Chapter 3: Research Management

(rev. Nov. 2011)

3.1 Introduction

3.1.1 Overview

This chapter addresses best practices for research thrust leaders, the research team leaders who are positioned on the Engineering Research Center (ERC) organizational chart between center directors and individual faculty researchers, with responsibility for one of several "thrust" areas within the center's overall research program. Although aimed at ERC research thrust leaders, the chapter's content may also be of value to other members of a center's leadership teams (e.g., directors and deputy directors, faculty, testbed leaders, and industrial partners).

This section begins with background summarizing the quarter-century experience from which these best practices have emerged, followed by an explanation of the importance of research thrust leaders and the challenges they face. Perspectives on the types of best practices discussed in this chapter are then followed by a roadmap of the remaining sections.

3.1.2 Background

The National Science Foundation's ERC Program has, since the mid-1980s, supported centers to join universities and technology-based industries in focusing on next-generation advances in complex engineered systems (see Endnote 1). To enable a long-term collaboration, ERCs are funded for 10 years (11 years in the early days of the program). Of the more than 50 ERCs formed since the program began, 13 are currently being supported as of late 2010, with five more planned for initiation in early 2011; 29 of the 35 "graduated" centers are still in operation and self-sustaining (Endnote 2).

ERC activities are at the interface between the discovery-driven culture of science and the innovation-driven culture of engineering. ERCs have created synergies between science, engineering, and industrial practice while facilitating industry collaboration with faculty and students. Through ERCs, partnerships that strengthen academic contributions to U.S. industrial competitiveness have been formed, many undergraduates have become involved in focused research, and the knowledge and experiences of engineering graduates have been broadened.

Against the backdrop of an increasingly global economy in which U.S. competitive advantage rests heavily on innovation, five third-generation ERCs were established in 2008. These Gen-3 ERCs reflect the proven results of earlier ERCs but, with a greater emphasis on innovation, look to establishing more and stronger partnerships with small firms and startups, other entrepreneurial organizations, and foreign universities.

3.1.3 The Importance of Research Thrust Leaders

As the name implies, research and engineering are at the heart of ERCs. *Within the ERCs, research thrust leaders are at the heart of research management. They are the ones expected to lead a diverse group of researchers to deliver on ERC research and technology-translation goals in a timely manner and within a limited budget.*

Being a research thrust leader is challenging—a far cry from a simple research advisory role. It is the classic middle-management situation. Often research thrust leaders are:

- not in control of their research budgets;
- not involved in all decisions or interactions affecting their projects;
- not (in many cases) at the same location as the main lead institution; and are
- not provided additional compensation for time spent in their leadership role.

Despite these challenges, they are responsible for organizing a team of relatively independent investigators to deliver on a common thrust-level goal and are expected to lead the projects in their areas of responsibility to successful completion. The success of the ERCs in the overwhelming majority of the cases proves that they are able to accomplish this task.

3.1.4 Best Practices for Research Thrust Leaders

Many general management principles have proven useful over the years to guide research, development, and engineering endeavors and create competitive advantages (see, for example, Endnote 3). These principles include:

- Good top-level leadership with demonstrated commitment
- Strategic organizational vision and planning
- Adequate human capabilities and financial resources
- A customer focus
- Value creation
- An enduring focus on quality
- Good metrics for measuring inputs, outputs, and outcomes over time.

This chapter accepts such principles as valid bases for successfully managing highly technical efforts. However, it reaches beyond these layers of generality to describe the “how-to” methods that practicing ERC research thrust leaders have found to work in their real world. In other words, this chapter focuses on “best practices” gleaned from years of ERC experience.
The following list sets forth broad areas in which best practices are addressed in this chapter:

- Defining the roles and responsibilities of research thrust leaders in the context of developing strategic plans at ERCs
- Executing pragmatic approaches for strategic plans, such as sustaining buy-in of plans, enhancing communications up and down the ERC leadership chain and across the various thrusts, and developing and using metrics to assess ongoing projects
- Integrating the center’s research efforts, both with the long-range needs of industry partners and with the education activities of partner universities.

Naturally, all of this has to recognize that ERCs vary in many ways. For instance, there are differences in numbers and locations of partnering universities and industries; internal organizations, policies, and procedures; heterogeneity in problem solving; and types and numbers of disciplines involved, as well as in the basic technology fields and industrial sectors on which the centers focus.
In other words, best practices for research thrust leaders at one ERC are not necessarily the best fit at another. So, *in considering the best practices that follow, research thrust leaders must adapt the concepts to the particulars of their own ERC.*

3.1.5 Chapter Roadmap

Sections 3.2 and 3.3 tackle two of the most important elements of good research management—development of a strategic plan and its execution. Section 3.4 deals with integrating the research and the industry partners. Section 3.5 addresses the integration of education and research. In each of these sections the emphasis is on best practices—solutions that have been found to work in real ERC situations. Practical examples or case studies are included in each section to illustrate the best practices.
Recognizing the newness of Gen-3 ERCs, Section 3.6 looks into similarities and differences in best practices that might apply to these partnerships. This section also suggests ways to develop Gen-3-specific best practices. Section 3.7 identifies the key contributors to this chapter, and Section 3.8 furnishes sources and references in the form of endnotes.

3.2 Best Practices for Strategic Planning

3.2.1 Strategic Planning is Important

Each ERC develops a top-level strategic plan for all of its operations using the ERC Programâ€™s 3-level strategic planning chart that depicts how engineered systems goals guide and motivate the centerâ€™s fundamental research, enabling and systems technology research, and testbeds. The core of the plan contains the major elements involving researchâ€”a research strategy that reflects and supports the ERC vision plus a comprehensive plan that:

- Covers the three levels of ERC research (i.e., fundamental knowledge, enabling technologies, and engineered systems)
- Identifies clear barriers in the way of achieving the systems goals
- Identifies clear research goals derived from those barriers, by thrust and overall, as well as milestones for their achievement
- Contains adequate human and dollar resources
- Articulates metrics for measuring progress toward final completion of individual projects.

Amplifying these general guidelines, five strategic-planning best practices for research thrust leaders are described below.

3.2.2 Clearly Define Roles and Responsibilities

The strategic plan must define fully the roles and responsibilities of the thrust leader, each member of the team, and their relationship to the rest of the leadership teamâ€"from the top to the bottom. Full definition encompasses three elements:
1) the reporting structure within the ERC;
2) how decisions are made on funding or discontinuing a project; and
3) an appropriate balance of industry interests against long-term research goals.
Aspects of the following best practices contain elaborations of these three elements.
However, definition of roles and responsibilities has to include the added mandate that research thrust leaders must be delegated *authority* commensurate with their responsibilities. In other words, the thrust leaders cannot be held *responsible* for leading if they do not have sufficient authority to do so. This problem is generally avoided if thrust leaders are able to participate in early strategic research planning, are included in the ERCâ€™s leadership team, and can negotiate their role as members of that team to fulfill the thrustâ€™s/ERCâ€™s goals.

Management references often contain discussion of authority accompanying responsibility. For example, *â€œTypically, an employee is assigned authority commensurate with the task. â€¦ When an employee has responsibility for the task outcome but little authority, accomplishing the job is possible but difficult. The subordinate without authority must rely on persuasion and luck to meet performance expectations.â€•* (Endnote 4.)

3.2.3 Capture the Components of a Good Plan

A good strategic plan has many components. Inclusion of the following components is very important:

- An ERC has to establish a team culture versus the more traditional, individual-research culture, both intra- and inter-university;
- Ensure that the overall ERC vision and mission are articulated in the plan and shared by those in the research thrust leaderâ€™s area of responsibility;
- Define resource and budget needs, given the goals;
- Lay the groundwork to take advantage of the best communication technology (e.g., to facilitate â€œbrainstorming sessionsâ€• and other necessary interactions).
- Define succinct deliverables and outcomes on reasonable timelines.

3.2.4 Define a Structure for Adjusting the Plan

Research thrust leaders should never assume that, once a plan is completed, it will not need to be changed. In fact, change is more likely the norm. Therefore, at the outset a structure must be defined in which adjustments or corrections relating to the research plan can be made. Among other things, this type of structure would ensure that financial resources can be distributed or redistributed, both within and among universities.
To help measure progress and determine adjustments, metrics should be defined for successful research within an ERC. Proper metrics should not be just numbers of papers published or students graduated. Rather, they should:

- Measure each projectâ€™s contribution to the thrust, such as advancing the testbed
- Exhibit an incentive to improve the thrust
- Consider additional funding from other non-ERC Program sources, attracted by the ERCâ€™s research
- Take account of industry funding obtained for the thrust.

3.2.5 Ensure the Research Tasks Can be Accomplished with the Resources Allocated

Despite the fact that budget reallocations will probably be needed at times, the initial plan should contain budget estimates that adequately cover the research tasks as well as the necessary administrative and management support. Donâ€™t volunteer to do too much for too little. Since budgets are likely allocated in the beginning from top levels of the ERC downward, be sure the plan contains commitments to do only what the budgeted resources will allow, and no more.

3.2.6 Create a Transparent Organizational Structure

A transparent organizational structure, preferably one that is â€œflat,â€• should be created and set forth in the plan. This type of structure would succinctly identify the various interactions and dependencies that exist, both within individual thrusts and between thrusts.

3.2.7 Examples

The following excerpts are from the strategic research plans of three ERCs [1-Synthetic Biology Engineering Research Center (SynBERC, with overall objective: enabling technologies); 2-Mid-InfraRed Technologies for Health and the Environment (MIRTHE, with overall objective: enabling technologies); and 3-Collaborative Adaptive Sensing of the Atmosphere (CASA, with overall objective: specific system product). The excerpts furnish examples of the general strategic planning guidelines and best practices described in this Section 3.2.

Note that the objective statement for each ERC signifies the type of overall goal for the center. There is a difference in strategy when the goal is a very specific system versus breakthroughs in process or understanding that would make possible a variety of different system developments.

Referral to the planning details for the individual research thrusts contained in these and other ERC plans should further expose research thrust leaders to a range of strategic planning approaches. *Nevertheless, each thrust leader faced with developing strategic plans should try to ensure that the best practices outlined in Section 3.2 above are accommodated, regardless of past or current practices at any particular ERC.*

3.2.7.1 Addressing the Three Levels

ERC strategic plans normally display the standard â€œthree-plane diagramâ€• showing effort devoted to fundamental knowledge (bottom plane), enabling technologies (middle plane), and engineered systems (top plane). Although involved most heavily in the lower planes, research thrust leaders must recognize the great importance of their work to achieving success in the top plane.

To portray a variety of concepts, several three-plane diagrams appear below (see Exhibit 3.2.7.1(a-c)). The last (c) has text associated with it as an aid to understanding the diagram in subsection 3.2.7.2.

EXHIBIT 3.2.7.1 (a)

SynBERC Year Four Annual Report

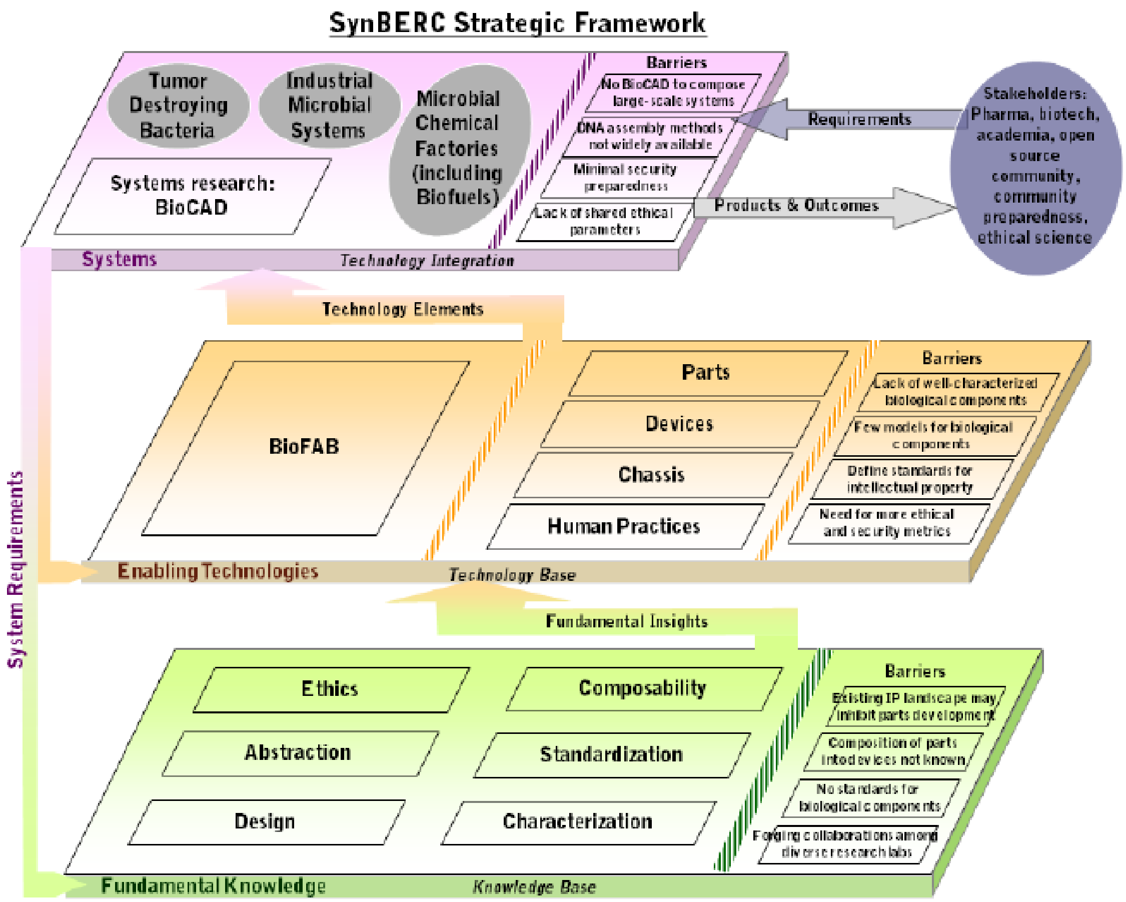
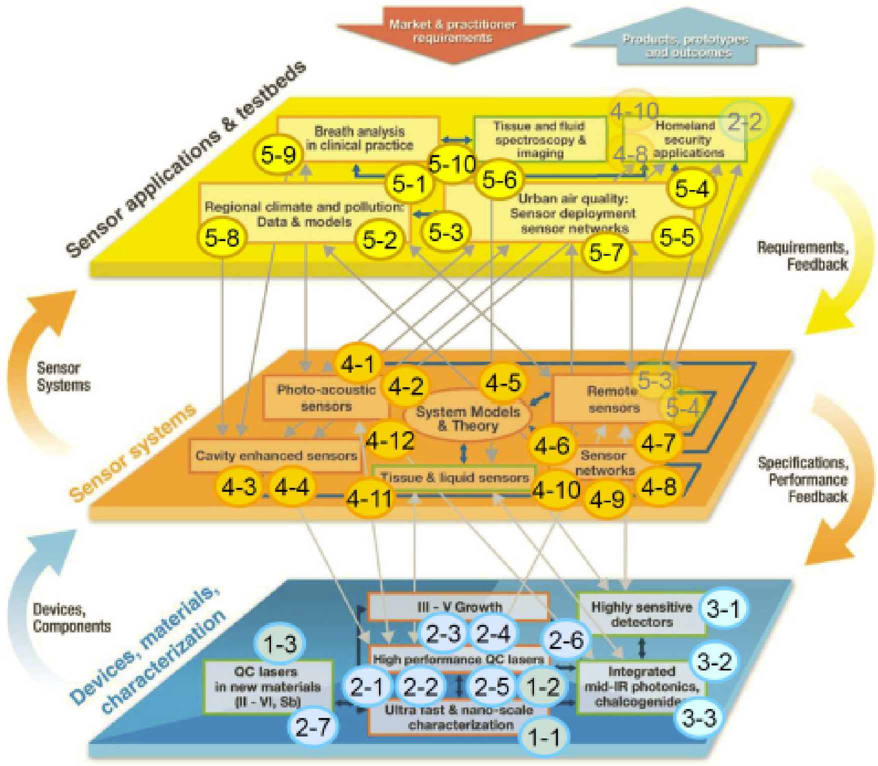


Figure 5.1-1. SynBERC three-plane strategic diagram. Last updated January 4, 2010.

EXHIBIT 3.2.7.1 (b)



Project assignment to MIRTHE's 3-level ERC strategic framework

Thrust –index	Project name …
5–1	Coupled Water, Carbon, and Nitrogen Cycles in Urban Environments
5–2	Coupled Water, Carbon, and Nitrogen Cycles in Urban Environments
5–3	Monitoring Trace Gas and Aerosol Properties in the Urban Environment
5–4	Monitoring Trace Gas and Aerosol Properties in the Urban Environment
5–5	Nitrous Oxide Instrument Development Using a Single Mode, Continuous Wave,…
5–6	Ultra Sensitive Ammonia Sensor for Urban Air Quality
5–7	Monitoring of Ammonia Mixing Ratios in Houston Using MIRTHE Technology
5–8	Gas Sensing Using Mid-Infrared Technology in Fish-Smoking Areas In …
5–9	Breath Ammonia in Humans, a Pilot Study
5–10	Development of Mid-Infrared Based Instrumentation for In Vitro Toxicity Testing

Thrust –index	Project name …
4–1	Development of Quartz Enhanced Photo-Acoustic Spectroscopy Based …
4–2	Development, Verification, and Validation of Three-Dimensional Models for …
4–3	Development of Trace Gas Sensor Platforms for Applications in Health , …
4–4	Development of External Cavity Quantum Cascade Lasers with High Speed, …
4–5	Develop Statistical and Deterministic Signal Processing Algorithms for …
4–6	Development of Ultra-Low Power, All-Digital-Signal-Processing Laser-Based …
4–7	Gas Sensing Wireless Networks
4–8	Optical Transmission and Signal Cancellation Techniques in Sensor …
4–9	Integrating MIRTHE Sensors into Wireless Meteorological Sensing Networks
4–10	Securing Sensor Networks
4–11	Mid-Infrared Cancer Detection and Monitoring
4–12	Confocal Microscopy Based on Quantum Cascade Laser and Single Hollow Core …

Thrust –index	Project name …
3–1	Novel Mid-Infrared Sources and Detectors Based on Resonant …
3–2	Photomodifiable Chalcogenide Glass Materials for Integrated …
3–3	Chalcogenide-on-Lithium Waveguides
2–1	High Performance (Threshold, Power, Efficiency) Quantum …
2–2	Spectrally High-Performance Quantum Cascade Lasers
2–3	3-5 µm Quantum Cascade Laser Gain Materials
2–4	Broadband Quantum Cascade Laser Gain …
2–5	Modelocking of Quantum Cascade Lasers
2–6	Integrated Tunable Quantum Cascade Lasers
2–7	Solid State Mid-Infrared Lasers Pumped by …
1–1	Nanoscale Characterization of Metal Organic Molecular Beam ...
1–2	Mid-Infrared Ultrafast Diagnostic Instrumentation for Quantum Cascade ...
1–3	Wide Bandgap II-VI Semiconductors for …

EXHIBIT 3.2.7.1 (c)

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SECTION 2 - STRATEGIC RESEARCH PLAN AND OVERALL RESEARCH PROGRAM

2.1 STRATEGIC RESEARCH PLAN

The innovation being pursued in the CASA project is to supplement - or replace - the present national network of 150 large weather radars with thousands of small radars that can be deployed on cellular telephone towers, rooftops and other infrastructure. The closer spacing of the new radars will avoid the obstruction caused by Earth curvature and allow forecasters to directly view the lower atmosphere with high-resolution observations. This new dimension to weather observing leads to improved characterization and better forecasting of storms, resulting in improved warning and response to tornadoes and other hazards. In addition to the many engineering challenges associated with the radar network itself, software architectural problems to be solved include managing the system's many resources and data volume and designing an effective user interface. The central challenge is in designing and deploying a system that can sample the atmosphere where and when the user need is greatest to reliably issue alerts that the public trusts and responds to appropriately.

The solutions to the different problems posed by this project are to be found through CASA's working on three planes of engineering research as shown in figure 1. CASA's system focus (upper plane) is a real-time distributed system capable of focusing its resources onto particular sub-volumes of the atmosphere and delivering forecasts and other data that enable forecasters, emergency managers and the public to generate accurate alerts and make effective decisions when weather strikes occur. Realizing an effective and efficient system requires creating a number of new enabling technologies (middle plane) and conducting fundamental research to create new knowledge (bottom plane). Multi-disciplinary research in the lowest plane spans several disciplines, from electrical engineering investigations of how electromagnetic waves interact with the atmosphere, to atmospheric science investigations related to detecting and forecasting storm cells at high resolution, to computer science investigations related to resource optimization, to sociological and decision-theoretic studies about how individuals and organizations respond to severe weather hazards, utilize warnings and ultimately take protective action. Whereas the lowest plane tends to be the "comfort zone" of academic faculties, CASA's strategic concept is an interdisciplinary orchestration of work in all planes, from the definition of the system in the upper left, through targeted technology and fundamental

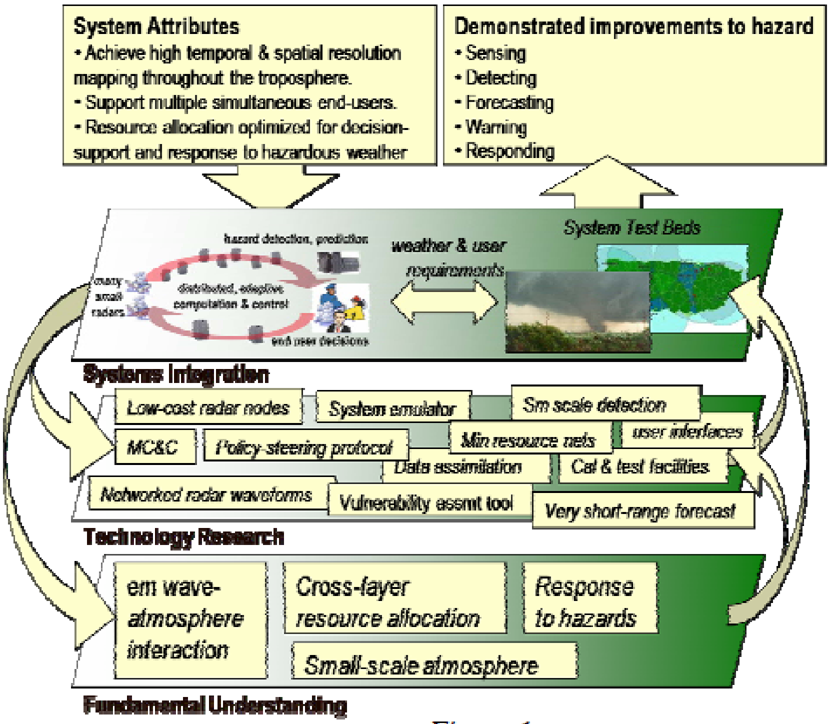


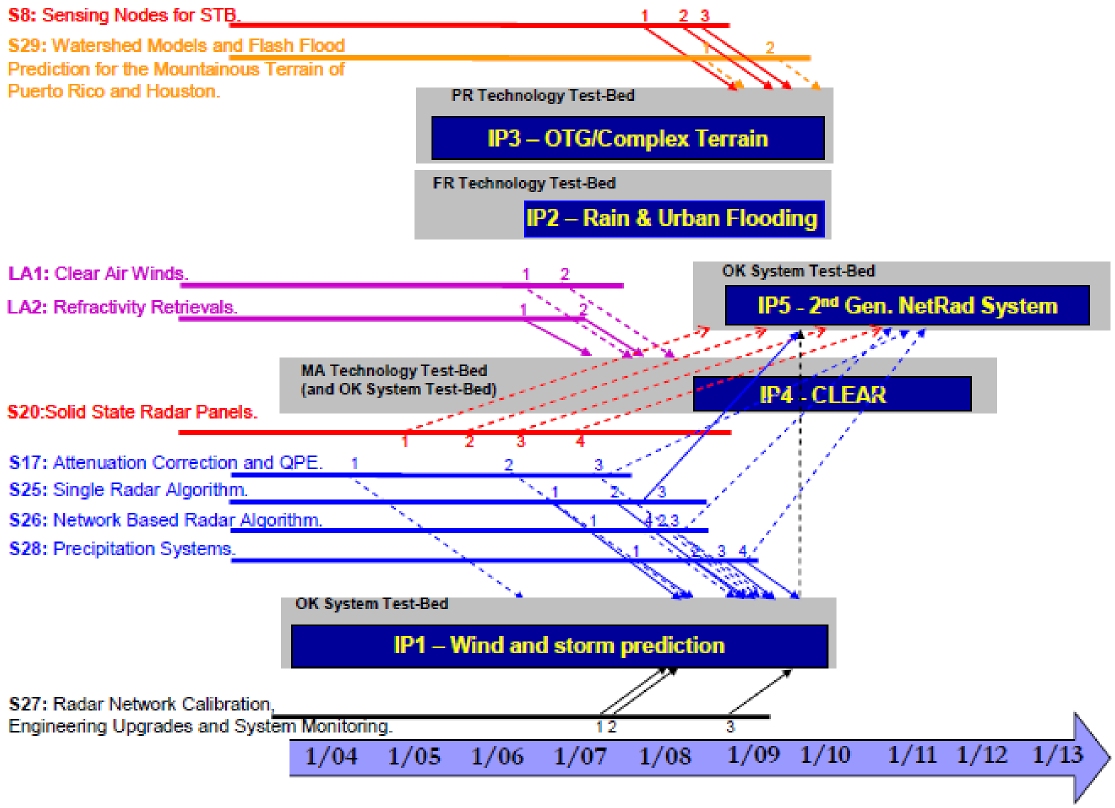
Figure 1.

3.2.7.2 **Identifying Clear Goals and Milestones**

The CASA thrust-level example below (Exhibit 3.2.7.2) amplifies the general guideline of identifying clear goals and milestones by emphasizing the best practice of *defining succinct deliverables and outcomes on reasonable timelines*. This project-level milestone chart extends the CASA three-plane diagram shown in Exhibit 3.2.7.1 (c) above.

EXHIBIT 3.2.7.2

The milestone and deliverable chart for the Sensing thrust are shown in Figure (17). Sensing hardware (S27) and algorithms (S17, S25, S26, S28, and LA2) were extensively tested, evaluated, and improved through the successful operation of IP1 radar network. Other significant completed milestones include development and installation of sensing nodes (S8, S20), system calibration for IP1 operation (S27), system planning of test beds (S8, LA1), and application development (S17, S28, S29, LA2). The sensing system design of DCAS systems progresses through the IP1 test bed and the IP3 test beds, following system engineering approaches and CASA's strategic plan, and then progresses into the design of the IP5 test bed. The exploration of new processing algorithms and network based system models is on going with actual radar observations of the IP1 system level test bed.



S8.1 First OTG radar installation in Puerto Rico	05/09
S8.2 Second OTG radar installation in Puerto Rico	08/09
S8.3 Cross-validation of PR1 radar and OTG radars	12/09
S17.1 Operational attenuation correction algorithm	04/06
S17.2 Development of IP1 rainfall estimation system	07/08
S17.3 Development of IP1 hydrometeor type classification	07/09
S20.1 Antenna and TR module performance review	04/08

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S20.2 Antenna and TR module fabrication	05/09
S20.3 Radar system integration	03/10
S20.4 Field test at MA1 / CSU-CHILL	06/10
S25.1 Dynamic waveform selection and processing	06/08
S25.2 Digital waveform generator	04/09
S25.3 Integration of wideband waveform with solid-state transmitter	12/09
S26.1 Real-time implementation of network reflectivity retrieval	10/08
S26.2 Implementation of networked waveform system	07/09
S26.3 Statistics of rain attenuation in IP1 network	08/09
S26.4 Interface Q-function algorithm with MC&C	06/09
S27.1 Implement networked waveform structure	02/08
S27.2 Implement clear air mode	03/08
S27.3 Transition to IP5	12/09
S28.1 Real-time implementation of DARTS	06/08
S28.2 Including DARTS nowcasting in MC&C	04/09
S28.3 Scale analysis for nowcasting	10/09
S28.4 Evaluation of network resolution enhancement system	12/09
S29.1 Prototype real time flood alarm system	05/09
S29.2 Radar rainfall mapping in STB	03/10
LA1.1 Statistics of insect scattering	02/08
LA1.2 Analysis of scan strategy for insect scatters	06/08
LA2.1 Implement real time refractivity retrieval	10/07
LA2.2 Clear air scan for refractivity measurement	05/08

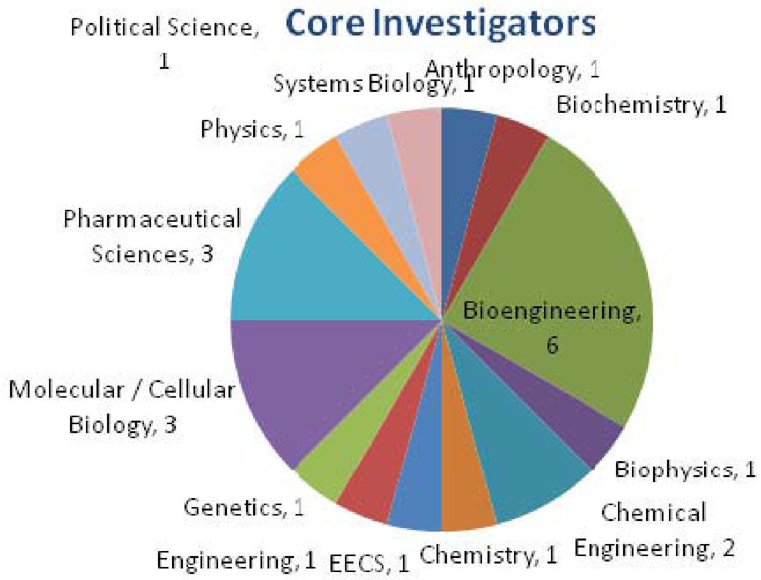
Figure 17. The milestones and roadmap for Sensing thrust research

3.2.7.3 Adequate Human and Dollar Resources

Exhibit 3.2.7.3 (a) shows the range of human resources needed by one ERC for its research program. This diversity of participants underlines the importance of best practices that establish a group culture, share the overall ERC vision and mission, and make use of the best communication technologies.

Rather than providing examples showing dollar resources that are merely accumulations of pages of ERC cost estimates by research project, the second exhibit below (3.2.7.3 (b)) amplifies a part of the best practice of defining a structure for plan adjustments, which could include financial adjustments. The example suggests that the original resource estimates may have been a bit short, which highlights that a priority emphasis for strategic planning should be on ensuring that the research tasks can be accomplished within the originally allocated resourcesâ€" requests for later â€œadjustmentsâ€• in the form of budget increases will not likely be received favorably. Another example of adjusting the original strategic plan appears in subsection 3.3.8.1.

EXHIBIT 3.2.7.3 (a)



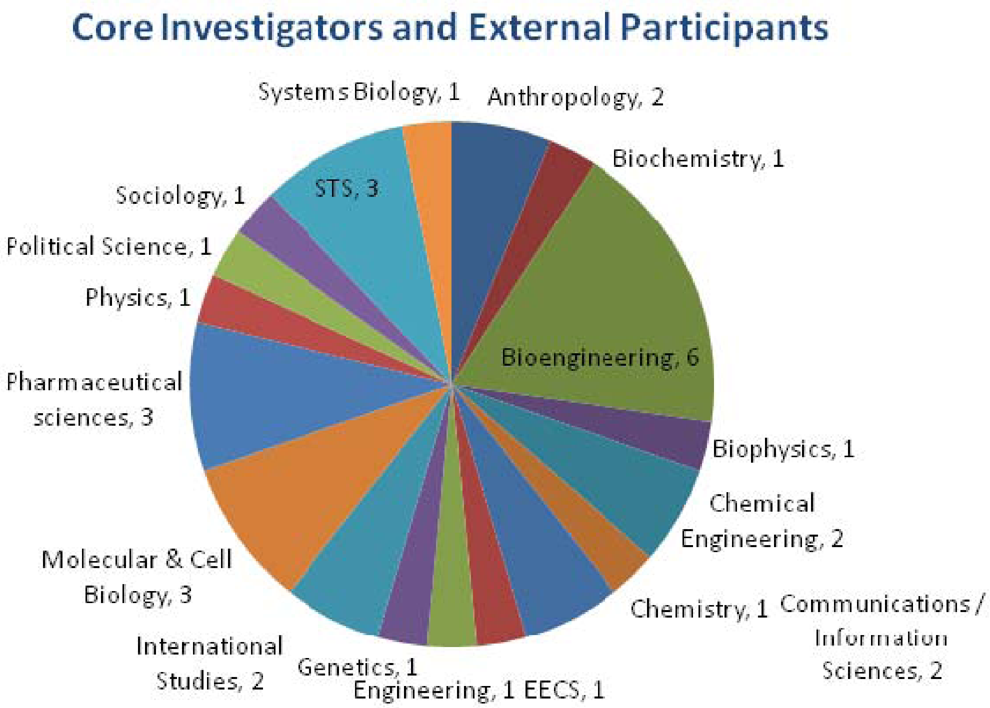


Figure 5.1-5. Research project investigators by discipline

EXHIBIT 3.2.7.3 (b)

2.1.8 Changes in MIRTHE's Budget

MIRTHE is still in the budgetary ramping up phase, and requests an additional $250k of NSF core funds in year 5, after which the budget is expected to be flat. These additional $250k are being used to support MIRTHE's ongoing research program, off-setting inflationary costs, and strengthening or supporting new programs with special attention to:

(i) Supporting MIRTHE's junior faculty;
(ii) Instituting a new mini-grant competition for post-doctoral researchers;
(iii) Supporting the speed up of the wireless sensor network projects;
(iv) Supporting student internships at industry/practitioner sites; and
(v) Providing more opportunities for direct student–industry interaction.

Overall, no major funding shifts are anticipated in the short term.

3.2.7.4

Articulating Metrics

The importance of good metrics cannot be over-emphasized. Several examples of metrics appear below (note the emphasis on â€œuser-definedâ€œ metrics). See Exhibit 3.2.7.4.

EXHIBIT 3.2.7.4

Apart from storm motion and temporal correlation, in collaboration with the predicting thrust we will also produce Very Short-Range Forecast (VSRF), directly serving the end-user groups. This product will be initially built upon the current operational nowcast system in IP1. Currently, the nowcast product is used to predict the storm locations in a short-term. The performance will be quantitatively evaluated by Critical Success Index (CSI), as well as POD and false alarm rates. In IP5, the VSRF product will be also used to impact the "siren blows". The impact on the use by the end user group (emergency managers) will be the primary metric used in the operation process. We will work with the End-user thrust to define additional quantitative metrics to evaluate the performance, where the missed detection needs to be emphasized and the location of interest needs to be subjectively selected. A simple but significant example of the impact of VSRF on the end user group is spotter deployment (Collaborative System Goal). This collaborative system goal spans into three stages of development namely, a) demonstrate real-time detection, analysis, and VSRF products to Emergency Managers, b) demonstrate optimum MC&C protocol to maximize VSRF skill and c) demonstrate optimum MC&C protocol to maximize spotter deployment decision support. The metrics of effective spotter deployment are different from the direct metrics for VSRF such as CSI. For example the spotters may want to be located in a region, close to escape routes (good roads), as well as good vantage points with better visibility as well as the potential to get ahead of the storm. These needs will be mapped, via the MC&C into the scanning strategy to

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Goal #1 Plans: In years 7 -10, we will begin to implement more objective measures for determining user needs and socioeconomic benefits to allocate system resources.

- *Users Needs* – We will develop user-defined metrics for data quality for response based goals such as emergency manager deployment of spotters. Metrics include FAR, POD, spatial and temporal requirements, and display considerations. This information will be determined as part of the EUI thrust's on-going decision modeling of user groups.

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- *Weights* - Evolve from static trade-off coefficients to dynamic coefficients, based first on optimizing forecast skill and detections based on performance metrics developed by the scientific community, then based on user defined metrics for data quality, and ultimately based on higher level socio-economic goals.
- *Scan quality* – Quality is defined as obtaining the best data for users based on the user defined-metrics, or for the VSRF products. The user will no longer define scanning strategies, rather the spatial, temporal and physical properties of the phenomena of interest and the capabilities of the radar network determine the scanning.

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Infrastructure Goal #2: Deploy 2 escan radars in the IP5 domain by 1/12; Infrastructure Goal #3: Deploy a 2nd generation MC&C by 1/11. In Version 4 of User Rules/MC&C, users state their preference for scanning frequency and coverage. The addition of escan radars creates a hybrid network containing radars with distinctly different scanning capabilities. Escan radars have agile beams that can be repositioned many times more quickly than mechanical radars. In addition, the user community is not familiar with the capabilities of escan radars. Therefore, as part of the deployment of escan radars and a second generation MC&C, the End User group will collaborate with the Distributing and sensing thrust to evolve a new set of user rules, multi-attribute utilities, and trade-off coefficients based on user-defined performance metrics for CASA products and decision goals. (See System Goal #1 for milestones related to user-defined performance metrics) In addition the EUI will collaborate to create the following system features for MC&C:

- Flexible data formats to enable visualization of base moments and new CASA products through existing software packages, such as AWIPS, the operational data platform used by NWS Forecasters, OKFirst, the operational platform used by emergency managers, a mobile platform for Blackberries and Iphone, and 3D multi-radar programs such as GR2 Analyst.
- Interfaces for dynamic user input into the system by weather spotters and by the NWS.

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5.2.1.5 Challenges to the thrust

A remaining problem is to appropriately and systematically characterize part behavior, including the development of standardized metrics (e.g., promoter output in units of polymerases per second) and ways to assess composability and generalizabiliy in multiple contexts, as well as experimental protocols for their measure. Systematic characterization in many contexts is often beyond the scope of a typical student or post-doc-driven project, although much progress has been made in this respect with the first "datasheet" for an engineered device [33] and work to characterize promoter activity using an *in vivo* reference standard [34]. The development of the BioFAB will drive progress in part characterization, both by providing data on generalizability and interoperability of components, as well as by development of measurement standards that can be used in the individual SynBERC-funded projects.

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- Standardized experimental protocols and metrics for measuring characteristics including:
    - part specifications;
    - part composability;
    - part compatibility;
    - part interoperability.

â€¦

These features can be standardized with weighted metrics to indicate the usefulness of any chassis that contain all or a subset of such features. Chasses are then compared to one another based on these weighted metrics so as to determine the most appropriate one for a specific application. For example, a chassis with natural competency and high recombinogenicity may be best suited for genomic manipulations while ones with stable genomes and robust growth may be appropriate for metabolite production. Chassis characteristics are quantified and indexed in a database; an optimization search algorithm can be used to determine the most appropriate chassis within the database for use. Currently, chassis features are being characterized and quantified to determine the most effective implementation of such chassis standardization.

3.3 Best Practices for Executing the Strategic Plan

3.3.1 Executing the Strategic Plan is Vital

A research thrust leader's work doesn't stop when the strategic plan is formulated; that's only the beginning, a prelude to the real effort. Constant follow-up is necessary (e.g., continually checking progress and resource expenditures against the plan). Also, as noted earlier, research thrust leaders have to be willing to make adjustments to the plan if necessaryâ€"especially with respect to budgets, resource allocations, and schedules.
â€œMany [businesses] have plans; few execute them well. In fact, intensive research out of Harvard University indicates at least 85 percent of businesses do not execute their strategies effectively.â€• (Endnote 5.)
Below (sections 3.3.2â€"3.3.6) are five pragmatic approaches and one important open issue (section 3.3.7) for research thrust leaders charged with executing their strategic plans.

3.3.2 Create and Sustain Buy-In

The goal here is to show how a particular thrust fits into the overall strategic plan of the ERC and to convince thrust members of the importance of their roles in fulfilling the centerâ€™s larger vision and mission. To an extent, some buy-in may have occurred during preparation of the strategic plan. However, that buy-in may only be transitory as the real work gets underway and the relevance of a particular project to a distant vision or mission dims in the minds of participants. Accordingly, the research thrust leader must constantly reinforce the relevance to the ERCâ€™s goals and the consequent need for buy-in as the projects continue.
Budget and resource allocation issues must be part of this best practice (e.g., what dollar and human resources will be allocated, and when?). Ideally, research thrust leaders should participate in the center-level budget and resource-allocation processes and have a clear understanding of budgetary and resource-allocation responsibilities and authorities, from the top of the ERC downward. However, the extent to which this is possible depends on the ERC and university leadership. In any event, research thrust leaders must communicate clearly and often with the ERC director, colleagues, and subordinates about budgets and resource allocations.

3.3.3 Identify and Optimize Critical Paths

Critical path chains should be optimized to achieve the most efficient timelines, bearing in mind that some fundamental challenges may take time to resolve. Further, although interactions among team members are to be encouraged, extraneous interaction should be avoided so as to not complicate each critical path with unimportant connections. The project goals can be accomplished without all players in the thrust being engaged with every aspect of the work.
In addition, the thrust leader should ensure there is no overlap in deliverables, such as two research efforts producing the same results. Coordination of deliverables between thrusts is also important.
When necessary, research thrust leaders should support changes within the center to clarify the critical paths. Rationale for such changes could include achieving more realistic schedules, attaining better balance of budgets and resources along the paths, or implementing successful â€œworkarounds.â€•
To illustrate the last point, there might be a situation in which a research thrust leader has to decide how to keep a research team productive when waiting for a deliverable from another thrust. Alternatively, a thrust leader may be faced with developing workarounds when an outside deliverable fails to materialize. A best practice would be to request every project to have a Plan B if Plan A, which reflects input from another thrust, has a schedule slip or

doesnâ€™t happen at all.

3.3.4 Establish Effective Communications within Thrust and with Rest of Center

Continuous and effective communications, both up and down the chain of command, are essential. With respect to levels of management above the thrust leader, communications must be clear, convincing, and concise. For levels parallel or below, in some cases research thrust leaders may need to rely on persuasion. Direct orders to other thrust leaders or independent researchers are likely to be seen as abrasive and fail.
Best practices to overcome communication difficulties include the following:

- Define the goals and milestones as a team.
- Use video-conferencing and web-based communication systems.
- Establish regular schedules for meetings.
- Record minutes for key meetings and decisions.
- Develop a knowledge repository.
- Always communicate with principal investigators and project leaders.
- Donâ€™t forget the telephone or face-to-face communicationsâ€”an e-mail can be misunderstood.
- Push to attend and interact at national meetings and professional society meetings (where ERC budgets permit).
- Schedule retreats for university students to show or present their work.

3.3.5 Monitor Progress and Deliverables

This topic addresses the following two aspects:

- Meetings and reports that illuminate various projects
- Metrics that measure progress and accomplishments.

Consideration here of meetings extends the preceding discussion of communications. Weekly or bi-weekly project meetings would be desirable, if possible, as would monthly meetings with center executives. However, a proper balance needs to be struck between meeting and doing. In other words, are the meetings worth the time spent? Meetings that involve thrusts across several universities are also challenging from travel and time standpoints.
On reports, research thrust leaders should establish and disseminate reporting schedules for interim progress, outcomes, and other deliverables. Monthly reports from individual researchers to thrust leaders along with quarterly reports from thrust leaders to higher levels of ERC management are probably sufficient. Caution should be taken to not overly burden the individual researchers who furnish inputs for such reports (i.e., they should not be too distracted from doing their projects). An online system might work well here.
Metrics for assessing performance are essential. As discussed in the previous section on strategic planning, the correct choice of metrics is very important. Much preferred are metrics that measure outputs and outcomes rather than inputs. It may not be possible to develop during strategic planning a complete set of worthwhile metrics, so research thrust leaders might be faced with this task during the execution phase. NSFâ€™s requirements for center metrics, in the context of both annual reporting and on-site reviews, must be taken into account here. The centerâ€™s Administrative Director/Manager is likely to be the most cognizant staff member regarding these requirements, and should be consulted.
Developing metrics in collaboration with other members of the research team as well as with top ERC leaders is most desirable; that way everyone in the management chain will know what to expect in the assessments. Once established, the metrics should be reviewed in light of project realities, timely feedback should be provided to project leaders, and there should be willingness
to adjust the metrics if a situation warrants. The project assessments would also be used to support recommendations for adjustments in budgets or resource allocations.

3.3.6 Adopt Effective Management Styles and Strategies

Several best practices regarding management styles are to:

- Use team-building approaches.
- Know and take account of backgrounds and capabilities of collaborators in the ERC.

- Develop and articulate a conflict-resolution strategy that everyone is likely to buy into.

Thrust leaders have to set research direction, so if people disagree on that direction an issue is raised on how to reach resolution. Depending on the issue, third party input (e.g., from some type of scientific advisory board or other technically savvy authority) can help resolve the matter. But clear articulation of the issue and what is done to reach agreement is important.
Note that possibly more contentious disagreements could arise on budgetary and resource allocations (see earlier discussion). Here the best practice would be to discuss the matter openly with participants in the team as well as other thrust leaders to gather information about various options for handling the situation. Then put it on an agenda for discussion with decision-makers in the ERCâ€™s leadership team.
Finally, uncomfortable personality conflicts might emerge between individuals at various levels. If these cannot be worked out by face-to-face dialog, one suggestion is to consider bringing in a conflict-resolution expert. At a certain point, such conflicts become a matter for center leadership to address.

3.3.7 The Issue of Compensation for Thrust Leaders

Thrust leaders expend much time and energy on their leadership tasks. Other than an occasional â€œgood-jobâ€• recognition from ERC management, their management work is not compensated. Should these leaders have some type of more tangible compensation for their important responsibilities? Several best practices are suggested below, but these are ultimately dependent on the ways individual ERCs and universities operate.

- Extra pay or vacation are at the top of the list of possible types of compensation for at least some of the considerable time and effort spent by thrust leaders to carry out their responsibilities associated with the ERC (e.g., through summer support or regular-year effort).
- Other forms of compensation could be making special training or professional-development opportunities available to thrust leaders; a variation could be a professional-development coach. (To help accomplish one or more of these possibilities, NSFâ€™s ERC Program office could be a resource to provide contact information concerning such opportunities.)

3.3.8 Examples of Adjustments to the Plan

It is useful to see examples of improvements that were made when strategic plans were being implemented. The first example below shows how fundamental elements of a strategic plan had to be modified based on lessons learned during implementation. (This experience also feeds back to Section 3.2, which contains a best practice of defining a structure that can accommodate adjustments.) The remaining examples, from ERC strategic plans described in subsection 3.2.7, show selected responses to various suggestions made by visiting reviewers after observing aspects of the implementation.

3.3.8.1 Changes to the Three-Plane Diagram

The example shown in Exhibit 3.3.8.1 starts with the original relationship between the planes of the diagram; it then explains why that relationship had to be changed. The example also illustrates this ERCâ€™s approach, after discussions with other ERCs, to achieving stronger faculty buy-in and team integration.

EXHIBIT 3.3.8.1

The Center uses a top-down, systems-vision approach in defining specifications and deliverables. The FREEDM system must be demonstrated with properly defined voltage and power levels for residential renewable energy generation and distribution. Research milestones and a quantitative matrix used to measure success will be defined by projected breakthroughs in three fundamental research areas: FREEDM system theory; post-silicon power devices; and advanced storage technology. To link the fundamental research results to the final system demonstration requires that several enabling technologies must be developed. Figure 2-2 shows the proposed sub-thrusts and their key relationships to the fundamental research, enabling technologies, and engineered systems planes. At the top plane, two subsystem test beds, IEM and IFM, are identified as integral parts of the ultimate 1 MW FREEDM System test bed. The new PHEV/PEV test bed is not shown. These test beds can only be developed by the integration of the five enabling technologies and by the synergistic team effort.

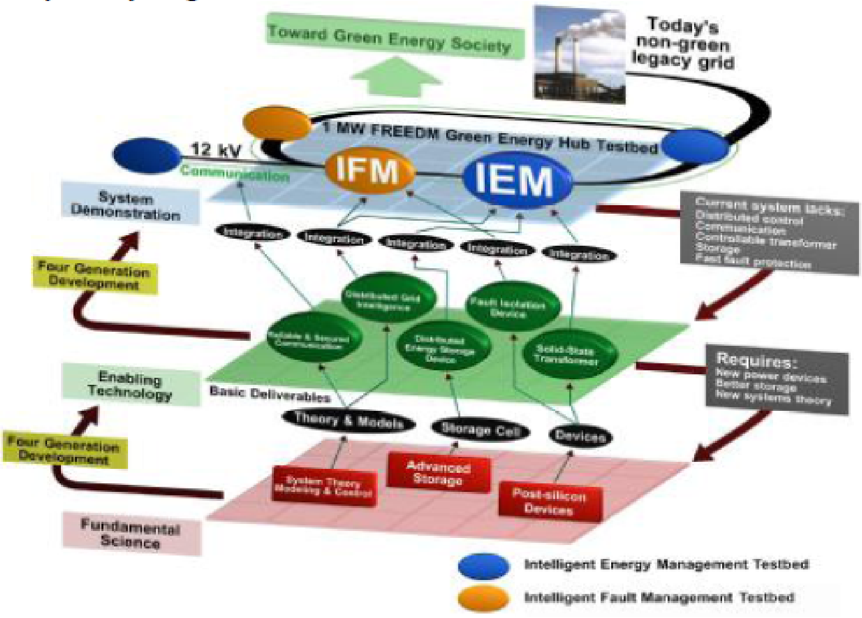

Figure 2-2. Original Center Research Area Strategic Plan

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At the end of the first quarter of the Center's research program in December 2008, we started to notice that the center research program integration through three horizontal planes/thrusts in fundamental science, enabling technology, and demonstration is not effective. For example, PSD subthrust and AS subthrust are both part of the fundamental science thrust area. But these two subthrusts do not have much need for interaction due to their very different technical fields. On the other hand, they have a much stronger interaction with the enabling technology subthrusts they support, namely SST and FID for the PSD, and DESD for the AS. Therefore we have realized that it is much more natural to achieve research program integration through vertical plan integration. This is especially true for our center because the center's system vision (FREEDM System) strongly depends on the test beds, and these test beds can only be achieved through a strong integration of technologies in the vertical direction. The test bed needs determine the requirements of the fundamental and enabling technologies, and what can be achieved in the fundamental and enabling technologies in turn determines what can be demonstrated in the test beds.

At the December ERC conference in Washington, DC, we have also learned a lot from other ERCs on how to revise strategic plan of the center and on how to use this process to achieve stronger faculty buy-in and team integration. Therefore, in January and February 2009, the Center's executive committee met several times through teleconferences, and discussed how to reorganize the center's research program. The committee then recommended the following strategic plan changes in February 2009:

- Add a PHEV/PEV test bed to emphasize our integration from fundamental storage research (AS), to DESD enabling technology, to DESD application inside the vehicle (PHEV/PEV).
- Eliminate the three thrust leaders and the horizontal integration concept, instead, empowering the leadership of the three test beds. Dr. Mischa Steurer will serve as the IFM test bed leader. This test bed integrates vertically DGI, RSC, FID, PSD and SMC sub-thrusts. Mariesa Crow will serve as the IEM test bed leader and drive the vertical integration of DGI, SST, RSC, PSD and SMC sub-thrusts. The new PHEV/PEV test bed will be led by Ewan Pritchard, a well known pioneer in plug-in hybrid vehicle technology who recently joined the Center. This will allow vertical integration of AS, DESD, and PSD sub-thrusts.

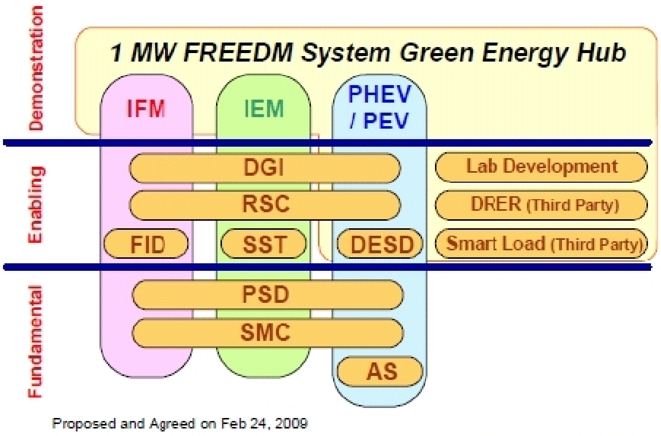

Figure 2-3, New Revised Center Research Area Strategic Plan

Figure 2-3 shows the revised three plane diagram, emphasizing the vertical integration among the various sub-thrusts.

The Center has recently further clarified the strategic relationship between the FREEDM Systems Center and NCSU's Advanced Transportation Energy Center (ATEC). ATEC was established in Feb 2008 by an investment from the state of North Carolina, Duke Energy and Progress Energy to facilitate the development of PHEV/PEV technologies. It has been agreed that ATEC activities will be considered core research projects of the ERC. The research activities in ATEC are mostly complementary to what are supported by the ERC, yet they both support a single strategic vision. ATEC will focus on advancement of PHEV/PEV hence will provide most of the funding in PHEV/PEV test bed. Additionally, ATEC's activities in motor drive and electric motor expand the center's activity into a very important area. A single industry membership will support both ERC and ATEC missions. A transportation working group will be formed under the FREEDM IAB to provide advice regarding ATEC specific activities. ATEC will remain as a Center of excellence at NCSU in order to develop technologies specifically for the transportation industry.

3.3.8.2 Communication and Interrelationships

The following example, responding to comments from a Site Visit Team (SVT) relates to best practices in the areas of communications and interactions that could identify commonalities.

Exhibit 3.3.8.2

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5.1.2 Response to Site Visit Report – Strategic Research Plan

- **The SVT recognized the complexity and dynamics of this framework in the execution of the research plan. While the topology has proven to be quite useful, the SVT recognized that just as the components of the framework are dynamic and based on biological principles, so should the strategic execution of the framework. In this spirit, the SVT recommends that the communication among the leaders in the Center be frequent and include examination of the overall strategy as well as the day-to-day operations. The temporal frequency of looking at this strategy is important and leaving it solely to semi-annual retreats may not satisfy the dynamic nature of all of the moving components of this complex center.**

We readily acknowledge that examination of the overall strategy should occur on a regular basis. In fact, we held a PIs meeting specifically to discuss and refine our strategic vision in between the semi-annual retreats this year and we likely continue to hold such meetings as the Center progresses.

- **The SVT suggests that, as part of this frequent strategic analysis, the SynBERC team examine the inter-relationships of Parts, Devices, Chassis, frequently and look for where there is commonality in moving advances between different levels of biological complexity (as represented by bacterial, yeast, plant, or mammalian systems).**

This is a good suggestion. In addition to considering how our foundational engineering research ideas can be applied across the kingdoms of life, we also anticipate extending our work on engineered biological abstractions to still higher levels of biological organization, such as synergistic relationships among organisms, including tissues and ecosystems. For example, Radhika Nagpal of Harvard is being recruited onto our SAB; she is an expert on developing programming abstractions for controlling pattern formation in systems comprised of thousands of independent agents (e.g., cells).

3.3.8.3 Keeping the Entire ERC Team Coordinated

Here the example (Exhibit 3.3.8.3) illustrates the need to ensure that all elements of the team continue collaborating and working together in a coordinated fashion.

EXHIBIT 3.3.8.3

- **The SVT did not see sufficient evidence of integrated, coordinated activities. Human practices researchers have been working on IP, biosecurity, and health and safety issues; the IAB called for policies in these areas; and scientific/engineering researchers have been active in development of policies, for example, with Bio Bricks and the proposed IP policies presented at the site visit. These efforts seemed to be disconnected from one another. It was not clear how work in one area would be informed by, and inform those in another area. The SVT also could not see anyone who was responsible for assuring that there was active, ongoing collaboration in moving any of these issues forward. For example, someone to assure a policy is in place that is responsive to IAB concerns about security, or IP.**

It is true that we have many activities proceeding simultaneously and that these could be better coordinated. We have addressed many of the coordination issues in other sections of this report. With respect to the Human Practices Thrust, Rabinow is now the sole thrust leader. We hope that having one thrust leader, as opposed to two, will help to improve coordination in the Human Practices thrust. We have designed the Thrust 4 research cluster on safety, security, and preparedness as a conceptual strategy for integrating and coordinating efforts. Our proposed project on "Globalized Forms of Preparedness and Risk Management for Synthetic Biology" will extend and formalize this integrated approach. We have submitted an FTE request to conduct this project.

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- **The Human Practices Thrust seems to be treated in a different way from the other research Thrusts. The SVT didn't see evidence of an active, ongoing exchange of ideas between scientists/engineers and humanities/social scholars in the human practices arena comparable to the sharing of ideas/equipment/platforms associated with other research areas. Is there a real give and take between scientific/engineering and human practices researchers?**

We generally agree with this diagnosis, although it should be noted that in the very first line of the SVT's report, Human Practices was not listed as one of the Center's Thrusts. Further, as the SVT points out in the report "Science/engineering researchers do not seem to fully appreciate that there is an opportunity – of the same kind as in other technical areas – to provide world class leadership in an influential, emergent area of [human practices] research." In general, it is often difficult to engage scientists/engineers in human practices aspects of their work, maybe because they view it as a distraction. However, in general, we believe that SynBERC's investigators are more engaged in ethical issues of synthetic biology than other scientists have been in the ethical issues of their own scientific disciplines. Nonetheless, SynBERC needs to improve in this regard, and we intend to do so. Rabinow will propose to Keasling a structured formula to address these issues.

3.3.8.4 An Important Element of Research Not Being Addressed Adequately

In this example (Exhibit 3.3.8.4) it was learned that changes had to be made to include more attention and investment so that one important element of research (in this case, packaging) could be addressed adequately.

EXHIBIT 3.3.8.4

- **Packaging, a critical element to component integration, is not being adequately addressed.**

  We are aware that this critical element needs additional attention and investment. While much of the actual packaging research is in fact ongoing within MIRTHE's industrial partners, who have the requisite resources and incentive to optimize packaging, a smaller core of our industry members have approached MIRTHE to address packaging issues. When the opportunity arose to compete for ERC Innovation Awards in 2009, we proposed – and were awarded – a program termed "MIRTHE Industry Experts in Packaging." Through this program MIRTHE is able to retain a significant fraction of time and effort of two industry experts, who have long-standing experience in semiconductor device packaging (a more detailed description of the program can be found in Volume II). The program commenced January 2009, and new (used) packaging equipment has been ordered; the new packaging lab-building will proceed through the spring of 2010. With improved equipment, and – more importantly – industrial-level packaging expertise we expect to greatly enhance MIRTHE's packaging capabilities.

  Furthermore, MIRTHE's basic research in component integration in Thrust 3 has seen great progress through this reporting period; hence promising true packaging innovations originating from the center soon.

3.3.8.5 Monitoring Progress and Deliverables

This last example (Exhibit 3.3.8.5) reveals that a site visit team discovered that achieving the centerâ€™s system-level goals would not be possible without further advances in component-level technologies. One element of the response was to continue bringing new faculty into the center to provide needed expertise. The earlier that monitoring of progress during implementation (a best practice) can identify shortfalls such as this, the earlier that corrective actions can be put into place.

EXHIBIT 3.3.8.5

- **System level goals are not possible without further advances in component level technologies, i.e. detectors, passive optics, integration, and thermal management;**

  We agree with the SVT's assessment of the need for advances in component level research; this is why an entire plane (the lowest one) of MIRTHE's strategic plan is dedicated to component development. We believe we have been able to demonstrate continued improvement in performance of our systems as individual component performance is enhanced. The QEPAS sensors are an example of an area where we are already making great strides towards our system level goals for medical and environmental applications. Nevertheless, it is clear there are fundamental technology barriers which must be overcome to achieve some of the particular proposed goals. One of our strategies to achieving this is continuing to bring new faculty into the center because of the need for expertise in specific areas (e.g. detectors) to meet system goals.

3.4 Best Peactices to Integrate Research and Industry

3.4.1 Why Integration with Industry?

The very nature of ERCs dictates continual involvement of industry (e.g., through strategic planning, by providing an industrial perspective on the research connected to specific projects, and with joint projects). The end objective is transferring tangible deliverables to industry, thus accomplishing a successful hand-off.

The subsections that follow discuss several aspects of this integration with industry in the context of the research thrust leaderâ€™s role, best practices, and things to avoid. A case study for one second-generation (Gen-2) ERC is at the end.

Readers should be aware that some of the best practices delineated in this section received additional comments in late 2010 and early 2011 from persons very familiar with ERC interactions with industry. These comments were of two general types: (1) suggestions relating to Gen-2 ERCs that were intended to clarify relationships between the ERC Director, the Industrial Liaison Officer (ILO), and research thrust leaders with respect to their industry-focused responsibilities; and (2) comments most applicable to the newer third-generation (Gen-3) ERCs. Because Gen-3 ERCs are addressed in Section 3.6, comments most related to Gen-3 integration with industry appear there. Three comments that typify some of the interchange appear below:

â€œExcellent write-up â€¦ [but] written for decentralized management model and a product (not process) center ...â€• [Editorial Note: Gen-3 process center addressed in Section 3.6.]

â€œ... this technical industry interface stuff is a force fit, whether you are Gen-2 or Gen-3. Some of it would be more appropriate if the Center has a testbed manager structure, but it should all be coordinated by the ILO.â€•

â€œ[Several] comments mainly refer to the role of the 'Industrial Collaboration and Innovation Director' and his/her interactions and relationships with other leadership members, in particular Thrust Leaders. The Industrial Collaboration and Innovation Director is a requirement of the Gen-3 Centers, and the functions and responsibilities are somewhat different [from] the ILO required in Gen-2.â€•

3.4.2 Research Thrust Leaderâ€™s Role in Integration with Industry

The research thrust leader is an important technical interface between an ERC and its industrial partners. Depending on the ERC, and recognizing that the Center Director is the top technical interface with industry, the Director may delegate to one or more research thrust leaders certain responsibilities. These responsibilities could include (a) helping to identify opportunities for effective collaborations between principal investigators in various thrusts and appropriate industrial partners, or (b) helping to manage the expectations of industrial partners. (Individual research faculty are also valuable in providing leads for the ILO to further develop.)

Roles of the thrust leader may include

- identifying critical bottlenecks that industry will encounter;
- developing strategies to lead and focus the thrust to find solutions to these bottlenecks; and
- aiding the Director as technical â€œco-gatekeeper,â€• which entails monitoring progress of industrial deliverables while ensuring the long-term scientific goals of the thrust are accomplished.

Finally, one of the most important functions of a research thrust leader lies in balancing the individual projects within a thrust and facilitating opportunities for coordinated interactions among an ERC's thrusts. With respect to industry, this function bears with it a responsibility of being aware of what industry currently requires and will require in the future as well as the expectations of various industrial partners relative to the research thrusts.

3.4.3. Best Practices Regarding Portfolio Balance, Communication, and Roadblocks

As part of a successful research thrust, there should be a mixture of both short- and long-term deliverables that are of interest to industrial partners. The portfolio should also be balanced within the thrust without compromising the ERC's scientific and engineering vision. Moreover, it is incumbent on the Center Director, aided appropriately by thrust leaders in concert with the ERC's industrial and scientific advisors, to establish a balance between more fundamental scientific work and work that will further the technological state of the art.

Based on technical insight into the capabilities of principle investigators working within the thrust, the research thrust leader can communicate with *senior technical* industry personnel to ensure that their needsâ€”both short- and long-termâ€”are being addressed. The ILO should be kept well apprised of such interactions to be effective in maintaining the overall engagement of industry members over the long term. From time to time, research thrust leaders can also organize meetings, panel discussions, and other mechanisms that involve both industry representatives and researchers. These â€œget-togethersâ€• might, for example, address the needs of industry, explain research progress as well as the lack thereof, and reveal potential technical roadblocks that must be overcome.

3.4.4 Best Practices for Industrial Collaboration

The research thrust leader should foster a culture of collaboration between industry in general and the ERC. This type of collaboration will enable access to the latest technology advances made by the ERC, thus helping to ensure that industry is kept abreast of the current state-of-the-art and allowing efforts of the center to be focused on extending these advanced capabilities rather than reproducing them time after time for different segments of industry.
As an example of collaboration, an industrial mentorship program should be enabled. This would involve seeking appropriate mentors from the industrial partners who are well versed in the relevant technological and scientific disciplines of the university partners. These mentors would be available to students, preferably at regularly scheduled opportunities.
It is important to establish ERC-wide consistency with regard to industrial collaborations. To achieve this consistency, a common set of collaboration policies should be determined among the research thrust leaders within the ERC and in close consultation with the ILO.

3.4.5 Things to Avoid

To manage a research thrust effectively it is best for research thrust leaders to avoid intellectual-property issues, instead delegating those to the administrative and industrial liaison/legal staff of the center. Research thrust leaders should focus on the technical, not the legal, goals of the ERC and technology transfer. It must be noted that this type of delegation should not be interpreted as reducing the ILO to an administrative functionary. In most cases, intellectual-property issues requiring negotiations are conducted by the responsible academic partner, thus allowing the ILO to avoid appearing to be industry's adversary in technology-transfer engagements.
In addition, bilateral financial â€œdealsâ€• (e.g., involving commonly held ERC intellectual property) between individual ERC investigators and industry should be avoided. Such an outcome would threaten the sustained support of the ERC from NSF. Negotiating financial terms with potential member companies should only be done on behalf of the ERC as a whole by the appropriate ERC staff. In fact, a consistent umbrella of industry-ERC partnership rules should be adhered to. (It should be noted that this guidance could impact any Gen-2 ERC that elects to use â€œhome-grownâ€• start-ups as a mechanism for technology transition and commercialization.)
Conflicts between the desire to continue basic research versus the need to produce development products, which are usually under the purview of testbed managers, should be dealt with only through clear and mutually subscribed-to policies and procedures. Research thrust leaders should note that industry can sometimes serve a role in this situation by stepping in and helping to make sure that the research ideas get turned into desirable end products.

3.4.6 Case Study: Project Mentor Program at the Center for Structured Organic Particulate Systems (C-SOPS)

One instrument for promoting scientific collaboration and a better integration between academic and industrial colleagues is the establishment of a formal mentor program reaching all projects in the thrust. Such a program has been successfully implemented at the Rutgers-based C-SOPS, with a membership exceeding 30 companies. The mentor program is best described in terms of the roles and responsibilities of both the industrial and academic personnel.

3.4.6.1 Industrial Roles

Lead Project Mentor

- Is the primary contact with the academic project team
- Acts as chair of the mentor team composed of all projectsâ€™ mentors
- Coordinates project evaluation on behalf of the center
- Working with the project leader, provides feedback to the Steering Committee and makes recommendations on any changes needed
- Attends the annual NSF site visit when required
- Acts as a center champion with NSF

- Provides input for technical reports as requested by the project leader.

Individual Project Mentors

- Participate in monthly project team teleconferences
- Assist lead mentor in project progress evaluations
- Provide an industrial perspective to center researchers
- Evaluate progress in project on behalf of their companies
- Help students (and faculty) gain an understanding of issues that are important in using center research findings in practical applications
- Facilitate incorporation of center findings into industrial practice
- Serve as project "champions," helping convey to their companies and the center executive committee a sense of the value delivered by the project
- Help center researchers gain additional resources (e.g., materials, equipment) from vendors and industrial contributors
- Provide other support in agreement with lead project mentor and project leader, including examples like:

o connecting to cutting-edge research relevant to the project;
o proposing or supporting advanced experimental approaches, design of experiments, or data analysis;
o providing tools, input, or support for capacity analysis, resource utilization, and project scope;
o conducting additional literature searches, such as using advanced search engines available to industry; and
o providing research technical expertise, where relevant.

3.4.6.2 Academic Roles

Project Leader

- Develops overall research plan for project
- Coordinates all project research activities with respect to participants, universities, and interrelated projects within and outside the thrusts
- Assures that all project participants are aware of the overall ERC strategic plan and their places within it
- Proposes and harmonizes deliverables with testbed leader
- Tracks and reports progress relative to thrust-level scientific goals and testbed deliverables (includes early communication of deviations from plan)
- Identifies and procures needed project resources (includes leveraging external funding)
- Organizes monthly project meeting for entire project team
- Maintains Social-Text (enterprise networking) workspace for project
- Prepares two technical reports annually and provides input to the thrust leaders in compilation of the project report and site-visit presentations in a timely manner
- Provides timely project-level input to the center-wide NSF annual reporting process.

Project Participants (Faculty)

    - Propose research plans for allocated project tasks
    - Participate in monthly project meetings and teleconferences
    - Work with the project leader to ensure that all project-task participants are aware of the overall ERC strategic plan and their place within it
    - Provide frequent updates on status to project leader
    - Provide formal, written inputs to project leader in a timely fashion when project reports and presentations are due.

3.5 Best Practices to Integrate Research and Education

3.5.1 Why Integration with Education?

Integrating research and education in the ERC curriculum is an effective way to bring undergraduate and graduate students together into the vision of the ERC and its connection to professional practice. The resulting courses can stimulate undergraduates to join research teams, provide a means to incorporate research findings into future curricula, and can change the engineering and science culture through interdisciplinary emphases. The projects for these classes can be inspired from the ERCâ€™s strategic plan â€“ designing and building systems supporting the top two planes of the three-plane chart. In addition, these courses could select some of the fundamental technology on the first plane to incorporate into their system, thereby accelerating the readiness of the technology for use by others. The topics and case study below illustrate best practices to achieve the desired integration

3.5.2 Culture Change and Joint Responsibilities

One way in which ERCs have changed the traditional discipline-oriented culture of ERC-participating universities through education is by creating new interdisciplinary courses, including interdisciplinary ABET (Accreditation Board for Engineering and Technology)-accredited Engineering Capstone Design Courses, and even new interdisciplinary degree programs. An even more aggressive goal is to have the interdisciplinary courses recognized as fulfilling capstone design requirement in multiple engineering departments.

There are joint responsibilities between research thrust leaders and ERC education or outreach directors with respect to education at all levels, from K-12 to undergraduate to graduate. In addition, there are responsibilities with respect to faculty. In particular, this joint team has to resolve allocations, such as:

- receiving credit in home departments for developing and teaching ERC-related, multi-disciplinary courses;
- materiel costs (e.g., for system building);
- laboratory space; and
- intellectual-property issues.

3.5.3 Challenges

Research thrust leaders within each ERC must strive to develop innovative solutions and structures to secure adequate resources for curriculum development and other education-related activities. Resources may be obtained from multiple sources, including deans, department heads, industry, and research contracts, as well as the ERC budget. The situations in each ERC will be different, and indeed they may be different for each university member of a multi-university ERC.

Another challenge for geographically distributed ERCs is how to engage students in the overall research plan. To address this, one ERC holds a mandatory one week long summer workshop for the entire ERC. The venue rotates among the participating universities.

With the increased participation of foreign universities in third-generation ERCs, an additional challenge is maintaining balance in exchanges (e.g., of students or course-work) when the resources are unequal. (Section 3.6 on Gen-3 ERCs contains more discussion of challenges with respect to foreign universities.)

3.5.4 Opportunities

ERC integration with industry presents opportunities for education. To a great extent, industry focuses on shorter-term advanced development rather than longer-term research. This situation produces opportunities for student-led research teams to engage in industrial-inspired problems and gain access to hard-to-acquire data and support (e.g., equipment and money). Of course, associated challenges must be solved, such as industrial expectations of the robustness of results, intellectual-property ownership, and taking care that the student research is appropriate for education.

3.5.5 Case Study: Rapid Prototyping of Engineered Systems at the Quality-of-Life Technology (QoLT) ERC

With the advent of rapid-design methodologies and rapid-fabrication technologies, it is possible to construct fully customized engineered systems in a matter of months. Carnegie Mellon-based QoLT has developed a User-Centered Interdisciplinary Concurrent System-Design Methodology (UICSM) in which teams of electrical engineers, mechanical engineers, computer scientists, industrial designers, and human/computer-interaction students work with an end-user to generate a complete prototype system during a four-month-long course (see Endnotes 6 and 7).

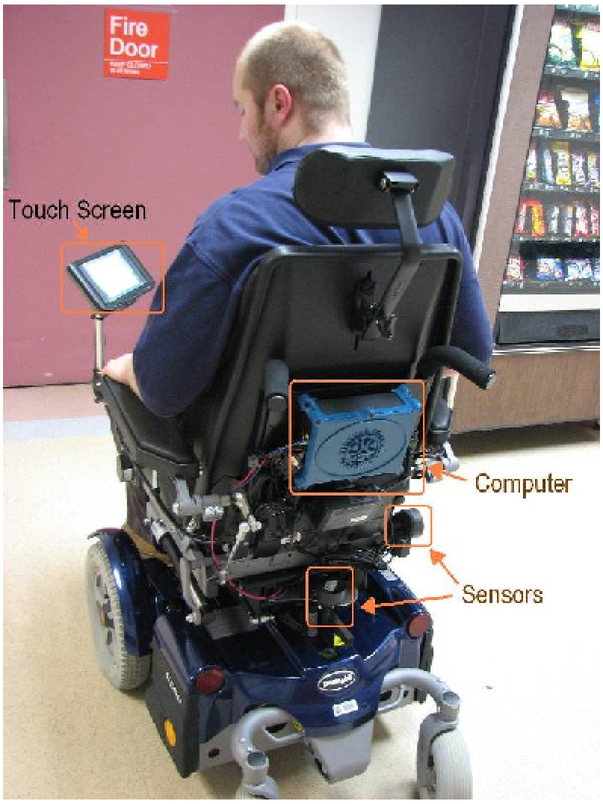
The methodology defines intermediary design products that document the evolution of the design. These products are posted on the Internet so that even remote designers and end-users can participate in the design activities. The methodology includes monitoring and evaluation of the design process by a dedicated faculty member and

proceeds through three phases: (1) conceptual design, (2) detailed design, and (3) implementation.
End-users critique the design at each phase. In addition, simulated and real-application tasks provide further focus for design evaluation. Based on user interviews and observation of their operations, baseline scenarios are created for current practice. A visionary scenario is created to indicate how technology could improve the current practice and identify opportunities for technology injection. This scenario forms the basis from which the requirements for the design are derived as well as for evaluating design alternatives. Both types of scenarios are reviewed with the end-user.
A technology search generates candidates for meeting the design requirements. Several architectures are generated next, each appropriate to the various disciplines and involving:

- Hardware
- Software
- Mechanical
- Shapes and materials
- Human-interaction modes.

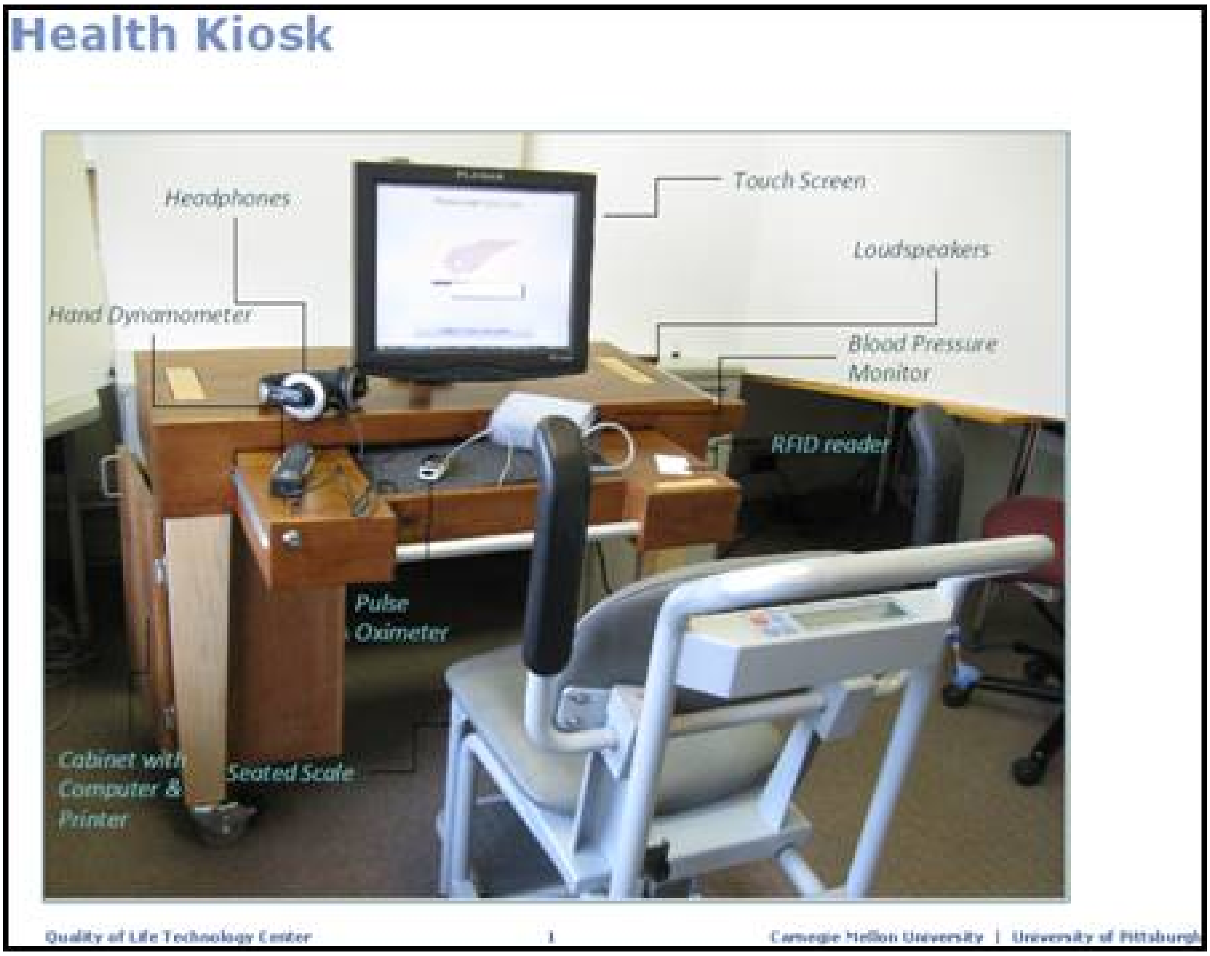
User feedback on scenarios and storyboards becomes input to the detailed design phase. Designers alternate between the abstract and the concrete. Preliminary sketches are evaluated, new ideas emerge, and more precise drawings are generated. This iterative process continues with soft mock-ups, appearance sketches, as well as computer and machine-shop prototypes, until finally the product is fabricated.
Iterative evaluation by end-users throughout the design process yields the equivalent of a second-level (i.e., beta) prototype that is much closer to deployment than a prototype produced by a traditional design methodology. Further development through the Summer semester by selected students from the class yields a prototype suitable for pilot studies. Engagement of between 20 and 25 students from multiple disciplines (computer engineering, electrical engineering, mechanical engineering, computer science, industrial design, and human-and-computer interaction) yields 4,000 to 5,000 engineering hours devoted to an integrated-system prototype.
UICSM has been refined through more than 15 years of experience resulting in over two dozen mobile systems. Applications have included heavy-equipment maintenance (e.g., aircraft, airport people movers), Pennsylvania bridge inspectors, manufacturing, off-shore oil platforms, language translation for NATO troops, plus three example systems of QoLT-designed access technologies shown in Figure 3.5.1 (a-c).

Seating Coach

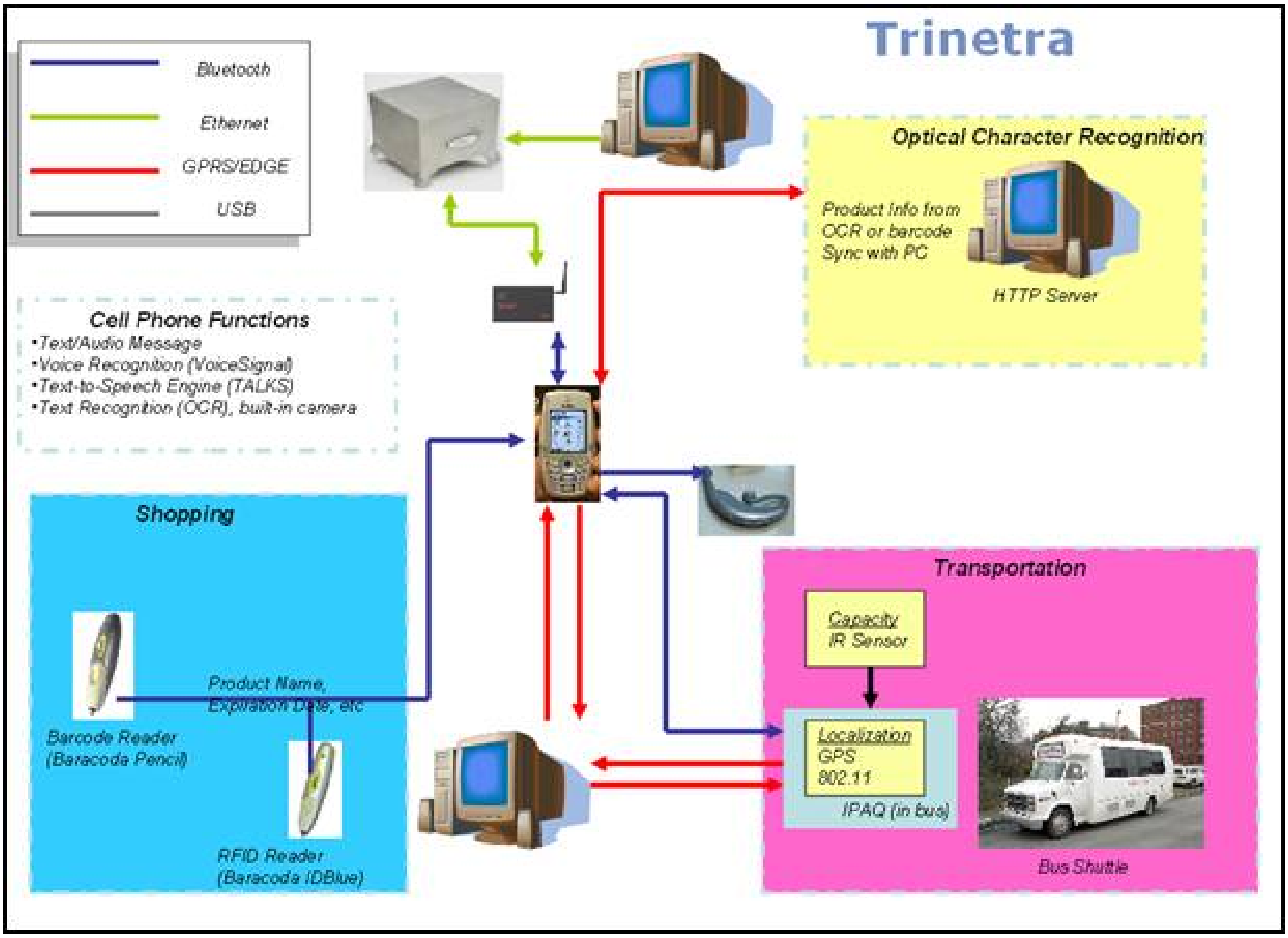


Virtual Seating Coach

3.5.1(a) Power Wheelchair Virtual Coach



3.5.1(b) Health Kiosk for Seniors Living in High-Rise Buildings



3.5.1(c) Trinetra Transportation and Optical-Character Sign Recognition to Aid the Blind
Figure 3.5.1 Three example systems of QoLT access technologies produced by the class using UICSM *(from Prof. Daniel P. Siewiorek; credit: Carnegie Mellon University)*.

3.6 Generation-3 Engineering Research Centers

3.6.1 Gen-3 ERC Features

Driven primarily by the goal of actively stimulating technological innovation, NSFâ€™s new third-generation (Gen-3) ERCs are characterized by features including the following (see Endnote 1):

- Advancement of cross-disciplinary, transformational research and engineered systems through engagement with small firms
- Partnerships with member firms and organizations dedicated to stimulating entrepreneurship and speeding technological innovation
- Development of an engineering workforce that is innovative and globally competitive
- Partnerships with foreign universities to provide cross-cultural, global research and education experiences
- Long-term partnerships with middle schools and high schools to bring engineering concepts to the classroom, thereby increasing interest in future enrollment in college-level engineering programs.

Because these Gen-3 features rest on the core ERC construct common to all ERCs, many best practices for earlier ERCs will prove useful for Gen-3 centers. Nevertheless, some Gen-3 featuresâ€"particularly funding small start-up firms for translational research from the ERC base budget, and partnerships with foreign universities and pre-college schoolsâ€"could suggest substantial changes to past best practices. The paragraphs below illustrate several situations.

3.6.2 Some Gen-3 Situations that Might Require Change from Past Best Practices

Consider, for instance, the best practices associated with the major topics of this chapter: preparing and executing a strategic plan and integrating research with industry and with education. There may be little difference between Gen-3 ERCs and prior ERCs in which researchers are located at several geographically dispersed locations in the United States. However, when one includes foreign universities, that introduces a new dimension.
For example, communications involving foreign universitiesâ€"even if by phone or â€œgo-to-meetingâ€• or sophisticated video teleconferencingâ€"could be difficult because of the very different time zones. But time-zone problems may be small compared to cultural and administrative differences between U.S. practices and those of foreign universities. For example, aspects of the following best practices for research thrust leaders could become substantially more complicated:

- Defining responsibilities and authorities for organizations and individuals
- Creating and sustaining buy-in
- Reaching decisions on budgets and resource allocations when the foreign component has to be funded by foreign sources of funds
- Deciding on deliverables and their schedules
- Establishing appropriate metrics
- Agreeing on financial terms and intellectual-property issues
- Resolving conflicts between research and industrial products
- Maintaining balance in education exchanges.

Similarly, dealing with pre-college schools could also complicate matters (the above section on integrating research and education recognizes K-12 affiliations). There is great interest within the United States on furthering STEM (science, technology, engineering, and math) education for young students. Nevertheless, preparing and executing strategic plans and integrating industrial firms (especially small ones) not only with U.S. and foreign educators but also with middle- and high-school teachers, is challenging for Gen-3 ERCs.

3.6.3 So What Is Needed?

It is apparent that some of the best practices delineated earlier in this chapter will need to be changed to accommodate certain Gen-3 features. Lessons learned from the early years of Gen-3 operations will shed light on just what changes are necessary. Therefore, a suggested best practice for start-up Gen-3 ERCs would be to document the kinds of best-practice changes they find necessary to accommodate the special features of Gen-3 operations.

However, there are other sources for best practices than ERCs themselves. At least two other groups come to mind.
First, many U.S. businesses operate on a global scale. They too prepare and execute strategic plans of global scope, and some also likely have ties of one kind or another to foreign universities. Several of these businesses should be good sources of best practices for the Gen-3 personnel (see Endnote 8).

Second, with all the U.S. interest in STEM education for pre-college students, several organizations could suggest best practices to the Gen-3 personnel. These organizations would include various entities in or associated with the Department of Defense (see Endnote 9) as well as the House of Representativesâ€™ STEM Caucus and STEM Caucus Steering Group.

When there is sufficient experience upon which to build a set of best practices for Gen-3 ERCs, revisions to this chapter and others in the Best Practices Manual will be developed and released.

3.6.4 Items of Particular Relevance

In late 2010 and early 2011, many additional comments relating to Gen-3 ERCs were received. This subsection summarizes those comments. To start, several important messages appear below. These are amplified in following paragraphs.

â€œ... agree with the speculated differences and also with the approach of allowing real experiences to develop and be incorporated later.â€•

â€œ[XXX University] will not allow us to enter into any export control licenses as these represent restrictions on academic freedoms. Instead we have had to find routes to basic research exemptions to export control. In a recent project in [YYY], we had to construct a locked structure to secure our testbed and hire a guard to monitor access to the prototype 24/7. Also, only US citizens were allowed to operate the equipment in [YYY] â€” except for one [YYY] student who had fortunately been trained on the equipment in [XXX University] during the prior year.â€•

â€œA major issue we have encountered to date is mentioned â€“ how to work with the foreign collaborators when you cannot provide a direct fiscal incentive. We don't have it successfully solved yet, but are trying.â€•

Concerns exist regarding intellectual-property issues and research-versus-product conflicts.

Significant differences exist between Gen-3 and Gen-2 ERCs relative to integration with industry (see introductory comments in Section 3.4).
Export Controls. As noted above, Gen-3 ERCs need to pay particular attention to potential International Traffic in Arms Regulations (ITAR) and Export Control issues. Export Control restrictions are especially challenging when it comes to operating testbeds in foreign countries, even in countries that are considered friendly allies. Beyond the complexities of sending prototypes lacking U.S. security classifications, export controls restrict information flows as well. For example, foreign students might be trained on U.S.- based testbeds, but foreign students at a foreign partner institution might not be allowed to train on the exact same testbed outside the United States.

Working with Foreign Collaborators. With respect to creating and sustaining buy-in, experience suggests that foreign-partner involvement is usually developed because of a specific relationship between individual ERC faculty and a collaborator at a foreign partner. Leveraging that professional relationship tends to create the most functional interactions. With respect to the possibility of learning from U.S. businesses that operate on a global scale, management of export-control issues remains critical (see above). Industrial processes for managing global technology interactions may or may not be applicable in academic situations, which require preventing information flow between U.S. and foreign subsidiaries except through carefully structured legal agreements and joint-venture arrangements. Some U.S. universities have detailed guidelines, others don't. With respect to working with foreign educators, finding ways to leverage foreign STEM initiatives could be attractive to U.S. educators. One challenge with also integrating smaller firms is that they are typically very lean and don't have the band-width for these types of initiatives unless there is support from their investors (probably a better place to engage).

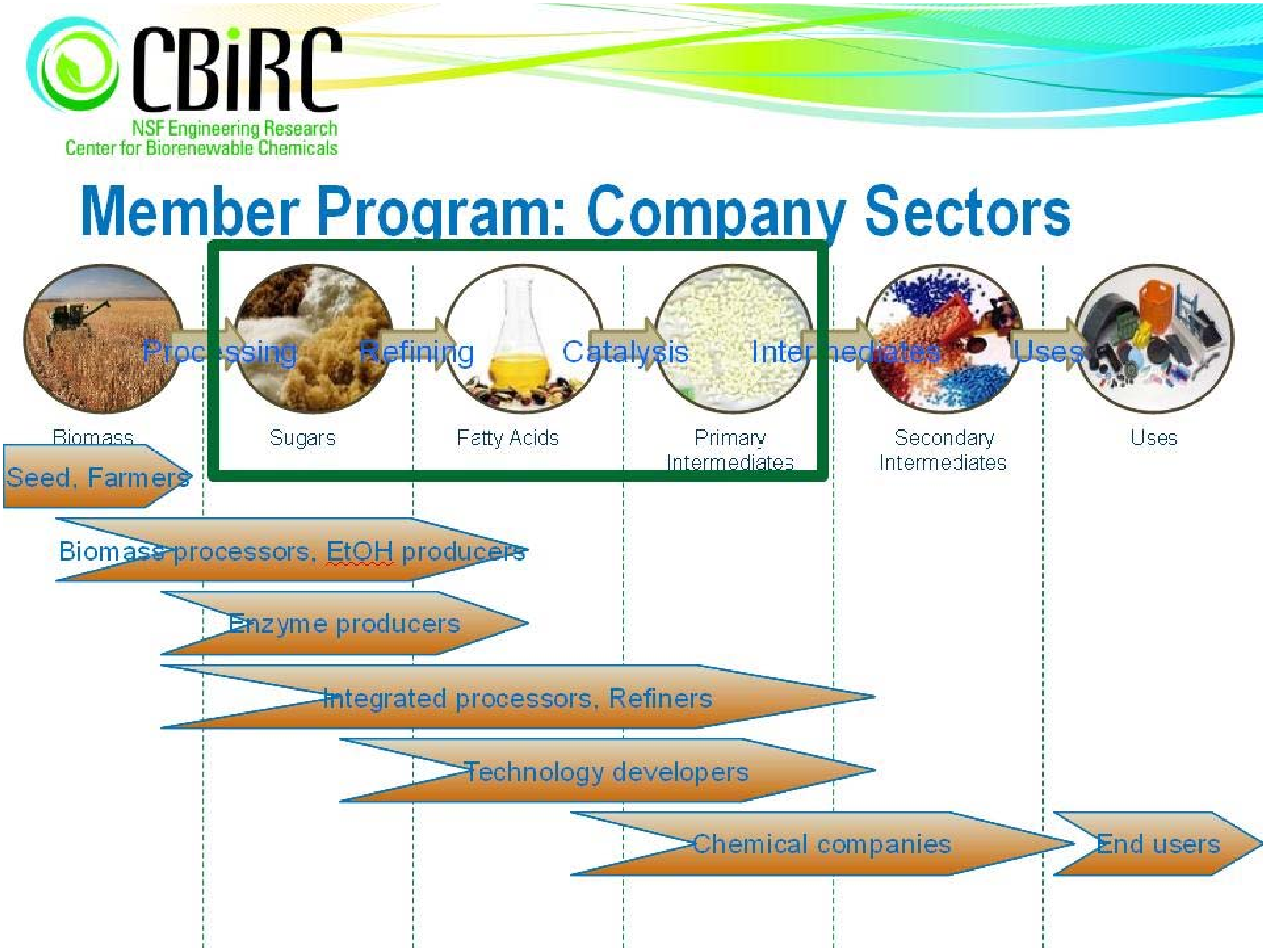
Intellectual Property Relative to Start-ups and Small Firms. Gen-3 ERCs are expected to have active start-up/innovation infrastructure, which may bring the ERC industry members' rights to intellectual property into conflict with fostering home-grown start-up firms, especially if exclusive intellectual-property rights are needed for start-up survival. One comment noted that, in a survey conducted last year, many of the Gen-3 ERCs did not have specific policies and procedures to navigate these â€œunchartered â€• waters, especially when the start-ups cannot afford to pay membership fees at a level comparable to existing member firms. Another comment indicated that, although the notion of an ERC playing an â€œangelâ€• role in start-up funding is being considered, it is highly unlikely that the funding levels being considered would ever be large enough to have an impact on start-up viability. It needs to be recognized that small, high-technology firms are frequently unwilling to risk diluting their intellectual-property-generation capability by partnering with an ERC developing intellectual property in a space the small firms consider their own. This situation has been encountered with small firms looking at the ERC core (most transformational) programs.

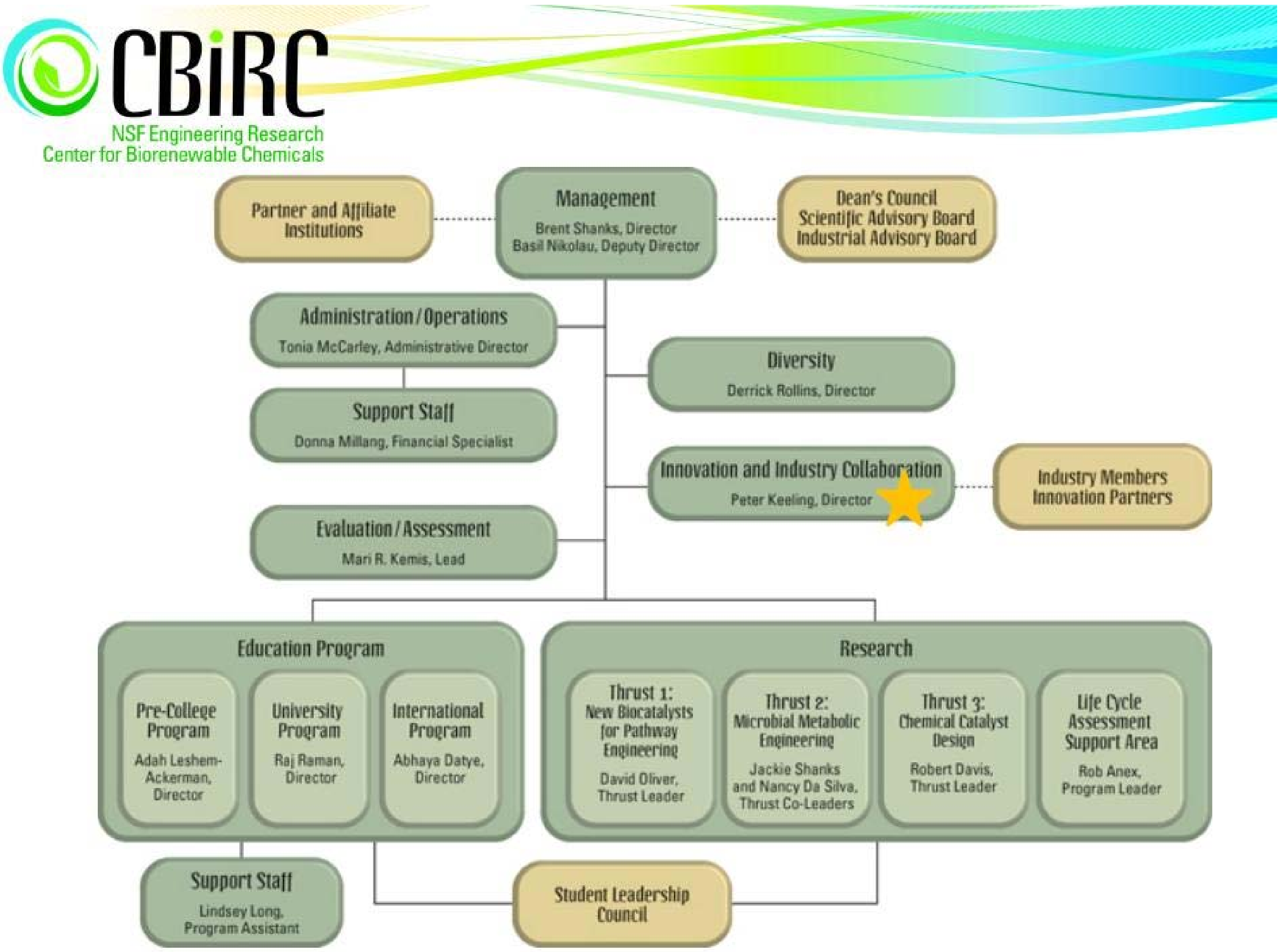
Resolving Research-versus-Product Conflicts. Relative to resolving conflicts between research and industrial products, clear delineation between core ERC research and development (accessible by all ERC industrial members) and non-core, synergistic-sponsored (or more applications-specific) research is important. Synergistic research can also be sponsored in particular areas to speed technology innovation and transfer.

Gen-3 Integration with Industry. One person from a Gen-3 ERC contributed valuable comments by means of a slide presentation. The presentation was specifically oriented at Section 3.4, which addressed best practices for integrating research and industry. Because Gen-3 is the primary focus of Section 3.6, it was deemed best to include elements of that presentation here.

- Best practices for Gen-3 ERCs should explicitly recognize inclusion of innovation/venture partners in addition to industrial partners. Such partners can bring significant opportunities for early stage innovations to materialize (e.g., through start-ups).
- In light of the importance of innovation/venture partners, best practices for Gen-3 ERCs should also include recognition of the Industrial Collaboration and Innovation Director (ICID) as well as appropriate interactions between this Director and research thrust leaders (e.g., the Director manages and the thrust leaders assist).
- Depending on the Gen-3 ERC, some intellectual-property issues may be taken care of by the ICID.
- Regarding portfolio balance, communications, roadblocks, and industrial collaboration, there should be general sharing of best practices between the ICID (broader, across-ERC issues) and individual thrust leaders (primarily within-thrust issues).
- Perhaps a workshop day could be set up to acquaint industry employees at one end of a process spectrum to a basic overview of research and technology at the other end of the process spectrum.

The three charts below furnish an overview of the ERC for Biorenewable Chemicals (CBiRC), the Gen-3 â€œprocess centerâ€• that was a basis for these suggestions. Note ICID (starred) in second chart.





CBiRC INDUSTRY MEMBERS AND PARTNERS

Industry Members: Allylix, Ashland, Chevron Phillips, Cibus, Danisco, DSM, Elevance Renewable Sciences, Genomatica, Grain Processing Corporation, Glycos Biotechnology, Novozymes, Poet Energy, Solazyme, The BioBusiness Alliance Minnesota

Innovation Partners: BioCentury Research Farm, Biomass Energy Conversion Facility, Center for Crops Utilization Research, Iowa Department of Economic Development, Iowa Values Fund, Iowa Demonstration Fund, Local Seed/Angel Funds, Pappajohn Center for Entrepreneurship, University Research Park, University Entrepreneurship Courses, University Offices of Intellectual Property, University/State Business Plan Competition

Venture Partners: Illinois Ventures, Khosla Ventures, Kleiner Perkins Caufield & Byers, Equity Dynamics, Mayfield Fund, Cimarron Capital

3.7 Contributing Authors

Norm Haller, a technical consultant working with SciTech Communications LLC, coordinated the contributions of a task group of ERC staff and wrote the chapter. **Court Lewis**, President of SciTech, organized and oversaw this effort. The ERC task group was led by **Wendell Lim**, Deputy Director of the Synthetic Biology Engineering Research Center (SynBERC), headquartered at UC-Berkeley, and **Henry Kapteyn**, a thrust leader at the ERC for Extreme Ultraviolet Science and Technology (EUV ERC), based at Colorado State University.*

The formative meeting for this work took place on December 2, 2009, as part of the National Science Foundationâ€™s ERC Program Annual Meeting in Bethesda, Maryland. Several teams met in an all-afternoon Research Thrust Leadersâ€™ Workshop to prepare a revised outline of Research Management Best Practices and develop some elements of the content. **Monika Ivantysynova,** Center for Compact and Efficient Fluid Power; University of Minnesota (CCEFP), was the team leader for Section 3.2. **Rich Schulz,** Quality of Life Technology ERC; Carnegie Mellon University (QoLT), led Section 3.3. **Alberto Cuitino,** ERC for Structured Organic Particulate Systems; Rutgers University, led Section 3.4. **Dan Siewiorek,** Quality of Life Technology ERC; Carnegie Mellon University (QoLT), led Section 3.5.

This chapter reflects the material developed there and subsequent reviews and additional inputs by workshop team members, as well as review by NSF ERC Program staff. In particular, in late 2010 and early 2011 additional comments relative to Sections 3.4, 3.5, and 3.6 were received by Court Lewis and Norm Haller. Some of these comments were from two original contributing members listed above (Alberto Cuitino and Dan Siewiorek). Other contributors were Joseph Montemarano, Executive Director, ERC on Mid-InfraRed Technologies for Health and the Environment (MIRTHE), Princeton University; Robert Karlicek, Center Director, ERC for Smart Lighting, Rensselaer Polytechnic Institute; Jacqueline Vanni Shanks, Thrust 2 Leader at the Center for Biorenewable Chemicals (CBiRC), Iowa State University; and William Wagner, Deputy Director, ERC for Revolutionizing Metallic Biomaterials (RMB), North Carolina A&T State University.

**Dr. Lim is on the faculty at the University of California at San Francisco, a SynBERC partner institution. Dr. Kapteyn is a faculty member at The University of Colorado-Boulder, an EUV ERC partner.*

3.8 Sources and References

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Endnote 2. Williams, J.E., Jr., and Lewis, C.S. (2010). Post-Graduation Status of National Science Foundation Engineering Research Centers: Report of a Survey of Graduated ERCs. Prepared for Engineering Education & Centers Division, Directorate for Engineering, National Science Foundation. Melbourne, Florida: SciTech Communications, January 2010. [http://erc-assoc.org/sites/default/files/topics/Grad_ERC_Report-Final.pdf]

Endnote 3. See the following source for discussion of the components of what a National Research Council committee judged to be mandatory considerations for a ÃƒÂ¢Ã¢â€šÂ¬Ã…â€œworld-classÃƒÂ¢Ã¢â€šÂ¬Ã‚Â• research and development organization. (National Research Council. 1996. *World-Class Research and Development: Characteristics for an Army Research, Development, and Engineering Organization.* Washington, D.C.: National Academy Press).

Endnote 4. Cliffs Notes: Concepts of Management 2. Give team members the correct amount of authority to accomplish assignments. [https://www.cliffsnotes.com/study-guides/principles-of-management/creati...

Endnote 5. Hal Johnson. Transition Issues: Create and execute a strategic plan for your company. Sacramento Business Journal. [https://www.bizjournals.com/sacramento/stories/2003/12/01/smallb7.html].

Endnote 6. Siewiorek, D.P., Smailagic, A., and Lee, J.C. (1994). An interdisciplinary concurrent design methodology as applied to the Navigator wearable computer system. Journal of Computer and Software Engineering, Ablex Publishing Corporation, 2(3), 259-292.

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for electronic/mechanical design. Proc. ACM / IEEE Design Automation Conference, 514-519.

Endnote 8. One source for the names of global companies who have disseminated best practices for their operations is Plant Success. [https://web.archive.org/web/20100417024213/http://www.plantsuccess.com/a...

Endnote 9. Information on the nationwide STEM education program for youth, known as StarBase, is available from Ernie Gonzales, Office of the Secretary of Defense, Reserve Affairs. [Ernie.gonzales@osd.mil] Other sources for STEM information include the National Defense Industrial Association, the Air Force Association, and The National Academies.