FREEDM SYSTEMS CENTER SUSTAINABILITY PLAN

MARCH 2015

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VISION

The FREEDM Systems Center is a systems focused collaboration of industry, research, and education professionals who work to overcome the barriers to the widespread adoption of clean distributed renewable energy. It is anticipated that by 2018, when the center graduates from NSF funding, the center will have successfully implemented four generations of technology that paves the way towards this reality. In addition to implementing these four generations of technology, it is anticipated that the center will be able to report significant strides toward creating commercialized products with industry partners to meet these goals, and produce a well-educated workforce to aid in the development and deployment of these products in industry.

It is anticipated that while significant milestones will be achieved under the initial 10 years of work within the center, it is merely a beginning for the change needed to deliver and to manage higher and higher percentages of our electric energy from distributed renewable sources. A recent Deutsche Bank Securities report[1] shows that grid parity (i.e., the levelized cost of ownership (LCOE) of solar power being equal to or lower than that of energy delivered from an electric utility) is anticipated to occur in 27 states by 2016. This market movement is a significant driver for electric utilities to embrace the FREEDM System rather than move to a series of fully disconnected systems. This being said, there is significant work to be accomplished before widespread use of the technologies espoused by the FREEDM System are realized.

The notion of cost parity should be seen as a pressure on the marketplace rather than an actual change. The degree and direction of movement will be a significant opportunity as well as a challenge for the Center.

The plan laid out in the following sections describe how the center intends to grow and build the means to address the significant impending change facing the way electricity is delivered and managed with the United States by building upon the success afforded to it by the NSF ERC seed funding.

[1] Deutsche Bank Securities, Inc., “F.I.T.T. for investors, Crossing the Chasm”, February 27, 2015.

BACKGROUND

ERC Sustainability is a key goal for the FREEDM Systems Center over the next five years. According to the NSF report published in January 2010 regarding a survey of graduated ERCs, 82% of graduated ERCs were able to continue operating after graduation; therefore, with the current trajectory in FREEDM activities and plans, sustainability is expected albeit with some changes. According to the report, the centers that were most successful in sustaining themselves were those that retained the core ERC characteristics of systems driven approaches and the core elements of Industry engagement, Research, and Education.

The Center will "graduate" from the ERC program in three years, in 2018. After that point, it is envisioned that the Center will be able to sustain itself in both its mission and in finance. While the Center has had a sustainability team for the past two years, over the past year, it has increased actions toward sustainability. The members of the Center's sustainability team are shown in Table 1.

Table 1: FREEDM Systems Center Sustainability Team	
Name	Affiliation
Staff	
Ewan Pritchard (chair)	Associate Director
Rogelio Sullivan	Managing Director
Ken Dulaney	Director of Industry and Innovation
Pam Carpenter	Education Director
Audrey Callahan	Administrative Director
Martin Baucom	NCSU Engineering Foundation
Industry	
Kent Crawford	Schneider Electric
Nawaf Marjan	Triangle Technology Ventures (TTV)
Ed White	Research Triangle Cleantech Cluster (RTCC)
	Duke Energy
	ABB
Faculty	
Mariesa Crow	MS&T Campus Director
Chris Edrington	FSU Campus Director
Gerry Heydt	ASU Campus Director

The Center has created an Associate Director position to focus on long term relationships and opportunities. This position has the primary goal of establishing and implementing the Center's sustainability plan. The position was filled in September of 2012 by Dr. Ewan Pritchard, who previously ran the Center's Industry, Innovation and Collaboration program.

Internal discussions have confirmed that the university team members are dedicated to keeping the key NSF-ERC characteristics of systems focused research combined with industry engagement and deeply engaged education programs. From both the graduated ERC study and interviews with centers near graduation, there are several key changes that can be expected of the Center. The goals of this plan are to positively manage those major changes and develop creative approaches to augment the core programs of the Center in other ways.

The FREEDM sustainability plan has four major pillars:

Financial: NSF and other funding supports a number of Center features, and once these funds expire, the funds must either be replaced, or the programs must be reduced or eliminated.

Programmatic: Programs that are currently part of the ERC construct which are considered to be necessary post-graduation will be supported. New programs that might enhance the Center's attractiveness to industry and others must be planned and implemented.

Cultural: A major element of the sustainability of an ERC is the culture of interdependence of multiple researchers, industry, and universities. Innovation and diversity objectives will continue to be key drivers.

External: Sustainability also relies on the changing business climate and need for the Center. The Center will need to adapt to keep the research and activities of the center relevant to the direction that industry and the research community move. Additional effort may be directed at exploring the competitive landscape to ascertain future trends.

LESSONS FROM OTHERS

There are a host of resources to draw experiences from for sustaining the ERC. Primarily there is the NSF itself, the ERC Association, the 37 graduated ERC's, and the 17 existing ERC's.

From the report of graduated ERCs and interviews with other centers, there are a number of major pitfalls that centers seem to fall into, which FREEDM will avoid altogether, such as:

- Hoping to win another ERC to continue the work of the center
- Dependence on using a similar construct such as I/UCRC or IGERT
- Expectation of an increase in industry membership
- Decrease in the need for home institution support
- The reduction in the multi departmental approach to research and education
- Lack of quality leadership from the management team
- Lack of administrative funds

Based on these pitfalls, it is apparent that the sustainability plan must include:

- Significant home institution administrative support
- A high quality leadership and management team
- Increased grant and affiliated industry funds
- Plan for an expected overall downsizing
- A strong education program with curriculum development and expansion
- A cohesive team of multidisciplinary faculty and staff with a commitment to center sustainability

OPERATIONS/INFRASTRUCTURE

Maintaining the center's infrastructure is critical to it's sustainability. The staff of the center provide vital services to the faculty, industry, and students of the center. Many existing processes of the center will need to be examined and methods to adapt sustainable models must be created in order to maintain this infrastructure. In general, the sustainability team is seeking ways to allocate many of the infrastructure costs to the programs providing the services. Examples of this are the Industry and Innovation Director, Lab Manager, and Education Director. Each of these center segments have developed programs that bring their own levels of financial sustainability and mechanisms have been put into place to support those components. An example of this infrastructure funding is the portion of membership dues that is dedicated to supporting the Industry and Innovation Director position.

For infrastructure beyond those items where costs can be allocated to the units providing the services, agreements are being negotiated with the universities for project administration (overhead) returns. These returns are being used to pay for time, materials, and travel for essential administrative efforts.

At each partner university, there will continue to be a Campus Director in addition to shared staff for other essential functions. The FREEDM Systems Center Headquarters Staff will continue to provide the following functions:

- Strategic Planning
- Budget and financial management
- Project selection and coordination
- Reporting and information dissemination
- Marketing, outreach, communication, promotion
- Proposal writing
- HR/IT/Programmatic activities
- IP management
- Industry recruiting and support
- Education program coordination

The Student Leadership Council will continue to operate in order to give students a voice in Center activities.

A positive and supportive relationship between the Center and the host university(s) will be vital because institutional support and commitment will continue to be critical to the success of the Center.

FINANCIAL

The FREEDM Systems Center has established and maintains a long range budget, which looks at expenses, revenues and cash reserves, significantly beyond the funding of the NSF. This budget assesses revenue sources and spending allocated toward the major program elements (education programs, lab expenses, personnel costs) and administrative costs. As the NSF sustainability study points out, ERC funds typically support a large proportion of the administration and management of a Center that typical grant funding does not.

The center has been working to identify those funds and work with the directors of each major program element to minimize the administrative costs of each specific element, and work to create individual sustainability for each program. Additional funds for supporting these activities will come from the center's endowment fund and from university administrative returns.

The current 10 year revenue plan is shown in Figure 1, and shows both the expiring NSF funds as well as other planned funds. In Figure 1, the unrestricted funds that can be used for these activities beyond NSF Funding are: Endowment Fund Interest, Industry Funds, and University Internal Contributions.

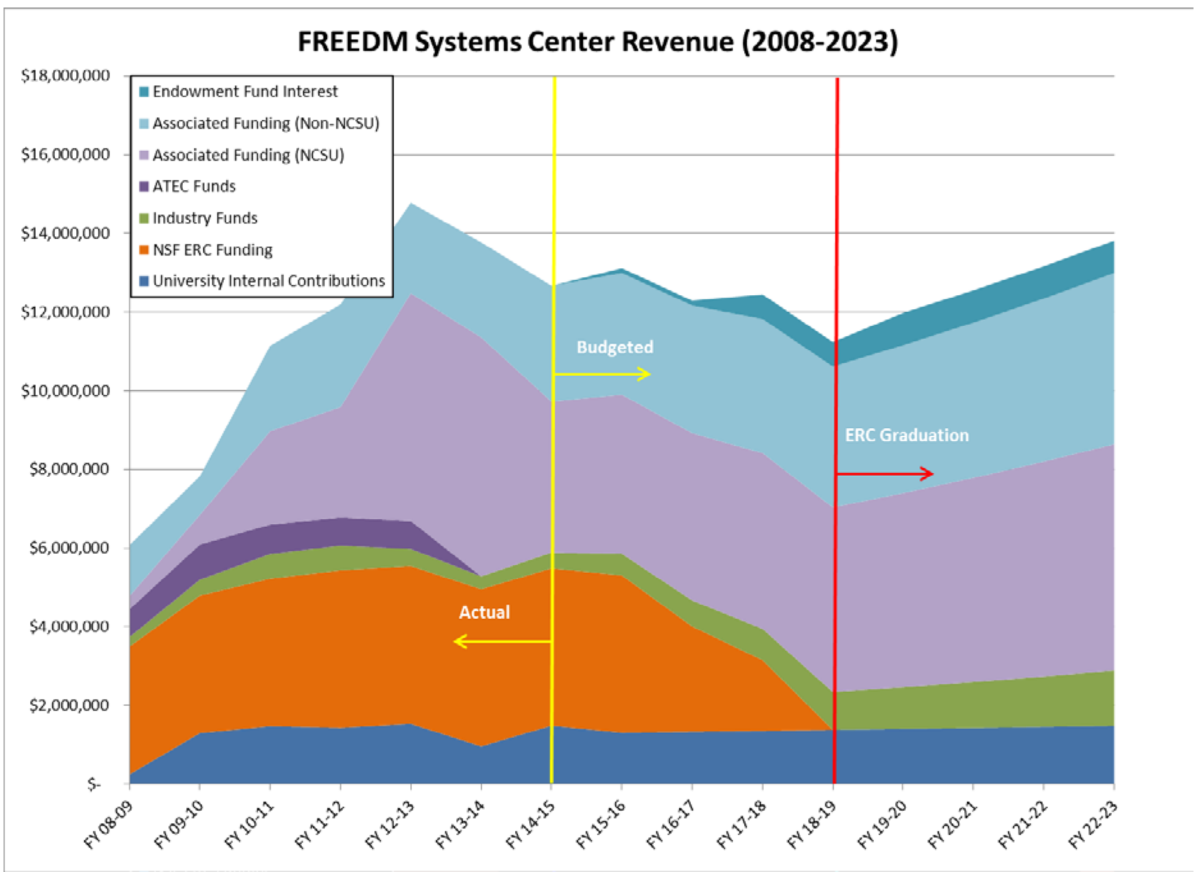

Figure 1: FREEDM Revenues Projected to 2023.

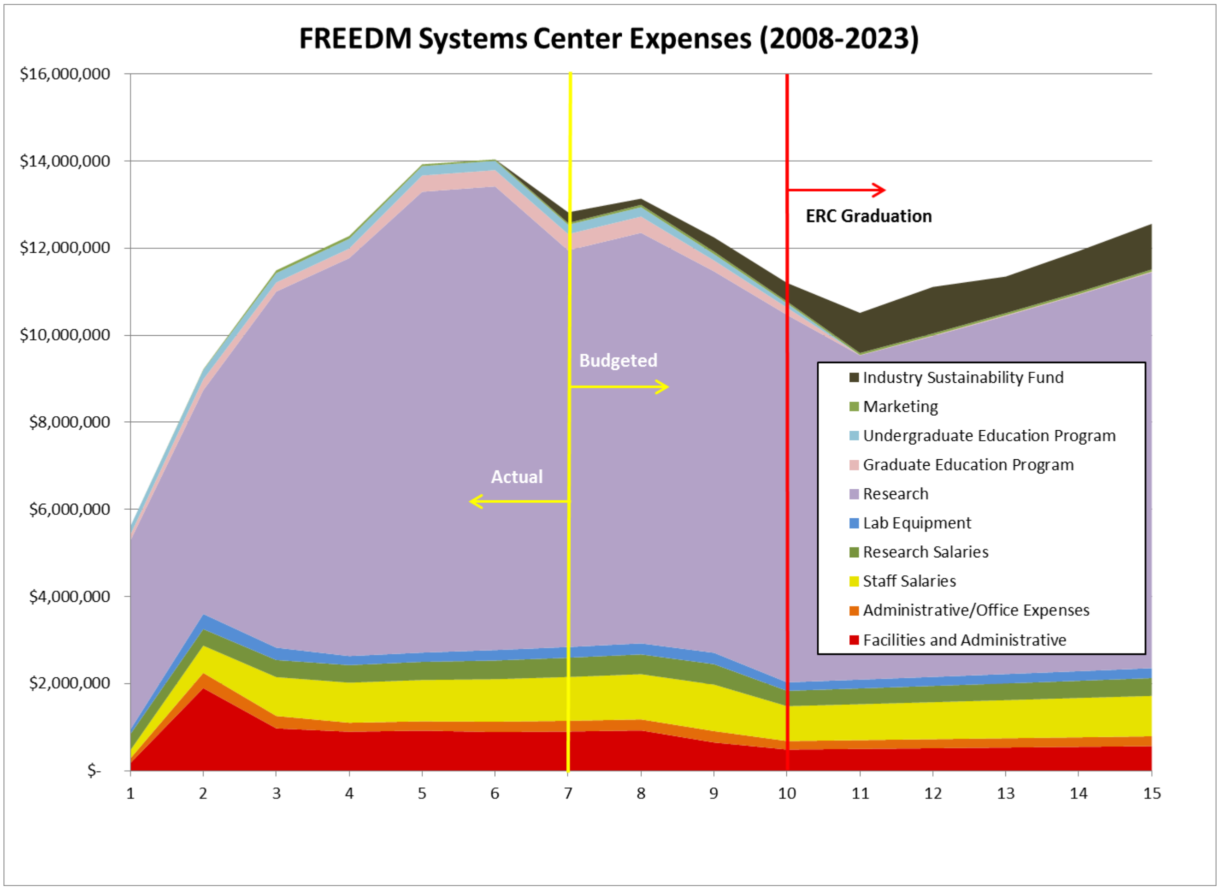

Figure 2: Center Projected Expenses to 2023.

Figure 2 shows the center's anticipated expense budgets for the same timeframe. The expense components that generate unrestricted funds are Marketing, Staff Salaries, and Administrative and office expenses.

In order to sustain the center, these financial plans depend on a series of aggressive steps, which are currently underway:

- Seek Center Endowment Funds to achieve a $10M endowment by graduation.
- Aggressively manage memberships and dues payments to adhere to the 60 day payment deadline.
- Begin an initiative to exceed $800k in annual membership dues by 2018 through increasing member benefits and increasing membership levels.
- Identify several service center functions from center related laboratories and begin this revenue generating service. The initial service centers being planned are:
    - RTDS Modeling and Simulation Facility
    - Advanced Transportation Energy Lab
- Determine similar labs that exist at partners and establish use agreements for joint work.
- Push project expenses into individual project budgets and clarify true center overhead.

- Piloting short courses to be offered for a fee and discounted to members. Revenues from these short courses should be reserved for sustaining center education programs. Examples of such programs are:
    - Real Time Simulation and Modeling for Electric Utility Operations
    - Distribution Level Energy Storage Control and Management
    - Basics of Solid State Transformers
- Implementation of Industry Seed Funding Projects, where a majority of membership dues are dedicated to competitively fund projects awarded by the Center and IAB. A majority of these funds will be held until year eight to help smooth the transition to sustainability.

PROGRAMMATIC

The programmatic sustainability plan includes each of the key program areas: industry, research and education; each with a systems level approach to problem solving. Each element will establish a plan for how each can bring value to the Center after graduation and whether it can continue to thrive in this environment and what interdependencies will be needed. Current plans include:

Industry

As the Center has experienced turnover in its membership over the last six years, it has found the most manageable number of members to be in the range of 45 members. Once the membership increases above that range it becomes difficult to provide the desired value to each member. The current goal is to achieve $800,000 in membership dues by graduation in 2018.

The Center has expanded Sustainability to become a Working Group within the Industry Advisory Board. The Center has asked the group to determine the best methods for retaining and deepening the relationships with current members, as well as opportunities to grow the membership. Changes to the amount of membership dues charged at each level will be evaluated and the value proposition at each level will be more clearly defined. This change is anticipated to occur near to center graduation, but cannot occur until the membership is more highly engaged and the value of membership is clear. A clearly defined value proposition will also make it easier for all members to increase their membership level.

To deepen the relationship with all industry members, the Center has expanded its inclusion of members in the project proposal and selection process. A methodical and transparent project proposal system has been put in place to allow members to take advantage of the larger pool of funding that results from their shared investment. Members are also able to propose projects that are vetted and approved by the other industry members. The Center believes this will also lead to research projects that are supported by multiple companies.

In addition to the industry membership, the Center must ensure that certain key industry members will continue their level of support after the center graduates. While most members have provided additional support on top of their membership dues, a number of members have provided significant contributions to the Center. ABB, Siemens, Total, Duke Energy, Eaton, Samsung, Cree, and Southern California Edison have all provided a significant amount of additional support of associate projects, professorships, fellowships and endowment funding on top of their membership dues. The Center must work closely with these members to ensure their generous support will continue once NSF funding ceases.

FREEDM is the only ERC to spin out a DOE funded institute; the newly formed PowerAmerica Semiconductor Manufacturing Innovation Institute. The center has formed a working agreement which describes the relationship and the nature of work between the two entities, and there is significant promise of ongoing contract research to be conducted by the center. The creation of this institute is a testament to the power of collaboration with member partners such as ABB, Cree, Toshiba, ASU and FSU. PowerAmerica is working closely with the Center to commercialize a number of high power wide bandgap semiconductor applications, including the Solid State Transformer. The Center will continue to target additional opportunities to grow and collaborate with industry members on proposals much like was done with PowerAmerica. The Center will develop an online database of proposal opportunities related to its research roadmap. Industry members will be able to view these opportunities and collaborate on proposals.

A new fund, taken from membership dues, will be initiated called the "Industry Seed Funding". This fund will have 60% held until 2016, while 40% will be used to fund an internally competitive project funding process. The funds held from years 7 and 8 will be dispersed over the years between 2019 and 2020 to smooth the transition as shown in Figure 2. Any researcher, staff, or student from any partner school through an intranet based RFP process may apply for the funds and annual awards will be evaluated each summer by the IAB. A pilot of this program was begun in Year 7 using NSF funds. This will allow research, education, or even new innovation programs to compete for funding internally and allow for significant industry input on priorities and research.

Education

The Education program is a critical part of the center, and will be vital to the sustainability of the center. The center's education programs are currently predominantly NSF funded and will need to transition towards a model that aligns more closely with other existing education programs and finds ways to leverage these existing programs to meet the FREEDM Mission.

The Education program at FREEDM runs from K-12 programs with precollege research experiences, to undergraduate research programs, to full graduate curricula and overall graduate experiential programs. Presently, the precollege education programs include an Expert Classroom Visitor Program, a weeklong engineering summer camp for middle school participants, and a five-week research and professional development program for middle and high school educators as well as high school students. The college education programs include development of curricula (degrees, certificate programs, and courses), a Student Leadership Council, Graduate Diversity Fellowship, Workforce Advising Program, graduate intercampus and international exchange, graduate portfolio program, and undergraduate research experiences. Both the precollege and college education programs receive formal assessment through surveys.

In addition to leveraging existing funded programs, the center will work with Industry members to work to transition existing programs to industry funding. Currently, the education team works closely with the industry-led Education Working Group. The relationships created from this group have brought a greater understanding of the importance of the Center education programs to its industry members. It is anticipated that by partnering with industry, the education program can build a sustainable model for financial support and facilitation of the education programs.

This close partnership with industry allows the center to seek grants targeting STEM education efforts and partner with Industry. Currently, the Center has received several grants to support the sustainability of the education program. One particular grant collaborates with ERC ASSIST to create precollege activity kits that can be placed within every county in NC. This will help to sustain precollege efforts beyond the scope of its targeted county in NC. Low cost programs, such as the graduate portfolio program, workforce advising program, industry-sponsored programs for international and intercampus student exchange as well as travel awards, fellowships, and undergraduate research stipends will continue to be served by the Education Director.

An important objective of the education program will be attracting a diverse population of students. In particular, recruiting more women, and domestic students from underrepresented minorities and Hispanics will be a key differentiator of the center. This is both an acknowledgement and response to the changing demographics of our society as well as a strongly voiced desire of the industry. By attracting a large population of students from these targeted groups, the center will both provide valuable human resources to the industry membership and also improve the culture, creativity, and dynamism of the center.

Research

A number of key grants such as the recent PowerAmerica, the Plug and Play PV, and the Microgrid Controls Project, can certainly sustain longer-term research at the Center. Currently, the center generates approximately $6M annually in associated research revenues as shown in Figure 1. By having smooth processes for grant writing, support for faculty looking to submit proposals, and Industry participation, it is believed that this level of support is likely to continue and even increase. The Center will continue to seek out similar large, multidisciplinary funding opportunities that capitalize on its key strengths and allow it to team with existing members and potential members as well as work with faculty and staff to further streamline the proposal teaming and response process.

Undoubtedly, the strength of the Center and the industry program serve as a key element in winning such grants. This sustainability plan looks at elements of the center's administrative and programmatic costs to determine ways to ensure future grant proposals fill in a lot of the funding void. The Center's headquarters facility at NC State will also figure prominently in these deliberations. Much has been invested in the Green Energy Hub and there are significant expenses associated with the lab's operation and upkeep as well as recurring equipment needs. Sustaining and continuing to improve the capabilities of this valuable asset will be a top priority that will require significant institutional support.

Florida State University Research Sustainability Plan

FSU and in particular the Center for Advanced Power Systems where all of the FSU FREEDM System Center research effort is being conducted has the following plan for conducting research in the years before and after center graduation.

FSU's core competence is in the area of systems modeling, analysis and control in the context of real-time digital simulators. Secondary to that core competence area are areas such as: superconductivity, thermal systems, power electronics and electric drive systems. The Center for Advanced Power Systems excels in all applications centered on the concepts of HIL (hardware-in-the-loop), in particular CHIL (controller hardware in the loop) and PHIL (power hardware-in-the-loop) and to a lesser, but developing, extent THIL (thermal hardware-in-the-loop).

FSU possesses state of the art laboratories and facilities that embrace the real-time environment, with dedicated facilities based on dSPACE, RTDS, and OPAL-RT computational platforms. Moreover, FSU has placed considerable resources and effort into unique FPGA and DSP real-time modeling and system emulation platforms for highly specialized or nonlinear device applications.

In addition to the computational facilities that symbiotically connect all laboratories at the CAPS facility, FSU has devoted considerable resources and attention for the development of a variety of "at power level" demonstration and testing platforms for: machines, drives, converters for renewable energy applications, smart grid, distributed grid intelligence, and distributed control. The physical platforms vary from approximately 10KVA to 5MVA in power and from 208Vac to 4160Vac and 0 – 24kVDC.

FSU considers itself to be positioned primarily for systems level testing, demonstration, analysis, and modeling for applications where new and advanced technologies require de-risking in dynamic environments and conditions unavailable in most laboratory settings. This capability is deemed unique in the United States and is approaching becoming a predominate full cycle technology development methodology that is being extensively utilized by industry and DoD partners. Secondarily, FSU considers itself to be a key player in power electronics, control, and machines design, modeling, and analysis.

Overall, FSU is well positioned not only to address the critical needs in technology and system development and analysis, but will be a critical asset in systems level studies for new technology insertion, characterization and de-risking, during the center's post-graduate stage.

Arizona State University Research Sustainability Plan

The ASU affiliates of the FREEDM Center have main interests in power systems, high voltage engineering, distribution engineering, and power electronics. The interests of the group are focused on four areas:

Power Systems: This includes the interface between the primary distribution system and the sub-transmission system, and the use of power marketing principals for control of the distribution system.

This subject also includes the power quality issues in the distribution primary, mainly as a result of unipolar PWM converters, instrumentation of high frequency voltages and currents, and long line considerations of high frequency signals in distribution systems. The application of three-phase state estimation to enhance instrumentation is also of interest, especially in problematic cases of mixed single-phase and three-phase loads, three-phase unbalance, and high R/X ratio. Fundamental methods of hybridizing controls by utilizing both conventional and solid state transformers may yield solutions to difficult problems encountered in the FREEDM system.

High Voltage Engineering: This area includes resolution of key issues of basic impulse level (BIL), safety, high voltage distribution primaries and solid state controls, and the impact of lightning and switching surges.

Distribution Engineering: Progressive engineering includes variable frequency designs, higher distribution primary voltages (e.g., 35 kV class and higher), relaxation of voltage and frequency standards, and the use of high phase order for high load density distribution applications.

Power Electronics: This area includes hybrid electronic / non-electronic designs to solve difficult BIL and safety issues, advanced converter design, and electronic power conditioning at the substation level.

The ASU team places at the disposal of the FREEDM center the following facilities: A complex of one dedicated power computation lab, three high voltage and three power electronics laboratories exists at ASU. Two of the power electronics laboratories contain provisions for measurement of rotating machine parameters and performance. In these laboratories, there are high speed digital oscilloscopes, a power waveform generator, and a full provision for LabView instrumentation. One of the high voltage laboratories is on the roof of the Engineering Research Center building at ASU, and that laboratory can accommodate high voltage testing through 250 kV. The facilities also contain provisions for 20 kW studies up to 440 V three-phase; 100 kV 60 Hz testing; 250 kV rooftop testing (AC); and 60 kV DC testing. All facilities contain laboratory grade CTs and PTs capable of high bandwidth measurement. There are power quality instruments available to all the laboratories such as the BMI 8080 power quality analyzer. One power electronics lab contains a top end Fluke digital oscilloscope. Infrared video-imaging equipment is also in place. A dedicated power engineering computational laboratory is available to all power engineering students. Access is only to faculty and students in the electric power area. That lab contains 40 high end PCs with full (i.e., not student version, but full commercially licensed) versions of PSCAD, PowerWorld, ETMSP, EMTP, PSAT, TSAT, SSAT, PSLF, CymeDist, Open DSS, and about 20 other widely used commercial software packages. The laboratory has optimization packages for Gurobi and Knitro, and there is high end access to parallel processing capability (known as the Sahuaro system). Funding for annual licenses comes from the Power Systems Engineering Research Center, an NSF Gen III IUCRC. It is believed that the facility is one of the best equipped power engineering computational laboratories at a university.

Florida A&M University Research Sustainability Plan

The FAMU affiliates of the FREEDM Center have main interests in energy storage materials, devices, and applications. The interests of the group are focused on three areas:

Li-air batteries: We will continue some fundamental research and material developments targeting some crucial issues in order to improve the energy density of Li-air batteries. Our research objectives include (1) development of catalytic materials which have high oxygen reduction reaction activity; (2) development of air electrodes with three dimensional in catalytic nanoparticle distribution and porosity of the air electrode; (3) design and stimulation of air electrode structure using an in-house simulation software for optimizing the energy and power densities of Li-air batteries.

Fuel cells: The FAMU team will work with Bing Energy International (BEI) to scale up the membrane electrode assembly technology developed by FSU-FAMU and manufacture affordable fuel cells. BEI and FAMU teams will explore and demonstrate effective and scalable techniques to fabricate affordable large size, gradient-structured, Pt/buckypaper electrodes for fuel cell stacks. We will systematically investigate the effect of various components in the membrane electrode assemble (MEA) on the performance of fuel cells and optimize the MEA structure to achieve cell performance as close as to the DOE 2017 targets for automobile applications as possible.

Supercapacitors: The FAMU team will work with General Capacitor International (GC) to achieve the design goal for Li-ion capacitors which include a high specific energy (>30 Wh/kg), high specific power (>5 kW/kg), and long cycle life (> 100,000 cycles). The research tasks can be divided into 3 research major tasks including 1) understanding the Li intercalation process in anode and the finding optimal loading between carbon anode and lithium powder in order to obtain a high specific capacity and good cycle life; 2) studying different binders and electrode fabrication processes for maximizing capacitor's performance; and 3) developing new electrolytes with high ionic conductivity, wide temperature and electrochemical stability windows which are highly desirable for use in the Li capacitors.

Both BEI and GC are FREEDM spin-off companies. In the past, we have closely worked with BEI, GC, and Maxwell Technologies Inc, Evans Capacitor Company, and Ionova Technologies Inc. to develop various technologies for fuel cells and supercapacitors. The Center will continue work with US companies to solve critical problems in energy storage materials and devices.

The FAMU team also has the equipment and facilities necessary to accomplish the proposed research effort. The proposed research will be conducted at a recently completed research building, Aero-Propulsion, Mechatronics and Energy Building (AME), with a total of 58,000 square feet, including a 250 square foot dry room for Li anode preparation and assembly. Our research laboratories are equipped with a comprehensive suite of analytical, processing, and characterization systems for various materials. The equipment includes battery test stations, glove boxes, electrochemical measurement stations, surface area and pore size analyzers, high temperature furnaces, ovens and environmental chambers, a complete pouch cell battery assembly line, thermal characterization (DSC and TGA), mechanical characterization (TMA and DMA), optical characterization (Raman spectrometer, FT-IR spectrometer, and UV-Vis-NIR spectrophotometer), and advanced imaging (AFM and HRSEM).

Missouri University of Science & Technology Research Sustainability Plan

At the completion of the FREEDM ERC, Missouri S&T will continue to pursue funding associated with modeling, control, simulation, and experimental validation of hybrid AC/DC distribution systems and microgirds. This research will expand upon, and use, the initial results developed as part of the DGI, LSSS, and SST research thrust areas of FREEDM. We will continue to seek collaborative opportunities with established groups from NCSU, FSU, FAMU, and ASU. Possible areas of research collaboration include hybrid AC/DC system stability, islanded microgrid operation, grid energy storage modeling and applications, and microgrid protection.

The Missouri S&T faculty team has considerable expertise in microgrid applications. Missouri S&T is home to several microgrid test beds that support our research in this area. Missouri S&T is integrating a variety of energy generation, storage, and management technologies into a central campus microgrid. One microgrid is located within the Missouri S&T Solar Village, optimizing energy within four student-built and inhabited solar homes. The photovoltaic (PV) arrays on the solar village homes are designed to generate a total of approximately 25 kW of power. A 960V lithium ion battery array donated by A123 Systems provides 60 kWh of energy storage for the microgrid. In 2014, a residential fuel cell and heat recovery demonstration unit will be installed in the Solar Village as an additional microgrid component. Future expansion of the microgrid will include wind, electric vehicles, generators, and electric vehicle charging infrastructure.

The Missouri S&T Smart Grid Demonstration Project provides a test bed for renewable and small conventional energy sources, energy storage devices, and communications and control methods inherent to developing future smart grids. Located north of campus in the HyPoint Industrial Park, the existing system comprises a 5.4 kW power array (twenty-seven BI-156-200W-G27V Brightwatts panels) with two Flexmax 80 maximum power point trackers, a Bergey XL.1-24 wind turbine rated at 1 kW, a fuel cell and electrolyzer (Ballard FCGen 1020), a battery bank (totaling 48 V at 258 A-hr), an ultracapacitor bank (totaling 48 V at 660 F), a diesel generator, and a number of power converters for interface and regulation. These facilities enable the Missouri S&T team to experimentally validate microgrid behavior in the presence of multiple loads and differing seasonal variations.

CULTURE

The culture of the Center, as defined by its values, norms, traditions, sense of community, communication tools, and social environment, is a key element of its success. These characteristics determine how students, faculty, industry and others, have come to experience the Center and would describe it to an external audience. These defining characteristics have evolved over the years and will be equally important post-graduation. In spite of the expected internal and external pressures brought by graduation, the Center must find ways to retain its essential culture, or adapt it to the new post-graduation operating environment. Much of the NSF influence on culture has been extremely valuable; essentially mimicking what is practiced in industry, and should remain and even be strengthened. These valuable elements include the systems focus, interdisciplinary collaboration, and the emphasis on translational research integrated with education.

The following are areas of emphasis for building and sustaining the culture of the Center:

- Collaboration - Greater efforts should be made to collaborate with partners within the Center on grant proposals preferentially; over other potential collaborators. This can help to reinforce the FREEDM name and visibility throughout the engineering community
- Business process improvement – A streamlined, standard set of business tools for communication, data archiving, financial planning and reporting will be adopted
- Continued emphasis on linking research, education and innovation
- Emphasize cross-disciplinary research (key element of graduation success according to graduated ERCs). This will require outreach to other disciplines at each partner school such as business, economics, social sciences, and behavioral sciences
- Integration of research, education, and industrial interaction with a focus on cross-disciplinary, engineered systems research (key element of graduation success according to graduated ERCs)
- Teaming and pursuing visionary projects that are beyond the capabilities of single investigators
- Fostering a cross-disciplinary culture, systems approach, and industry orientation and nearer-term technologies

EXTERNAL

The external plan includes mechanisms to continually measure the heartbeat of both industry and society and evaluate the center's roadmap to look for deviations between the two and quickly adapt to change. The Center's roadmap will need to find the appropriate balance of continuity to ensure plans aren't changing so often that the center becomes ineffective, but also allow for regular slow progression over time to ensure that center goals do not become misaligned with industry and society.

In addition, the Center must keep abreast of external policy and regulatory issues as they evolve. Though research and education will continue to be at its core, these must be informed by important public issues such as climate change, the new era of inexpensive domestic fossil fuels, and the potential for a carbon tax, cap & trade, and other broad market drivers. This can be accomplished through the following mechanisms:

- Enhanced Ambassador program; or similar effort to integrate FREEDM into influential external bodies throughout the engineering and policy professional community
- Participation in panel discussions at professional conferences
- Participation in webinars, discussion groups and other electronic and other social media focused on these topics
- Collaborating with more policy focused organizations
- Sponsoring research studies in these areas,
- Stimulating these policy discussions at the Center annual meeting.

The Center will need to build and grow its strong network of external collaborators and strengthen those relationships in order to maintain its prominence and relevance in the power electronics, electric power, and smart grid space. Although the prestige of association with NSF and being part of the ERC family will certainly be felt, the Center can continue to enjoy high name recognition and a reputation for engineering excellence through strategically partnering with external organizations.

Organizations with similar missions, related research endeavors, complementary educational programs as well as policy makers, national labs, state, local and federal government organization and others will be important. The following is a partial list of such organizations:

- Emerge Alliance
- PowerAmerica
- Electric Power Research Institute (EPRI)
- Department of Energy and ARPA-E
- National Labs (NREL, ORNL, NRL, others)
- IEEE and associated societies such as PELS, PES, IAS, IES, and VTS
- Department of Defense
- National Association of State Energy Offices (NASEO)
- Association of State Energy Research and Technology Transfer Institutions (ASERTTI)