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Collaboration to Facilitate Research and Education in a Transitioning Electric Power Industry

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Abstract

The electric supply industry is in transition from its traditional objectives, structure, ownership, operating practices, planning processes, and customer services. The transition may be characterized as "end-less" without a well-defined end-point. From this perspective, thinking about the challenges of transition should not only focus on "solutions", but also on means and processes for finding the solutions. Research and education can make significant contributions if they are considered as much a part of the electric supply industry infrastructure as poles and wires. By putting greater reliance on collaborative research programs involving the "triple helix" of industry, universities and government, synergies can be captured from multi-institution, multi-discipline collaboration for clarification of research needs and developing research plans to address them. But collaboration requires attendance to interpersonal dynamics as well as other principles of effective collaboration. In this paper, we give examples of structures of collaborative research programs and offer some principles of effective collaboration. An extended case study is used to illustrate ways in which the principles of collaboration can be applied. The paper concludes with comments about possible issues facing developing countries in using collaborative research.

1 Introduction

The electric supply industry is in transition from its traditional objectives, structure, ownership, operating practices, planning processes, and types of customer services. Yet the basic function of the industry – to produce and to deliver affordable energy safely and reliably consistent with public policy – has not changed. Challenges abound for meeting that basic function successfully. In general, those challenges arise from decisions that must be made about new market structures and ways of doing business, new technologies, meeting demands of customers for customized services, strategic choices between centralized and decentralized technologies, institutional changes, preparing well-trained power engineers, new environmental priorities, and country-specific needs (such as for modernization, financing and social concerns). Issue scope and complexity along with uncertainty about solutions and their distributional effects call for study, creative thinking, and discussion, in some cases over an extended period of time.

Historically, the electric-power system has been vertically integrated with one or more utilities assuming the responsibility for power supply from generation to load. The system has been configured to deliver electric energy produced by a mix of generation to the various loads by means of complex interconnected transmission and distribution systems. Power systems are generally inflexible with respect to accommodating rapid changes in load, generation, and/or delivery conditions, or even rapidly changing economic, environmental, or regulatory policy changes. While present-day system operations may have been designed for "least cost supply of electricity" based on the slowly changing environment of the past, it is just beginning to reconfigure so as to adapt to growing demand and introduction of new technologies (particularly information technologies). Power systems in transition need managed re-designs. The alternative is to accept unmanaged change and to operate the system in ways that were not anticipated by the original designers.

Thinking about these challenges should not only focus on "solutions," but also on means and processes for finding the solutions. The power industry may be more reasonably characterized as being in a period of "endless transition" without a well-defined end-point [1]. In this transition, research and education should be considered as much a part of the electric supply industry infrastructure as poles and wires. New research program structures are needed to facilitate multi-disciplinary research required in the new power industry environment. Furthermore, industry, government and universities each have unique contributions that they can make in finding solutions to the challenges facing the electricity sector. Collaboration is key. It can be used to inform decision-making, broaden perspectives, and create and transfer knowledge. However, collaboration is not easy for institutions (and the people in them) that may not have collaborated before. An understanding of collaboration principles and organizational mechanisms is needed to increase the likelihood of success.

In this paper we discusses trends in collaborative research, give examples of structures of collaborative research programs, and offer a few principles of effective collaboration. An extended example of a collaboration is used to illustrate one collaborative center's structure and ways in which the principles of collaboration are applied. The paper concludes with comments about possible issues facing some developing countries in using collaborative research.

2 Collaboration in Research

Historically, departmentalization of research has occurred either by type (that is, basic, applied, etc.), by discipline (such as engineering, economics and public policy) or by research organization (principally university, government, public research laboratories, and industry). A transition is occurring in research. Science and technology Etzkowitz [1] identifies three "boundary breaking" characteristics of transition in science and technology research:

- No strict boundaries between basic research, applied research and product development.
- Interdisciplinary collaboration ending the strong boundaries between disciplines.
- New institutional configurations comprised of university, industry and government members.

Increasingly, research programs are turning to collaborative models for achieving research objectives. For example, in its new roadmap for accelerating medical discovery to improve health, the U.S. National Institute of Health, one of the largest research organizations in the world, announced that it will establish a "Liaison for Public-Private Partnerships" to expand collaboration among researchers in academia, government and the private sector [2]. In support of the restructuring, Dr. Michael Friedman notes the “NIH is betting that, in the near future, the focus of the scientific process will move from encouraging individual scientist interests to ensuring the success of more collaborative research enterprises. Think ensemble rather than soloists” [3].

Reasons for the growth of collaboration in research programs are varied. The ‘triple helix’ thesis is that the relationship among the three institutional spheres of university, industry and government is central to innovation [1]. Other reasons for supporting collaboration in research include:

- addressing research questions that are increasingly multidisciplinary in nature
- grounding researchers in research needs of industry and government
- convincing industry of the value of research with long-term benefits
- capturing the synergies among universities, industry and government
- leveraging government research funds with private sources
- reducing the time for commercialization of new ideas
- reducing inequalities for less research-intensive regions.

The extent to which any particular collaborative effort achieves one or more of these benefits depends upon the structure and mission of the effort. Some collaborations are established with the purpose of meeting a specific research need without necessarily any enduring change in the way research is done. Some triple helix programs of the Natural Sciences and Engineering Research Council in Canada are examples. Other collaborative research programs are established with an explicit mission of creating enduring change, such as the European Networks of Excellence program and the U.S. National Science Foundations Industry/University Cooperative Research Center’s Program. The appendix provides short descriptions of these collaborative programs. Besides the characteristic just described, these selected programs illustrate the following defining characteristics of collaborative programs:

- mission (research, education, commercialization, etc.)
- lead organization (such as university, private non-profit [14], etc.)
- specificity of research direction (self-directed, targeted to meet governmental priority, etc.)
- role of government (creating and supporting the collaborative, co-managing the collaborative, participant in the research, etc.)
- level and duration of government support
- extent to which industry co-funding is expected.

3 Achieving Collaboration

Achieving collaboration is not an easy task because of the changes collaboration requires in normal research behavior and processes. True collaboration is not simply separate researchers working in isolation on their portion of a larger research effort, even if multiple researchers and organizations are involved. True collaboration requires engagement among participants through joint decision-making, communications of research needs and questions, problem solving, planning, strategizing, etc. Fundamentally, collaboration requires relatively more attention to program management and to the social interactions of the participants than in the past. This section identifies some principles in achieving effective collaboration.

3.1 Building Trust to Achieve Success in Collaboration

Government can act as a catalyst to create an environment where two institutions (industry and academe) that operate on/with very different metrics can come together and develop a track record of working together successfully − and thus develop the trust that is foundational to true collaboration. This happens when the collaborative structure makes behavior more predictable across and within institutional boundaries, and minimizes the possibility that the "worst fears" of each institution about the other will be realized. For example, industry may fear that academics will pursue research that does not address its most pressing needs. On the other hand, academics may fear that fundamental research with long-term benefits will not be supported and that innovation will be stifled by a micro-managed research work plan. The “worst fears” are going to be situation specific.

Trust in group working relationships is typically observed to develop through a three-phase sequence [4][5]. When a group is first brought together, DETERRENCE tends to be the basis for trust; that is, people "trust" that their co-workers will act appropriately mainly because there is an authority figure who has called them together, structures interaction, and controls sanctions that will be brought to bear if people do not live up to responsibilities. As people work together under this framework, they begin to learn about each other − their capabilities, track record, responsiveness, etc.

Assuming that the work goes well and that the participants really do bring to the party good information that contributes to group success, the group transitions to KNOWLEDGE-based trust. Obviously this is a more profound level of trust, based on our understanding of the others' abilities and actual contributions.

With time and with obvious recorded success that brings value to each of the participants (that is, each party begins to truly get important needs satisfied through the working relationship), the group transitions to the most profound level of trust − that based on IDENTITY. Participants in the relationship begin to strongly identify with the group; to internalize and promulgate its values; to make sacrifices to assure its continued success, and thus, defining themselves in part through their membership in the group.

The structure for the collaboration needs to create the possibility for this developmental sequence to occur. Indeed, the "success" of the collaboration (probably defined in terms of mutually met needs) will be a function of how far it has transitioned along the trust continuum. The structure must channel behavior of each of the institutional members to make that behavior predictable and understandable to the other side of the partnership.

3.2 Other Keys to Successful Collaboration

The capacity for true collaboration is tied to the existence of trust between the participants. What else influences collaboration? Insights can be found in the literature on conflict negotiation, particularly win-win/collaborative/mutual gains conflict resolution described by Fisher and Ury [7]. Fisher and Ury define four principles that are essential to collaborative conflict resolution:

- INTERESTS - focus on interests (needs, desires, concerns, fears), not positions
- OPTIONS - invent/generate lots of options for mutual gain to address the problem that divides the conflict participants
- CRITERIA - insist on using objective criteria to evaluate potential solutions (that is, work together first to develop the criteria that you will use to evaluate potential solutions to the problem)
- PEOPLE - separate the people from the problem (recognizing that when negotiating, people issues related to our humanity, such as emotions, perceptual accuracy, and communication tendencies, become intertwined with the substance of the negotiation, and should be dealt with as they become evident, so they do not interfere/distort the capacity to search for a solution tied to interests).

These conflict resolution principles suggest that, for collaboration to occur, there needs to be:

- a mechanism for participants to surface their interests (which undergird any "positions" they may have) and to search for intersections of interests that may be the basis for working together
- an opportunity for generating lots of options for how they might work together
- explicit standards to judge whether the relationship is working
- a mechanism for addressing the inevitable "people" issues which will arise when vastly different folks are coming together to accomplish something.

Evaluation of collaborative programs also suggests that attention needs to be paid to objectives and the structure of the relationships among the parties to achieve effective collaboration [8]. Collaboration will be more effective if people understand the merits and incentives for collaboration, and then have the opportunity to structure their relationships in the research organization accordingly. Simply imposing the requirement that multiple institutions be a part of the collaborative program or project does not insure that true collaboration will occur, nor that there will be a fundamental change in the way research is done.

Collaboration among university researchers is not “natural” to the academic world. Generally speaking, there is little reward for working with others in academic research. Indeed, there is almost a disincentive to do this if one hopes to get tenure. There is clearly no cultural value that reinforces collaboration. Thus, when presented with an opportunity to do collaborative work, most senior academics say they will do so if they really want to be funded to do the work. However, being very busy and stretched, they take the easy (and less time consuming) way out – they apportion the work following a division of labor and only really communicate with each other when it is time to prepare the final report. This behavior reflects the lack of profound cultural belief in and commitment to collaboration. Only when there are clearly defined and enforced procedures and structures for collaboration, does true collaboration occur.

It has been observed that "One of us is not as smart as all of us." It is doubtful that many in academia would present this as one of the driving principles for how they do their work, despite the fact that we often say that every scientist stands on the shoulders of preceding scientists. Academia seems to be collaborative far more in a cumulative, historical sense, than in terms of co-working relationships that add value in a real time way.

Collaboration of university researchers working together with people from industry and government also has disincentives. Because of each party's stereotypical beliefs about the other, the parties often come together rather superficially. Academics want the financial support and possibly access to data. Industry and government want operating problems solved, or intelligence that will provide competitive advantage or will help resolve policy issues in a way that wins public support. Perhaps the best way to overcome these disincentives to true collaboration is to select problems that really do require the expertise (as in knowledge, skill and experience) of both parties to solve the problem. This would require taking a larger problem and break it down into smaller problems. Thus, government can facilitate the identification of smaller problems that truly require the intellectual resources of all three institutional domains in the triple helix and then create environments where planning can occur to evaluate and overcome those problems.

4 Example of a Collaborative Research Effort: Power Systems Engineering Research Center (PSERC)

The Power Systems Engineering Research Center (PSERC) draws on university capabilities to creatively address the challenges facing a power industry in transition. In PSERC, twelve U.S. universities are working collaboratively with industry to:

- engage in forward-thinking about future scenarios for the industry and the challenges that might arise from them
- conduct research for innovative solutions to these challenges using multidisciplinary research expertise in a unique multi-campus work environment
- facilitate interchange of ideas and collaboration among academia, industry and government on critical industry issues
- educate the next generation of power industry engineers.

PSERC provides:

- efficient access to experienced university researchers in an array of relevant disciplines and geographically located across the U.S.
- leading-edge research in cost-effective projects jointly developed by industry leaders and university experts
- high quality education of future power engineers.

The multidisciplinary expertise of PSERC's researchers includes power systems, applied mathematics, complex systems, computing, control theory, power electronics, operations research, non-linear systems, economics, industrial organization and public policy. There are currently about thirty-five researchers working with about the same number of graduate students on PSERC research projects.

4.1 Industry/University Cooperative Research Center Program

PSERC is one of the centers in the National Science Foundation's (NSF) Industry/University Cooperative Research Centers (I/UCRC) Program. NSF's I/UCRC program promotes "win-win" partnerships that strengthen the ability of universities to conduct high quality and relevant research, and the ability of industry members to meet their business objectives effectively [9]. As noted in the appendix, the I/UCRC program strives to achieve long-term partnerships among industry, universities and government (that is, the triple helix). Some fifty other centers in the I/UCRC program focus on a wide array of competitive industries. PSERC is the only center in power systems. It is also the largest multi-university Center.

PSERC first joined the program in 1996. Dr. Alex Schwarzkopf, Program Director of the I/UCRC program, states that "Industry-University collaboration is at the heart of the I/UCRC program. PSERC's commitment to collaboration using many universities as the research base is essential to meeting the wide-ranging challenges facing the electric power industry" [10].

4.2 PSERC as a Multi-University Center

PSERC is organized as a multi-university center for several reasons. First, there is insufficient expertise at any one school to address comprehensively the challenges of the new electric power industry. Restructuring requires the marriage of economics and engineering, thus calling for more multi-disciplinary work than ever before in the industry. And no single school can afford the breadth of expertise because of limited resources. Another reason why multi-university appealing is that industry itself is geographically dispersed yet business and policy issues are increasingly interlinked across the industry, such as in designing regional markets while maintaining system reliability.

4.3 Industrial Members

As an Industry/University Cooperative Research Center, PSERC receives more support from its industry members than from NSF. Members join PSERC by signing a membership agreement and by paying an annual membership fee. PSERC has almost forty members that include energy companies, government agencies, companies providing consulting and other technical support services, and associations. Recent new members include new organizations to the industry: independent system operators, regional transmission organizations and for-profit transmission companies. There are also international members. PSERC provides its industrial members:

- opportunities for collaboration with leading researchers in power engineering and markets
- results of innovative research and early access to research publications
- means for sustaining high quality power engineering programs in a time when the industry and professoriate are graying [10]
- contacts with students about job opportunities
- business opportunities for commercialization of intellectual property
- education and professional development opportunities such as through workshops, short courses and on-line seminars.

4.4 Organizational Structure

There are three central components to PSERC's organizational structure: Center Management comprised of the Director, Executive Director and Executive Committee; an Industrial Advisory Board of PSERC's industrial members; and Stem Committees. Figure 1 provides an overview of the structure.

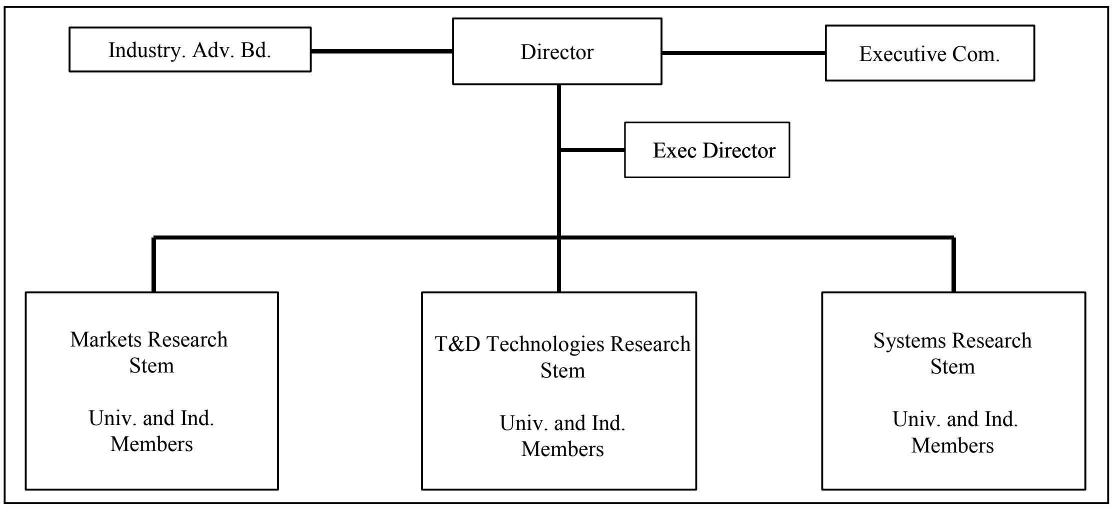

Figure 1. PSERC's Organizational Structure

4.4.1 <u>Center Management</u>

The Director is responsible for overseeing all affairs of PSERC. A primary function of the Director is to represent the Center before its industrial members and the electric energy industry as a whole. The Director is also responsible for the creation of a collaborative infrastructure, recruiting and supervising Center staff at the lead university, and ensuring smooth operation of the Center. The Director also coordinates the assessment of the Center's quality through feedback from industry members, working with PSERC's management facilitators (officially known as "NSF Evaluators"). The facilitators are experts on organizational effectiveness and help the Center develop its management and strategic planning processes. Finally, the Executive Director assists the Director in industry relations and Center management.

The Site Directors are PSERC's local campus representatives serving as the spokespersons to university faculty, staff and administration. The Director and Site Directors comprise PSERC's Executive Committee (EC). The EC works with the Director and IAB to provide guidance on strategy, policies and procedures for PSERC, to ensure compliance with established policies and procedures, and to maintain efficient operations at the university level. The EC is chaired by PSERC's Director.

4.4.2 Industrial Advisory Board

An Industrial Advisory Board provides the critical linkage between the industrial members and PSERC. The Board:

- works with the universities to identify research and education needs
- prioritizes projects and recommends project funding levels
- reviews research results
- addresses policy matters brought to it by PSERC's Director and Executive Committee.

The Industrial Advisory Board meets twice annually. At the meetings, industrial members meet researchers and students from the member universities, hear progress reports on research projects, conduct PSERC business, engage in current issue discussions with researchers and other industrial members, and advance their professional development through tutorials.

4.4.3 Stem Committees

The three stem committees contribute substantially to the collaboration in PSERC. Industrial members join university researchers on the stem committees to:

- conduct technical oversight of on-going research projects
- solicit and process new project proposals
- update the PSERC research plan
- facilitate research collaboration within PSERC
- promote Stem plans, activities and research to entities outside PSERC.

Stem committees have primary responsibility for gathering industry and university perspectives on research needs, and assisting the Director in developing a portfolio of research projects to take to the Industrial Advisory Board for review and recommendation. This is a collaborative process involving a summer retreat where industry and university stem committee members meet to discuss needs and update the research plan, and then develop a solicitation for new projects. Subsequently, industry members evaluate and prioritize the proposals for subsequent action by the Director, Executive Committee and Industrial Advisory Board.

4.5 Education Program

Education is a most important dimension of PSERC. One of the key arguments for the value of PSERC lies in its power engineering degree programs. As noted above, critical personnel issues are facing the industry and the continuation of strong power engineering programs is essential to addressing future employment needs [10]. By taking innovative research findings to the classroom and involving students in research, PSERC faculty introduce students to the cutting edge of power system technologies, analytical techniques and industry practices. Not only does PSERC help students become technically prepared for their next job, it also assures that they will be knowledgeable about the challenges and trends transforming the industry. PSERC also facilitates efficient employment searches through industry-student interactions at industry meetings, student involvement in PSERC projects, web site postings, and email announcements.

University and industry members recognize that support of PSERC's research program is intertwined with support of its educational mission. Student education is enhanced through student participation in PSERC projects, through improved awareness of industry issues due PSERC activities, and through the expanded industry knowledge that PSERC faculty bring to their classrooms as a result of the industry-university relationships that PSERC fosters.

PSERC's education program also includes professional development. Through short courses, monthly tele-seminars, and on-site seminars, PSERC meets continuing education needs of engineers from its industrial members. The PSERC website has tutorials, analysis tools and narrated slide seminars along with papers, reports and presentations by PSERC researchers.

4.6 Research Program

Industry restructuring and technology change is creating new challenges for the operations, security and reliability of the power system, for the physical and institutional structures, and for delivery of economical and environmentally acceptable electricity services. PSERC's research driven by those challenges is a major initial reason why industry members join (although as they continue membership, PSERC's ability to facilitate networking, to advance understanding of future industry issues, and to link industry with students become of high value, too).

4.6.1 Markets Research Stem

The electric power industry is in transition toward greater reliance on market-based decision-making. The research under this stem emphasizes the design and analysis of market mechanisms, computational tools and institutions that facilitate efficient coordination, investment, and operations while recognizing the economic and technical characteristics of power systems. Market design research includes verification in advance of design implementation, and validation after implementation to provide feedback for market redesign when needed.

4.6.2 Transmission and Distribution Technologies Research Stem

The power delivery infrastructure is critical to achieving efficiency, safety, security and reliability in electricity supply. Potential improvements in this infrastructure could be achieved through innovations in software, hardware, materials, sensors, communications and operating strategies. Therefore, a central goal of this research stem is the improvement of transmission and distribution systems through the application of technological advances.

4.6.3 Stem 3: Systems

Restructuring is leading to large and complex operational entities (such as independent system operators or regional transmission organizations), while small-scale, dispersed generation technologies are increasing their penetration in the market-place. The challenge is to develop new operations frameworks and approaches that effectively cope with the growing complexity of a restructured industry. Systems research concentrates on all aspects of operation of complex, dynamic systems.

4.6.4 Leveraged Research Projects

In PSERC, support from industrial members and NSF is leveraged into other research initiatives. PSERC has provided a one-stop shop for organizations outside of universities to quickly access university resources and has made it easier for PSERC researchers to form teams to respond to research opportunities. For example, PSERC played a key role in helping form the Consortium for Electric Reliability Technology Solutions (CERTS), in 1998 to research, develop and commercialize new methods, tools and technologies to protect and enhance the reliability of the U.S. electric power system [13]. The leveraged projects in PSERC have added some 30 percent to its overall funding.

4.7 Successes in PSERC

Besides its success in forming a collaborative organizational, PSERC has identified the following as particular successes:

- Power System Visualization Tools. This technology advance integrated new visualization techniques with power system modeling methods to create for the user visual insights into the condition of power systems. A business spin-off is commercializing the tools.
- Market Design Testing. PSERC has successfully introduced the institutional concept of testing power market designs and policies to verify and validate that anticipated market outcomes would be consistent with policy objectives. Results are informing public and business policy-making.
- Power System Reliability Expertise. Through involvement in national studies and investigations on power system reliability concerns, PSERC has brought university expertise to addressing significant problems in the U.S. power grid.

5 Embodying Collaboration Principles in PSERC's Structure and Practices

This section selects elements of PSERC's structure and practices that illustrate how the collaboration principles identified in section 2 are put into practice.

5.1 Movement along the Trust Continuum

As discussed in section 2, DETERRENCE tends to be the initial basis for trust. In PSERC, the authority figure who called the organization together, structured interaction and controlled sanctions (through control of annual university grants) was NSF. The structure of the organization was founded on university and industry memorandums of agreement (that included intellectual property understandings) following NSF guidelines. Many practices were governed by NSF requirements, such as the requirement to have industry provide project feedback to the university researchers using specified feedback forms.

A structural requirement that also advanced KNOWLEDGE-based trust was the requirement that PSERC (and other I/UCRC's) have "NSF Evaluators." Evaluators survey industry sponsors to ascertain how well their expectations are being met, listen to concerns of industry and university members, and assess the successfulness of the center in meeting its mission while complying with NSF requirements. However, in PSERC, these individuals also serve as organizational consultants and facilitators, bringing the organizational and collaboration expertise that the researchers who provide the center management do not have. The Evaluators provide a mechanism for delicate interests among and university members to surface, for the "translation" of values across institutional boundaries, for mutual understanding of the separate "languages" of industry and universities, and for the "people" issues to be raised and addressed (both within institutional groups and across boundaries between the groups).

Movement along the trust continuum to KNOWLEDGE-based trust is also facilitated by regular orientation programs for industry members. This orientation allows the efficient transmission of the Center's values and operating practices to new members, and helps them to better understand how those values and practices protect institutional interests. Trust is not just among "institutions." More basically trust is among people. Therefore, the orientation sessions provide a way to communicate the culture as well as the policies and procedures of the Center.

To put it simply, institutions do not collaborate. People who represent those institutions collaborate. Thus, the model for institutional collaboration must address fundamental human interpersonal dynamics. The I/UCRC protocol and PSERC's implementation of that protocol consider those dynamics in addition to the process mechanics of a research institution.

Movement along the trust continuum is also facilitated by an organizational structure in which industry and university share decision-making roles. The stem committees require regular interactions among industry and university by having them jointly participate in discussions of research plans, technical issues associated with on-going research, and dissemination of research. At an annual retreat, industry and university participants meet to communicate research needs and explore ways of meeting those needs, leading to the next project solicitation.

5.2 Implementation of Other Principles

The institution needs to integrate collaboration throughout its organizational practices. In a research organization, collaboration in the research projects is fundamental. If researchers can avoid collaborating in their most valued activity, collaboration will not blossom in the organization. In PSERC, every project requires at least two university and two industry collaborators, and at each industry-university meeting, the project leader dialogues with industry members on the progress of the project. In addition, many advisors on projects also serve on stem committees, thus enabling participants to see the "bigger picture" of PSERC's research program and participate in research planning affecting multiple projects.

The following examples briefly illustrate how the other collaboration principles are addressed:

- mechanism for surfacing interests: annual research retreat and regular stem committee meetings
- opportunity for idea generation: annual research retreat, semi-annual industry-university meetings, stem committee meetings, project team collaboration
- standards to judge whether the relationship is working: industry surveys, stem committee discussions, protocols described in an operations manual for all to use
- mechanism for addressing people issues: Evaluator/facilitator interactions with industry, management structure that incorporates representatives from every industry and university member to make the Center a representative institution through which people issues can be addressed.

5.3 Role of Government

The governmental role in the triple helix affects the quality and sustainability of collaboration. In the I/UCRC program, NSF (as the governmental body) does not come to a center as an institution focused on the research products. Instead, it comes as a catalyst for making the other two institutions (industry and universities) interact effectively. For example, the fact that the

I/UCRC program is located in the U.S. National Science Foundation is an important factor in enticing the best universities to participate. NSF is seen by most U.S. scientists and engineers as the elite funding organization for U.S. research. There is great prestige in being funded by NSF and to have the imprimatur of NSF clearly advances one's career. Thus, even eminent researchers are attracted to work on more applied problems and to take on the burden of collaborative working relationships largely because they see value in NSF sponsorship.

On the other hand, industry may be attracted to these NSF-sponsored collaborations because NSF dollars largely fund the infrastructure to create the collaboration. Industry participants can have confidence that their scarce membership dollars go directly to the research efforts of the center, and are not asked to pay for what they would see as non-value-adding activity. This is a quite comforting for industry when there is the scarcity of resources typically found in an industry environment dominated by powerful competitive pressures forcing costs lower.

Relatedly, NSF requires that the universities contribute financially by reducing (or eliminating) the normal university overhead on industry member fees. This, too, is a structural requirement that facilitates collaboration. Universities can correctly go to industry and say that they also have a financial stake in the collaborative organization. They are not merely recipients of industry support, thus making the relationship between industry and universities one of cooperation rather than of a client and consultant.

6 Potential Challenges in Extending Collaborative Models to Developing Countries

There are numerous country-specific issues that may need to be addressed to achieve success in a collaborative research program that follows the triple helix thesis. One issue results when a developing country has a vertically-integrated, publicly-owned electricity sector. In this case, the role of government as a facilitator of a collaborative enterprise can overlap with the need for government to be a recipient of the research products. In this case, government may have difficulty in simply being a catalyst for the collaboration. Also, in such a case, the potential number of collaborating organizations that could add diversity and, thus, value to a collaborative enterprise is reduced.

Forming a new collaborative research program typically requires institutions to alter their historical relationship. Historically, government and industry interactions with universities often may appear as “client-consultant” relationships, wrapped in the administrative process of requests for proposals, etc. A collaborative relationship based on trust (rather than contracts) will cause new forms of interaction that will be “process-oriented” rather than “product-oriented.” This change may be more challenging in some developing countries where the historical relationship between government and universities has a particularly long history.

Finally, there is the resource challenge. Financial resources for research and education naturally compete with financial resources for infrastructure investment. Developing countries have to respond to rising electricity demands on their infrastructure for their economies to grow. Viewing research and education improvements (achieved through collaboration) as critical infrastructure may advance the incentive for collaboration. Ways of achieving an appropriate balance between meeting physical infrastructure needs with research and education needs will have to be addressed. The “triple helix” collaborative model may also be a way to generate new funds for the research and education needed for the long-term health of the electricity sector.

Appendix: Brief Summaries of Selected Collaborative Models (synopses of excerpts from the given references)

1 European Networks of Excellence [4]

The European Networks of Excellence is a collaborative effort focused on building research capability more so than achieving a specific research product. The Networks of Excellence are designed to create an enduring integration of needed resources and expertise among Member States while advancing knowledge on a subject within the thematic areas of the Sixth Framework Program of the European Commission. Networks of excellence are viewed as an instrument to overcome fragmentation of European research to achieve European leadership and act as a world force on the research topic. Each network's mission is to spread scientific and technological excellence beyond the boundary of its partnership. Networks of excellence must involve at least three legal entities from three different Member States or Associated States, of which at least two should be from Member States or Associated Candidate Countries. Participants may be research entities in industry and universities, and other organizations that are users of the research if they can contribute to the network's goals. There are no restrictions on the number of participants (and researchers) and volume of resources to be integrated as long as the number is compatible with a) the overall objective of a meaningful long-term integration of the research capacities of the participants and b) the manageability of the whole endeavor. The European Community will support a new network for up to five years (and perhaps as many as seven years) with annual payments dependent not on the research products, but on the success in achieving the desired integration. However, the Community does not support a network 100 percent since the networks need demonstrate durability to get funded and since the Community funds are to target barriers to changes required to achieve durable networks. The main factors that will need to be examined by those assessing the quality of the integration in a network will include the following:

- the extent of mutual specialization and mutual complementarity, particularly through the regular co-programming of the partners' activities, through the building up of strengths and the shrinking of weaknesses, and perhaps through the relocation of resources
- the sharing and development for common use of research infrastructures, equipment, tools and platforms
- the regular joint execution of research projects
- interactive working between the partners using electronic communication systems
- the joint management of the knowledge portfolio
- joint program of training for researchers and other key staff
- a coherent management framework that encourages staff mobility, staff exchanges, the interoperability of data and other systems, common approaches to science and society issues and gender equality in research.

2 Canadian Energy Research Institute (CERI) [14]

CERI is an independent, non-profit research institute that focuses on analysis of energy economics and related environmental policy issues in the producing, transportation and consuming sectors. Its mission is to provide relevant, independent, objective economic research and education in energy and environmental issues to benefit business, government, academia and the public. A central goal is to build bridges between scholarship and policy, bringing the insights of scientific research, economic analysis, and practical experience to the attention of government policy-makers, business sector decision-makers, the media, and citizens in Canada and abroad. CERI staff members are assisted in these endeavors by independent research forums comprised of recognized experts in the fields of oil, gas, coal, electricity and alternate fuels. Its studies and reports assist Canadian companies, governments, consumers and scholars. The research program addresses the impacts of policy, technological, and economic changes on Canada in general and on Canada's international competitiveness. It also encourages awareness of energy issues by providing forums for discussion and debate.

As part of its strategy, CERI establishes networks for the exchange of information, technology and expertise among and between companies, government departments and agencies, the University of Calgary, and other Universities and organizations, and a forum for discussion among Canadian business, government and university leaders. CERI encourages and facilitates industry/government dialogue on energy matters. Collaboration is fostered as government and industry representatives determine and direct studies of interest to both the public and private sectors. CERI invites interested organizations to participate as a Sponsor to jointly fund studies and involve their staff with CERI economists on a project-specific basis through participation on advisory committees. Such advisory committees provide expert advice on the content of research reports. CERI's Private Sector Sponsors contribute about two-thirds of the Institute's core funding with the rest coming from the public sector.

The Institute's principal mandate is to conduct studies to assist industry and government parties in finding solutions to energy problems and formulating practical energy policies. Studies are selected by a Board of Directors that represents the sponsor organizations. The interpretation and findings set forth in CERI publications are those of the author(s), who maintain sole responsibility for the content. CERI studies are made available to the Institute's sponsors, including all members of the Private Sector Sponsors and international associate sponsors, without charge.

3 U.S. National Science Foundation's Industry/University Cooperative Research Centers Program [15]

The Industry/University Cooperative Research Centers (I/UCRCs) program of the National Science Foundation (NSF) develops long-term partnerships among industry, universities and government. The centers are catalyzed by a small grant from NSF for a five-year period to seed partnered approaches to new or emerging research areas. Principal financial support actually comes from center industry members and other sources. The participation of NSF**,** although small financially, nevertheless sets the tone for the I/UCRCs. NSF provides guidance, and sets structural and managerial requirements that enhance center development and evolution with the goal of creating sustaining centers. Strong program management ensures that each of the Centers continues to follow the I/UCRC model—each in its individual fashion—and that each remains strong.

Currently there are more than 50 I/UCRCs. More than 750 faculty members, along with some 750 graduate students and 200 undergraduate students, carry out the research at these Centers, which encompass almost the entire spectrum of current technological fields. A primary purpose of the I/UCRC Program is providing high-quality interdisciplinary education. The Centers have produced several thousand M.S. and Ph.D. graduates, who can be found throughout American industry and academe.

I/UCRCs stimulate industry/university collaboration by focusing on fundamental research recommended by Industrial Advisory Boards. With industrial and other support totaling 10 to 15 times the NSF investment, I/UCRCs facilitate "leveraged" funding. NSF supports these Centers through a cooperative leveraging mechanism. NSF's financial contribution to the Centers is relatively small—about $5.2 million in FY 2000. Funding from sources other than NSF is much larger, totaling more than $68 million in FY 2000. Currently, the Centers have well over 700 memberships. Of these, about 90 percent are industrial firms, with the remaining 10 percent including State governments, National Laboratories, and other Federal agencies. Most universities also provide direct and/or indirect support (e.g., cost sharing) for their Centers.

Each center’s research programs usually consist of projects with a coherent focus on an industrial interest. Research is often done by graduate students under the direction of faculty researchers. Across the Program, these Centers have a partnership with industry. This partnership takes full advantage of the strength of each participant. University faculty contribute their skills in research and their understanding of the knowledge base; industrial researchers contribute their knowledge of both the technical needs of industry and the challenges associated with competing successfully in the marketplace. NSF also influences industry to take a longer term view of its needs, with appropriate attention to research quality. This ensures that the fundamental research conducted in the Centers continues to add to the knowledge base that will be vital for solving the problems and meeting the needs of the future.

The industry-university partnership is formalized in each Center's Industrial Advisory Board (IAB), which advises the Center's management on all aspects of the Center, from research project selection and evaluation to strategic planning. All IAB members have common ownership of the *entire* I/UCRC research portfolio; however, individual firms can provide additional support for specific "enhancement" projects. This extensive industrial involvement in research planning and review leads to *direct* technology transfer, bridging the gap that traditionally has kept U.S. industry from capitalizing fully and quickly on the fruits of research at American universities. In the cooperative research model, all Center developed research products are owned by all the members.

4 Natural Sciences and Engineering Research Council (NSERC) in Canada [16]

NSERC helps Canadian companies by jointly funding collaborative R&D projects with scientists and engineers in universities across the country. There are five different program options:

- Collaborative Research and Development Grants Program that partners industry with a university and shares costs with industry.
- Research Partnership Agreements Program that partners industry with a university and a government research lab, and the costs are shared three ways.
- Strategic Projects Program connects industry to university research in strategic areas with no requirement for a cash contribution.
- Research Networks Program brings industry and others together to address complex R&D challenges of common interest.

- The Idea to Innovation program helps industry bring promising university research results to the market.

The **Collaborative Research and Development** (CRD) program is intended to give companies operating from a Canadian base access to the special knowledge, expertise and educational resources at Canadian postsecondary institutions and to offer opportunities for mutually beneficial collaborations that result in industrial or economic benefits to Canada. CRD grants support well-defined projects undertaken by university researchers and their private-sector partners. CRD awards cover up to half of the total eligible direct project costs, with the industrial partner(s) providing the balance in cash and in kind. The industrial cash is normally at least one half the NSERC award. Projects may range from six months to five years in duration but most awards are for two or three years.

The National Research Council of Canada (NRC) and the Natural Sciences and Engineering Research Council of Canada (NSERC) have established a jointly managed and funded partnership program entitled the "**NRC/NSERC Research Partnership Program**" that will:

- capitalize on the complementary R&D capacity existing in the universities and in NRC institutes to generate new knowledge in selected areas required to meet identified economic, industrial, social and environmental needs and opportunities
- build strong three-way linkages and create synergy between the private sector and researchers in NRC institutes and universities
- achieve the efficient and effective transfer of research results and technology to receptors in the public or private sectors
- train and develop highly qualified personnel in priority areas consistent with the future human resource requirements in the public and private sectors.

Approved activities may be supported for terms of up to five years with funding beyond the first year contingent upon evidence of satisfactory progress and, where applicable, evidence of continuing support from the industrial partner(s). To be eligible for support, a proposal must involve a collaborative effort with at least one NRC institute. Normally, at least one Canadian-based company, incorporated and operating in Canada, will be involved and will make cash and in-kind contributions to the project. Proposals should address the priority research areas as agreed to by NRC and NSERC.

The **Strategic Project Grants** program funds project research in target areas of national importance and in emerging areas that are of potential significance to Canada. The overall objective of the Strategic Project Grants program is to accelerate research and training in targeted and emerging areas of national importance. The research is early stage with the potential to lead to breakthrough discoveries. A strategic project must support the objective of the program and the research must fall within one of the areas identified for support. In addition, the project must be well defined in duration, objectives and scope. Strategic grants are awarded for one to five years, the normal duration being three years. The participation of one or more academic researchers with one or more non-academic organizations that can apply the results is a requirement. Non-academic organizations include: non-governmental organizations, industries or industrial consortia and government agencies/departments. A cash contribution from the non-academic participant(s) is not required. They should, however, be actively involved in all stages of the research project from the development of the proposal, through ongoing interaction with the academic researchers on the results and direction of the project, to guidance relating to exploitation and/or commercialization of the results. The level and nature of their involvement in the project will depend on the type of research proposal and the ability of the organization to participate.

The **Research Network Grants** program fosters:

- creation of knowledge and expertise that can most effectively be attained through large-scale multidisciplinary research projects
- collaboration between university- and/or college-based researchers and Canadian-based organizations
- transfer of knowledge and expertise to Canadian-based organizations
- training of highly qualified personnel
- social and/or economic benefits to Canada.

Research Network Grants fund large-scale, complex research programs that involve multi-sectorial collaborations on a common research topic. The topic to be investigated can be of local concern, requiring a focused local network, or of regional or national importance, requiring a larger, more complex network. Research Networks must involve a minimum of five researchers, eligible to receive NSERC funding, from at least three separate departments, faculties or institutions. Research Networks should also encourage interaction and exchanges of personnel between postsecondary institutions and partner organizations as part of the training of highly qualified personnel, e.g., reciprocal laboratory visits, joint workshops, and seminars. A management structure is required to direct, manage, and integrate the activities of the network. Research Networks normally require in excess of $500,000 annually from NSERC. Both private- and public-sector partner contributions will be assessed in the determination of an appropriate cost-sharing ratio. Networks are normally funded for five years.

The **Idea to Innovation** program is to accelerate the pre-competitive development of promising technology and promote its transfer to Canadian companies. The program supports research and development projects with recognized technology transfer potential by providing crucial assistance to university researchers in the early stages of technology validation and market connection. The program provides funding to university researchers, through defined stages, for research and development activities leading to technology transfer to a new or established Canadian company. Two distinct funding phases are proposed which are characterized by the maturity of the technology or the involvement of an early stage investment entity or an industrial partner. These phases are limited in time. In the first phase, the direct costs of research will be entirely supported by NSERC; in the second phase, they will be shared with a private partner. The technology development may begin with a Phase I (Proof-of-Concept) project followed by a Phase II (Technology Enhancement) project, or, if the development is at a later stage, can start directly with a Phase II project. In any case, a maximum of three years' funding will be available for any given project.

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