established organizational field had become so dependent on.

Whereas for the first three quarters of the twentieth century the number of actors involved in shaping wind power technology was relatively small, as soon as wind power became a possible technology for FIELD 1 to pursue, the number of relevant social groups dramatically increased. This was because the product provided by FIELD 1 (electricity) had become central to almost all aspects of modern American society. Everyone in the nation had a stake in the way that electricity was provided and produced, even if this stake was as minor as simply desiring the cheapest rates. This fact makes it difficult to bind the technological frame of wind power because so many RSGs became increasingly included in the shaping of the technical system. By 1980, for example, actors in both FIELD 1 and FIELD 2 were involved, but so were actors not directly involved with either field. In FIELD 1, for example, the range of actors included: federal and state oversight and regulatory agencies such as the newly established Department of Energy (DOE) created in 1977, the Federal Energy Regulatory Commission (FERC), and state Public Utility Commissions (PUCs); existing power producers and distributors such as regulated electric utilities, energy holding companies, federal, municipal, rural, and cooperative utilities; and large research and development (R&D) organizations such as the federal government, NASA, the aerospace industry; and the Electric Power Research Institute (EPRI, founded in 1973). In FIELD 2, independent power producers, natural gas companies, industrial firms operating cogeneration facilities, and a few smaller companies such as foreign and domestic turbine manufacturers and plant operators were also involved. Outside of both these fields, unorganized environmental advocates, nuclear fuel opponents, and utility customers also became involved in shaping wind power technology.

The point is that any social constructivist account of how modern wind turbines came to their current incarnation is forced to consider almost all social groups as relevant ones. Such an account must also acknowledge that the technical frame itself constantly changed as new groups entered the scene. A blow-by-blow technical history of the designs of specific turbines made by individual companies is beyond the scope of this current paper. However, some general trends and competing definitions can be highlighted and traced over time as the industry evolved. The construction of the modern wind turbine really began with the research carried out by the federal government and a few private corporations during the decade of the 1970s in response to the perceived needs of FIELD 1. This research program was guided by a particular conception of what a "working" wind turbine would look like. On top of the conceptual goals of this program, the vantage of historical perspective also reveals that certain tactics and practices were essential for the evolution of wind power technology. Field testing was incredibly important for wind turbine design as it gave researchers hands-on experience with the technology in real world contexts outside of the laboratory. But the nature of this R&D environment was essential for more than just technological improvements; it also helped build relationships between actors from different fields. It was the simultaneous construction of wind power technology alongside the construction of organizational networks and relationships between fields that lay the foundations upon which the success of FIELD 2 was built in the late 1990s. In order to understand the quality of these relationships, however, the R&D environment of FIELD 1 needs first to be discussed.

The Federal Wind Energy Program in the 1970s

As noted in the last section, the oil crisis of 1973 caused RSGs associated with FIELD 1 to reconsider the technologies that the nation had become so dependent on. Knowing that existing electric utilities were not likely to develop new technologies on their own due to their aversion to innovation, the federal government began a research program aimed at developing new renewable technologies. One of these programs, called the Federal Wind Energy Program (FWEP), began in 1973. This program was aimed at developing wind technology for use by existing electric utilities. This meant that the new technology had to fit into the existing technical frame of FIELD 1. In other words, a "working" wind turbine meant massive output on the scale of existing fossil fuel plants. The perceived needs of actors in FIELD 1 thus directed the research agenda toward the development of very large scale turbines.

The federal program partnered with several aerospace corporations like Boeing, General Electric, and Westinghouse who had expertise in economies of scale as well as helicopter and propeller engineering (Williams and Porter, 1989:224). As Serchuk writes,

> . . . [t]he FWEP chose to develop megawatt-scale horizontal axis machines, which they believed showed the greatest potential and modest development risk as low-cost energy generators. . . . As successive designs sought to lower capital cost, for example by reducing weight, engineers pursued maximum economies of scale by constructing larger and more powerful turbines. (1995: 103)

The FWEP did experiment with a number of different turbine designs, most notably a windmill that used vertically mounted blades and looked similar to an eggbeater. Even though this design had a number of potential advantages,[6] it was abandoned in favor of the horizontal blades primarily because technical data from the aerospace industry and turbine designs from earlier in the century "lowered development risk and time" (Serchuk, 1995: 118). The idea was thus to create machines of massive proportions using lightweight materials that would be able to produce power to compete with conventional fuels.

A number of social and technical barriers presented themselves in the process of designing these large scale turbines. On the social side, Serchuk notes, for example, that "[t]he spinning metal blades of the big turbines interfered with television reception—a shortcoming guaranteed to enrage even those Americans normally unlikely to ally themselves with environmentalists (1995:134). Other barriers were a lack of accurate information about wind resources and permitting and zoning regulations prohibiting industrial development. On the technical side there were also many problems. They ranged from being able to safely connect an intermittent power source to the existing utility grid to redesigning blades to reduce noise to minimizing blade vibration at high speeds to prevent cracking and damage to the tower. Perhaps most importantly, investing in a gigantic machine meant that all the resources went into one object, and if something went wrong the whole thing was often lost.[7] Whereas airplanes

[6] One advantage was that all of the electrical equipment was at the base of the turbine and not four-hundred feet in the air, which made replacing parts and maintaining the windmill much easier.

[7] Righter explains how one of Boeing's test sites in Medicine Bow, Wyoming displayed one 2.5 and one 4 MW turbine. After four years of periodic functioning, the main bearings in one of the machines broke and the replacement cost was $1.5 million. Instead of fixing it, the company decided to take the whole thing down. They dynamited the base and let it fall, and then when no one would buy it as a turbine they sold it as scrap metal for $13,000 (1996:176–179).

and helicopters could be serviced every couple of days and run intermittently, wind turbines had to be relatively maintenance free and run all the time, day and night, rain or shine. The federal government and the aerospace industry started designing turbines with the idea that skills from other industrial experiences were transferable and that a big turbine operated the same way as a small one, only it needed bigger parts. Both of these assumptions turned out to be incorrect, as constructing a large turbine was much more difficult than anyone had anticipated.

By the end of the 1970s, the federal program had little to show in terms of a working, cost competitive turbine despite the almost $150 million dollars it had invested in wind R&D from 1975 to 1979 (Serchuk, 1995: 165). While in retrospect the program had its flaws and was perhaps misdirected, its actions seemed the most rational at the time given the circumstances and were aimed at achieving what at the time were realistic goals based on an understanding of the problems and potentials of the technology. It is clear that the perceptions of the FWEP, of the aerospace industry, and of the electric utilities themselves were largely influenced by the historical and institutional context of FIELD 1. The structure of the market environment significantly shaped the perceptions of central RSGs, which caused subsequent changes in technological design even though these designs may not have been the most "efficient" or "best" technical arrangements.

The Emergence of the Wind Power Industry

The relevant social groups and the technological frame that constituted the wind industry in the 1980s were largely the same groups from the previous decade, with some notable exceptions. PURPA in 1978 created a new class of actors legally able to generate electricity outside of the model of FIELD 1. It also ensured a market for this type of power, and it was soon booming with companies also ready to take advantage of the investment credits now offered by the federal government for alternative, green energies like wind. While there were some small turbine manufacturers in the 1970s, these companies were largely unsuccessful at securing the necessary capital investments to make their turbines efficient and cost competitive. As such, existing utilities would not purchase them and saw them as a potential threat to their market share and would therefore refuse to carry this type of power over their transmission systems. Furthermore, these small companies often found themselves subject to the regulatory structure of the existing industry if they produced enough capacity. PURPA removed two of these major institutional barriers by requiring that utilities offer a "fair rate of return" for this power and that they accept it into the grid. PURPA also exempted these small facilities from the rate ceilings that the regulatory system imposed, opening the door for tremendous profits to be made if the turbines actually worked. Furthermore, because the fuel was virtually free, wind held a competitive edge over existing fuels.

But to say that the relevant social groups were largely the same is somewhat misleading, as the role of the federal government and the aerospace industry, for example, receded significantly from the wind power landscape. Instead of enormous companies receiving large federal grants for research and development, the wind industry was populated with small entrepreneurial startup companies pursuing smaller, more manageable turbines. These new companies constituted FIELD 2 (populated by nonutility IPPs). As opposed to the vision of the FWEP where a few enormous machines were purchased by utilities to replace conventional fuels, the vision of the nonutility IPPs and turbine manufacturers in the early 1980s was of clusters of medium sized machines making up wind farms (Serchuk, 1995: 230). These wind farms were still envisioned as working within the framework of the centrally located power plant (FIELD 1), but the risks associated with turbine failure were lower if many turbines were in operation. The owners and inventors who five or six years before had made up a small peripheral counterculture of renewable energy junkies now found themselves courting bankers and investors on wall street and running private companies.

This new field constituted the new wind power industry. Whereas the federal programs of the previous decade attempted to engineer a "working" technology according to the perceived needs of FIELD 1, there really had never been the establishment of a wind industry. It was not until the 1980s that a sector of like-minded organizational actors converged to collectively shape the industry's economic and institutional future. During this time, actors in FIELD 1 by and large held back and waited for the technology to become more reliable and less expensive. They were reluctant to sign long term contracts using an unproven technology, and this reluctance hindered some developers in FIELD 2 from securing the capital needed to manufacture and install enough turbines to produce a significant output. In this environment, field testing became a very important aspect of the wind industry for old and new developers, as it gave them first hand experience with the technology outside of the laboratory. California became the center of the wind industry in the 1980s—largely due to a favorable political environment—and much of the essential field testing was carried out in the hills in the northern part of the state.

In the early 1980s, California's lucrative state tax credits, when combined with federal credits for renewables, meant that many investors were eligible for up to fifty percent tax credits by investing in the emerging wind industry (Serchuk, 1995). California thus became the hot spot for commercial investment in wind power. Much of this investment, however, was not based on an ideological vision of a future of renewable energy as much as it was on the possibility of making a quick buck. The wind farms that came to populate the California landscape were known as “tax farms,” and many of the companies that put them up had little experience with turbine design and maintenance (241). Furthermore, because the tax credits were tied to investment and not to production, there was little incentive for wind farm owners to fully test and design the most efficient turbines before erecting them. As a result, many of the turbines broke down or fell apart and failed to generate the electricity that had been promised. When the tax credits expired in the middle of the 1980s, companies that had been quickly expanding were left hanging, as they could not offer a viable product for anywhere near a reasonable price. Thus while the owners of the initial companies were often skilled practical engineers who had experience designing and maintaining small windmills, the craze at the beginning of the decade created a rush to put up as many turbines as possible whether or not they actually produced any power. The tax credits largely failed to create a thriving wind power industry that significantly contributed any power to the state’s energy supply. However, the credits did provide the much needed capital in order to get the machines out into the field and to learn from their performance.

The Importance of Field Testing in the 1980s and 1990s

For most of the 1980s, turbine development in both FIELD 1 and FIELD 2 involved a process of educated trial and error. It consisted mainly of field testing and experimentation to see what worked where and, perhaps more importantly, to see what failed. As Righter (1996) and Gipe (1996) discuss in their research, often times the early machines simply did not work. Manufacturers would build a machine and put it up, and sometimes it would spin so fast it would literally fly apart and other times it would not spin at all. This was also noted by Robert Thresher, Director of the National Wind Technology Center at NREL, when he said,

> [i]n some ways the 1980s was a disaster, these machines didn’t work very well they needed a lot of repair they were very high cost. It was really a tremendous learning experience from a technical point of view of putting the machines in an operational environment and making them work and beating the cost out of them. (Interview 1)

On the technical side, field testing revealed problems that engineers would not have even thought were problems before the turbines went into operation. In speaking of the DOE/EPRI Turbine Verification Program, Rick Walker, Director of Renewable Energy for American Electric Power (AEP) answered,

> . . . we learned that there is a lot more lightning in Texas than on the West Coast and it does a lot more damage to wind turbines than the manufacturer thought it

> would, and that the dry soil in west Texas is not very good grounding material. . . . We had to do a lot of work to improve the lightning protection. (Interview 14)

Lightning was also a problem mentioned by Glenn Cannon, General manager of Waverly Light and Power (WLP), the public utility for Waverly, Iowa. The first turbine WLP installed was struck by lightning and was down for several months, although new turbines have different lightning protection so now there are no problems. But, Glenn Cannon said, "lightning is always an issue"(Interview 4).

Vice President of Generation for PG&E Greg Rueger relayed another such story about the importance of field testing. One developer in the Altamont Pass area in California, he said,

> . . . was not getting the same generation out of their turbines compared to the other developers operating in the same wind area, and when we finally analyzed what it was that was affecting their performance it was the color of the paint they were using on the turbine blades. . . . They picked a color that the bugs seemed to like and the bugs would sit on the blades and that would mess up the hydrofoil. So it is little things like that made a big difference in wind project performance. (Interview 11)

Along the same lines, he also commented that, ". . . you didn't think about and discover the problems until you started to deploy the technology and find out what some of the issues were that would make the difference between a marginal economic wind generator and one that was doing better" (Interview 11). Field testing was extremely important for discovering problems associated with the interaction between the machine and the natural environment and for future turbine designs.

In many of these cases, the "working" versus "not working" of the technology was wholly physical: did it spin when the wind was blowing and did it produce energy? But as certain components became more reliable (i.e., more stable), the innovations became increasingly smaller and smaller until the very process of technological change became more and more incremental. Robert Thresher's comment is exemplary. He said,

> [i]t has really been a sort of a brute force and ignorance approach . . . you put some experimental machines together, you don't know a lot, you make some mistakes, you learn from the mistakes, you build better codes, you build standards, you build an industry, and you build a cadre of people that learn from that experience . . . it is a complicated process that does not go in big jumps, *it is much more evolutionary than revolutionary*. Back in the science is where you see some of the revolutions and some insights, but making technology work is sort of a day to day "rat killing" process . . . you find the problems and you fix them, like debugging a computer code . . . and that's a lot of what technology evolution involves. (Interview 1, emphasis added)

This statement highlights that the early years of the industry were characterized as a time when things were in much greater flux. As the industry matured, the developments become aimed more and more at refining existing designs to increase efficiency and prevent the problems that arose as the machines operated on a daily basis over a number of years. As the industry grew and more experience was gained with these types of turbines, this basic design increasingly became the industry standard. Smaller incremental modifications were continually being made to increase performance and keep the machines from flying apart.

Reliability and availability were also significant forces shaping the technology. Because the goal of utility scale turbines was to be connected to the existing power grid, they needed to operate within the context of the normative and technical expectations of system operators and utilities. Thus wind turbines needed to consistently produce power in order to be considered a viable alternative to other sources of generation. As Ed DeMeo, former manager of Wind Power Integration at the Electric Power Research Institute (EPRI) stated,

> . . . go back to the 70s early 80s, costs were in the 25 cent/KWH range, equipment was young, there was difficulty keeping it operating over extended periods. Utilities talk about availability, the measure of its reliability, and a typical utility has a power availability in the 90% range and above meaning that they are ready to operate that amount most of the time. In the early 80s with wind you were lucky if you got 80%. Today with all the experience that has been accrued over the years, availability is typically 97 or 98%, which is terrific, it's excellent, and that is a large part of the reason why the costs have come down, is that these plants are producing energy when the wind is blowing instead of sitting there being fixed. So costs have come down because of experience factor and because of ongoing product improvement in the components and the operating strategies, and the machines have gotten bigger. (Interview 12)

Field testing allowed this sort of ongoing product improvement to take place. New problems arose with the actual operation of the machines and as the technical system into which these machines were being integrated demanded certain types of outputs that directed the technology to take certain types of forms over others.

Field testing remained a central feature of R&D in both FIELD 1 and FIELD 2 in the 1990s. Despite being highly risk averse and not being likely to directly undertake R&D efforts within their own companies, electric utilities from FIELD 1 were still interested in using new technologies to help cut costs or make operations more efficient, as long as the risks associated with them were low. This support is demonstrated by the fact that in the 1980s and early 1990s, many utilities were significant contributors to the Electric Power Research Institute, the utility trade association with significant R&D activities. Indirectly, then, utilities were involved with R&D by providing capital through membership contributions that were important for R&D

on unproven technologies such as wind, R&D that was essential for their refinement and subsequent decrease in cost.

In the early 1990s, the budget of the Electric Power Research Institute (EPRI) was quite large and membership was strong. EPRI's main role as an industry association was to market, help distribute, and educate its members about products that came out of research programs. In a sense, EPRI was the research and development arm of FIELD 1, representing the interests of the established electric utilities. As Chuck McGowin, Manager of Wind Power at EPRI said, "EPRI's role historically has been to manage rather than perform R&D" (Interview 8). When asked to clarify what was meant by the "management of R&D," he responded,

> when you think of a research institute you think of labs where you do measurements and there are people with white coats, and we do actually have some facilities and cases where that is done . . . but what I mean is that we are managers of the programs, we have resources that we receive from members of EPRI . . . and our job is really to look at the big picture, design a research program, receive input from our members about what they need, and help get input about priorities and about how funds and resources are used, and then we go out and hire the contractors and manage the research and publish the results either in reports or demonstration projects. (Interview 8)

EPRI was very receptive to the needs of utilities and worked closely with manufacturers to ensure that those needs were met. In commenting on EPRI's role, Robert Thresher from NREL said,

> EPRI was great at this boundary operating as a bridge between prototypes of commercial hardware and actually running machines of sufficient size to make them profitable, EPRI bridges this gap, the "valley of death" where you can get a great prototype sitting there running but everyone is afraid to take the risk to go into production to make 100 units and try and sell them . . . (Interview 1)

As these comments reveal, EPRI had a large role in helping legitimate wind technology to its members—the end-users—as well as in helping refine existing technologies to make them cheaper and more reliable.

Although indirect utility involvement in the form of trade association membership has historically been a central feature of large scale wind R&D for FIELD 1, several utilities were also more directly involved with R&D by taking part in testing programs. In the early 1990s, EPRI and the DOE started a program called the Joint EPRI/DOE Turbine Verification Program. The goal of this program, like the FWEP of the previous decade, was to promote wind power to electric utilities in FIELD 1. The Turbine Verification Program was a way for manufacturers to have their turbines placed in test sites with willing electric utilities in order to see them operate in the field and help the utilities gain confidence with the technology. As Ed DeMeo, former manager of Wind Power Integration at EPRI commented on the Turbine Verification Program,

> its focus was to take wind turbines that were beginning to emerge from development programs that were looking pretty good and then to find interested and willing utility partners who would agree to test a small number of these machines to get some statistical info about how they would operate in the field. So we wanted to test machines that had had the early bugs run out of them and were now ready for utility service, and that turned out to be a very successful program in that we verified the performance of some of the turbines, we also helped the manufacturer shake out some remaining bugs that helped them to avoid having those problems on their first sale of a 100 machines. So it helped the manufacturer, but what it really did for the utility was to help them gain confidence in the technology, and that was really what we were about, to try and seed the market for the technology. (Interview 12)

This comment reveals some important aspects of the Turbine Verification Program. It took machines that were being developed by manufacturers but had not yet had extensive field experience and placed these machines with potential customers. This helped refine the technology and get the potential customer more familiar with it through experience. This program also involved a fair amount of cooperation and communication between actors responsible for actually making physical changes to the technology as well as the ultimate end-users.

While EPRI was involved with managing R&D and pursuing technologies that it believed were needed or its members had a specific interest in, the National Renewable Energy Laboratory (NREL) was much more involved in the basic science of wind technology. The literature has criticized the Federal Wind Energy Program (conducted mainly through NREL) for not being sensitive to utility demands and for not working closely enough with potential end-users in FIELD 1 to get their input on designs (Serchuk, 1995). This view was generally confirmed in the interviews. Interviews revealed that IPPs had little interaction with NREL and that the few utility viewpoints represented in the data were positive but vague in terms of NREL's role, although to varying degrees. Thus it is important to note that when Robert Thresher at NREL comments that, "[w]e do R&D but it is really industry driven, we have cost shared contracts with the industry so we work pretty closely with them. We can't decide everything, so there is a lot of discussion because it is a lot of their money . . . ," the perceived industry in this case is electric utilities but a lack of communication between the two sets of actors may hinder technology deployment (Interview 1). While the data from this current research is not representative enough to make solid conclusions about NREL's effectiveness or success in generating a working technology, the following comment from one interviewee is illuminating. In talking about some current NREL research, the interviewee said,

> NREL recently embarked on developing more highly efficient, high-speed turbines with lighter materials. But people in the industry told me that it was yet another "NREL project" and that these turbines are not going to make it into the market. They are too expensive, too loud, and too noisy. "Yeah, maybe it is more efficient, but I can't sell it, because no one will buy it."

While NREL was perhaps uniquely situated to carry out research on high risk innovations because it was a branch of the federal government, its relationship with potential end-users appeared to be different—and somewhat less effective—than that of EPRI, its industry association counterpart.

Even though most utilities historically have been quite risk averse, the interview with Greg Rueger from PG&E revealed that, at least in the 1980s, his utility had been quite actively engaged in performing in-house R&D on renewables. Part of the reason was that PG&E saw the potential for renewables early on and part was also that California had a favorable political climate that encouraged renewable development in the state. When asked to discuss the company's R&D efforts, he answered,

> When you go back to the late 80s early 90s we actually looked at wind as *the* technology that had perhaps not the largest potential, because we thought that you could use PV [photo voltaic] more extensively, but it was the closest of what was then referred to as renewable and non conventional projects to being competitive with conventional generation. . . . We were actually fairly disappointed in what was going on at the time [with R&D] and we supported various pieces of legislation to try to encourage these types of technologies since our feeling was that these technologies did have promise—though they still had to go quite a ways to be fully economic—but we felt wind was further along than others . . . [and] that you would never actually have them here unless you were willing to put some additional funding in, and the industry itself, the wind industry, was too small to do all of its funding itself without some sort of subsidy. (Interview 11, emphasis in original)

PG&E also worked closely during this time with EPRI and with California state agencies. When asked about PG&E's role in the wind industry more generally, Greg Rueger answered,

> [i]f you go all the way back to about the mid 1980s PG&E developed what we called the green resource plan, which focused on energy efficiency and renewables to meet a good portion of our future demand. As a part of that we had a fairly good size R&D program that was funded by the California PUC and our rates but administered by [our utility] to develop some of these technologies. . . . We owned a very large Boeing designed wind machine, with blades the size of a football field, that generated more electricity than any other turbine ever . . . but it had a lot of stress corrosion problems and we eventually took it down but it ran

> for quite a few years . . . we did quite a bit of research on that. In addition, we would fund through our research program some of the development that a number of wind development firms were doing themselves, we would provide some additional dollars . . . and some advice from our perspective on how to go about developing this technology. (Interview 11)

PG&E was thus both directly and indirectly involved in testing and developing early turbines. The utility owned and operated test turbines in the field, it worked with developers to shape the technology, and it was one of the larger supporters of EPRI at that time.

As much as field testing helped improve the designs of the machines, it also brought the concerns of new RSGs into the R&D environment, further changing the technology. As the literature extensively documents, the history of the wind industry has been intimately entwined with public perception and environmental demands focusing on the issues of noise, visibility, television interference, wasted subsidies, and avian and bat mortality (Asmus, 2001; Gipe, 1995; Righter, 1996; Sawin, 2001; Serchuk, 1995; and Thresher, 2002). The demands of the public at large and local residents living near wind farms have had a significant role in shaping the designs of individual wind turbines and of wind farms more generally.

Perhaps the most commonly mentioned problem with wind turbines relates to the death of birds as a result of them flying into the moving blades. This was a much more substantial problem with the earlier wind farms than it is today, although it is still perceived as a large problem by a skeptical public. The first turbines that developers erected in the California hills in the 1980s used a lattice tower and operated at higher RPMs. Birds would roost in the tower framework and would frequently be killed by the rotating blades. Dead birds scattered at the feet of windmills—especially when some of them were endangered species—angered many environmentalists and animal rights activists who began to vehemently oppose wind farm development. This opposition drove developers to study the problem and learn about siting wind farms outside of migratory paths. It also, however, led to changes in the physical design of the windmill itself.

Gerald Jacobs commented on how a project undertaken in southern Wyoming by Public Service Company of Colorado (PSC) in the late 1990s was affected by such concerns. "Initially to keep cost down," he said,

> they looked at using a lattice work tower . . . [which is] an easy tower to erect and fairly inexpensive, but the problem that people saw with that type of tower is that they were attractive to roosting birds, especially in that part of Wyoming were there were few trees. . . . A lot of the overall opposition to the project was because of the choice of tower. But the site was not in a flyway at all . . . [and] they did a longitudinal and habitat study in the area to see about resident bird populations . . . and they found that there really was not much of a bird population. . . . What eventually happened is that they did go with the solid

> cylindrical type of tower, and I think that had to do with the fact that those types of towers were more widely produced . . . [and] many of the turbine manufacturers were going to this type of tower because you can run all the wiring internal and there is no bird problem. So eventually that was the type of tower that got used in the end. (Interview 3)

Because the project relied on some federal grant money, the company was required to do an environmental impact study and be receptive to public concerns about avian mortality. Even though the initial proposed design was deemed acceptable in the end, an alternative was chosen that the industry had established as a viable design which minimized bird kills and at the same time concealed the electrical equipment. In relation to the design of the tower, the enclosed, solid tower that has become the industry standard resulted in part from public opposition to earlier designs but also became readily accepted because it offered some other identifiable functional purposes.

Oftentimes the noise created by the earlier high RPM machines also spurred opposition from local residents to wind development. This opposition pressured developers to design different blades and rotors that spun more slowly. Pressure to increase reliability also came from the public, as wind farms with machines that were constantly being fixed did not go over well in the public eye and led to opposition from local residents that would make siting and permitting more difficult. As Righter (1996) has noted, wind technology development has been uniquely open to public scrutiny because many of the early test sites were in places with the highest winds which are also the places with highways and other public travel. Coupled with this was a significant amount of Not-In-My-Backyard (NIMBY) opposition where residents support the use of renewables in theory but oppose them in local areas. As a result, developers increasingly sought out sites that might have lower wind speeds but would not stir-up opposition to the facility because of a more remote location. As will be discussed later in Chapter Four, locating wind farms in more remote areas has also created significant problems associated with transmission, as many of the most ideal wind sites are quite far from urban centers. Especially in the earlier years of the industry, wind turbines were subject to a fair amount of public scrutiny which led to significant changes in turbine design and the locations of wind farms.

As the industry matured, however, and the designs became increasingly established and stable, public scrutiny and opposition has had less influence on the physical design of the turbine. This is partly because instead of redesigning a turbine, developers have learned to educate the public and assure stakeholders that perceived problems are not really issues of great concern. For example, Rick Walker from American Electric Power (AEP) relayed a situation in Texas where a local TV station was concerned that the new wind facility would interfere with broadcast signals. As a result, further testing was done by the utility before and after the project was built in order to prove that the facility had no effect, and the issue was dropped (Interview 14). Had there been an effect, it is likely that the utility would have chosen another location instead of going back into the lab and redesigning a machine that interfered less with TV signals. Similarly, Zeina El-Azizi, Development Manager for Cielo Wind, a privately owned operations, maintenance, and development firm, acknowledged that one of the first things the company does when it locates a potential site is to establish a relationship with land owners, environmentalists, county planners, local politicians, and universities to educate people about how the facility works (Interview 10). Thus field testing initially brought new RSGs into the R&D environment who subsequently exerted influence to shape the designs of wind turbines. As the industry has matured, including these RSGs and educating them about wind power technology has become regular practice.

European Influence

The last section highlighted the importance of field testing for the R&D efforts of actors in both FIELD 1 and FIELD 2. It also suggested that field testing caused many RSGs not typically directly involved with R&D to become involved with wind power technology and exert their influence on the designs of the machines. It is important to note, however, that despite these early R&D efforts, many industry participants and scholars give neither FIELD 1 nor FIELD 2 much credit for developing the modern wind turbine despite the substantial efforts of the federal research program and turbine manufacturers over the last two decades. In fact, many participants feel that it is only because wind power matured in Europe first that it has been able to take hold in the United States. The federal wind program and the efforts of manufacturers, even with substantial funds and field testing, were largely unable to create a cost effective, reliable wind turbine. Several interviewees explicitly commented on European technological development as an essential influence on the modern wind turbine. When asked about the history of wind technology and why wind as opposed to other renewables has become so prevalent, Arnold Leitner, Senior Consultant at Platts Energy, answered that, among other things, ". . . there was a mature technology coming back from Europe . . . " (Interview 7). Furthermore, he said,

> . . . wind came from Europe with a couple of characteristics: production capability, dependable technology, and a good price. Wind power returned as a ready technology; it was proven and no longer an experiment. There is really nothing experimental now about buying wind. But no one in the U.S. can claim much credit for that. No one in this country can really say we are the ones who had the vision and foresight to make it happen. Instead, the foresight and the vision occurred in Europe. . . . (Interview 7)

Although the current analysis does not reveal how much of the physical technology from Europe has been adopted by American firms, it is clear that wind's acceptance in Europe has led to increases in production and further field testing, both of which drove the price of turbines down and make wind more appealing to American developers. This beginning of a stable world market has also allowed for some standardization of parts. Doug Larson, Executive Director of the Western Interstate Energy Board, commented that,

> . . . [wind's] revival is fundamentally due to economics. They have improved the turbine technology, a lot of that is due to, I think the fact that, not the U.S. but Europeans in particular, have begun to reach economies of scale largely due to the introduction of wind in places like Denmark and Germany. (Interview 9)

These comments reveal that some in the industry believe that the influx of European designs and the stabilization of an international market have been important factors for the recent increase in wind technology applications in the U.S.

However, this sentiment is not shared by everyone. While almost no interviewees dismissed European designs as being influential, the level of importance varied. Obviously persons deeply committed to the DOE program at NREL were less forthright about the criticisms of their supposed failures. From their point of view, and from the point of view of several utilities and of EPRI, NREL has been an extremely instrumental force in shaping modern wind technologies. While this will be further explored in the following chapter when the context of industry R&D is discussed, it should suffice to say for now that participants do not seem to explicitly share the same opinions about which designs from which nations have been most successful. Despite this, it is clear from the interviews that European companies represent a significant portion of modern turbine manufacturers.

Almost all interviews with regulated utilities, IPPs, and wind farm developers revealed that European companies have been able to repeatedly offer reliable, low-cost bids on wind projects. Whether or not these turbines are selected is a more complex matter. When a company wants to undertake a wind farm, they essentially send out a Request For Power (RFP) and then receive bids from manufacturers. The company models these bids to determine the best option and then makes a selection based on these factors. While the models vary from company to company, several factors came up in multiple interviews. For one thing, financing the project is of course extremely important. The comments of Zeina El-Azizi at Cielo Wind are suggestive. When asked about how Cielo decides which turbines to use, she answered,

> [t]here are several things that go into place. The perception of the finance industry of the turbine manufacturer. So someone like a Bonus or a Vestas or a Mitsubishi is much more likely to get financing than someone like a Nordex whose had trouble financing their turbines in the past because of a warranty or

> operations issues.[8] So experience in the market is extremely important when it comes to choosing your turbine. . . . At least in the U.S.—and the variance is significant between here and Europe—there tends to be a handful of turbines that are used that are much more successful . . . you have to balance the cost and the power output when you model this and essentially you get bids from different manufacturers and you run the model and there is a point at which cost, power curve, and [financing] meet, and that is essentially how you make your turbine choices. (Interview 10)

The use of international turbines was also highlighted by Greg Jaunich, President and CEO of Navitas Energy, an IPP with facilities in over ten Midwest states. When asked about turbine selection, he answered,

> [w]e tend to work with . . . the same manufacturers, just the major ones, we've used all different kinds of equipment. In the past, we've used GE, NEG Micon, we've used Vestas. Currently our company is using Gamesa wind turbines because of the ownership relationship they have with us and because the equipment is the best in the industry . . . (Interview 13)[9]

These comments reveal that the modern wind industry is truly international in nature. It is clear that the European influence is strong, but it is too simple to see things only in terms of the Danes "getting the technology right," perceptions of technologies from other countries have also improved and stabilized.

Interviews also suggested that the use of European turbines may be more prevalent among IPPs than among regulated power producers. Regulated utilities appear to typically use U.S. machines, and part of this may have to do with the nature of the ties between federal R&D and utilities (i.e. the direct influence of the government as an RSG). In some cases, grants to help finance wind projects stipulate that a significant portion of the turbine be manufactured in the United States. The joint DOE/EPRI Turbine Verification Program, in which manufacturers would get help placing test turbines with willing utilities, required that these turbines be U.S. made so as to encourage the domestic wind market. Rick Walker, Director of Renewable Business Development for AEP, stated that,

> [t]he Fort Davis wind farm was the first project built under the EPRI/DOE Turbine Verification program. One of the stipulations of that was that the developer had to use an emerging U.S. manufactured technology. We used the very first commercially produced turbines from Zond, which became Enron Wind and is now GE Wind. (Interview 14)

[8] Bonus and Vestas are both Danish firms, while Nordex is a US firm.
[9] Micon is a US company, Vestas is Danish, and Gamesa is Spanish. It should also be noted that Navitas and Gamesa just recently signed a joint stock agreement in which Gamesa will acquire seventy-five percent of Navitas stock. This helps explain why Navitas would use Gamesa turbines while few other participants mentioned them.

But as the turbine market has become increasingly international, the boundary between U.S. and non-U.S. machines has become increasingly blurred. When talking about a project undertaken by Public Service Company of Colorado (PSC) in the late 1990s,[10] one of the environmental consultants for the project, Gerald Jacobs, commented that the project used a significant amount of federal grant money as a source of funding and that one of the DOE requirements was that turbines needed to have a significant U.S. component. He said that because PSC was working with a European turbine manufacturer at the time, what ended up happening was that the towers were domestic and the turbines and components were from Denmark but were assembled in the U.S. (Interview 3). This was also expressed by Ed DeMeo, former manager of Wind Power Integration at EPRI, when he stated that,

> as time goes on the whole industry is now becoming more and more international in that, yes we are still putting many Danish and German machines in, in this country, but more and more of the components and in some cases the whole machines are being assembled in the U.S. from parts made in the U.S. by a foreign company. . . . Plus we now have American firms that are setting up operations in Europe . . . so its becoming a global industry and that's a sign of maturity. (Interview 12)

Whereas in the early years of the industry many developers using federal funds were required to use U.S. technologies, this has become increasingly difficult as the technology itself has become more and more international. At the same time, companies that face no restrictions about turbine selection find that European technologies are often cheaper, more reliable, and have an established track record that lowers the risks of using them.

Of course, seeing European technology as "objectively better" also begs the question of the social context of its *own* development. While the scope of this current research does not allow a complete account of the rise of this international market and of the specific technological differences between European and U.S. turbine designs, interview data offers some insights into the reasons for success in Europe as well as some of the forces that helped shape turbine design in the United States. As Arnold Leitner from Platts Energy commented,

> [E]uropeans are just ten years ahead of the U.S. because of a cultural attitude. . . . [In Europe] there was a lot of willingness to accept [wind]? some of which was not at all economic; it is just purely cultural. People wanted it, for reasons that related to deep seated European traditions of a more mature and settled society . . . more educated, more awareness, more global integration. (Interview 7)

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[10] PSC of Colorado was an operating utility and a holding company that merged with Southwestern Public Service company in 1997 to form New Century Energies, a holding company. New Century Energies merged with another holding company, Northern States Power, in late 2000 to form Xcel Energy, one of the largest U.S. IPPs.

In terms of how this cultural attitude translated into turbine design, he further stated that,

> . . . the California turbine was an aero-derivative, very high speed and high performance but with poor reliability. The Europeans took a pedestrian approach and built very big turbines with very big blades that spun slowly. The made the turbine blades out of wood and made everything as cheap as possible. European turbines looked more like windmills than propellers on planes. The advantages were that they were cheaper, more reliable, and quieter. It was an example where less was more; the simple solutions worked best. (Interview 7)

While cultural differences may have played a role in the acceptance of wind in Europe, many interviewees also commented on the different political atmospheres and the scarcity of other resources in many European countries. These other factors have been explained in detail by Sawin (2001) and will be addressed in the following chapter when policy is explicitly discussed as one extremely important driver for the modern wind industry in all countries.

The maturation of the global wind industry has thus been one very important factor for the U.S. wind power industry. In particular, even though the R&D efforts in the U.S. may have failed from a technical point of view, they succeeded in establishing relationships between actors in both FIELD 1 and FIELD 2 that were essential for the spread of the "best working" wind turbines coming from Europe. Without the foundations that this earlier R&D helped put in place, wind technologies from Europe may not have been so readily accepted by actors in both fields in the 1990s.

Technical Stability and Future Change

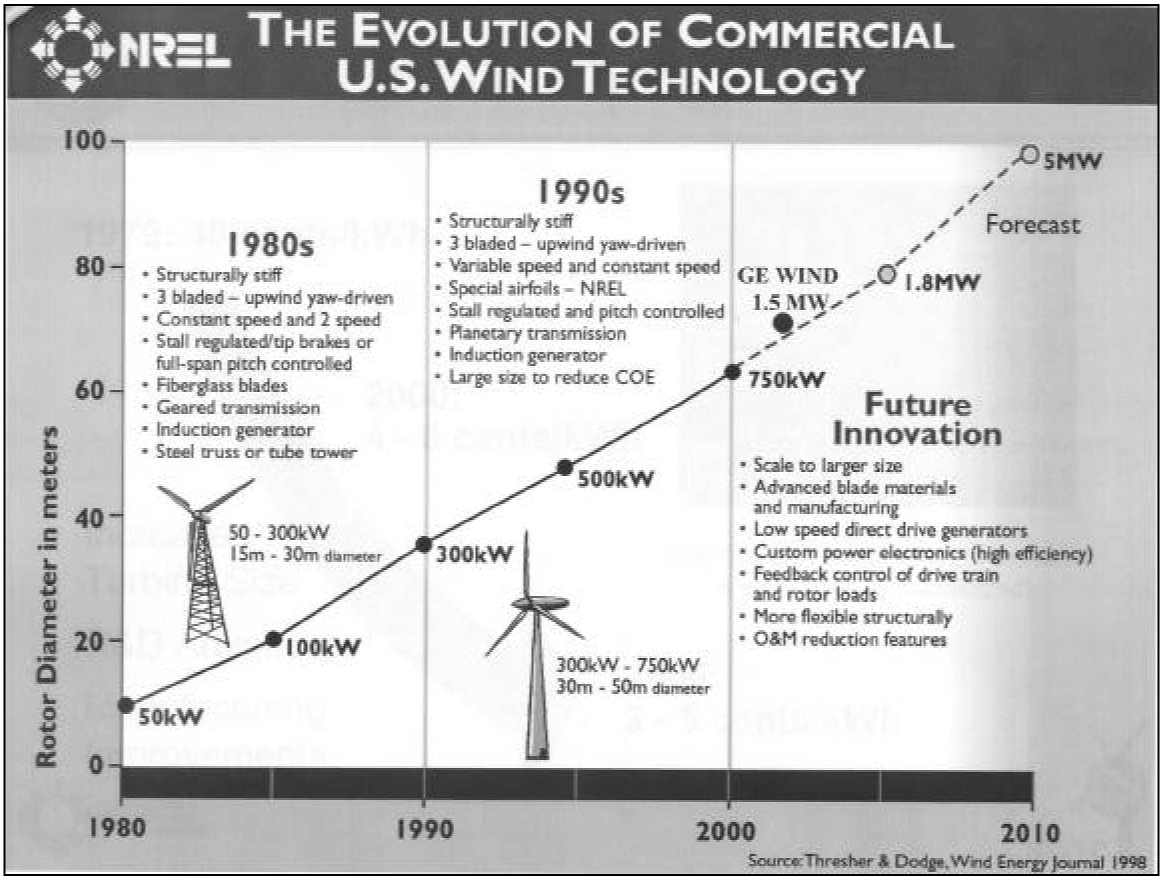
Even though radical innovations may have become less and less likely as the industry has matured, wind turbines continue to evolve. In fact this evolution involves simultaneous perceptions of stability and change on the part of actors in both FIELD 1 and FIELD 2. In 2003, most participants agree that, by and large, turbines have settled around the three bladed, solid tower, upwind facing machine producing upwards of 1.5 MW of power. However, most participants also agree that the future of wind turbines involves bigger machines with simpler gearboxes and lighter-weight materials operating in areas with lower wind speeds or in offshore locations. How is it possible for these seemingly opposing views to be conveyed, sometimes in the same sentence? A statement by Chuck McGowin, Manager of Windpower for EPRI, is exemplary. "We recognize that some technologies like wind," he says, "with current configurations are pretty mature right now, but there are still some issues that need to be dealt with [laugh], which they are dealing with . . ." (Interview 8). These issues are mainly mechanical and have to do with the wear and tear on machines during the course of their operating lives. As he also states,

> . . . the technology is approaching maturity. There was a lot of experimentation in the 1980s and before . . . there is still a lot of experimentation, we get letters all the time about new designs, some are very wild ones that people have built without knowing about all the commercial experience. . . . There are some new ideas that are being looked at, [but] other than some minor changes in the tower type things are pretty stable and they operate more or less the same way. (Interview 8)

The technology is thus both "approaching maturity" and still subject to a fair amount of experimentation and minor changes. Zeina El-Azizi of Cielo Wind commented on the amount of substantial innovation occurring in terms of turbine design by saying, ". . . I think the essential structure of the turbine is there. I haven't been approached with an eggbeater [pause] ever [laugh]. I would say the advances are mostly within the three blade technology" (Interview 10). These statements do not mean that industry participants cannot make up their minds about the current state of wind technology. That is not at all the case. Rather, participants have a very clear sense about turbine design and possess a great deal of knowledge about how they work and about the fundamental science behind their engineering. What these statements do reveal is that the very concepts of innovation and stability need themselves to be revisited in light of how technologies are perceived by the people who use them. For developers, the technology is mostly stable and "works pretty well." To utilities, the foundation is there but bigger and bigger machines are still the end goal. The technology could still "work better." While not a direct one-to-one correlation, the perceptions of stability seem to vary between IPPs and IOUs.

The current design of modern wind turbines is overwhelmingly an upwind facing, three-bladed machine with a solid tower and a 1.5MW output. Figure 5 shows NREL's version of the evolution of utility scale U.S. wind technology since the 1980s. The future

Figure 5: The Evolution of Commercial U.S. Wind Technology



Source: EPA Air Division Directors Briefing prepared by Robert Thresher on October 10, 2002.

of turbine technology is by most accounts moving toward larger and larger sizes so as to achieve economies of scale and access lower wind speed locations. Within the federal research program, the current goal is to reduce costs by using lighter materials, by simplifying design, by accessing new, untapped, commonly occurring wind resource regimes, and by increasing the output of the machine so as to achieve economies of scale (Interviews 1 and 2).

Many industry participants from different institutional locations stressed the upcoming trend of offshore facilities. Arnold Leitner from Platts Energy stated that ". . . offshore power is where the second wave is headed . . ." (Interview 7). Similarly, Zeina El-Azizi from Cielo Wind stated, "[o]ffshore will probably be next and they [i.e. turbines] will be a lot bigger there" (Interview 10). Offshore locations have a number of advantages that make development appealing. In terms of turbine design, offshore arrangements theoretically allow for larger turbine sizes because transportation and installation costs are lower than for land facilities. Especially in the United States, where most ideal wind locations are in the Midwest, getting gigantic turbine parts to these locations can be costly and difficult. An offshore facility, however, can be erected by contractors that have experience working on the ocean with heavy equipment building oil rigs, and turbines can be carried directly to the site via ship and offloaded into place. Locating turbines farther out to sea also minimizes NIMBY complaints, one of the barriers to industrial development that will be addressed in relation to wind in a later section. In terms of efficiency, offshore winds have a lower shear factor that causes less strain and increases reliability, and ocean winds are less gusty which leads to steadier capacity. Thus while offshore wind plants have yet to become the dominant model and will surely present new technical challenges related to anchoring in deep water and salt-water corrosion, this seems to be the direction that utility scale wind is moving.[11]

Conclusions: The Application of SCOT to the Wind Industry

This chapter has demonstrated how technology is shaped by competitions over meanings associated with physical technologies. But it is also apparent that RSGs differ in their ability to establish *their* vision as *the* vision ultimately accepted by other actors. During the early years of wind power technology, complaints about bird deaths, noise, and view-shed led to significant changes in turbine design as developers were forced to reckon with environmental concerns and local opposition to projects. As the industry matured and some aspects of the technology stabilized, the concerns of many of the same RSGs became allayed by education and communication efforts on the part of manufacturers and developers instead of making physical changes to the technology itself. In other words, RSGs had a significant impact on the ways that technologies are marketed, sold, and presented without actually changing the physical artifact itself.

This confirms some of Bijker's (1995) notes about power asymmetries, as certain groups are more capable of framing decisions and presenting solutions in order to retain control over the technical frame. It also engages some of the more general criticisms leveraged against the SCOT methodology about the unequal distribution of power, as the case of wind power shows that some less powerful groups were able to participate in the debate but had little influence in the actual design process (Klein and Kleinman, 2002). This is captured by the comment of Zeina El-Azizi when she says, "[r]ight now the only market for wind is large scale wind" (Interview 10). By and large the definition of "working" wind turbine technology is a machine that produces consistent, reliable, and cost-effective output from centrally located wind facilities in order to supply power into the existing electric grid for purchase by large electric utilities.

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[11] Although not directly quoted here, many of these insights about offshore wind facilities and their potential benefits came from Arnold Leitner during the interview with author on January 3, 2003.

This definition came out of FIELD 1, as established electric utilities helped define the overarching context into which wind turbines ultimately needed to conform. FIELD 1 presented a technical frame that was the result of older historical and technical developments. The desires and competing meanings that other less powerful RSGs (outside of FIELD 1) brought to the table did play a role in shaping the "nuts and bolts" of early wind turbines, but the relationships within the technical frame were asymmetrical in terms of power distribution. While it is true that the current turbine designs might have been different had noise or bird deaths not been a concern, it is also true that aspects of the current design were very much influenced by the existing framework into which the technology was being integrated. In this case, large-scale, centrally located plants better served the existing institutional and technical framework (of FIELD 1) in which more powerful actors were entrenched, even though these technical arrangements were perhaps less efficient and more costly in the long run (Interview 15). Thus the context of technical development is extremely important and is highly correlated with the nature of the relationships between actors as structured by organizational fields.

This chapter has shown that wind power technology did not evolve in a strictly linear manner, and that the modern wind turbine underwent substantial changes as a result of multiple types of pressures and demands exerted from many different sources of influence. The first significant pressure affecting the modern wind turbine was exerted from FIELD 1 itself, as the perception in the 1970s was that wind power could replace polluting types of power plants by using a cleaner technology. This first pressure established an end goal held by both FIELD 1 (electric utilities, federal research and development laboratories, and private companies from other industries) and by FIELD 2 (newly formed nonutility IPPs). Despite this similar goal, however, organizations in each field had differential access to resources as a result of their position within a network of the electric power industry, and this position subsequently influenced their opinions of what the appropriate design for such a machine should be. Utilities and federal R&D focused their efforts on gigantic machines so as to achieve economies of scope and scale (in line with FIELD 1). Their idea was to produce small models in the laboratory by understanding the basic science and then to scale dramatically upward to construct enormous machines so as to increase output. Nonutility IPPs, however, like European manufacturers, focused on medium sized machines arranged into wind farms (in line with FIELD 2). Their idea was to achieve economies of production in order to reduce cost and spread the risk of failure out over a larger number of turbines.

Both approaches in the United States largely failed to produce a turbine that "worked" by all definitions. First of all, many of the turbines of the 1980s literally did not function and did not produce consistent, reliable output. They flew apart or did not spin at all, they killed birds, or they were "ugly" and scarred the landscape. Although practical testing for both approaches was essential for incremental improvements to be made, neither approach was successful at producing a turbine that was believed to be competitive with the cost of other fuels without federal and state subsidy, an issue of central importance to the story of wind power that will be addressed in more detail in the next chapter. While early attempts at creating a working wind turbine did not come to full fruition, these attempts were essential for the later success of wind power because they set the technical and organizational foundations upon which the modern wind power industry was eventually constructed.

The next chapter shifts the focus of analysis to the organizational environment since 1978 and emphasizes how the nature of the relationships between RSGs from each organizational field involved with R&D changed with the simultaneous maturation of the wind power industry and the restructuring of FIELD 1. Understanding these relationships is essential for understanding the success of the modern wind power industry because they served to establish wind power as a legitimate pursuit by giving electric utilities in FIELD 1 direct experience with the technology. Even though neither FIELD 1 nor FIELD 2 was successful at ultimately designing *the* wind turbine that was eventually adopted by both, these early experiences set the stage for the acceptance of "*the* working" turbines that came from Europe. Perhaps more fundamentally, this shift in focus emphasizes that the construction of the modern wind turbine was not only a processes that involved shaping physical artifacts but also involved the creation of a new organizational field (FIELD 2) containing nonutility IPPs. Even though early turbines may not have "worked" in the sense that they failed to produce power, they "worked well enough" to secure FIELD 2 a foothold in the electric power industry. This foothold was subsequently used to push for political and regulative changes that allowed the industry to move forward and become an established force in the power production landscape. The following chapter expands upon some of the data already presented to emphasize further the insight that technology and organizational form co-evolve with each other.

CHAPTER THREE – Constructing Groups: Policy and the Reshaping of Organizational Fields

The last chapter focused on wind technology and the context in which it emerged and developed. Field testing was shown to be extremely important, and pressures exerted from the organizational field of the existing electric utility industry significantly influenced the ultimate vision of what a "working" wind turbine would look like. The last chapter also discussed the relationships between R&D organizations and, perhaps most importantly, it showed how the relationships created as a result of R&D activities—which often spanned between FIELD 1 and FIELD 2—set the stage for the acceptance of "working" technology from Europe by both sets of organizational actors in their respective fields. This "mature" technology, while continually being altered as the industry grows, was by and large accepted as "working" by members of both organizational fields. So far in this analysis, policy and institutions have largely been absent from the discussion except to provide a backdrop for the activities of members in each field. The last chapter thus focused on technology as the object of analysis in order to show how wind turbines developed and changed within the contexts provided by FIELDS 1 and 2. This current chapter, on the other hand, turns away from technology as the immediate object of analysis and focuses on the organizational environment, specifically as related to changes in policy.

Making this analytical shift is important for understanding the success of wind power because this success is not only about wind turbines but also about a new organizational form—as contained in FIELD 2—that managed to secure a place within the framework of the established FIELD 1. The primary cause of this change has been public policy, which has structured the nature of the relationships among the relevant groups both in terms of R&D on wind technology and in terms of the perception of this technology by powerful actors. *Furthermore, policies have fundamentally altered the self-perceptions of organizations in both fields concerning their respective roles in relation to each other, and this has caused changes in fundamental distributions of power, influence, and resources.* As this chapter will show, policies have both helped and hindered the development of wind power, but they have nonetheless been essential for its success.

The new organizational field of nonutility IPPs (FIELD 2) was formed in the late 1970s by a public policy that partially deregulated the established electric utility industry (FIELD 1). One of the consequences of the Public Utility Regulatory Policy Act (PURPA) of 1978 was that it created a new type of power provider charged with creating a technology that would compete with the existing technology already used by electric utilities. Since that time, continuing deregulatory efforts have significantly affected the nature of R&D on wind power technology by redistributing financial resources and redefining organizational roles in both fields. In addition to these regulatory changes, subsequent policies have also affected the ways that actors in both fields make investment decisions related to specific technologies. Concerning wind power, such policies have included subsidies (in the form of tax credits) and other environmental regulatory actions (in the form of Renewable Portfolio Standards). This chapter will discuss the impact of these three kinds of policy—deregulation, subsidies, and renewable requirements—in turn, demonstrating how the success of the wind power industry has involved the simultaneous development of policies encouraging particular ways of acting toward specific technologies *and* the development of those technologies themselves. The success of the wind industry is best understood as the merging of two organizational fields (FIELDS 1 and 2) to create a new model for providing electric power. This merging has involved the co-evolution of both fields—individually and in relation to each other—in terms of their relative power, their roles, and their perceptions of specific technological options, all of which have been shaped by different policies.

Deregulation and Restructuring

The restructuring of the old electricity industry (FIELD 1) was not a single event experienced similarly by all industry participants. However, there are some general trends and features of this deregulatory process that affected participants both directly and indirectly. It should be noted that what is termed "restructuring" varies from state to state. In general, restructuring is defined by the U.S. Department of Energy as:

> [t]he process of replacing a monopoly system of electric utilities with competing sellers, allowing individual retail customers to choose their electricity supplier but still receive delivery over the power lines of the local utility. It includes the reconfiguration of the vertically-integrated electric utility.[1]

This section is not a comprehensive overview of the restructuring movement in all its details and consequences. Instead, it is aimed at explaining restructuring in very general terms and then engaging what the data reveal about the ways in which these regulatory changes have affected technology selection and development in the electricity industry more broadly.

In response to the sharp increase in the price of oil as a result of the 1973 embargo and out of the growing realization that the nation was extremely economically vulnerable due to its

[1] This definition was accessed from the online EIA glossary on April 16, 2003 at http://www.eia.doe.gov/glossary/glossary_r.htm.

dependence on foreign oil, President Carter drafted PURPA, which was approved by Congress in 1978. One of the purposes of the Act, broadly stated at the time, was to diversify the nation's electricity supply by encouraging the use of newer, more environmentally sound, and more efficient generation technologies, primarily natural gas (Corrigan and Kirschten, 1978). This was done by creating a new class of electricity providers—nonutility independent power producers (IPPs)—who were largely exempt from the existing regulatory restrictions that applied to electric utilities. IPPs could not be more than fifty percent owned by a holding company owning a regulated utility, and they could apply to operate Qualifying Facilities (QFs), which were small scale plants using renewables or cogeneration technologies producing under 50 MW of power. Companies operating QFs could also apply for federal grants and were eligible for tax breaks and investment incentives.

PURPA removed many of the major institutional barriers for renewable energy development by opening up the regulatory system so that innovation and investment in new technologies was actively encouraged and financially supported by the federal government (Gipe, 1996: 31). Perhaps most importantly, PURPA required that electric utilities from FIELD 1 purchase surplus electricity from the IPPs of FIELD 2, thereby ensuring a market for their product. The size limitations of QF's for solar and wind facilities were removed in 1990, and in 1992 the Energy Production Act (EPACT) was passed by congress which renewed many of the credits and incentives provided by PURPA which had expired in the late 1980s (Sawin, 2001:123–125). EPACT also opened up the renewable energy market to regulated utilities, introducing direct competition into the power production industry for the first time since before regulation began in the 1930s.

During the 1980s, several additional legislative acts allowed these QFs to increase their capacity, and the new organizational form within FIELD 2—the unregulated, nonutility IPP—became increasingly prevalent. In 1992, EPACT further opened the industry to competition by requiring that utilities consider the full range of fuel source options when planning their future mix of energy and by further requiring open access to transmission (Sawin, 2001: 106–107; EIA, 1993). After EPACT, a number of states began to require that regulated utilities divest of generation alltogether. In essence, the model shifted so that utilities were responsible for transmission and distribution but would purchase all the power they needed—as they needed it—from the wholesale generation market.

These changes had significant effects on both the R&D environment for wind power and on the ways that electric utilities perceived their energy options and their roles within the industry. On the most basic level, deregulation increased the risk adversity of an already risk adverse industry. This sentiment was expressed by participants in almost all categories of interviews conducted for this current research (see Table 1). While these comments varied in terms of their level of applicability—from speaking of wind in particular to all technologies—it is clear that introducing a system of competition fundamentally altered many of the normative, legal, and regulatory institutions that framed the perceptions of appropriate action for electric utilities, for nonutility IPPs, and for both federal and private R&D organizations.

Surprisingly perhaps, restructuring seems to have impeded the introduction of wind technology and hindered its continued development within FIELD 1. When asked how structural changes in the 1990s influenced the perception of wind by electric utilities, Robert Thresher at the National Renewable Energy Laboratory (NREL) answered,

> . . . I actually think it delayed the introduction of wind. Now it's a much more competitive industry so you are much more likely to be held [accountable], you can try a new technology when you had a regulated utility and you could put in your rate base and you could use some arguments with the utility commission about diversifying your fuel base . . . and now it is strictly based on dollars. . . . If anything, it [changing structure] has put stumbling blocks in the way of new technologies that weren't pruned and didn't have a track record. . . . I think deregulation actually made things worse because it added risk and uncertainty. (Interview 1)

This statement highlights the fact that competition decreased what little incentive there was for utilities to innovate and try new technologies. Not only would it be difficult to justify the innovation if the technology failed or was unpredictably expensive, but electric utilities in FIELD 1 were less encouraged to own generation all together. Commenting on the situation in California, Greg Rueger from PG&E stated,

> . . . the utilities were being told that over time they were going to divest their generation and just purchase power from the market, so the utilities themselves started having less interest and less push towards developing new generation technologies . . . (Interview 11)

In some states this divestiture was a formal requirement and utilities had little choice about whether or not to stay involved in generation (Interview 11), while in others, the decision to divest of generation was a voluntary choice (Interview 14). In both cases, however, the general consensus that emerged from the data was that the 1990s was a time when electric utilities were becoming less and less directly involved in the processes of generating electricity and that this was largely left to nonutility IPPs.

In addition to FIELD 1 utilities being less inclined to actually own and operate generating facilities under the new market model, they were also less inclined to invest in R&D of new technologies. The comments of Glenn Cannon are revealing in this regard. Even at the small public utility of Waverly Light and Power (WLP), changes in the way that the industry has acted toward new technologies have been noted. When asked how deregulation affected WLP's operations, he answered,

> [u]tilities are very nervous and skeptical of adding new resources, and you can see dramatic declines since talking about deregulation in R&D programs for utilities. EPRI funding has gone down, people are unwilling to test new technologies, they are hunkering down, everyone is worried about the bottom line, larger utilities are merging and spending all their time worrying about next quarter and not about the technological advancements, so I see deregulation as being disadvantageous to the long term health of the industry. (Interview 4)

When asked what Iowa's regulatory status was, he answered that "Iowa came dangerously close to passing deregulation . . . it has been a huge collective sigh of relief that they didn't pass it" (Interview 4). These comments reveal two things. One, deregulation is generally not welcomed by actors in FIELD 1 (electric utilities) because it forces them to substantially change the way they do business and introduces uncertainty into their operations. Two, many electric utilities are currently in dire financial straits and are not able to invest as they once did in R&D. Deregulation forces these utilities to take a short term outlook, both in terms of where they will get the power they need to serve their customers and in terms of where the future of the industry is headed technologically.

The comments of Greg Rueger from PG&E are also revealing in terms of how deregulation has changed R&D among electric utilities. "With deregulation," he said,

> there was a change in terms of how R&D dollars would be managed and spent. Funds used to be provided through rates to PG&E and PG&E managed its own R&D program. We spent about 40-50 million a year, not only on renewables but on all types of R&D. After deregulation in California the utilities were essentially taken out of R&D and the CEC [California Energy Commission] was given ownership of the state's energy R&D. The state still allocated about the same amount toward R&D but it was and is now treated as a pool for the whole state that the CEC manages. So the utilities become the collection agent to pull those dollars out of rates but they get turned over to the CEC, the CEC then hands out contracts for doing R&D. (Interview 11)

As this comment suggests, deregulation fundamentally altered the roles of the various actors in relation to each other. These changes also significantly affected industry-wide R&D.

One of other ways that R&D was affected in FIELD 1 was through declining contributions to the Electric Power Research Institute (EPRI), a main FIELD 1 R&D organization. For example, Chuck McGowin at EPRI mentioned that the organization had been "streamlining" in recent years. When asked to clarify, he answered with the following comments:

> As our industry has been streamlining, the contributions to EPRI have been decreasing so we have had to streamline also. It used to be, when I first came here in the mid 1970s, we had a lot of members that were contributing millions of dollars a year, individually, and they were buying 100% of the program whether they needed it or not, including nuclear power, so we were under a much different situation than we are now . . . so now they dictate where they put their dollars and what the priorities should be. I suppose that puts us in a pretty good position now relatively speaking because of the growing interest in renewables, but it still, although there is growing interest, I am not sure that the growing interest is enough [laugh] to offset the declining ability of our industry to support research. They are very cost conscious, it has been in economic straits and it is hard for them to justify spending money on research when they are trying to survive economically . . . so these are challenging times for the industry, and I guess you could say for EPRI also. (Interview 8)

Comments like this do not mean that EPRI no longer has any role to play in the industry. Instead, they reveal that its role has changed as has the structure of the industry, and electric utilities have increasingly become focused on the short term health of their businesses. In the world of the middle and late 1990s, electric utilities and EPRI were decreasingly involved with directly refining wind technologies and putting them into operation.

The state of industry restructuring at present (in 2003) is incredibly muddled. The so-called "energy crisis" in California in 2000 caused many states to reconsider their deregulatory efforts and put restructuring on hold. While space in this paper does not allow for a comprehensive review of the situation in California leading up to this crisis or for a full explanation of what happened, it is important to note that the perception at the time of the event was that restructuring had hindered the development of new generation and that this led to a large energy shortage, causing rolling blackouts in several areas of the state. Let it be said that this interpretation is highly contested and the jury is still out concerning what actually happened and who, if anyone, can be held responsible (McCullough, 2002). The essential observation for the purposes of this research is that this crisis was perceived as being directly related to restructuring and, subsequently, a number of states halted this process within their own borders.

The future of restructuring is thus unclear. Many interviewees commented that the current era is largely one of a return to a regulated framework, although this is far from certain. On the surface, this was expressed in the interviews when participants did not have a clear definition of what even to call the state of the industry at the present time. At one point it was referred to as the "post-deregulation" era, but with a tone of uncertainty, almost as a question. In other words, many participants are unclear about their roles and there is a fair amount of variation in terms of what is now considered appropriate action. This uncertainty has serious consequences for R&D. When asked how PacifiCorp was currently involved in R&D, Virinder Singh answered,

> [t]his is a big problem in post deregulation. With deregulation utilities were doing less and less R&D, it is more of a long term thing you don't get rewarded for it in the short run . . . and EPRI used to get a lot of money for R&D. When that started drying up they had to change their business plan . . . now that we are back to regulation, that exit from R&D has not been corrected, and we don't do R&D but I don't know who is doing it. From what I understand the energy sector spends a lot less on R&D than other sectors and you read about all sorts of international innovations but not as much in the U.S. We get phone calls all the time from people with great ideas and I just don't know how to help them because we don't have any mandate to do R&D right now. (Interview 5)

Similarly, when asked who was doing R&D in the industry right now, Adam Serchuk answered, "I've been told that EPRI used to be about a 550 million dollar organization and now it is about 300 million, so its not just that R&D isn't happening at utilities but that less of it seems to be happening at EPRI as well" (Interview 6). EPRI and NREL still have substantial programs and are continually working to refine wind technology in particular, but the overall sense is that R&D in these organizations and among utilities has dramatically decreased as the structure of the industry has changed since the early 1990s.

As the industry has backed away from deregulation and electric utilities from FIELD 1 might again have the opportunity to invest in new technologies and perform internal R&D, there are several pragmatic reasons why this might also not occur. Electric utilities have been out of the loop for so long (technologically speaking) that they are mostly unfamiliar with the specifics of new innovations and even with technologies that have now become mostly stable in their designs and have been accepted by actors in FIELD 2 (nonutility IPPs). Pragmatically, it makes more sense for utilities to leave R&D to those who took over that role as restructuring occurred and to use these new experts as outside contractors rather than undertake R&D internal to the firm. As Greg Rueger from PG&E commented,

> I think now [after the failure of deregulation in California] the utilities are going back into long term contracting to meet the power needs of their customers . . . and those relationships [between utilities and developers] will be built up again as we go forward, and they actually may in some ways be stronger because there used to always be at least the potential that the utility developed most of their generation themselves and could be viewed as a competitor to the developer. Well, in the future, I don't think we can totally turn back the clock [to before deregulation] and even though California is looking at getting the utility back into the development of generation it owns, I think most of the utilities, to the extent that there is still a viable power market out there, we are more likely to contract for power than develop it ourselves. (Interview 11)

In the post-deregulation era, even though in some cases utilities might consider getting back into the generation side of things, there is also a mature industry (FIELD 2) with large firms who possess expertise about innovative technologies that they can do business with. In this situation, actors in FIELD 1 seem to be pursuing a particular course of action not because it is inherently "better" in some abstract functional sense, but because "that is just what you do." As New Institutional theory points out, this is precisely the sort of taken for granted frame of appropriate action that is defined by the institutional and organizational context.

While up until this point this section has focused almost entirely on the R&D efforts of EPRI, DOE, and electric utilities, restructuring also further opened the market to nonutility IPPs. As Doug Larson from the Western Interstate Energy Board (WIEB) stated,

> [e]lectric restructuring has had one very beneficial effect and that is that it has opened up the generation market, a lot of new players came into it, the utilities no longer were the predominant builders of generation so their old biases no longer drove the decisions as to which kinds of electricity generation technology to buy. (Interview 9)

It was these nonutility IPPs from FIELD 2 that became increasingly involved with refining and developing wind technologies outside of the FIELD 1 framework by continually gaining field experience with the machines and absorbing European innovations and designs more readily than utilities or the DOE were willing or able to. Nonutility IPPs became experts on this innovative technology and were ensured a niche in the market due to EPACT (see below). As a result, they have became an established force in the industry such that they are now able to compete directly with FIELD 1 actors who at one point almost completely held the upper hand. As Doug Larson also commented,

> . . . there are big companies in this now like Enron Wind, which became GE Wind, and FPL . . . these utilities who are accustomed to dealing with large corporations, comfortable doing that, now have people in the wind industry who look like people they have dealt with over the years. So the level of comfort in investing in wind goes up somewhat . . . (Interview 9)

All of this illustrates that nonutility IPPs (FIELD 2) not only were able to enter the market as a result of deregulation, but the organizational form that they ended up taking meshed closely with that of the established, powerful actors. Furthermore, this integration has been important for their success. This finding of mimetic isomorphism on some levels of organizational functioning is also in-line with previous New Institutional work. It means that in the current model of power production, electric utilities are only confronted with a new technology and not an entirely new system. In other words, they only need to change their perceptions of the risk associated with an innovation—perceptions that are allayed by these new firms' expertise and by the reliability and competitive cost of the product—instead of substantially changing the way they do business. This shift toward a division of labor in the wind industry helps explain how a "working" wind turbine developed even in the face of decreased R&D in FIELD 1.

But deregulation has not been the only political change affecting the behavior of organizational actors and firms in each field separately. In fact, as mentioned briefly in Chapter Two, subsidies in the form of tax incentives have been extremely important for encouraging investment in wind power technology. While restructuring changed the types of relationships between actors associated with each field by redefining roles and responsibilities, tax incentives served to make the wind power industry appealing to electric utilities (FIELD 1), to nonutility IPPs (FIELD 2), and to fields outside of the electricity industry, such as investment banks. The tax incentives helped integrate these two main fields and other RSGs. These subsidies have thus been important for helping to make wind power a profitable business venture by stabilizing the perceptions of FIELD 1 actors about the new model of power production. Because this was frequently mentioned in the data by participants in both fields, the following section focuses on these policies and their role in shaping the modern wind power industry.

Tax Incentives and Subsidies

As mentioned in Chapter Two, investment tax credits existed in the 1980s and these subsidies were largely successful at helping developers build wind farms. Unfortunately, however, because these subsidies were tied only to investment and not to production, there was little impetus to make sure that the technology actually worked and produced electricity as it was supposed to. By contrast, EPACT in 1992 implemented a production tax credit that was tied to output, and this credit has been viewed as one of the most essential factors driving wind development in the United States. While the data reveal that there is a fair amount of uncertainty concerning the continued importance of these credits, it is certainly clear that they make wind more appealing for developers and subsequently increase the actual implementation of wind power. When asked if wind would still be considered an option by many developers without the tax credits, Doug Larson from the Western Interstate Energy Board (WIEB) answered,

> [y]es, but it would be a pretty low level. The tax credits are a real sweetener. . . . As long as the industry can get money they are going to take it, just like any other business . . . clearly if the tax credits were not there this level of development would not be occurring . . . (Interview 9).

Investors and developers respond to these credits, which makes wind an increasingly appealing option.

This fact was perhaps most directly revealed in the comments of Zeina El-Azizi from Cielo Wind. “With the introduction of the production tax credit,” she said,

> it became extremely viable for large scale wind to be competitive with coal, gas, any sort of generation, plus you got the added benefit of renewable energy credits if they existed in a particular state. (Interview 10)

She reiterated this point later in the interview. "What you *cannot* do away with," she said, "is the production of tax credit."

> Wind energy in the U.S. is not cost competitive without the tax credit. It is a *significant* increase in the price of power. Even utilities are shocked when we give them what the difference would be . . . $18/MWH is on a pre-tax basis, so if you run a model, and most people don't realize this, but on a real dollar basis the dollar amount is significant in what the power price ends up being. So let's say you are looking at a facility and the price is, say in California, $35/MWH, well if you try to pull out the tax credit, the price will jump up to about . . . $60/MWH. So it is more dollars per MWH than it looks like in the documentation. (Interview 10, emphasis in original)

Even as a nonutility IPP with a small appetite for tax credits, Cielo Wind posits that it would be very difficult to get investors interested in a project and to be able to offer a competitive price without the production tax credit's substantial subsidy.

The importance of the credit was repeated by Ed DeMeo, former Manager of Wind Power Integration at EPRI. When asked what he thought the significant drivers were for the recent boom in wind, he answered,

> I don't know if I would call it a boom yet but it is significant, it is a lot of activity. What drives it? More than anything else are public policies. You will find that the states which have instituted some sort of incentive, that is where wind is happening. Mother nature has to cooperate here, the economics of the machines have to be somewhat affordable also . . . what has happened is that there is a convergence of this policy driver aspect and the reduction of cost. (Interview 12)

Subsidies appear to be extremely important for getting investors and developers to consider an innovative technology, but this policy alone is not enough. The product also has to be sufficiently developed so as make the investment pay off in the end. But even these subsidies are problematic for the industry, not because they create a dependence on federal and state funds for continued growth, but because their implantation is cyclical and the expiration and renewal of the credits creates substantial uncertainty which leads to bust and boom cycles of development.

The intermittency of the production tax credits is a significant problem facing the industry and was mentioned by almost all interviewees. But the perspectives on the purposes and future role of the credits vary and can be classified into two main categories. On the one hand there are those who believe that the credit levels the playing field and allows wind to compete with other heavily subsidized technologies. Its continuance is therefore essential. The intermittency of the credit is a problem that can be solved by extending the credit for longer periods of time. On the other hand there are those who believe that the credit is no longer essential and that wind can make it on its own. As long as the credit continues to be extended, companies will wait to take advantage of it instead of just moving on without it. The intermittency of the credit is a problem that can be solved by removing the credit altogether. Both of these perspectives, while differing in their views on the purpose of the credit, agree that intermittency—and therefore uncertainty—seriously hinders the progress of the industry.

The reasons for the cyclical expiration and renewal of the credit are not solely tied to the cost of the technology. In fact, some of the pressure to continue the credits simply comes from political pressure from beneficiaries of the credit. The justification for continuing the credits is often the observed decrease of development every time the credit expires. When asked if wind was competitive with other technologies, Arnold Leitner, Senior Consultant at Platts Energy answered,

> [i]t probably already is. But right now critics say: “You know, when the tax credit expires and people stop building wind farms that's proof that the tax credits are needed and that wind can't make it on its own and that it's not competitive.” Well, there is a slip of logic in there. If I know that I can make a killing by holding off building [a new wind farm] for two weeks until the credit is renewed, why in the world would I want to start building now? Tell them that there will be no tax credit, period, any more, and see if they build turbines. But as long as you tell them that you are working on an extension you would be out of your mind to build anything in the interim. That cyclicality [which was recently seen in the North American wind market], the boom and bust, is no proof that the credits are required. (Interview 7)

Similarly, when asked if the tax credits were no longer needed for wind to be competitive, Chuck McGowin from EPRI answered,

> there are people that think that. The wind industry is of course out there saying that they are needed. . . . My feeling is that we ought to phase it out because we are getting close to the time when it will make it on its own. (Interview 8)

This view that subsidies should be phased out was shared by Robert Thresher at NREL as well. “The goal,” he said, “ is to eliminate the need for subsidies, and we see that happening in the next decade” (Interview 1). As these comments reveal, there is a sentiment shared by some in the industry that the technology is close to cost competitive and that the credits may no longer be essential, but that they continue because of the obvious financial benefits they provide. Or, as Robert Thresher also stated, “I think as long as there are credits it will move forward. It is cost effective” (Interview 1).

While most agree that the bust and boom cycles are problematic, some feel that the credits should remain a permanent feature of the wind energy landscape. Interviewees who held to this latter stance used as a justification the perpetual subsidies that are granted to almost all other technologies currently in use by the industry today. When asked he thought the credit was still important for wind to be competitive, Greg Jaunich of Navitas said, "[y]es. . . . All forms of power receive some form of subsidy from the federal government, and the tax credit is something that is very important for the dynamic of how profitable a wind project is . . ." (Interview 13). Similarly, when asked if the idea behind the credits was to spur initial growth to decrease costs and then be phased out, Rick Walker from AEP answered,

> I guess I would not necessarily agree with the first assumption because I think you probably still have a lot in incentives to invest in oil and gas, and that has been around a long time, right? I think credits are more used to influence national policy whichever direction we want to go. So I think that the U.S. may say renewable energy is good and we want to encourage it, it is coming along right now and we want it to continue to come along, [so] there might be reasons to always give a tax credit for wind energy if it is better than importing oil . . . (Interview 14)

Thus several participants believe that credits are still needed in order to level playing field.

This belief was perhaps most clearly presented by the comments of Ed DeMeo, former Manager of Wind Power Integration at EPRI. "If the credit were to disappear at this point," he said,

> my sense is that some wind development would still continue because the costs have come down enough that it begins to make sense in some cases even without that credit. But, what really arrests development is uncertainty . . . [and] as long as there is uncertainty about whether or not it is going to get extended, nothing happens because people don't know which game they are supposed to be playing. You can wait and get a better deal, but on the other hand if you know there isn't going to be a better deal, you go ahead and you do the best you can, you play by a little different set of rules but you play. So what is really needed is consistent policy for some extended period of time, not two or three years but ten, and then whatever the game is people will play it. . . . Now, but should be there be a production tax credit? Well, people complain that wind is no good because it has to have an incentive. Well, those people are ignorant of the subsidies in place right now for conventional energy. All the energy we buy in this country has some significant subsidy that has been internalized into our whole economic system that doesn't show up in your electricity bill. (Interview 12)

He continued to explain some of these other subsidies, none of which are usually included in the costs of energies associated with other fuels. "The whole point," he concluded, "is that this production tax credit for wind goes part of the way toward leveling the playing field for wind because all of the things it competes with already get very significant subsidies that are built into our system" (Interview 12).

This section has presented data revealing that subsidies are incredibly important for the growth of the wind power industry, even though the technology might be "cost competitive" by some accounts. Some participants feel that subsidies should eventually be phased out, while others feel these subsidies are still essential because they level the playing field. Whether or not they are still needed, subsides do encourage investment in wind power by organizations in both fields. Electric utilities (FIELD 1), on the one hand, some of whom may have a large appetite for tax credits, find it in their best interest to invest in wind technology instead of other types of fuels. Nonutility IPPs (FIELD 2), on the other hand, find that the existence of these incentives send strong signals to investors and thus helps them secure the capital they need to build wind plants. This policy keeps these two fields working together, and the viability of their relationships has nothing to do with the standards of the technology or the efficiency of this type of organizational arrangement.

It is clear that the apparent disagreement over the continuation of the subsidy contrasts with the consensus over the stability of wind power technology itself. In other words, participants accept that the technology "works," but only in the context provided by a particular policy framework. This demonstrates that technology and organizational form co-evolve within the environments structured by policy regimes. However, direct subsidies in the form of tax incentives are not the only policies that affect the perceptions of wind power by organizations. While perhaps not as essential, environmental regulations also serve to signal to organizations in both fields that wind power is a technology worth pursuing. The next section examines in detail one type of this regulation, the Renewable Portfolio Standard (RPS).

Renewable Portfolio Standards

Renewable Portfolio Standards (RPS) are important policies for renewable technology diffusion, although they are not as essential as tax incentives and subsidies. An RPS usually accompanies state-level restructuring legislation and requires that utilities include a certain percentage of renewable energy in their generation mix. California, for example, recently implemented an RPS in 2002. It requires that the state "increase the use of renewable energy by 1 percent per year until 20 percent of retail sales are generated from renewables. Investor-owned utilities and direct access providers must reach the 20 percent mark by 2017."[2] PG&E

[2] Information concerning California RPS was accessed from the EIA website on April 16, 2003 at http://www.eia.doe.gov/cneaf/electricity/chg_str/california.html.

is required to enter into some short term contracts to raise the amount of renewables in their mix by one percent this year as a result of that requirement (Interview 11). The RPS serves several purposes: it mandates the adoption of non-fossil fuel technologies, it helps establish a credit trading system which encourages the addition of more capacity than required by the RPS, and it sends a symbolic statement to industry participants about the future direction of the industry.

This last aspect was expanded upon by Ed DeMeo, former Manager of Wind Power Integration at EPRI. When asked about the importance of a federal RPS, he answered,

> [w]hat an RPS does is provides a strong direction for the electric power business in the state. . . . What has become really clear is that the utility industry, left to its own priorities, will not begin wind development, or development of any new technology. It is not that they are bad people, it is just they have a different job to do. Their job is not to try new stuff; their job is to keep your lights on. Reliable power, and to try to do it as low cost as they can. . . . So if you go beat on the utility and say "why don't you put in more of this new wind or solar or whatever it is?" they say "you know, we'd like to do that but really it is such a tremendous change in the way that we operate that it makes us really nervous and really we would rather not." And you can't really blame them. . . . [This] means that if society really wants this change and wants clean energy, then society has to make this known and tell the utilities that we really need this. [We] have to help them not get burned by letting them recover the cost. . . . So you take the driver out of the hands of the utilities and put it in the hands of the public, and policies are created, that's what happened in Europe, and that is what a RPS is. (Interview 12)

This comment stresses the importance of such policies for helping to frame the context in which electric utilities make decisions. If the public desires renewable energy, it has to make this known to the businesses that provide it with power, and an RPS is one way of doing just that.

Other interviewees were less adamant about the necessity of an RPS for wind development, although most agree that it can be an important driver in many cases. When asked if there are important roles for the federal government to play in helping the industry along other than direct subsidies, Robert Thresher from NREL answered that a federal RPS "would probably make a big difference in terms of driving the initial stages of infrastructure change." He continued,

> [t]he Europeans did it solely with very high tax credits, but I think that the portfolio standards make sense, and I believe that once people get started and used to wind and . . . get over some of the operation concerns associated with variable generation technology . . . then the comfort level rises. (Interview 1)

Part of the issue, then, is helping electric utilities in FIELD 1 get comfortable with the innovation by sending a strong message that renewables are something they should actively pursue. In talking about the recent interest in wind from public and private utilities alike, Chuck McGowin from EPRI commented that,

> [a] lot of them [i.e., utilities] have been driven not by a great desire to look like great public citizens but by [laugh] state renewable portfolio standards, and they don't mind being able to get credit for doing it either. It's not something they would be doing necessarily unless they were told to do it, [at least] not at the level they have been doing it. (Interview 8)

Interestingly, PacifiCorp is one of the few utilities that actually supports the implementation of an RPS. Virinder Singh commented that PacifiCorp was interested in pushing for these requirements at the national level and that this stance was not widely held by many other utilities (Interview 5).

Although it is clear that state mandates in the form of an RPS will certainly encourage development, these policies are not viewed as being as essential as tax credits. This is demonstrated by the many states across the country, including Oregon and Washington, that do not have an RPS but still have significant wind development.[3] When asked if companies would be able to offer wind at competitive prices without the forced demand created by an RPS, Zeina El-Azizi answered,

> I think it depends on the state and what the wind regime is. In states that have a lot of wind then you can get the a competitive price without the RPS, I think it is reasonable that you could get to a point of being able to say that you could sell the power without the RPS. (Interview 10)

This view was supported by the activities of Navitas Energy, which operates in over ten Midwestern states, few of which have an RPS. When asked what was then mandating renewable development in these states, Greg Jaunich responded,

> [s]ometimes their public commissions have said you should add a certain proportion of green power to your energy mix, sometimes their customers have wanted it, sometimes . . . and Minnesota is an example, Exel Energy . . . has requested to store radioactive waste on Prairie Island, and in exchange for doing that they had to add a certain amount of renewable energy to their energy mix. So there are quite a few different programs. (Interview 13)

As this comment reveals, there is no one policy that is responsible for driving wind facility development, and the variation of development across states with different supports this

[3] The Renewable Energy Policy Project website (http://www.repp.org/rps_map.html) contains a map of all the United States that have an RPS. Comparing this map to the map available from The American Wind Energy Association website (http://www.awea.org/projects/index.html) reveals several states that do not formally have Renewable Portfolio Standards but do have significant wind development.

conclusion. The data reveal that these policies are perceived as being important, though not essential, for the continued growth of the wind power industry.

So far this chapter has shown that policy is extremely important for providing actors in both organizational fields with cues about appropriate and rational behavior. But policies also define the types of relationships among actors from different organizational fields. Changes in policy over the last thirty years have simultaneously re-arranged and redefined actors from each field in relation to each other as well as altered the perceptions of all actors toward an innovative and risky technology. These legal changes would not have been effective at causing the wind power industry to grow without a technology that "worked." But the perceptions of this technology as "working" also largely depended on a new legal environment in which a particular type of technology made sense. Because the current success of the wind power industry involves the selection of wind technology by members of both FIELD 1 and FIELD 2 as a viable alternative to other fuels, it is important to discuss this process, albeit briefly, because it highlights the cognitive perceptions of actors as related to their understanding of their environment. This discussion points out that policies influence the selection of both technology *and* organizational form. In deciding to pursue wind power, electric utilities from FIELD 1 have two options: 1) they can own and operate wind farms themselves to provide their own power, or 2) they can negotiate to purchase wind power from facilities that other firms own and operate. As it turns out, most electric utilities from FIELD 1 choose the latter, and this has important repercussions for the development of the wind power industry.

Selection of Technology and Organizational Form

Most of the wind power in the United States is currently provided through long term contracts between electric utilities from FIELD 1 and nonutility IPPs from FIELD 2. As Ed DeMeo, former manager of Wind Power Integration at EPRI, stated: ". . . generally wind plants are owned by IPPs who negotiate a power purchase agreement with the utility" (Interview 12). In discussing the current model of power generation, Rick Walker from AEP also said,

> [p]rimarily that is the way it works these days, for the last several years, new generation is built by IPP and it is usually owned by some non-affiliate company. That is just the way it has been evolving for some time now, but there is not an outright prohibition on us building our own wind farm and selling to our own affiliated retail companies, it is just a lot harder to do that because of the regulatory process. (Interview 14)

As these comments reveal, the institutional environment affects the types of strategic decisions made by actors regarding power production. During most of the 1990s in California, for example, these decisions were mandated by policy. In this situation, electric utilities from FIELD 1 did not own and operate new generation facilities. In other cases, electric utilities turned to IPPs from FIELD 2 because these organizations had substantial experience with the technology.

All of these decisions concerning technology selection play themselves out in economic modeling. If an electric utility from FIELD 1 looks into the future and projects that demand will increase, it then has to determine how it will meet this projected demand. In the current market situation, these utilities have a number of options: 1) they can purchase power from the spot market, which is risky and often times quite expensive because of its unpredictability; 2) they can pursue long term contracts with power producers; or 3) they can build their own facilities. Legal, normative, and technological factors all influence this decision. For example, PacifiCorp's most recent Integrated Resource Plan (IRP) came out quite favorable to wind. As Virinder Singh said, "[t]he biggest impacts in our modeling that benefited wind were carbon, production tax credit is very important, though periodic availability is a bit of a problem, and natural gas prices" (Interview 5). After commenting on the increased, industry-wide dependence on natural gas since the early 1990s, he continued,

> . . . well, our supply [of natural gas] is not as plentiful as we thought it was and demand keeps increasing. So you look at your options: gas has volatility, coal has this environmental regulatory issue, nuclear is too prohibitive and of course you have terrorism to worry about now, and then you have hydro, and there is not much room for hydro expansion, so what do you do? And that is where wind is coming in right now. It's because this country is running out of other options. So that is where wind comes in for us. It is in our most economic plan. We have 1400 MW of wind in the plan because it has low variable cost, there is no fuel cost, and it's good on carbon. So that's why it's doing well . . . and of course the technological innovations have made it a viable technology . . . (Interview 5)

These comments reveal that first, the technology had to be developed enough; it had to "work." Second, financial incentives were needed. And third, other options were less desirable. This third aspect contains multiple factors, ranging from supply and demand issues associated with entrenched technologies (natural gas) to expenses associated with existing technologies due to fuel prices and the possibility of future environmental regulations. Choosing wind power at PacifiCorp involved legal, technological, and organizational considerations.

Also significant in terms of influencing the choice of wind power is the current financial state of both fields. "I think what we are seeing now," said Doug Larson from the Western Interstate Energy Board,

> is that there is concern, not just from folks concerned for the environment, but from pure risk management, there is concern from utilities . . . of being too

> dependent on natural gas for generation because of price volatility, and that leads to companies looking around, so what are the alternatives? . . . Right now you see companies looking at wind, companies who historically had not, partly because the economics have improved, partly because of the hedge against gas prices, partly because the major alternative is coal fired generation and . . . the part that creates the uncertainty is what happens with carbon in the future. (Interview 9)

This comment reveals that uncertainty surrounding possible environmental regulation of CO_2 and the volatility of other fuels makes wind increasingly appealing to companies that are seeking new generation. Coupled with this is the dire financial straits many companies find themselves in as a result of restructuring. As Doug Larson also commented,

> restructuring of the industry has led companies to not want to make long term, large capital investments because the uncertainty about where the market is going to be in a few years out is so immense and the consequences, as we saw in the electricity crisis in the West, are so enormous. . . . [There are] lots of bankruptcies in the industry related to restructuring . . . lots of downgrades in stock . . . all the new players in the business are all either bankrupt or junk status and are sort of hanging on by their fingernails. . . . So the bottom line is that it's not the sort of environment where you want to walk into the board room and say "Hey, I'd like to put down two billion dollars for an investment which will start generating electricity in 8 or 9 years" . . . so all of those things lead you to the conclusion that, well, maybe we ought to take a look at this wind stuff . . . (Interview 9)

These comments reveal that although regulation and subsidies may help shape the perceptions of actors by providing cues about appropriate action, they do not function in a vacuum, nor are they solely responsible for the success of the modern wind power industry. In fact, as the next chapter discusses, changes in policy can create profound uncertainty, thus potentially inhibiting future growth.

Conclusions: New Institutionalism and Wind Power

This chapter has focused on how changes in the institutional environment of the electric power industry in general have affected the organizational fields and the technological development associated with wind power. It has highlighted how policy created a new organizational field by partially deregulating an old one, and how the perceptions of actors in both fields concerning wind technology and their relationships with one another have subsequently been reshaped. Specifically, tax incentives stimulated investment in an emerging industry that was intimately connected with an old model of generating electricity. At the same time, deregulation changed the perceptions of actors in the old field about their roles in providing electricity altogether. These developments also shaped the nature of the R&D environment for wind technology and the perceptions of what a "working" wind turbine looked like. In the 1980s, a machine that looked like a windmill "worked well enough," and helped the emergent industry establish itself as a major player providing electricity generated from the wind. This conception of "working," however, was not satisfactory to all RSGs, and this drove additional changes in policy and technology, thus forcing actors to reevaluate their activities. In short, fluctuations in policy created profound uncertainty about the respective roles of each field in relation to the other, and the success of the wind industry involved the simultaneous construction of a new "working" wind generator and a stable set of relationships between actors in both organizational fields.

This chapter has combined the insights from SCOT about the malleability of technical options with those of New Institutional sociology to reveal a framework in which technological and organizational changes could be viewed. The data provides evidence for the notion that changes in the legal/political environment of an organizational field influence organizational behavior by changing the perceptions of actors about appropriate courses of action concerning technological choices. Organizational outcomes are not the result of simple economic factors but involve the complex interplay of institutional forces that frame and give meaning to certain types of behavior over others. If applied in isolation to this case, the New Institutional puzzle would be to understand how a new industry—as new organizational field—survived and flourished in an institutional environment historically considered extremely barren and harsh toward anything new at all. However, because the wind power industry also involved a new technology, this puzzle was engaged by combining SCOT and New Institutionalism into a single analysis. The result has been encouraging, as industry emergence appears to involve the co-evolution of technology and organizational form.

In order to demonstrate this connection still further, the next—and last—chapter presents findings from the interview data concerning the perceptions of actors in both fields about the barriers that face the wind power industry in the future. A discussion of these barriers is the essential last piece of this analysis. On the one hand these barriers involve the entrenched technical frame of the nation's transmission system that actors in both organizational fields are forced to confront as each field moves forward. It is clear that altering this technical frame in order to overcome these barriers is essential for all electric power technologies, not only wind power, and involves highly contested political decisions, of which there is little agreement among actors even within each field. On the other hand these barriers also involve normative and cultural perceptions about wind power in particular that are framed by entrenched organizational and institutional relationships among actors in multiple fields, not only the two major fields that this analysis has focused on. The data presented in the next chapter suggests that the future success of wind power does not only involve having a “working” technology, as organizational factors continue to hinder its widespread acceptance. But neither does this success only involve policy or organizational factors, as larger technical systems also hinder its proliferation. Discussing these barriers will help complete the analysis undertaken in this thesis by emphasizing the systems of feedback between organization and technology.

CHAPTER FOUR – Feedback and the Co-evolution of Technology and Organization

While it is clear that the wind industry as the combination of FIELDS 1 and 2 has become established at the present time, its future is far from certain. In fact, for as many obstacles as the industry has overcome since it began in the late 1970s, equally as many still remain. These obstacles range from the institutional—legal codes and normative practices—to the technical—an entrenched, inflexible national transmission system. This chapter focuses on these barriers in order to demonstrate how technical systems feedback into organizational relationships, and vice versa. Looking at the problems currently facing the industry helps to clarify not only the process of wind power development and acceptance, but also industry emergence and success more broadly. In other words, this last chapter highlights how the perceived stability of a technology and an organizational field feed into each other and hence push future development in a particular direction.

The analysis conducted so far in this thesis has already touched on some of these obstacles. For example, Chapter Three discussed how the cyclical expiration and renewal of the production tax credits leads to a bust and boom cycle of industry growth and technological development. This creates significant uncertainty among organizational actors in both fields and sends mixed signals to them about appropriate actions. Also, the lack of cooperation and communication between firms in the post-regulatory era have had serious consequences for the type and extent of R&D. This causes serious concern among actors about the future of the industry and about the development of new technologies down the road. Furthermore, restructuring has left many actors uncertain about their roles in relation to each field. When asked how PG&E went about deciding whether or not to own and operate generation facilities or to purchase power from the market instead, Greg Rueger gave the following answer: "[t]he future is complicated in California right now," he began,

> because of the financial position of the utilities. Right now neither of the largest utilities here [PG&E and Southern California Edison] are rated as investment grade. My utility is still in bankruptcy working its way back, so we need to get back to being investment grade before we can effectively invest in new generation development. Long-term contracting for power others develop would be an option but the rating agencies now look at long term contract debt in a very similar manner to equity, or capital, investment. And the parties you contract with require collateral to be put forward to secure the contract if you are not rated investment grade—cash we don't have until we exit bankruptcy. So you have the issue of sub-investment grade rated utilities that we have to work through

> regardless of how we procure power in the future. . . . I think in general utilities will tend to focus more on the distribution/transmission business, the part that they are a regulated monopoly for, and are more likely to go through longer term contracting with other developers for the power they need rather than being the owner. On the other hand, you do earn on any capital investment you make in the system and not on expenses incurred, so there will be some incentive to be the owner of a plant rather than simply contract for the power [contract costs are treated as an expense that a utility does not earn on]. But the risk of that ownership in generation in recent years has been looked at as greater than the reward that can be made in a regulated environment. That can change over time, but my guess is that we will see some combination of the utility being an owner in some situations and a purchaser in others. We will probably be the developer, the owner, of last resort. We will go to the power market to see if we can get fair prices for purchasing power under long term contracts. If in some situations we can't . . . then the utility will step in and be its own developer, or own owner. I think that is still being worked out within each company—I know what our future generation development role ought to be is a topic of hot debate within my company. (Interview 11)

But these barriers, while they are significant, are not the only problems mulled over by the participants. In fact there are many more, some of which are quite severe and plague the entire electricity industry and not just nonutility IPPs or electric utilities in isolation. The remainder of this section focuses on some—but by no means all—of these issues. These issues are divided into two main sections: 1) barriers associated with the existing technical systems into which wind must become integrated, 2) barriers associated with legal practices and normative constraints. The first section emphasizes how the nation's transmission system is rapidly approaching capacity, and that there is no consensus on whose responsibility it is to build more. The second section emphasizes how entrenched bureaucratic procedures push wind development in a particular direction. With both of these issues, the perceptions of all actors in the industry about the viability of wind power technology are inextricably linked to institutional factors.

Barriers Associated with the Existing Technological Frame and System

The technical and systemic barriers revealed in the data fall into two sub-categories. First, there are problems associated with the nature of the product (i.e. wind energy) having to do with its intermittency. Second, there are problems associated with the entire entrenched system of electric power production and distribution in the most general terms. In relation to this second problem, almost all interviewees commented on the significant problems associated with the national transmission system, problems that have been exaggerated by restructuring and by the increasing division of labor within the industry as a whole. Each of these barriers will be addressed in turn.

The nature of wind as a resource presents some problems for actors in FIELD 1 because of their normative expectations. Ed DeMeo, former Manager of Wind Power Integration at EPRI, was particularly insightful about this issue. "The thing that worries them [i.e. utilities] a lot more than [the cost] is the variability of it" he said.

> The output for a wind plant goes up and down as the wind blows, and that is a new animal for an electric utility, they are used to having plants that you start up and they run and you shut them down when they are not needed more and they stop. So they use technology that they can have strong control over, and then here comes wind which is controlled by mother nature, and it makes them really nervous, particularly the people that are on the front line, buying power selling power turning units on, dealing with a steel plant that just turned on an arc furnace that draws 100 MW all by itself . . . so they are good at that, maintaining that instantaneous balance between generation and need for electricity in the market, but the variability of wind is problematic. You can't quite plan as well. Either it is not as fast of you have to buy it on the market for more than you fell you should have to pay for it. So they worry about that, and it is a legitimate worry—the biggest worry—so that is the risk. (Interview 12)

This sentiment was also echoed by Doug Larson from the Western Interstate Energy Board. "Even assuming that it is technologically feasible," he said

> there will still be a lot of resistance from, first, old line utility operators who don't like the uncertainty that this brings to the system, and second, among PUC folks who generally defer to the utilities for technical issues like this . . . so that will be an area that we [i.e. the Western Interstate Energy Board] have a role, overcoming the institutional barriers to integrating more wind. (Interview 9)

Actors in FIELD 1 are used to doing business in a particular way and are resistant to change, and they think that using wind technology will force them to change the way they behave because of its natural characteristics. This perception is a major barrier to wind's widespread acceptance, but it is a barrier that can perhaps be easily overcome. It has become clear to many that wind does not *really* require a significant change in functioning, nor is it much more costly. For example, as Ed DeMeo continued to explain,

> I can tell you though that several groups and individual utilities have studied this question in detail, looking at what it really is going to cost in actual terms . . . and what we know now is that cost impact of that is down around a tenth of a cent per KWH . . . it is really no big deal . . . [but] it is perceived as a *huge* problem. The utilities a year or two ago were putting in a contingency factor of one or two cents/KWH to cover this issue, and we have worked with a number of those utilities now and they know that number is totally bogus. (Interview 12, emphasis in original)

PacifiCorp has been one of the utilities that has "studied this question in detail," and the comments of Virinder Singh at this organization highlight some of the findings. "One of the challenges," he stated,

> was trying to figure out integration costs, knowing that it is intermittent and that you have to firm up capacity. So we had some people tasked on that, and the results turned out to be pretty favorable to wind, and in fact you are actually starting to see studies pop up here and there, there was one done by Exel Energy and another by BPA [Bonneville Power Adminstration] . . . everyone is trying to figure out integration costs for wind, and we are all getting pretty decent dollar figures, which was not what the assumptions were in the utility world even up to a couple of years ago . . . the assumptions were that it was going to 10 to 15 [cents per KWH] and that it would be a pain to deal with. . . . The way to deal with wind intermittency is to just take into account that the system already has some fluctuations based on supply already, and wind does not add a whole lot more variation into this picture . . . (Interview 5)

Thus because electric utilities already deal with so much variation associated with fluctuating demand, incorporating wind into the system really only requires a change in economic modeling and not in physical operations. This was also summarized by the comments of Greg Jaunich of Navitas Energy when he stated:

> I think the biggest drawback to wind energy is intermittency, and that's always been used as an excuse for utilities not to add wind generation. However, wind does produce a certain amount of power and does have a certain capacity factor associated with it, and with that . . . some of those intermittency issues are just poor utility planning versus actual physical drawbacks to intermittency. (Interview 13)

This barrier thus proves to be mainly normative in that actors in FIELD 1 are used to thinking about their operations and costs in a particular way, and this barrier can be overcome by altering the perceptions of wind power instead of changing actual operations.

While certainly the normative expectations of electric utilities in FIELD 1 do hinder some aspects of wind's diffusion and acceptance, there are also significant legal and economic factors that reinforce the institutional status quo. Imbalance charges are one such factor. As Zeina El-Azizi from Cielo Wind stated: ". . . different utilities have imbalance charges . . . I believe that there is a shift in the understanding of wind energy facilities . . . in the last year, but [it] started about 3 years ago, a shift towards removing imbalance charges, especially BPA has done this" (Interview 10). One way to solve this problem is to implement what is referred to as a Standard Market Design (SMD). Adam Serchuk's explanation is helpful. "The transmission system," he said,

> . . . is set up so that if you reserve room on the system and you end up not using it, you get penalized. This penalty is meant to stop you from playing games with the system, and the penalty is pretty high. Well, wind sometimes gets penalized just because of the nature of the product even though the purpose of the penalty is to alter behavior and the intermittency of wind power is not, in fact, a result of the operator's behavior. So the wind people have always argued that they will pay the cost to the system of the intermittency but should not get hit with the penalty. . . . When you actually sign a contract you usually have a friendly transmission owner who is willing to get around those issues, but if you get someone who is not willing to work with you and who goes by the letter of the law, it makes transmission so expensive that it wrecks the project. . . . What SMD could do would be in part to eliminate those penalties so as to make things easier. (Interview 6)

As this comment reveals, existing rules and regulations that make up the institutional environment in which firms operate still significantly affect the ways that new innovations are perceived and subsequently adopted or rejected.

The continuing problems associated with integrating this new type of resource into the electrical grid bring up a closely related but broader dilemma concerning the nation's transmission system. Problems associated with transmission were consistently identified in the data. "Transmission siting is a huge problem nationwide" commented Adam Serchuk. "I recently managed a project," he said,

> that had us interviewing transmission managers at utilities and talking with them about their vision of the future, and they basically feel like they are up against the wall. What you hear them say is that it is a disaster, no one can site anything anywhere, the only way its going to change is if the federal government comes in an takes control from the states and jams it down their throats, and the only way they think that is going to happen is on the heels of a large transmission related disaster. . . . So whether that's true or not, I don't know, but the industry believes that it has a real transmission crisis and wind is part of that. It is not just a wind problem." (Interview 6)

This comment highlights that the shortage of transmission is a system-wide problem that affects the entire industry and is not just a special case related to wind. As Ed DeMeo also stated,

> [t]here has been very little new transmission built in this country for the last fifteen or twenty years, the system is very taxed, there has been a lot of new generation built, a lot of it by IPPs who now as a result of the Energy Policy Act of 1992 and a number of bills and regulations since then, these new people have access to the transmission system but it hasn't been up upgraded yet. . . . [So] we need to increase the infrastructure of the country, it is a major, major problem right now, and wind is the tail on the dog here. (Interview 12)

While it is clear that transmission issues will continue to be problematic for the future of the industry as a whole, wind is in some ways uniquely plagued by this problem because often times the best wind sites are also far away from urban centers, and thus also far from the electrical grid.

Robert Thresher at NREL revealed that on top of intermittency issues, transmission is an added complication for wind because the sharing of the system is something that has not been worked out yet and is something that will take a long time to solve. Part of the problem, he said, is that that financiers only want to consider big plants, but that big plants often require transmission upgrades, sometimes even completely new lines. This is especially problematic for wind because of most wind projects' distant locations. Figuring out who is responsible for building this new transmission is still an open-ended question, and a hotly debated one at that. As Robert Thresher put it, "it goes reliability council by reliability council in terms of dealing with it . . . it is a minefield of interlocking jurisdictions, not like the highway system that has one set of rules, although there is some movement in that direction. It goes back to a state by state legislative issue . . ." (Interview 1). The problem of figuring out who pays for new transmission was echoed by Virinder Singh at PacifiCorp. "The world was different in the past," he said,

> because [now] you get a fair amount of competition in the wholesale level. There are a lot of emerging merchant power plants, and when they come up they want equal access to the grid and they don't have to pay that much compared to existing plants. Who pays for the boost in transmission? If you tax only the new guys, then you add a lot of cost for power that could be green, for example, but the old guys are using the grid just as much as the new guys. Those sorts of cost allocation issues are unique now because the utility doesn't own all the plants. If the utility owned all the plants and they wanted to add another plant, it would all be part of the same company and you would deal with it, but now that you have different companies building different plants this cost allocation issue is pretty significant. (Interview 5)

Despite these open-ended questions about cost allocation and jurisdiction conflicts, it is clear that there may not be one final solution to this problem, and indeed different states deal with this problem in different ways.

Several interviewees commented on the unique situation related to transmission in Texas. "Texas is a transmission utopia," said Ziena El-Azizi from Cielo Wind. "The cost of additional transmission," she continued,

> gets spread across the entire reliability council [i.e. ERCOT] and distributes the cost to all of the members, to anyone operating [i.e. regulated and non-regulated entities], so yes, they do have an extremely pro transmission build-out structure. That's good and bad. It's good in that if you are a small developer you can compete with huge utilities that can afford to build transmission. It's bad in the sense that it is very easy to build new transmission . . . there are too many lines in my opinion. (Interview 10)

Arnold Lietner at Platts Energy also commented on this and stated that Texas was unique in that the ISO would help provide service to anyone, making the western part of the state appealing to wind developers because of the coupling of good a good wind resource and fewer barriers associated with transmission. Rick Walker from AEP is quite familiar with the situation in Texas. While he verified that Texas had a unique situation, he still said that it was not without problems. When asked how transmission works in Texas, he said, "its bad [laughs]. Well, on some criteria" (Interview 14). He elaborated that there had been a lot of simultaneous development in west Texas by multiple companies and that the ERCOT ISO was in its early stages of formation. At that time there was little communication between developers and that part of the system got maxed-out. "You can build the wind farm pretty quickly," he said, "if you've been collecting data and make the decision to build, you can put it up in a year, but with transmission, to build big lines, it can take five to seven years, and therein lies the big problem" (Interview 14).

In other parts of the country, transmission remains problematic. In the Midwest, Glenn Cannon at Waverly Light and Power commented that there was "transmission gridlock" and that it was very difficult to move power from one point to another (Interview 4). Also in the Midwest, Greg Jaunich at Navitas echoed that transmission has been a problem for wind development. When asked who was responsible for building transmission in the states where Navitas operates, he answered,

> [w]ell, right now that's a big open question. The utilities have been creating independent system operators which control the transmission jurisdiction, but there are a lot of companies . . . the question is out, part of the problem is [that there] is not a lot of new transmission infrastructure being put in. The point is that no one knows who's going to build it and how they are going to get compensated for building it. (Interview 13)

In California, Greg Rueger at PG&E speculated that some wind developers, like other power producers, might be impacted by transmission constraints because covering the cost of building new transmission would raise the overall cost of the project considerably, making it less feasible (Interview 11). In sum, as Ed DeMeo stated, ". . . transmission will become—in some cases is has already become—the limiting factor for wind deployment because in most cases wind happens to be quite far from the major need for electricity" (Interview 12).

This problem could perhaps be overcome in a number of ways. One way is through better regional planning. The move towards a competitive industry, Doug Larson from the Western Interstate Energy Board commented, "diminished cooperation and there was a void left over, no one even knew what transmission was needed" (Interview 9). In order to counteract this, open communication between utilities and state agencies is essential for the future health of the industry. This solution is macro-institutional and involves setting up networks between actors and bringing in overarching planning organizations such as the Western Interstate Energy Board, FERC, or some other federal transmission agency yet to be created. Another type of solution, however, occurs simply though the daily functioning of companies in this problematic environment. The adaptive capabilities of firms when confronted with such barriers were emphasized in the comments of Zeina El-Azizi and her experiences with Cielo Wind. "In the region where I spend most of my time [i.e. the southwestern U.S.]," she said,

> it [i.e. transmission] is a nightmare. Not only does the cost [vary], but the rules and regulations around every state vary so much that it can be a barrier to entry. It is especially a barrier to entry for small wind energy developers who do not have the legal infrastructure internal to the company like a utility would, to understand the steps involved in both requesting and building out transmission wheeling and new building. (Interview 10)

In order to overcome this barrier, "we outpost a lot of transmission" she said.

> It tends to be extremely expensive . . . [and] it has been a pretty steep learning curve but we are comfortable now that we are at a point where we are just as savvy as a large utility on transmission. It did take us about two years for us to get there and it did cost quite a bit of money. (Interview 10)

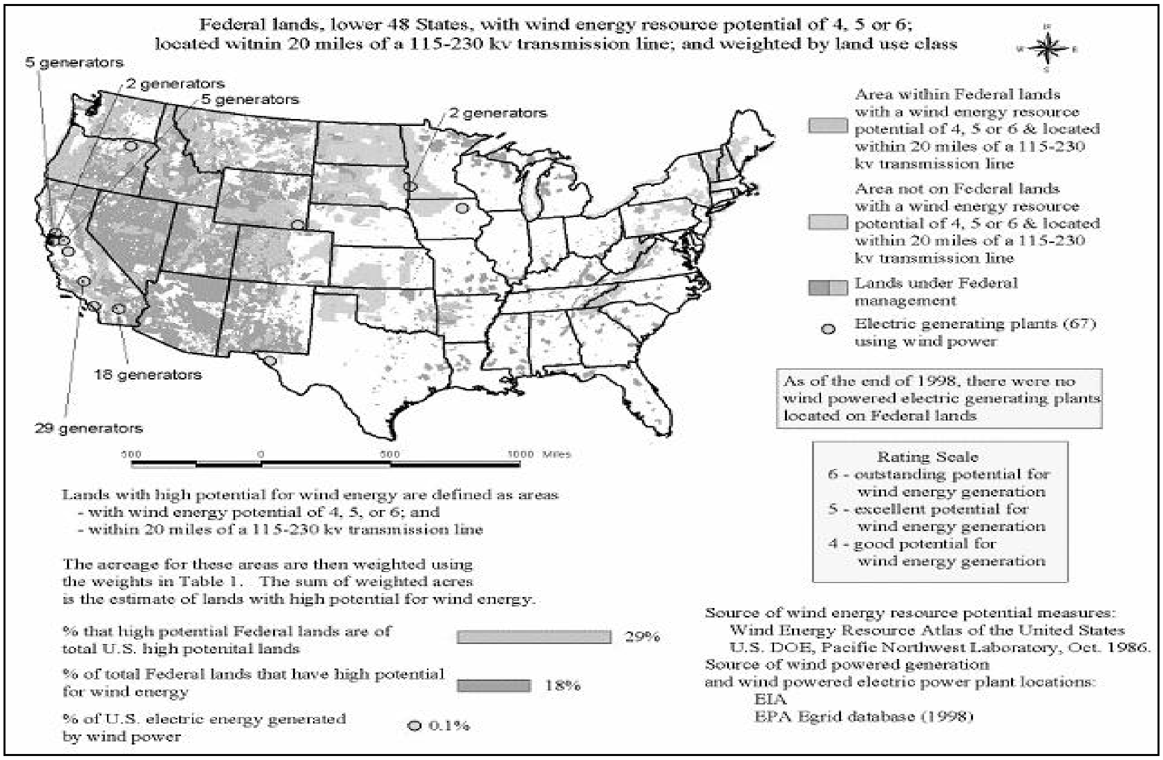
Thus the technical and the systemic barriers confronting wind power developers and electric utilities are not insurmountable. However, their complexity reveals how perceptions of working technology and viable organizational form are still co-evolving. Understanding the nature of these problems in detail and the ways that the actors overcome them is therefore revealing about the feedback between organizations and technology.

Barriers Associated with Permitting and Siting Wind Facilities

The barriers associated with the locations of wind farms also continue to be intimately connected with public perceptions about electricity and about land use more generally. While these issues are important and need to be addressed, there are also other institutional barriers that come into play. Deciding where to locate a wind farm is still not a simple matter. The first criterion is of course the nature of the wind resource. Due to the current tax credit and the nature of the technology, it makes sense to develop sites with the highest wind speeds first. This turns out to be both a blessing and curse. It is a blessing because people usually do not live in windy areas, and this means that public perception of facilities is reduced. But, as the last section discussed, it also means that facilities are further away from existing transmission lines. Furthermore, there is the question about whether or not to use public lands for wind farms or if private lands are more ideal. As it turns out, there are significant institutional barriers that hinder wind development on public lands.

Figure 6 is a map of class 4, 5, or 6 wind resource potentials in the United States in relation to federal lands. Perhaps the most striking piece of data from this map is the

Figure 6: Wind Resource Potential and Federal Lands, Lower 48 United States



Note: This map is publicly available and was accessed on March 24, 2003 from http://www.eia.doe.gov/cneaf/solar.renewables/page/wind/wind.gif.

suggestion that "[a]s of the end of 1998, there were no wind powered electric generating plants located on federal lands" despite the obvious potential for such facilities as indicated on the map. While the current data does not allow a full analysis of the permitting and siting procedures for wind facilities on federal lands, it does offer some insights about why wind facilities are overwhelmingly located on private property.

Doug Larson from the WIEB explicitly commented on this issue. When asked how permitting and siting might present problems for wind farms, he said,

> that has become an increasing problem, they [i.e. wind farms] are currently sort of a novelty item in many areas, but the sitting problem happens on the east coast. The biggest problem with permitting has to do with federal lands. Not because of opposition but because existing federal law requires certain types of resource plans for specific regions. Most existing plans do not have wind resource plans because they were done in the 1970s before wind was a factor. When a developer goes in to get a permit, they find that there are no wind use

> designations and it will take the BLM a number of years to get around to redoing their planning. So this means that people are sort of staying away from federal lands right now. The BLM is trying to rectify this because there seem to be lots of potential on federal lands. There is no economic advantage from going federal, but some of the best resources are mainly located on these lands. (Interview 9)

When asked if federal lands were appealing for developers, Virinder Singh at PacifiCorp answered similarly. "Environmentalists hate the idea of using public lands," he said.

> . . . the BLM is trying to streamline its permitting process. Federal land has been difficult to get permits for because of all the studies they want done, there is no streamlined way of dealing with this. This is one of the things that create those chronic splits in the environmental community. (Interview 5)

This hesitancy cannot be explained by a blanket generalization about reluctance to using public lands for industry, as both logging and mining rely on extensive use of these types of property. Instead, the barriers for wind in this regard are purely institutional and result from outdated rules and regulations. Developers thus have little choice but to use private lands, but doing so opens up an entirely new can of worms in many places having to do with NIMBY attitudes and public opposition.

Public opposition to facilities in the form of NIMBY attitudes is usually overcome by education and time. For example, in commenting on wind farms that AEP has helped develop in Texas, Rick Walker said,

> we have questions from the landowners. Some were reluctant to initially sign the lease, [but then] some people came back and would say that they can see them just down the road and their neighbors are getting paid so go ahead and put some on my land because I can see them anyhow and I would just as soon have the check [laugh]. (Interview 14)

Similarly, when asked about siting and permitting problems with PacifiCorp's operations, Virinder Singh answered,

> [i]t depends on the setting. In the Northwest if you have land that's not used for recreation, if it's not part of a scenic view, and if you have ranchers who can make money off it, you have a much easier time than if you are trying to build something on a ridgeline overlooking a vineyard or something. Conservative communities are more into these types of big projects. So it comes down to ascetics. I think if there is something in it for the neighborhood, the landowner, and you don't have the big aesthetic issue hanging over it, it works out, and you see that in the Midwest and parts of the Northwest. (Interview 5)

This was confirmed by Glenn Cannon at WLP. "We have not had any problems with people complaining about the appearance of the turbines, we have not had any avian issues, the only problem that I have really had has been farmers," he said. When asked to clarify, he answered, "[t]here has been a non-stop stream of farmers coming to us wanting us to put turbines in their land because they can make more on the lease than they can on any crop they can raise" (Interview 4). Even though developers face a sometimes skeptical public and have difficulty siting projects on federal lands, these cultural and legal barriers can be overcome in a variety of ways.

Conclusions: Feedback and Co-evolution

This chapter has used data from actors in different organizational fields to further highlight the interconnectedness of technology and organization. It has shown how many of the barriers currently facing industry participants involve technical and institutional constraints. Wind power as a technology is perceived as extremely problematic for actors in FIELD 1 because of its intermittency. The acceptance of the technology is initially hindered by the normative and cultural expectations imposed by FIELD 1. However, this barrier is overcome when actors in FIELD 2 alter these normative expectations by delivering a product that does not require a substantial change in business practices. As mentioned in Chapter Three, overcoming such barriers is also helped by the fact that many actors in FIELD 2 have come to resemble the firms that actors in FIELD 1 are used to doing business with.

Aside from wind technology specifically, the existing national transmission system is approaching capacity, thereby limiting the extent to which additional power can be added without costly upgrades. This problem is at heart a technical issue: the existing technological frame in which actors from both FIELD 1 and FIELD 2 are embedded is physically limited. But the problem is still also institutional and organizational, as the restructuring of FIELD 1 left a void in terms of who ultimately is responsible for physically building additional transmission, and who is financially responsible for footing the bill. There is little consensus about how to solve this latter problem, and the issue is a highly contested one. On the one hand, the existing transmission system was initially built by vertically integrated electric utilities from FIELD 1 to serve the power plants that they also owned. Legal mandates then required that FIELD 1 actors give FIELD 2 actors access to this transmission system. But as FIELD 1 played less and less of a role in generating electric power, they also became increasingly skeptical about paying for transmission upgrades to someone else's plant. To complicate things further, over the last several decades actors have become increasingly aware of the extent to which different regions of the country are connected via the power grid. But this grid was constructed under the ownership of different organizational actors at different points in history. Unlike the national highway system, there is no central organization charged with transmission planning and upkeep. Again, the extent to which this technical system should be co-opted by a federal oversight agency is hotly debated.

Aside from the transmission issue but also connected to it, several institutional barriers also exist which specifically hinder the development of wind power. Siting and permitting procedures have not adapted to the changing energy landscape as rapidly as some believe they should have, and this pushes wind facilities to locations on private lands instead of federal lands. In many cases, these locations are far from adequate transmission, thus bringing to the fore the issue of who builds the transmission needed to get power from these new facilities to urban customers. In this case, the barriers start as technical; they involve the newness of wind power and an attempt to push it into an outdated institutional system. The barriers continue in this institutional framework, as the federal bureaucracy is slow to update its permitting procedures. Finally, the barriers end with the technical *and* the organizational, as transmission enters the picture.

This chapter further demonstrates the claim that understanding the success of an industry requires an awareness of the ways that technology and organization interact to shape each other and to influence the perceptions of each by actors from different organizational fields. The future success of the wind power industry does not just depend on having a technology that "works" or having an organizational form that is "legitimate." Instead, success depends on the co-evolution of these factors within the context of the shifting framework provided by changing institutional arrangements. Perceptions of stability at one moment in time concerning the technology or organizational form have profound consequences for the direction of future developments.

CONCLUSION

The central goal of this research project has been to explain the formation and success of a new industry in a sector that is historically both risk and innovation averse. In order to address this puzzle, two prominent schools of sociological thought concerning technology and organization were combined, and then insights from each were used to interpret qualitative and quantitative data on this specific case. This approach has been quite fruitful, both for understanding this specific puzzle and for understanding in more general terms the ways that technology and organization interact within institutional contexts. The main finding of this research has been that industry formation and success involves the simultaneous development of technologies that are believed to work, and new organizational arrangements that are perceived to be profitable. It shows that the development and use of windmill technology was not simply the direct result of technical breakthroughs or industry deregulation but was caused by the interaction of these factors with changes in industry organization, resulting in the development of a new "organizational field" in which a particular kind of wind generator makes sense. Finally, this research has shown how the stability of such a technology/field combination may be feeding back into policy decisions and hence pushing future development in a particular direction.

In order to demonstrate this claim, this thesis began with a review of the relevant sociological literature. The Social Construction of Technology and the work of Weibe Bijker provided many useful concepts for understanding technological change. This research posits that the notion of the individual genius working in isolation and inventing machines and artifacts is not an accurate conception of invention. It also posits that resultant designs cannot be understood solely by looking at the problems new arrangements appear to solve or at their physical characteristics. Instead, resultant designs can only be explained by looking at the problems and solutions as perceived by the many different groups that have the potential to influence the final outcome. In this view, technology development is not a linear path of progress moving forward toward more efficient and better technical designs; the very notions of efficiency and what makes a better design are themselves social constructs built up through the repeated interactions of social groups. Yes, Bijker concedes, not all groups have equal access to the resources needed to promote one design over another, but this does not mean that these groups take no part in the processes of shaping technologies. Bijker's theoretical and methodological approach to technological evolution requires identifying boundaries around objects by listening to those involved. The analyst then works within these boundaries to piece together a story about the circumstances under which actors were behaving and the tactics they used to promote and make real their definitions and visions about what the artifact should look like and what functions it should serve.

This theoretical understanding also provided a methodological framework with which to understand a specific technology. Understanding the acceptance of the modern wind turbine and its current design required that the groups associated with its development be identified and that their respective visions and interests be revealed. This was done by carrying out interviews with the participants themselves, and this demonstrated that it is not acceptable to explain the success of the modern wind turbine simply as a function of its efficiency or cost; such an explanation glosses over who defines what efficient means and what factors are included in the cost. The formation of these definitions is not only theoretically and intellectually interesting but is also essential for an accurate answer to be presented. Definitions of efficiency, cost, and the "working" or "not working" of wind turbines are not objective and stable concepts employed similarly by all participants. These definitions change with time and with location within the industry. The SCOT framework was thus quite helpful for starting to identify whose opinion matters and how these opinions were expressed in the resultant physical forms.

But while this framework was helpful in many regards, it was also problematic and incomplete. The case of the wind industry was not easily bound, and all social groups appeared to have some relevance in shaping the technological outcome. Furthermore, simply knowing what the actors think and believe is still only half of the story, as these beliefs and values are themselves constructs influenced by the social positions of the actors in relation to each other and in their relationships to the institutions with which they constantly interact. The SCOT framework does not fully incorporate the complexity of the environment in which actors behave.

New Institutionalism offered several insights in this regard. Normative, cognitive, and cultural influences all played a role in directing the behavior of organizations and influencing the diversity of organizational forms. Understanding why some groups over others were involved in research and development of wind technologies—an essential factor for understanding designs—required that the characteristics of these organizations and their relationships also be examined. Technology evolution is more than just different groups with different views about what needs to be done; instead these groups are situated in complex networks of interactions that are framed both by existing and constantly changing institutions. What makes sense at one point in time in terms of the desires and goals of a specific type of organization can be drastically different at another point in time as the roles of that organization is altered by changes in the institutional landscape. Thus actors directly involved in shaping early wind turbines became indirectly involved as the electricity industry in general underwent restructuring. Not only is the sphere of influence difficult to bound in the first place, but the meanings that certain actors assign to objects change as the industry matures and is affected by other external factors.

Furthermore, the range of potential forces is also quite large, as political, economic, and social facets all play a role in shaping organizational behavior.

These theories were combined to create the framework in which the wind power industry could be best understood. This research has shown how the potential for a wind industry was created by policy that established a new organizational field in which a particular type of technology made sense. At the time of its emergence, however, neither the new nor the old field had a technology that "worked." It was not simply a matter of the new field selecting a technology off the shelf; instead it had to create its technology at the same time it established its place in relation to the older, established field. In the 1980s, nonutility IPPs (FIELD 2) depended on electric utilities (FIELD 1) to buy their product, and this dependence caused them to pursue a particular vision of a wind turbine. Due to their newness and shortage of capital, however, this vision differed substantially from that of actors in FIELD 1. Tax incentives helped this new field secure enough capital to survive and grow, even though this growth was almost entirely propped up by the existence of the tax incentives. Additional changes in policy strengthened the role of FIELD 2 by partially weakening the role of FIELD 1, and FIELD 2 then adopted and gained expertise using a "working" technology imported from an international context. Facing institutional, political, and regulative uncertainty, actors in both fields sought to make sense of their environments and their respective roles.

In 2003, FIELD 1 is no longer completely vertically integrated, and this development is a departure from the historical situation. This development, however, is only partially the result of legal or regulative mandates. Instead, a new organizational field broke into this old field and largely co-opted the task of generating electricity using a specific type of technology. Instead of reverting back to the older model as the regulative environment has changed, actors in FIELD 1 find that it now makes sense to deal with actors in FIELD 2 as suppliers. While this model may not remain the predominant one, it is clear that the success of the wind power industry has involved the co-evolution of technology and organizational form.

As a final note, it is important to point out that the findings presented here are only the tip of the iceberg, both in terms of the wind power industry and in terms of the consequences for the sociologies of technology and organizations, respectively. The wind power industry has itself become increasingly complex as it has matured. For example, even within the wind power industry a significant division of labor has occurred in the last five or six years. Whereas in the 1980s and early 1990s wind power was largely developed, owned, and operated by organizations that often were themselves turbine manufacturers, the newer model increasingly involves separate firms performing each of these tasks. The chain of organizations providing wind power now involves nonutility IPPs who develop wind farms but contract out operations and maintenance to turbine manufacturers and who sell the output to electric utilities, sometimes directly but sometimes indirectly through third party power marketers. In fact, a large part of the current wind power industry involves the buying and selling of renewable energy attributes, called green tags. The current research does not explicitly engage this new market, something that clearly is important for the modern wind power industry and which remains a subject for future research.

This current research is also incomplete in terms of its depth of analysis of the electricity industry more broadly. Increasingly, the line between FIELD 1 and FIELD 2 becomes less and less defined, as many mergers in the late 1990s have brought electric utilities and nonutility IPPs under the same corporate roof a single holding company. This new development is sure to have profound effects for the diffusion of wind power, as the spread of information and conceptions of "legitimate" action is influenced by this new form of corporate control with access to broad political and economic capital. Lastly, this research has been limited in its reliance on interview data with a small number of industry participants. In many ways, this current research has served as a pilot study whose findings should be used to guide the direction of future research toward the engagement of each of the factors revealed here in more detail.

The findings of this current research call for the combination of the sociologies of technology and organizations. SCOT, while important in its insights concerning technological change, would benefit from a more explicit awareness of institutional mechanisms influencing organizational behavior. Similarly, New Institutionalism, while revealing about the populations of organizational fields and the processes of industry creation and development, would benefit from a more explicit awareness of technology as independent from but connected to organizational form. In other words, each theoretical paradigm treats the other as unproblematic and largely stable, something that this current research has shown is not always the case.

APENDIX I – List of Interviews

1. **Dr. Robert Thresher**, Director of the National Wind Technology Center, National Renewable Energy Laboratory. In person interview, Golden Colorado: January 2, 2003.

2. **Dr. Stanley Bull**, Associate Director of Science and Technology, National Renewable Energy Laboratory. In person interview, Golden, Colorado: January 2, 2003.

3. **Dr. Gerald Jacobs**, Environmental Consultant. Telephone interview, November 3, 2002.

4. **Glenn Cannon**, General Manager of Waverly Light and Power. Telephone interview, January 17, 2003.

5. **Virinder Singh**, PacifiCorp. In person interview, Portland, Oregon: January 31, 2003.

6. **Dr. Adam Serchuk**, Serchuk Associates. Telephone interview, January 31, 2003.

7. **Arnold Leitner**, Senior Consultant, Platts Energy. In person interview, Boulder, Colorado: January 3, 2003.

8. **Chuck McGowin**, Manager of Wind Power, Electric Power Research Institute. Telephone interview, January 22, 2003.

9. **Doug Larson**, Executive Director, Western Interstate Energy Board. In person interview, Denver, Colorado: December 23, 2003.

10. **Zeina El-Azizi**, Development Manager, Cielo Wind. Telephone interview, February 11, 2003.

11. **Greg Rueger**, Vice President of Generation, Pacific Gas & Electric Company. Telephone interview, February 24, 2003.

12. **Ed DeMeo**, Former Manager of Wind Power Integration, Electric Power Research Institute. Telephone interview, February 28, 2003.

13. **Greg Jaunich**, President and CEO, Navitas Energy. Telephone interview, March 7, 2003.

14. **Rick Walker**, Director of Renewable Energy Business Development, American Electric Power. Telephone interview, March 10, 2003.

15. **Roby Roberts**, Manager of Renewable Business Development, PPM Energy. In person interview, Portland, Oregon: March 20, 2003.

16. **Steve Bohlman**, Managing Director of Marketing, Alliant Energy. Telephone Interview, March 28, 2003.

17. **Lon Peters**, President, Northwest Economic Research. In person interview, Portland, Oregon: April 9, 2003.

18. **Jennifer Sirek-Love**, PPM Energy. In person interview, Portland, Oregon: October 9, 2002.

19. **Kevin O'Meara**, Senior Energy Economist, Northwest Public Power Council. In person interview, Portland, Oregon: October 10, 2002.

APENDIX II – Recruitment and Follow-up Letters

APENDIX III – Abbreviations and Acronyms

AEP .... American Electric Power
AWEA .... American Wind Energy Association
BLM .... Bureau of Land Management
CO_2 .... Carbon Dioxide
CSW .... Central and Southwest
DOE .... Department of Energy
EIA .... Energy Information Administration
EPA .... Environmental Protection Agency
EPACT .... Energy Policy Act of 1992
EPRI .... Electric Power Research Institute
ERCOT .... Electric Reliability Council of Texas
FERC .... Federal Energy Regulatory Commission
FPC .... Federal Power Commission
FPL .... Florida Power and Light
FWEP .... Federal Wind Energy Program
IOU .... Investor Owned Utility
IPP .... Independent Power Producer
IRP .... Integrated Resource Plan
ISO .... Independent System Operator
KWH .... Kilowatt per Hour
MIRP .... Minnesota Innovation Research Program
MW .... Megawatt
NAE .... Northern Alternative Energy
NASA .... National Aeronautics and Space Administration
NIMBY .... "Not In My Backyard"
NREL .... National Renewable Energy Laboratory
O&M .... Operations and Maintenance
PG&E .... Pacific Gas & Electric Company
PGE .... Portland General Electric Company
PSC .... Public Service Company of Colorado
PTC .... Production Tax Credit
PUC .... Public Utility Commission
PURPA .... Public Utilities Regulatory Policy Act of 1978
PV .... Photovoltaic
QF .... Qualifying Facility
R&D .... Research and Development
REA .... Rural Electrification Administration
REPIS .... Renewable Electric Plant Information System
RFP .... Request for Power
RPM .... Revolutions Per Minute

RPS .... Renewable Portfolio Standard
RSG.. Relevant Social Group
RTO.. Regional Transmission Organization
SCOT .... Social Construction of Technology
SEC .... Securities and Exchange Commission
SERI .... Solar Electric Research Institute
SMD... Standard Market Design
WEIB.. Western Interstate Energy Board
WESA .... Wind Energy Systems Act of 1980
WLP .... Waverly Light and Power

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