UCF Blue Ribbon Energy Panel

Final Report

Blue Ribbon Energy Panel Members

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Executive Summary: Blue Ribbon Energy Panel Charge and Process

The University of Central Florida assembled a Blue-Ribbon Energy Panel to strategize how UCF energy-related research can help meet the rapidly increasing demand for clean and economical energy. UCF has various groups and individuals conducting cutting-edge research in the areas of solar energy, alternative energy sources, electricity distribution, and power generation, among others, bringing millions of dollars of external funding. The US Energy Information Administration estimates an increase in US energy consumption as high as 11% by 2040 and the U.S. Bureau of Labor Statistics is forecasting that the number of jobs in solar and wind power industries will double in the next 10 years. Therefore, the time was right to look at what UCF is doing, what future opportunities may exist and how the university can position itself to lead innovation in this field well into the future.

Dr. Elizabeth Klonoff, VP for Research issued a call to campus faculty and staff to self-nominate to serve on the panel and recommend community partners who would add to the process. Over 27 nominations were received from internal candidates and 20 external; 17 invitations were made and all accepted.

The panel met three times. The first meeting was held on February 9, 2018. At this meeting, Dr. Elizabeth Klonoff charged the panel with the following:

- Create an inventory of all the energy related research underway at UCF
- Review current and emerging research trends in the field
- Review current and future funding opportunities from public and private agencies
- Learn about UCF community partner's research needs
- Analyze interdisciplinary research opportunities
- Analyze current and future needs from industry perspective
- Discuss ways to enhance the university's capacity to conduct innovative research
- Explore the idea of creating an umbrella organization for energy research

Jennifer Szaro, Senior Director with Smart Electric Power Alliance made a presentation to the panel. The panel then conducted a Strengths, Weaknesses, Opportunities, and Threats (SWOT) exercise as a first step toward developing recommendations. A poll of panel members produced the following subset of high-priority weaknesses that need to be addressed:

- Need to strengthen/ better align various energy research activities, clusters, institutes, centers, academic units, and groups to promote synergy.
- No dedicated academic focus in energy
- Lack of a university-wide coordinating unit that may facilitate, support, and promote energy related programs/activities.
- Few researchers on campus in energy policy or energy economics
- UCF reputation as research partners compared to other elites; UCF is a best-kept secret.
- Energy is interdisciplinary, but tenure is in department and department silos exist.

- We have limited resources invested in space and infrastructure; lack of facilities covering all areas of energy research
- We have limited expertise in system-level analysis, design, integration of various types of energy systems

The second meeting of the panel was on March 29, 2018. This meeting was open to the entire campus and over 60 people attended. UCF Trustee member David Walsh, President and Chief Executive Officer of Mitsubishi Hitachi Power Systems Americas, Inc. (MHPSA), provided a talk on the future of energy from industry perspective. The attendees broke out into groups and considered three questions.

- Q1. What major opportunities in energy research are we missing?
- Q2. How can we better communicate our expertise and accomplishments to our community, peers and future students and faculty?
- Q3. How can we promote collaboration among UCF disciplines?

Their responses are included in this report.

One of the objectives of the blue ribbon panel was to identify future research needs. We asked panel members to prepare brief summaries of the future of energy in their research areas. These summaries are included in this report and focused on the following research needs:

- PV: Integrated grid-tied PV+Storage solutions, PV manufacturing and metrology, maximized power generation,
- Meeting the highly distributed, highly connected future green electrical infrastructure to energize and monitor the projected one trillion IoT devices in use by 2022
- Design and optimization of module-based power electronics
- Power electronics for EV chargers (auto and air transportation)
- New material that can handle high temperature and reduce the on-resistance (less power loss)
- Photovoltaic systems research- maximizing energy generation through discovery
- Building energy demand: EV charging, integrated storage, HVAC/controls, IT, air quality, codes/standards, simulation, delivery, military applications, factory built structures, smarter architecture, kinetic facades
- Hydrogen and fuel cells
- Durable and reliable high temperature materials - transformative multi-materials science, requires coupled experiment- theory-simulation investigations to converge on ideal functional properties for manufacture and processing.
- Energy policy and economics - integration of renewable and sustainable fuel sources into the electric grid, including distributed and utility-scale solar and wind technologies
- Digitalization (digital twin) and use of gas turbines as enabler for renewable energy
- Directly and indirectly heated supercritical carbon dioxide based power cycles for fossil fuel applications
- Pressure gain combustion to improve combined cycle performance when integrated with combustion gas turbines

One of the objectives of the panel was to create an inventory of energy-related research underway at UCF. We reached out to investigators who conduct energy research at UCF, with a request to complete quad charts for their energy related research. Quad charts can be found at this link. Over 60 quad charts were received and used to generate a word cloud included in this report. The topics are distributed as follows:

- Transportation Energy Efficiency (2)
- Energy Storage & Transmission (2)
- Environmental Impacts (3)
- Fossil & Nuclear Energy (15)
- Policy & Economics (3)
- Renewable Energy (21)
- Energy Systems Integration (6)
- Data Analytics, Cyber Security (1)
- Devices, Materials, and Reactions for Energy Efficiency (10)
- Education (1)

From the panel and speaker input, we mapped UCF research experience to agency and industry funding priorities and trends. The map is included in this report. The panel identified strong expertise in soar, PV, fossil-fuel related, and building efficiency research areas. Little to know expertise is available at UCF in areas of alternative fuels and wind energy yet these are highly funded fields by NSF and DOE. UCF has few funded projects in energy storage, yet panel members and outside speakers repeatedly mentioned the need and research opportunities in storage.

The third and final meeting was held on April 16, kicked off by an open talk by Dr. Grace Bochenik, former Director of DOE NETL. Again, attendance was strong, supporting the campus-wide interest in energy. After the talk, the panel met and generated the following recommendations:

Recommendation 1: The UCF energy community should receive clear vision and direction from UCF leadership

Opportunities: A university-wide vision, strategy, and leadership focused on energy is important to improve connections with industry and major funding agencies and to grow our presence and prestige. We are fortunate in that we live in a municipality of growing energy demands with resources such as solar and wind. We also have the opportunity to work with a sustainably-minded community (e.g., Greenworks, Orlando Mayor Buddy Dyer Office of Sustainability Initiatives). Proximity to island nations and South America creates opportunities to facilitate energy needs of these areas (e.g., Puerto Rico, USVI). A clear vision also provides a message that can be shared with potential donors.

Weaknesses: The UCF community pointed out a number of challenges related to energy research and education, including a lack of resources (e.g., seed funding, facilities, student advising, website presence, events to increase collaboration) and processes (joint appointments, researcher databases, incentive structures to promote collaboration). It was also noted that increasing diversity in our energy faculty, staff and students could be improved by identifying the research ideas and topics that invite diverse members.

Action:

- Based on recommendations in this report, The VP for Research will distribute a vision for UCF energy research and education.

Recommendation 2: Create a university-wide coordinating unit around energy

Opportunities: Given UCF's years of active engagement in energy research and educational activities, coupled with the ever increasing number of energy-focused faculty, researchers, and Faculty Cluster Initiative (FCI) hires, exciting opportunities exist to leverage this success in the energy area and position UCF to become a leader in energy, not only at the state level, but nationally and internationally. One proven approach to building a strong energy focus across a large institution like ours is to create a university-wide coordinating unit around the energy area. This unit would provide the needed platform to engage internal stakeholders across campus, in collaboration with industry, in coordinated and focused efforts to achieve collective and visible excellence in energy research and education at UCF. Moreover, this dedicated unit would steer the energy research by setting the vision, strategic direction, and alignment according to UCF's strategic plan. Also the unit would help carry out supporting functions such as mentoring of new faculty, hosting regular seminars, coordinating research efforts across campus and identifying research barriers to tackling large proposal opportunities. The unit could provide seed funding and disseminate relevant news, activities and coming opportunities to UCF and the community at large. The energy office would also better engage students interested in energy through seminars, projects, and internal and external competitions.

Weakness: UCF's current energy activities on campus are somewhat fragmented and lack collective coordination and unified energy vision and direction. This lack of targeted and focused effort leads to lost opportunities and limits awareness and recognition of UCF's energy successes, not only within UCF, but also in Central Florida and beyond. Also, funding opportunities may be lost when response to a given opportunity requires the participation of a large and diverse number of faculty with complementary research skills and facilities.

Actions:

- Announce the need for a campus-wide Energy Unit with clear goal and objectives.
- Appoint an interim director to set the chart for the new unit.
- Form an ad-hoc committee, including industry and utilities, to develop a strategic plan that identifies specific tasks that need to be undertaken by this office, as well as the required facilities and budget.
- Present a report to the VP of Research and Commercialization to define fully the functions of the Energy Unit and the needed qualifications for the permanent director.
- Announce the Search for the Director for the Energy Unit position
- Conduct an Internet-based benchmarking of 2-5 UCF peer energy research universities.
- Identify and assess other Florida University System energy programs.
- Review UCF energy affiliated labs and Institutes based on information provided by the Office of Research; summarize current capabilities and deficiencies.

- Identify and assess energy industry, nonprofits, foundations and investors in Orlando FL regional area; summarize potential partnerships.
- Define UCF's Energy Innovation Ecosystem
- Draft UCF's Energy Vision to include technical thrusts
- Identify future research opportunities and thrusts

Recommendation 3: Evaluate current and future energy-related courses and curriculum

Opportunities: As the foundations and basic concepts of energy sustainability continue to evolve in the presence of an ever-increasing penetration of highly connected and smart renewable energy resources, educational institutions must step up their efforts to prepare the necessary next generation workforce. Energy sustainability is a rapidly growing industry and there is an urgent need now for a workforce that is equipped to design systems in a highly connected and integrated environment, put appropriate policy and regulations into practice, and develop institutional-wide effective sustainability plans. This is why UCF has an opportunity to offer new certificate and master degree programs to help address the above pressing needs. UCF has an unparalleled opportunity to create a structured program and/or a set of targeted courses for credit/audit/professional development, because of the local mix of companies, and the associated group of working professionals and job opportunities. Examples of educational opportunities include the following two distinct groups:

- One of the biggest industries in the central Florida area is building/HVAC. Even though no single company is as big as, say Siemens, all companies combined employ a large number of students, many of whom are post-secondary. These companies are also closely affiliated with the Green Building council and the American Society of Heating, Refrigerating and Air-Conditioning Engineers, which are already well connected to UCF, and hence can help us market any educational program. This is an untapped potential for us.
- Siemens and Mitsubishi in Orlando, and a number of companies in Jupiter/WPB area are examples of highly innovative, international, high-tech group of companies concentrated in Florida. They are engaged in energy and employ directly 5000 highly-paid engineers (and some scientists), and another few thousands, if we count their vendors and suppliers. Many of these employees are UCF graduates. These companies provide significant research funding to UCF, supporting many UCF graduate and undergraduate students and PostDocs, and then hire heavily from those supported. This fact itself will be a big attraction to the potential students of any courses or programs that we create and will also increase UCF's international reputation.

Weaknesses: The panel identified the following weaknesses:

- We, as a group, never asked the local employers what type of courses they want their future employees to take. We need to align our programs with local employment opportunities. Creating courses for students to come from Silicon Valley or Minneapolis or Research Triangle Park (where many complementary energy opportunities are also available) will not create high return-on-investment.
- UCF lacks campus-wide energy degrees and certificate programs in energy sustainability for diverse majors and backgrounds.
- We are limited on teaching laboratory facilities. Many of the local employers would like to see more hands-on or laboratory training.

- Despite many strong energy academic and research assets at UCF, the panel noted a lack of awareness and recognition of these across campus and, more significantly, externally.
- No current effort is in place to market these assets, leading to limited knowledge internally and externally. UCF is therefore missing out on opportunities to better engage students interested in energy and to increase external partnership and funding for energy research.

Actions:

- Assemble a list of energy related course offerings at UCF and make the list publicly available online.
- Conduct a survey to collect feedback to gauge the interest of Florida's workforce in pursuing higher education initiatives in broad energy sustainability systems.
- Survey the professional industry to find out the best and most suitable educational delivery approach and focus the UCF's energy educational efforts on these in terms of online course and degree offerings. Engage with local employers with a large employee base, and ask them which courses are needed.
- Plan new courses, degrees (including Professional Science Masters), minors, certificates, and short courses to meet industry demands.

Recommendation 4: Market UCF energy research

Opportunities: UCF has the potential to leverage the strong interest in energy among students, the broader public, and external funders. Through targeted efforts, UCF can increase the level of awareness of its current/future academic and research energy assets, positioning it to better harness the opportunities among these groups. Improved student awareness will support an increased interest in energy course offerings and future academic degrees/certificates. Likewise, marketing to the broader public will strengthen continued education enrollment and lead to an increase in gift-giving from those interested in supporting energy at UCF. Marketing of energy research at UCF will assist in promoting industrial partnerships and external funding, growing the annual UCF energy research expenditures and the number of supported undergraduate/graduate/postdoctoral researchers.

Weaknesses: Despite strong energy academic and research assets at UCF, the panel noted a lack of awareness and recognition of these both across campus and, more significantly, externally. It was generally felt that much of the student body is not aware of the various academic and research opportunities in energy at UCF, likely due to a lack of a broader coordination. No current effort is in place to market energy research and education, leading to limited knowledge internally and externally. UCF is therefore missing opportunities to better engage students interested in energy and increase external partnership and funding for energy research.

Actions:

- Assemble a list of energy related course offerings at UCF and make publicly available online.
- Assemble a list of existing/future degrees in energy and make publicly available online.
- Organize regular seminars that show case both internal and external energy research.
- Establish a UCF energy research annual report/summary that is broadly marketed.
- Increase the quality of the website for the two current UCF energy clusters.
- Broadly market energy-related scholarships available to students (internal and external).

- Highlight/showcase successes in local workforce development and technology transfer.
- Market the energy IP portfolio.
- Create a central energy website at UCF that contains the content from the above bullet points.

Recommendation 5. Obtain legislative support for center/institute for research and education in energy and enhanced University/Industry research opportunities

Opportunity: Advanced energy employed 140,000 workers in Florida, nearly twice as many as Agriculture, in 2015. With 8,260 solar workers, the solar industry in Florida produced $1.69 billion in direct sales in 2016. As solar electricity (photovoltaic PV) electricity) as a source of electricity in Florida is becoming more economical each year, Florida can reduce its fuel imports. Energy efficiency, electric vehicles, and solar energy will shortly be an economic driver producing Florida made products and energy with economic benefits exceeding that of agriculture. As more electric vehicles and PV emerge on Florida's grid, the need for energy storage is paramount. Other states are investing in their industry and universities to develop and operate energy storage technology to stabilize the grid and minimize the import of fossil fuels. UCF has shown national leadership (research, education and workforce training) in Florida since 1975 (when the Florida Legislature created UCF's FSEC as the State's energy research institute) in solar and building energy efficiency, more recently it leads in electric vehicles, energy storage and in developing the smart grid.

Weakness: While Florida has a state-supported agriculture university, unlike other states it does not support university energy research and education. Florida spent $56 Billion on energy in 2014, most of this was on the fossil fuels that provided the primary energy used to transport Floridians and cool us. Fossil fuel is not produced in Florida and little to no manufacturing of power plants or vehicles that consume energy are produced in Florida. As such little to no research support is provided to university energy faculty by Florida industry. Florida electricity generation is accomplished through government regulated monopolistic utilities that are not required to compete for customers and as a result carry out limited research.

Actions:

- Work with the Smart Electric Power Alliance to develop Florida Working Groups (UCF/Manufacturers/Large Energy Consumers/Utilities) in Solar; Energy Storage; Electric Vehicles; Demand Response; Microgrids; Turbines: Combined Heat and Power; Distributed Energy Resource Management
- Work with the Florida Legislature to develop a Public Benefit Fund for Research to generate Florida made (farm fresh) electricity and transportation fuel.
- Consider a charge on the monthly electric bill of residents of $1.00 ($0.00089 per kWh) to invest in Florida Research to ensure a made-in-Florida Energy Future ($197 M per year)

Recommendation 6. Identify faculty needs in economics and policy needed to integrate energy across campus.

Opportunities: Energy research and funding opportunities are increasingly interdisciplinary, requiring a strong technical aptitude as well as an understanding of the economic and political factors of energy and environmental policy. Just as energy technology rapidly develops and evolves, so does the policy arena that drives the need and opportunity for innovative energy technologies. Multiple departments at UCF were established in technical and engineering-based energy research. Additionally, several research clusters are being developed to conduct interdisciplinary energy research related to renewable and sustainable energy systems. By integrating energy economics and policy research with technical research at UCF, students and researchers will be better able to apply their skills and desires to further smart and sustainable energy systems. Integrated teams of technical and policy researchers have a more holistic understanding of complex research questions and are typically better suited for a variety of funding opportunities in energy research.

Weaknesses: While UCF is strong on the technical side of energy research, few researchers across campus conduct economic and policy research related to energy. Despite rapid expansion of UCF and interdisciplinary research clusters, there are currently no plans to increase the number of faculty, students, or researchers in the fields of energy economics and policy. Existing scholars and students in these fields are underutilized; networks linking these scholars with technical researchers are slowly forming. The fields of energy economics and policy are quickly growing in rival institutions; UCF will be left behind if wedo not make an effort to grow these fields as well.

Actions:

- Increase capacity of energy economics and policy research at UCF:
    - Incorporate energy economics and policy topics in existing environmental policy, engineering, and economics courses and curriculum,
    - Develop more interdisciplinary, team-taught courses on energy that include energy economics & policy, and
    - Consider opportunities for hiring faculty in energy economics and policy.
- Build relationships:
    - Between energy economics and policy researchers and engineers across campus to increase in-house capacity for interdisciplinary research,
    - With local industry and policymakers at the local, state, and federal level to identify economic and political barriers to sustainable energy policies, and
    - With outside institutions established in energy economics and policy to learn best practices for growing UCF's capacity for energy economics and policy fields.

SWOT Analysis

Strengths

- Broad energy research foci including photovoltaics, electric grid, power systems, turbines, etc.
- Strong collaborations with national labs (e.g., National Renewable Energy Laboratory, Los Alamos National Laboratory, Pacific Northwest National Laboratory)
- Many regional technology partners in central Florida already engaged with UCF.
- Strong engineering program.
- Energy related Clusters (Resilient, Intelligent and Sustainable Energy Systems (RISES) and Energy Conversion and Propulsion (ECP)) and Centers (Center for Advanced Turbine Energy Research (CATER), Center for Research and Education in Optics and Lasers (CREOL), Florida Solar Energy Center (FSEC), Electric Vehicle Transportation Center (EVTC), Foundations for Engineering Education for Distributed Energy Resources (FEEDER))
- Senior researchers with strong track records
- UCF is a massive consumer of energy and a testbed for new technologies
- Strong funding portfolio
- Professors and students with aptitude and desire to develop smart energy solutions.
- UCF’s super computer HP cluster
- Building efficient flow batteries: vehicle to grid, electric vehicles, hydrogen/fuel cells
- Agility of university, desire to think outside of the box.
- Florida: solar availability, rapid population grown, large urban areas, potential for electric vehicles.
- Other supporting research areas that impact energy research (data analytics, simulation, cyber, economics, political science, space/aviation, and public administration)
- 100 schools with PV storage
- Energy Whiz Olympics
- Alignment between Business Administration and the College of Engineering and Computer ScienceS allows for multi-faceted research approach.
- Two large original equipment manufacturer in town and a unique ecosystem in Florida
- Strong patent portfolio
- Leverage UCF resources to identify and drive efficiencies in power generation, transmission, & distribution

Weaknesses

- Need to strengthen/ better align various energy research activities, clusters, institutes, centers, academic units, and groups to promote synergy; Integrated communication w/ UCF facilities, Mech. Engr. Dept., and policy/sustainability dept.
- Lack of relationships with regulators – need more clout with DC & Tallahassee policy makers; Political favoritism in Florida legislature
- A lot of changes with the University (downtown, President, Provost)
- Few researchers on campus in energy policy or energy economics
- Energy interdisciplinary, tenure in department, department silos
- Limited number of large solar and other renewable energy manufacturers in the FL region.

- Florida still not highly adapting of solar energy solutions.
- No dedicated academic focus in energy
- Student involvement needs to be improved
- Research with Department of Defense
- No current open-to-all energy seminars
- No chemical engineering department
- Electrical Engineering power generation facility
- Mentoring of younger faculty in energy (today – only department level mentoring)
- Time to get contracts/ NDAs competed
- 5-day regulations stop outside collaborations
- How do we compare with competitors in terms of internal policies and regulations?
- How quickly do we answer opportunities?
- We have to find better and faster ways to facilitate collaboration with industry
- Gas turbine research is dominant in Mechanical and Aerospace Engineering
- UCF reputation as research partners compared to other elites; UCF is a best-kept secret. We need communication that drive awareness & engagement to the outside world.
- We have limited resources invested in space and infrastructure; Lack of facilities covering all areas of energy research
- Limited expertise in system-level analysis, design, integration of various types of energy system
- Lack of a university-wide coordinating unit that may facilitate, support, and promote energy related programs/activities.'
- Hiring faculty at large rate could target department first, but energy second
- Faculty teaching overload is a roadblock to pivoting towards new R&D
- Interdisciplinary work is great, but how do we deal with credit splits, indirect return, & research faculty being so strictly C&G funded?
- Evaluation of $/impact of work depending on position at the university and promotion path/requirements. What are defined metrics of success and how can they be equal for all faculty?

<u>Opportunities</u>

- Increasing interest in moving electricity production into combined heat power
- Working with big energy users in collaborative research
- Interface design management systems
- Instrument and controls replacement
- Levels of automation and autonomy, anything human-in-the-loop: training, operator role, and consumer; shift of human role to supervisory control when moving to automated or soft controls. In facilities, how many crewmembers are/should be required?
- Assessment of safety risk to benefits ratio
- Many states are ramping up commitments in response to evolving energy policies
- New state specific funds for research could become available

- Interest in Integration of Smart building energy storage (in-home storage, building loads, smart power electrics w/ communication, energy storage, vehicle to X, solar energy production). Micro-apartments, co-living, etc. will decrease footprint of build environment, which reduces energy.
- Collaborative research with Florida Utilities in the evolution of new utility business models; Smart grid partnership with local utility (OUC) and vendor partners for create a live laboratory for R&D, demonstration, classroom learning, industry proofs, etc.
- Collaborative renewables and storage projects with Duke Energy and OUC
- Location. City of growing energy demands, sunshine & Green works , Orlando Mayor’s office of sustainability initiatives
- Piggyback onto newly developing V2X (vehicle to everything) software platforms. Could provide data back and forth between grid and EVs.
- Despite variation in funding, energy will remain a field of continuous research need. Big need for research in several areas: cybersecurity, distributed energy resource control, storage integration
- Research new business models. Tech can actually work now. What business models can unlock it? (P3, resilient rates, dynamic pricing).
- Availability of design tools to better integrate grid design, building design, and EV infrastructure design.
- Potential for international collaboration
- Varied expertise for interdisciplinary research
- Growth of university vs. other FL universities
- Increase in cost viability of renewable energy
- Several large potential partners in Florida: utilities, Disney, Publix
- Challenges associated with resilience such as how to manage energy during/after hurricanes.
- Interaction with K-12 building on PV on schools, Energy Whiz
- Central Florida’s unique reputation is in space technology. Establish synergy with space industry.
- Autonomous and connected vehicles that are electric
- Proximity to island nations and S. America open up opportunities to pursue energy needs of these areas (Puerto Rico, USVI)
- Rapid change in energy distribution and generation offers many opportunities for researchers.
- Leverage incubator to form energy focus startups

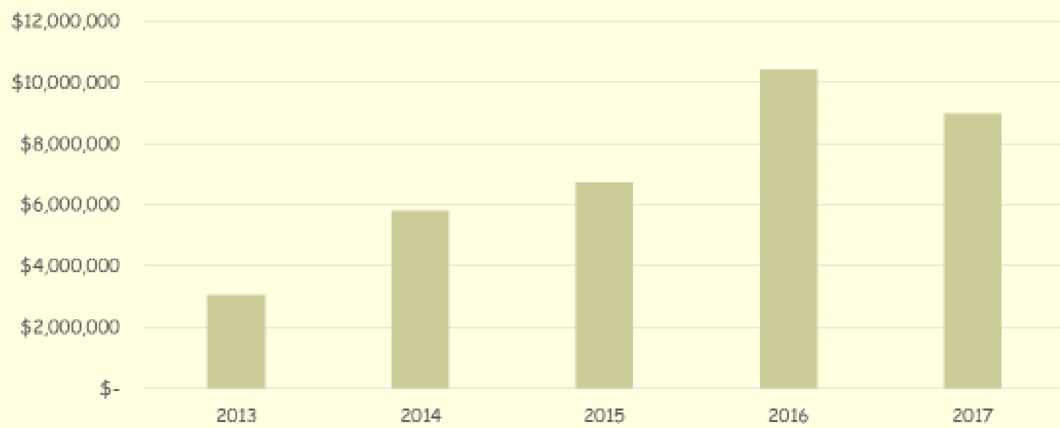
Threats

- State of Florida funding uncertainty
- Changing regulations and policies
- Large investments by peer universities (Ga Tech ~$30M, Purdue ~$15M, Penn State ~$20M)
- Federal budget cuts in energy research
- Disruption of large gas turbine business impacting CATER
- $ amount government and industry use for an academic institute to conduct research; ability to be responsive to commercial contract budget & time demands

- Energy is a crowded research space
- Conflict of interest when contracting with various utilities and agencies
- Lack of investment by utilities
- National labs, universities in states that have public benefit funds
- Government lack of interest in renewable energy
- Non-traditional & non-educational competition for R&D monies, could replace or challenge UCF
- Florida is a regulated market, operates differently than ISO/RTO (could be an opportunity as well, but less competition here, more utility and PSC collaboration)
- DOE policies leading to a move away from basic research to product based research
- Speed of technology change (fast) compared to research results
- Work for hire: should this type of work go through department or ARI, especially if commercial contract? What's the boundary for each?

UCF Energy Research Capacity Analysis

External Funding in Energy, FY 2013-2017



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UCF Funded Energy Research Areas

Funded Projects by Start Date 01/01/2016 – present:

Total unique projects UCF Wide	770 Projects
Total energy related projects	101
Non-renewable (Turbomachinery related)	47
Building Energy	20
Renewable (PV related)	12
Energy storage	7
Solar (Training and Other)	7
Alternate Fuel	2
Transportation/Autonomous (Energy)	2
Nuclear	1

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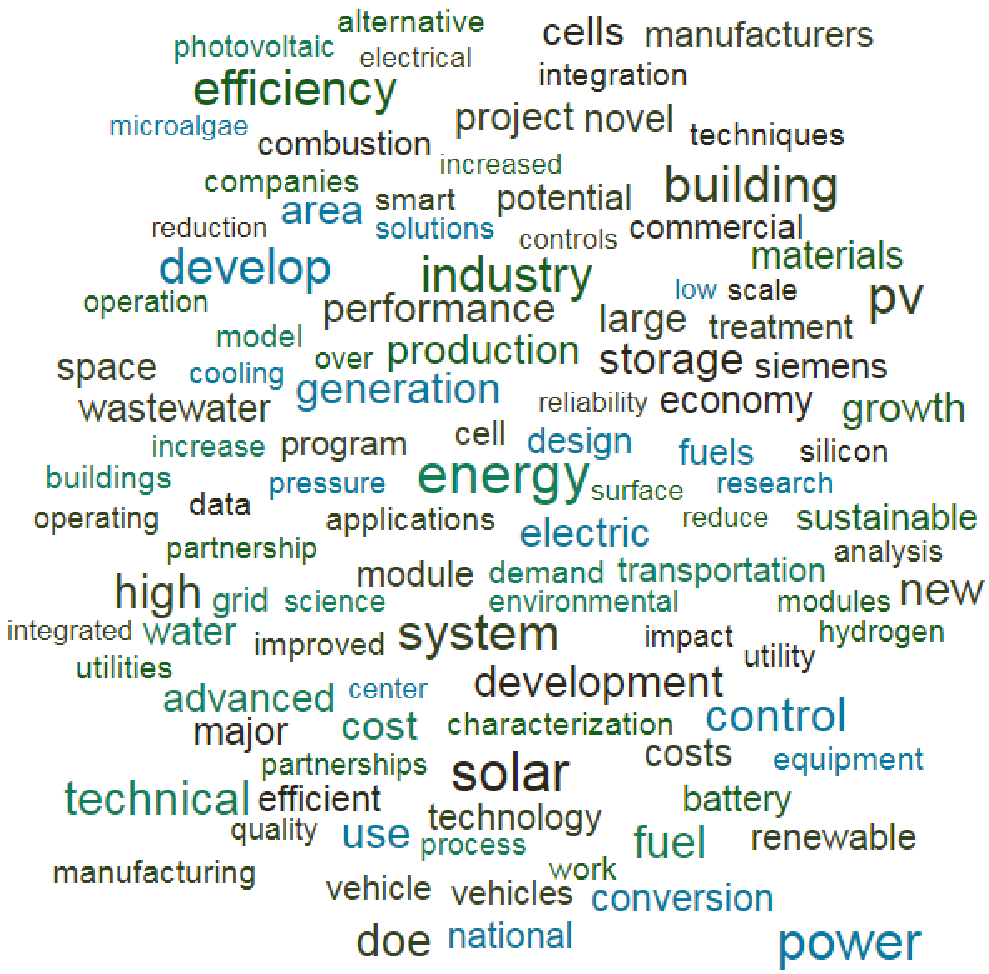
Quad Charts

Energy Research Word Cloud



UCF Expertise Mapped Against Funding Areas

Agency / Topics	Solar + PV	Fossil Fuel Related	Buliding Efficiency	Energy Materials + Reactions	H2 + Fuel Cell	Smart Grid + Power Electronics	Policy, Environment & Economics	Energy Education	Energy Storage & Transmission	Alternate Fuel (Biofuel)	Wind Energy	Nuclear Energy
NSF (Energy for Sustainability, 2012-2018; 169 projects funded)	X	X	x	**X**	X	X	**X**	**X**	X	X	x	x
DOE	**X**	**X**	X	**X**	**X**	X	x	X	X	X	X	x
DOD	x	X		x			x			**X**		x
NASA	X	x		x	x	x	x					
DOT							x					
EPA (Science & Archives Results)							**X**	x				
Industry		**X**					x					
DHS							X					

UCF's expertise heat map drawn based on last five years awarded projects and activities

Strong Expertise | Medium Expertise | Little Expertise | No Expertise

The Agency funding by Field is not comprehensive and may not be accurate, it is gathered from respective Agency website and Grants.gov based on historical funding

x Less Frequent

X Frequent

X More Frequent

The Future of Energy Research – Panel Member Summaries

1. The Future of Smart and Integrated Energy Systems

Issa Batarseh, ECE/FSEC

Integrated Grid-Tied PV+Storage Solutions. In the early 1970's, with very little policy support from utilities or government, off-grid installation of photovoltaic (PV) systems with batteries was the dominant market world-wide. As PV and power electronics technology improved, grid-tied PV systems without batteries were increasingly installed. In the nearly two decades since, grid-tied systems have clearly dominated the market. Given the giant power grid infrastructure in place, grid-tied solutions were the natural ones. In the nearly two decades since, however, grid-tied systems have clearly dominated the market. By the end of 2015, battery-based PV systems made up less than 1% of all PV deployment worldwide. But like every technology cycle, batteries are back and businesses and consumers are ready to embrace storage once again. It has been reported that the US distributed storage market alone will grow to 1 GW in less than ten years. The cost of Li-ion batteries has dropped by 40% since 2010 and expected to reach $100/kWh by 2030. It is anticipated (GTM Research) that the cumulative installed commercial storage capacity will grow from about 200 MW in 2015 to 740 MW in 2020. It is the most anticipated technological development in the solar energy space for residential, commercial, and utility scale applications. In fact, it is hard to imagine that future PV systems will be installed without storage.

Lithium-ion batteries, are abundant, getting cheaper, and are expected to follow its natural partner, photovoltaics, in popularity. As PV penetration increases, intermittency in power generation is causing grid instability, causing states, utilities and electricity markets to couple PV deployment with storage. There are additional benefits from storage, including voltage and frequency regulation, peak shaving, enhanced system stability and enabling microgrids solutions.

Integrating lithium-ion batteries, power electronics, and smart home energy management systems is the wave of the solar energy future. It is an emerging market that will make its big turn in the next 5-10 years, and its surge will disrupt the market. The future main research efforts must focus on integrating advanced power electronics with PV plus energy storage to achieve significant improvements in energy efficiency, reliability, and cost-effectiveness of electric grid. It is expected that future developments will include new control methods, power semiconductor devices, and packaging and system integration techniques.

Power System Infrastructure. Given the recent increased deployment of renewable energy sources and EV growth, the US electric power grid is evolving toward smart power electronics-based systems. Today, PV power offers a completely new paradigm for power generation and deployment. Billions of low-cost intelligent devices (internet of things, IoT) will be employed to control the power grid, with full communication capabilities. Major shifts in the electrical infrastructure will require highly flexible and efficient energy conversion design through out the grid. It is estimated that in the next 15 years, 80% of the infrastructure will transform to meet these changes. This dynamic grid landscape requires that future distributed generation systems be resilient, robust, adaptive, and cost-effective. Therefore, research and training will become necessary to meet the highly distributed, highly connected future green electrical infrastructure, and to support new and broad market opportunities. There will be the need to energize and monitor the projected one trillion IoT devices in use by 2022, while keeping the grid physical security intact and assured. In such a dynamic and ever-evolving environment, the challenge is to guarantee the security of the required power electronics technology for driving sensors and actuators.

Power Electronic for Integrated Systems. Power electronics is the enabling technology that transformed the field of energy, energy conversion and power engineering from a high-tech to a smart-tech frontier. It is the “glue” that makes the ushering of a new kind of smart energy technology revolution possible. However, the scope of research, education and training in the field of power electronics has dramatically shifted in recent years. This is due to the increasing importance of integrating renewable energy sources and storage into the grid, coupled with development of new and revolutionary high-temperature, wide power ratings devices and smart diverse digital integrated circuits.

Power electronics research is shifting from the component and circuit level into integrated systems-level, and as markets in renewable and distributed energy systems continue to emerge and expand, new applications continue to arise. This shift in focus will increase system’s reliability, and stability, expand functionality, enhance efficiency and reduce cost. The future power electronics systems are expected to modernize our electric grid, facilitate electrification of the transportation sector, allow for large solar energy penetration, and enable the deployment of the highest possible energy efficiency systems. For example, it is estimated that just the global information and communication technology (ICT) sector energy needs alone will increase three times by 2020 compared to 2007.

To address system-level integrated designs and expanding applications, the future focus will be on the design and optimization of module-based power electronics with increased emphasis on multi-disciplinary solutions to address increased system complexity. Such system-level solutions may include: (i) coupling recent battery technology developments and new distributed power architecture and reliable uninterruptible power supplies to meet the growing needs of data centers (ii) developing systems-level software and hardware tools for design, testing and validation of technologies required to address the integration of tens of thousands of devices, (iii) addressing regulatory requirements to meet various standards, electromagnetic interference (EMI), and constant shifting market demand, and (iv) providing access for data retrieval, storage, and processing, and how to use it to make better product and business decisions. Given the potential future of power electronics, educating the next generation of technicians, engineers and researchers will need to adapt to incorporate these new paradigms, as well as to identify approaches to make system-based power electronics part of other engineering disciplines.

Energy Electrification for Transportation. One of the most disruptive technologies in the near future will be Electric Vehicles (EVs) and Automated Vehicles (AVs), and could represent a significant change in the transportation sector. For the first time in history, EVs represent a significant and viable challenge to fossil-fueled vehicles for meeting the transportation needs of society. There is little doubt that EVs will become the transportation method of choice for the 21st century. The resulting challenges to the power grid will be significant, requiring new ideas for accommodating fast charging while supporting power generation and distribution infrastructure**.**

This will require new power electronics for EV chargers with improved efficiency, increased reliability and reduced size and complexity, while keeping the cost low, and accommodating new standards. New power electronics designs for EVs will be needed to increase long-range usage, accommodate and integrate renewable sources, and support both wired and wireless charging technology solutions. High-temperature devices, advanced controls, harmonics reduction, integration, and new module-based topologies all need to be explored and developed in the near future.

Energy electrification for air transportation, such as airplanes and drones, will also face some technical challenges in the near future as smart autonomous systems become more popular. This will require more efficient power distribution architecture, higher energy storage solutions to meet increased range requirements, the need for more efficient electric motors with increased compact and light weight designs, and advanced monitoring of components and systems for safety considerations. Finally, the need to have new compact and reliable battery packaging with energy management and protection software will be important in the near future.

High Temperature Power Devices and Integration. For the past half-century, industry has relied heavily on silicon (Si) as the primary semiconductor material for power devices, but interest in recent years has been steadily shifting towards new material that can handle high temperature and reduce the on-resistance (less power losses). Wide-Band Gap (WBG) semiconductors, such as Silicon Carbide (SiC) and Gallium Nitride (GaN) are such examples. Their entry into the commercial marketplace has been steadily and quickly rising. WBG materials have shown the capability to meet the higher performance demands of evolving power equipment, operating at higher voltages and temperatures and enabling switching frequencies with greater efficiencies compared with existing Si devices. Along with performance improvements, WBG-based power electronics can be fabricated with a much smaller footprint (reduced volume) compared with comparable Si devices due to decreased cooling requirements and smaller passive components, contributing to lower overall system costs. The main challenge remains the cost of WBG vs. the cost of their counterpart silicon devices, with more promised improvements in the near future. However, in certain power ratings, WBG devices are in parity with the cost of silicon devices. In fact, SiC and GaN are expected to completely replace silicon for high voltage, high temperature, and high frequency applications. Challenging technical issues remain including, transient responses, driving circuits, EMI, testing and characterization, smart packaging and integration, and thermal management.

2. **Photovoltaic Systems Research- Maximizing Energy Generation Through Discovery**
   Joe Walters, Winston Schoenfeld, Kris Davis - FSEC

With the exponential growth of PV system installation worldwide there is a concerted effort to ensure the power generation from these fields is maximized. From installation practices, operation standards, failure analysis, and power generation predictions the Florida Solar Energy Center is partnering with international and national organizations to discover methods that will maximize the energy production from these fields.

3. **Using Electric Vehicle V2G for Building Peak Demand Mitigation**
   Rich Raustaud, Paul Brooker – FSEC

Building electrical loads and therefore operating cost will increase as electric vehicles penetrate the market and building owners allow these vehicles to charge at the workplace. Building operating costs can be minimized by using the vehicle's battery as a resource. Active control of charging and discharging can limit increased electric utility demand costs which in turn may allow employees to charge for free at work.

4. **Energy Storage Systems**
   Paul Brooker and Jim Fenton - FSEC

Increased penetration of distributed renewable energy systems onto the existing grid will require distributed energy storage to ensure reliable power. These systems must provide energy for the existing electrical grid, but may also be used for energy delivery into an electrified transportation network. Novel applications for energy storage will result in new performance requirements for energy storage technologies, as well as new approaches to integrating multiple energy storage systems. Research areas for this topic are likely to include the following:

- Fundamental materials development (e.g. catalyst development, membrane durability, advanced electrodes for increased storage, new electrochemical systems)
- Usage profiles across multiple energy sectors, and identifying interactions (e.g. utilizing hydrogen as energy storage for commercial building electricity needs as well as transportation fuel in hydrogen fuel cell vehicles)
- Predictive algorithms for increased efficiency of energy systems (e.g. coupling predictive PV production with energy consumption forecasts at sub-hourly rates for improved utilization of on-site resources)

5. **Integrated Smart Building Energy Storage**
   Jim Fenton and Philip Fairey - FSEC

Advance the fundamental understanding of energy storage technologies, solar energy production systems, electric vehicle operation, and building load management within a micro-grid environment. Given the novel usage profiles that will result from these applications, we will also evaluate the durability of these technologies. Advances in materials, processes, architectures, and manufacturing methods will be critical to realizing smart, robust, efficient, and translational electrochemical and building thermal energy storage, all integrated through smart power electronics specially developed for use in utility or rooftop solar building load applications.

6. **Florida Clean Energy Training and Education**
   Colleen Kettles, Susan Schleith - FSEC

The Florida Solar Energy Center has been a leader in clean energy training since its inception 40 years ago. Recent programs have added another dimension to those training efforts, namely a workforce development component. FSEC now serves as a statewide, industry-driven resource for solar and energy efficiency energy workforce education and training to ensure the competitiveness of Florida's clean energy businesses. In order to create a pipeline to clean energy careers and higher education pursuits, FSEC's K-12 Energy Education program engages teachers to develop student interest at all levels about clean and efficient energy resources.

7. **The Future of Building Efficiency**
   Rob Vieira, Philip Fairey, Eric Martin, Danny Parker, Janet MacIlvane, Karen Fenaughty, Jeff Sonne, M. Swami

Building energy use represents about 40% of total U.S. energy consumption, or about 39 quadrillion Btus [U.S. Energy Information Administration]. New energy codes have helped make new building thermal efficiency very good but there are a number of opportunities requiring further research:

- **HVAC and Controls –**
  - Optimizing controls of HVAC and appliances including advancing real time predictive energy demand
  - Improving the efficiency of heating, cooling, water heating and distribution systems
- **IT energy use -** Integrating IT data center and corporate security with computer energy management and reconciling the economics and demand for digital currency and other services with the energy consumed.
- **Other Building End Uses –**
  - Improving lighting, motor, fan and appliance efficiency
  - Reducing the increasing energy use of miscellaneous electric plug loads in buildings
- **On-site Demand Options -** Integration of on-site power systems and on-site storage options, including electric vehicles, to reduce electrical demand and increase resiliency
- **Indoor Air Quality** - Determining risks of indoor air quality based on occupancy and building materials and functions, relative to societal risks of increased energy use due to ventilation.
- **Codes and Standards -** Improving codes, standards and advanced green building programs
- **Modeling -** Improving sustainable community and building simulation programs including energy, resiliency, food and water use
- **Improving delivery method** - Delivery (economic implementation that will achieve more units) of efficiency retrofits to existing residences and commercial buildings, particularly to tenant occupied buildings.
- **Mobile structures -** Improving the efficiency of mobile and temporary structures used in the military
- **Factory built -** Improving the efficiency of factory built structures

8. **Research on Hydrogen and Fuel Cell Technologies**
   Ali Riasi - FSEC

The Florida Solar Energy Center has been conducting research on hydrogen and fuel cell (H&FC) technologies since early 1980s. In the mid-1990s, the U.S. Department of Energy designated FSEC as one of only few Centers of Excellence for Hydrogen research and education. Benefactors of FSEC's H&FC research have included both government and industrial clients. FSEC's innovative hydrogen detection sensor received an R&D 100 Award in 2016. The present research programs in these areas focus on the development of novel materials for hydrogen storage under moderate temperatures and pressures, thermochemical water-splitting cycles, proton exchange membrane electrolytic cell integrated hydrogen sulfide scrubber, to name just few.

9. Trends in Photovoltaic Cell and Module Research

Winston Schoenfeld – FSEC

With considerable declines in PV manufacturing cost, there is now a high focus in identifying PV technology advancements that are manufacturing compatible, offering both increased efficiency and reduced cost. At the cell level, much of the current interest lies in advanced passivation and passivated contact technologies for increased efficiency. As one of the leading research institutions in this area, UCF is leading several projects targeting advancements in this field of cell research. Likewise, predictive metrology for manufacturing is an area of significant effort where there are current metrology needs for both manufacturing processes and in the system field.

10. Design for durability in material systems for energy applications

Dr. Seetha Raghavan, Mechanical & Aerospace Engineering, Dr. Ranajay Ghosh, Mechanical & Aerospace Engineering, Dr Jeffrey Kauffman, Mechanical & Aerospace Engineering, Dr Jihua Gou, Mechanical & Aerospace Engineering, Dr. Ali Gordon, Mechanical & Aerospace Engineering - Center for Advanced Turbomachinery and Energy Research (CATER)

Durable and reliable high temperature material systems are instrumental for applications such as alternative energy, power generation, propulsion and thermal protection systems under aerothermal conditions. The engineered combination of ceramic-metal or composite materials in a layered topology has extended the capabilities of extreme environment materials and the potential for designing revolutionary materials that push the envelope is promising. For example, in a study of the transformative research issues in alternative energy, technical challenges identified include understanding, controlling and mitigating the effects of defects in the active layers of photovoltaic systems, improving fatigue response of turbine blade systems and design of cathode-anode layered structures in fuel cells with tolerance to variation in expansion. Many of the challenges in designing these material systems can be met with the ability to elucidate the mechanics of the most promising material systems under extreme environments. Accelerating the development cycle of transformative multi-materials science, requires coupled experiment-theory-simulation investigations to converge on ideal functional properties for manufacture and processing. These properties must take into account geometric features and performance in extreme environments. The design space of preferred combinations must be supported with improved empirical studies to develop an adequate understanding of multiple, synergistic environmental degradation modes including mechanical, thermal and vibration loads on material lifetime to further cycle the design loop. An integrated effort including first principles and atomistic studies, experimentation under operational environments, advanced diagnostics as well as finite element analysis supported with manufacturing and processing capabilities forms the ideal incubator for the optimizing the design of novel hybrid material systems for durability to accelerate innovation in energy research.

11. Smarter Architecture 2050

Joe Kider - Institute of Simulation and Training

It's a play on Architecture 2030 and 2050 IMPERATIVE which basically talks about getting carbon neutral for new buildings, (major) renovations, and pushing the entire Built environment. The way to achieve these lofty goals is to utilize Simulation, Big data, Machine learning, and IoT for new and innovative strategies where buildings have on-site renewables, off-site power generations, adaptive controls, and kinetic designs. This process is embedded through the entire life-cycle of a Building from birth (early-phase design) through constructions, operation, maintenance, renovation, and demolition. Here is a more general topic on the Built and non-built environment and simulation.

12. Kinetic Facades

Joe Kider - Institute of Simulation and Training

A multidisciplinary, integrated planning approach by architects, engineers, scientists and manufacturers to reduce the energy consumption of buildings for designing, simulating and building skins and envelopes to be dynamic and responsive. You can generalize this to Smart Buildings and bring in more automation systems.

13. Policies to Promote Integration of Sustainable Fuel Sources

Research in the fields of energy policy and economics are expected to concentrate on the integration of renewable and sustainable fuel sources into the electric grid, including distributed and utility-scale solar and wind technologies. This research is expected to concentrate on policies and technological developments that affect: 1. the affordability and competitiveness of renewable technologies, 2. coordination between renewable power sources and transmission planning, and 3. markets and decisions for maintaining grid stability. Additionally, research in this field will focus on renewable energy interactions with climate policies and smart technology initiatives at the local, state, national, and global levels.

14. Digitalization and Use of Gas Turbines as Enabler for Renewable Energy

Jay Kapat, Mengyu Xu, Ranajay Ghosh - Center for Advanced Turbomachinery and Energy Research (CATER)

Introduction of renewable energy sources such as wind or solar energy contributing to the electric grid requires presence of one or both two types of components in the electric grid: (1) fast acting alternative generation technologies that can remain on stand-by until grid demands outpace production and/or when wind or solar input diminishes, and (2) grid-scale flow battery for electric storage. Until the latter option becomes practical and economical, gas turbines will continue to be used to complement the fluctuations in solar and wind energies; they can stabilize the grid because of their fast start-up characteristics. Because of lower capital cost of gas turbines, use of gas turbines on stand-by is the most economical among all other alternatives. From this point of view, gas turbines can truly be called renewable-enablers.

Frequent ramp-up and ramp-down of a gas turbine also comes with a detriment – the operating life of the machine can be reduced without frequent maintenance. Here comes the new concept of digitalization or creation of a digital twin of a gas turbine. A Digital Twin starts with the Digital Thread – the digital description of a gas turbine as assembled (and not necessarily as designed). With continued operation, the digital description of the physical system is continuously updated because of changes in the physical system. Such changes in the physical system can be due to normal wear or tear (e.g. rubbing of blade tips against the casing) or due to external reasons (e.g. sand ingestion into the inlet) or due to manufacturing defect that went undetected (e.g. engine failure in the very first Airbus 380 flight over Indonesia). In any of these cases, the myriads of real-time sensor data can help to detect the small anomalies (through comparisons against the predictions from the physical models) long before any human operator or a simple computer model (that does not contain entire system's digital duplicate) can detect a problem. Thus accidents or failures can be averted, overall reliability can be improved, maintenance can be done only as needed, and overall cost of operation will decrease.
Of course, the concept of Digital Twin need not be limited to a gas turbine. It can be expanded for an airplane, or a car, and will allow the UCF research to have far reaching impact on the society.

15. **Flow and Combustion under Extreme Environments of Turbines and Energy Systems**
    Subith Vasu, Kareem Ahmed - Center for Advanced Turbomachinery and Energy Research (CATER)

Gas turbines are among the most complex machines that humans have ever built. And they are very useful too. Turbo-machineries, in general, are responsible for more than 98% of electricity generated, and almost all of aviation – both military and commercial. Turbo-pumps for rocket engines such as the ones that make Central Florida proud also involve turbo-machineries. So any research under this category automatically serves multiple industry segments of great significance to Florida. With over 10,000 high-tech workforce involved in various aspects of these industry segments inside Florida, research in this area serves to train and prepare future engineers for very important FL companies.

Advanced Combustion –Pressure gain combustion (PGC) has the potential to significantly improve combined cycle performance when integrated with combustion gas turbines. While conventional gas turbine engines undergo steady, subsonic combustion, resulting in a total pressure loss, PGC utilizes multiple physical phenomena, including resonant pulsed combustion, constant volume combustion, or detonation, to affect a rise in effective pressure across the combustor, while consuming the same amount of fuel as the constant pressure combustor. The methodology resulting in a pressure-gain across the combustor relies on the Humphrey (or Atkinson) cycle, and is seen to have great potential as a means of achieving higher efficiency in gas turbine power systems, potentially reaching 4-6% for simple cycle systems and 2-4% in combined cycle systems. At the power system level this efficiency increase would reduce the cost and performance penalty incurred by capturing carbon.

Newer power cycles –Directly and indirectly heated supercritical carbon dioxide (CO2) based power cycles for fossil fuel applications. The supercritical carbon dioxide power cycle operates in a manner similar to other turbine cycles, but it uses CO2 as the working fluid in the turbomachinery. The cycle is operated above the critical point of CO2 so that it does not change phases (from liquid to gas), but rather undergoes drastic density changes over small ranges of temperature and pressure. This allows a large amount of energy to be extracted at high temperature from equipment that is relatively small in size. SCO2 turbines will have a nominal gas path diameter an order of magnitude smaller than utility scale combustion turbines or steam turbines. Studies suggest that a supercritical CO2 oxy-fuel PFBC system has the potential to significantly increase efficiency by 9 percentage points over other pulverized coal oxy-fuel combustion configurations with a 20 percent lower levelized COE and the potential for near 100 percent CO2 capture. Water consumption and other emission profiles are also very attractive for this cycle.

Recommendations from UCF Community Meeting
March 29, 2018

Q1. What major opportunities in energy research are we missing?

- Petroleum & fuel production and processing
- Upstream power generation research
- Internal combustions engine research
- Energy tailored courses, preferably interdisciplinary
- Donor identification & retention
- More energy related I.P. & engagement of industry
- Better handling of funds granted that have PIs in multiple colleges. Current system penalizes these type of projects.
- Increased involvement in energy storage, in order to facilitate this, perhaps create a new interdisciplinary, cross-departmental “cluster”
- IE engines
- Load-leveling energy policy
- Lab space
- Energy efficient post-CMOS drivers
- Grid-hardening
- Space-prop energy
- Geo-thermal research
- Tidal conditioning
- Super cap
- Nuclear fusion
- More efficient bio fuel
- More scholarships
- Accumulation of civilian solar integration into local energy grids

Q2. How can we better communicate our expertise and accomplishments to our community, peers and future students and faculty?

- Better marketing- focus on energy to students
- Training sessions
- Large national competition to invite corporations and universities to draw attention to energy research (e.g., solar powered boat, etc…)
- Humanitarian approach – project to provide distributed renewable power in areas of with lack of energy, big project & marketed
- Better academic programs designed to meet what industry needs, unique programs here (e.g. with Siemens)
- More scholarships specialized in energy research
- More energy-related academic certificate programs
- FEEDER – more marketing of FEEDER program, partnerships with other universities for classes
- Better websites for clusters – more ownership at the cluster level of websites to share more up-to-date information on our research
- More interdisciplinary courses (e.g., cluster co-taught courses, etc…)
- More unique course opportunities – requires support at administration level as well as how to count for P&T credit for co-taught classes (FCI MO was helpful)
- Seminar series for energy research, much like the talk today – stimulates conversations & networking, invites community & practitioners on campus, program managers, etc… & different perspectives
- Energy conference an workshop
- Promote diversity (i.e., more women involvement), find the research ideas & topics that invite diverse members, such as environmental policy
- Workshops
- Online, short informational videos
- Coordinate existing social platforms to highlight by topic
- You tube learning channel by topic
- Optimize search criteria so our audience can find UCF
- Alumni optimization
- Have “look up list” for faculty to go to pick guest speakers
- STEM connect – high tech corridor

Q3. How can we promote collaboration among UCF disciplines?

- Interdisciplinary seed funding (potential phased funding (25K/50K) requirements of full-fledged research proposal)
- Increased doctoral support in interdisciplinary research
- Stream lining co-advising/ joint appointment procedures
- Events to share research & identify potential future collaborators
- Unified proposal submission process across departments/ colleges
- Database of faculty & research areas (Facebook of energy research)
- Dedicated energy research center/institute representing UCF ('branding')
- University wide vision, strategy, & leadership focused on energy (to help make more connections, interface with industry and major funding agencies)
- Unified branding
- Central website that describes core strengths & directory of programs
- In the current model, PIs compete against each other of FOAs. It is hard to collaborate with this model. Need to provide some incentive structure to promote collaboration. This will require significant changes to the current system.
- Seed funding for interdisciplinary projects (e.g., summary salary, course release)
- Fund multiple PIs to travel to conferences or funding agency HQs or low-cost retreats
- Professional development fund to support multiple PIs, disciplines, training, etc…