

# FIVE YEAR STRATEGIC PLAN RUTGERS ENERGY INSTITUTE 2017-2022



The Rutgers Energy Institute is a “ground up” entity. It was created by the faculty of Rutgers University to solve a simple problem. How can the university, with its faculty, students and institutional collaborations with industry, make energy available, affordable and environmentally sustainable?

Dear President Barchi, Chancellor Edwards, Deans, and members of the Rutgers-New Brunswick Community:

On behalf of the entire Rutgers Energy Institute (REI) community, we are pleased to submit to you the Rutgers Energy Institute (REI)'s Five-Year Strategic Plan 2017-2022. This plan was developed over six months by the REI faculty, beginning with a one-day workshop in Fall 2016. We thank all the REI faculty, graduate students, and postdoctoral associates who participated in the strategic planning process, especially the team leaders, for their support, insight, knowledge, and commitment to advance the goals of the REI.

Over its first twelve years, the REI has become a key hub for research, education, policy advice, and outreach, and has added to the reputation and recognition of Rutgers as a whole in the area of energy. This report describes the strengths of REI, as well as the opportunities and challenges facing Rutgers as we strive to tackle the challenge of decarbonizing the global energy system.

Thank you for your support in this mission.



Paul Falkowski  
Director, Rutgers Energy Institute



Robert Kopp  
Associate Director, Rutgers Energy Institute



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Associate Director, Rutgers Energy Institute

## **Why an Energy Institute?**

Access to affordable clean energy is indispensable to the economic vitality of the nation, the health of its inhabitants, and the biodiversity of the planet. Its pervasive influence on all aspects of human activity, determines the range of opportunities in which citizens can participate, from local to global. The paths forward towards decarbonizing our energy sources require participation from scientists, engineers, economists, policy researchers, businesses, as well as an informed public. For these reasons, major research universities have identified sustainable clean energy as one of the most widely listed mission in their strategic plans.

## **What is Rutgers doing?**

Over the past decade, the Rutgers Energy Institute (REI) has provided a forum for discussion of issues and seed money for faculty, students and professional staff (from facilities, transportation, and procurement) to collaboratively work together to foster new research and educational experiences. The result has been a phenomenal growth of the University's research portfolio on energy writ large. However, the value of the REI is not simply monetary – it has developed an interactive forum across the schools that has enabled new collaborations to blossom, and both new energy policy frameworks and technological advances to be achieved. The REI has been instrumental in developing new courses and providing information about energy-related curricula for undergraduate and graduate students. Through seminars, symposia and virtual media, the REI also helps the broader community to understand the complexities of transforming our nation's energy generation in coming decades. Simply, if the REI had not been created, the university would have lost participating in the most pervasive topic of national interest to have arisen in the last two decades.

## **A brief history of the REI**

The Rutgers Energy Institute (REI) was created by faculty in 2005, when it was realized that research and education programs in energy were conducted in several schools across the university, but there was little to no coordination or synergism between programs, researchers, or schools. To that end, the VP for Research provided seed money to create an interschool institute with a focus on science and technology, policy, and economic issues relevant to energy. The goal was to develop a research portfolio that would propel the university into a critical area that is rapidly evolving. At present, approximately 77 faculty from five schools in RUNB are active members of the REI (see appendix on pages 12 and 13). Through FY 2017, funding has been provided by the central administration.

## **What is the role of the REI within the University?**

The REI was envisioned to become a “one-stop shop” for all energy programs at RUNB. Its initial scope was defined by a faculty charter and a seed budget of 250,000 in FY 2005. Today, with a budget of 300,000, REI plays several critical roles in and for the university, including, but not limited to:

1. Providing an informal forum for researchers to share ideas and interests. The REI has been critical in developing new, interdisciplinary research and educational programs that cut across traditional school boundaries.
2. Showcasing RU's wide and deep energy portfolio. Through seminars, workshops and symposia, REI has elevated the profile of Rutgers energy research among colleagues in other academic institutions, government, industry, and the community.
3. Developing and coordinating undergraduate and graduate courses in energy across the schools. The REI launched a multi-instructor, multidisciplinary undergraduate core course on energy, provides a graduate certificate in energy, and spurred the development of a number of other collaboratively taught courses.
4. Providing seed money to clusters of faculty to develop new, fundable research programs from

external agencies. The seed funds include, inter alia, support for undergraduate and graduate students, post-doctoral fellows, and visiting scholars.

5. Providing support for undergraduate interns to conduct energy-related research during the summer. REI-sponsored interns have worked in numerous research labs, at the Rutgers EcoComplex, and with Rutgers facilities. They have been accepted in the finest graduate programs in the nation.
6. Providing information to the public and to local, state governments and our federal representatives about sustainable growth and energy production. REI faculty have met with federal and state officials and served on external government panels. Our policy seminars frequently attract state officials, and our annual symposia have included former Energy secretaries and undersecretaries.

### **Relationship to the RU Strategic Plan**

The REI is critical to meeting the goals set forth in the Strategic Plan for Rutgers, a signature initiative of the present administration that was released to the public in February 2014. Sustainability is a major commitment of this plan. Sustainable energy development has been a cross cutting theme for the REI since its inception, and the institute promotes research and education in many conceptually distinct components: lowering energy demand, efficiency improvements in energy production and consumption, electric grid-reliability, new fossil energy technologies including carbon capture and sequestration, new nuclear energy technologies (including fusion), renewable energy technologies and materials (solar, bio, hydro, wind, etc.), flexible technologies for integration of these disparate energy generation systems, future energy systems, and energy economics, social sciences and policy analyses. A key role of the REI is to ensure that energy, writ large, is a core theme in the university's research and educational portfolios. This function is presently accomplished voluntarily within the framework of the REI, which presently serves an informational role to RUNB schools about energy and environmental issues in both education and research.

### **The Research Goals of the REI**

Broadly speaking, the research goals of the REI, which are set by the faculty, are to develop the science, technologies, economics and policies that provide efficient, cost-effective pathways for producing reliable, sustainable, energy sources with zero net carbon emissions. The motivation for this pathway – a central goal of the Paris Climate Agreement, reached by world leaders in December 2015 – is based on observations and models of our planet's changing climate.

Human emissions of greenhouse gases, primarily from the combustion of fossil fuels, are transforming our planet. Carbon dioxide concentrations in our atmosphere are now more than 40% higher than they were at the start of the Industrial Revolution – likely the highest in at least three million years.

Consequently, global average temperatures have risen by about 1°C over the last century and a half. Driven by this warming, as shown by a recent Rutgers study, global average sea level has risen faster since the start of the 20th century than during any time in at least 2800 years. And more warming is in store: at a global level, we are currently emitting about 10 billion metric tons of carbon as carbon dioxide each year, a rate that, if sustained, would warm the planet at about 0.15°C per decade.





**FIGURE E7: COMPONENTS OF 80 PERCENT GHG REDUCTIONS IN MCS BENCHMARK SCENARIO**



*Source: U.S. Mid-Century Strategy for Deep Decarbonization (White House, 2016)*

In 2016, the White House laid out a mid-century strategy for ‘deep decarbonization’, intended to get the country on a path consistent with long-term Paris Agreement goal of global net-zero greenhouse gas emissions in the second half of this century. Without action, net U.S. emissions in 2050 are projected to be about 10 billion ton CO<sub>2</sub> equivalent. The 2016 strategy document lays on a multi-prong approach to reducing emissions to less than 2 billion tons. Many of the key areas – transportation, buildings, and industrial efficiency; renewable electricity; carbon capture and storage; low carbon fuels; vehicle electrification; and carbon dioxide removal – are areas of active research at REI. Regardless of the approach taken by any one U.S. Presidential administration, a portfolio of technologies like these is needed to achieve international goals and limiting the amount of dangerous climate change.

## Clean Energy - The grand challenge of the 21st century

To stabilize the planet’s climate, we need to bring the net global carbon dioxide emissions to zero: a goal affirmed by the international community for the second half of this century in the Paris Agreement of the United Nations Framework Convention on Climate Change. This is one of the most difficult challenges facing humanity. To achieve this goal requires deep decarbonization of the U.S. and global energy systems (Figure E7). The REI was designed to meet this challenge through innovative basic and applied research, education, outreach and advice to policy makers.

## Structuring the REI to meet the challenge

The REI has five core, interlinked themes, cutting across school boundaries. These themes do not represent the breadth of the expertise of REI faculty; rather, they are areas of crosscutting strengths and opportunities that are fertile ground for collaborations and are critical to decarbonizing energy supplies in the coming decades. These themes are:

1. Catalysis
2. Nanomaterials, Photovoltaics, and Storage
3. Bioenergy and Bioproducts

4. Carbon-Negative Technologies
5. Energy Economics, Environment, and Policy Systems

The five themes represent current strengths and are topics in which REI has invested, and will continue to invest resources with reasonable expectation of fostering successful external funding.

This document outlines a vision for the Rutgers Energy Institute that will help build upon our existing strengths and promote Rutgers' faculty to becoming global leaders in these areas. The text that follows are based upon a strategic planning process that engaged REI faculty over the course of the fall 2016 semester.

## REI's Key Research Themes

### 1. CATALYSIS

**Motivation and Relation to Energy:** Catalysis is the fundamental process used in every chemical industry to transform essential chemical feedstocks to useful products. It is an essential technology for fuel cells and other energy conversion systems, combustion devices, pollution control systems, agriculture, chemical, materials manufacturing, and virtually every product that impacts our lives. Catalysts were discovered in the 19th century, and their development was critical to the incredible growth of industrial chemicals ever since. However, there are several key reactions that sustain society based on catalysts that were developed long before there was awareness of the need for energy efficiency and shortages of raw materials

**Key Challenges:** Future catalysis research must replace pioneering, legacy technologies with energy efficient processes that use less of scarcer raw materials and recalcitrant feedstocks. This shift cannot be accomplished by incremental steps on existing processes. It requires innovation of new concepts. We must significantly improve upon the efficiencies of both current catalytic chemical conversions (saving energy) and natural photosynthesis (reducing agricultural land use); electro-catalysts that operate using solar electricity as an energy source must be developed that replace legacy, heat-activated catalysts; we must improve catalyst selectivity (reducing material waste and processing costs); we must develop catalytic processes to replace fossil fuels and petroleum products with renewable (solar) fuels and synthetic biodegradable products (recycling combustion products and agricultural products).

**Strengths:** REI faculty are on the cutting edge of catalysis research. We have strong faculty at all ranks in multiple departments and schools. The faculty are working on several fronts to produce clean energy from renewable energy sources, such as hydrogen for fuel cells-produced by electrolysis of water, transportation fuels from non-edible biomass, and solar fuels produced from carbon dioxide and water using solar electricity. REI scientists and engineers are pioneering the development of electro-catalysts and solar cells needed to create solar fuels. REI researchers are also working on electrochemical alternatives to the energy-intensive Haber-Bosch process for producing synthetic fertilizers, which are key to feeding the planet. An electrochemical alternative powered by carbon-neutral electricity could prove transformative in this sector.



**Weaknesses:** Two primary weaknesses face the REI faculty in catalysis. First, there is a lack of national visibility of a centralized core program to “brand” the catalytic research efforts. No integrated SAS-SOE-SEBS teaching program exists and no virtual research umbrella exists in catalysis, despite a geographical location in the center of catalysis research in NA (BASF, EXXONMobil, Palmolive, Merck, BMS, etc). Rutgers has not capitalized on its multiple national achievements in education (two NSF IGERTs) and research discoveries, owing to a lack of centralized staff supporting communication. Multiple faculty and department sponsored websites exist related to catalysis that are inactive that lead visitors to out of date resources, non-existent programs, and dead-ends. This creates an impression of disorganization and frustration by visitors. Second, is the lack of institutional support for staff professionals who operate complex shared facilities and to recruit the best graduate students and post-doctoral fellows available in what has become a very competitive market. The cost and complexity of modern instrumentation necessary to compete for center grants and industry support cannot be entrusted to novice graduate students and short-term postdoctoral fellows. Graduate students and post-docs can serve as bridges across interdisciplinary divides – and those bridges are the key to developing new ideas and new approaches. The dearth of GA lines at Rutgers is a major weakness. The high cost to support GAs at Rutgers has caught the attention of the funding agencies. In the recent words of a DOE program manager “I think twice before awarding a grant to Rutgers in support of graduate students.”

**Vision for the next five years:** We envision developing a major center for catalysis at Rutgers, of which a core theme will be related to energy production/storage and developing alternative catalysts for energy intensive processes important to agriculture. For example:

1. renewable hydrogen by water splitting using solar electricity;
  2. replacing the 100 year old Haber-Bosch process use for ammonia production; and
  3. electro-catalytic conversion of carbon dioxide to fuels and chemical feedstocks to replace fossil sources.
- This effort has already begun with the submission of a center of excellence grant to NSF-CCI (Centers for Chemical Innovation) as well as a multi-investigator proposal to the DOE-EERE in electrocatalysis. These initiatives were developed with support from the REI.

## 2. NANOMATERIALS FOR CATALYSIS, SOLAR AND ENERGY STORAGE

**Motivation and Relation to Energy:** New nanomaterials may be key to the development of innovative catalysts. They are also crucial in at least two other core carbon-neutral energy solutions: solar photovoltaics and energy storage. Solar photovoltaics provide a small but rapidly growing share of world electricity generation. In 2016, the installed base of solar photovoltaics around the globe exceeded 260 GW, providing peak production equivalent to that of about 500 typical coal power plants.

**Key Challenges:** Solar and other intermittent renewables are inherently limited: solutions are needed to deal with the problem that the sun doesn’t always shine and the wind doesn’t always blow. Without such solutions, the U.S. will not be able to achieve the vision of its mid-century decarbonization strategy, which calls for wind and solar to provide nearly half of total electricity generation by 2050. The ability to use nanomaterials to store energy at large scale on the grid – as well as at smaller scale, enabling inexpensive electric vehicles – is thus a core decarbonization technology. This community has benefited immensely from the REI, especially from the seed funds offered. These funds have been leveraged into bigger grants and created new interdisciplinary projects.



**Strengths:** REI has several key research groups working on nanomaterials for clean energy, and for five years hosted an IGERT focused on this topic. Synthesis of nanomaterials is one of REI's strengths. We have experts that can synthesize a wide range of nanomaterials that can be utilized in a variety of energy applications, such as catalysis, energy storage and photovoltaics. Synthesis of nanomaterials is conducted by numerous faculty members and utilized for a wide variety of energy applications – for example, plasmonic metal nanostructures for solar cells and catalysis, two-dimensional materials for catalysis, solar, and energy storage applications. Rutgers' Energy Storage Research Group is a world-leading energy storage research enterprise. There is expertise in developing new materials for solar cells. In addition to synthesis, there is also expertise in characterizing these materials.

**Weaknesses:** One of our current weaknesses is in the integration of nanomaterial into devices, which currently happens primarily through collaborations with other institutions. The main weakness for this community at Rutgers is the lack of **expertise and infrastructure to make devices such as solar cells and batteries**. The community could benefit from expertise that utilize novel nanomaterials for the next generation of batteries. Similarly, we currently lack the expertise and infrastructure to fabricate proof-of-concept photovoltaic devices. The infrastructure required consists of clean rooms, glove boxes and other costly equipment.

**Vision for the next five years:** The best approach to address these needs would be to recruit new faculty members who bring the scientific knowledge regarding integration of interesting nanomaterials for solar cells and batteries. The equipment infrastructure could be built from start-up packages or future instrumentation proposals. These strategic hires would allow the nanomaterials community at Rutgers to leverage their existing resources. The absence of energy storage and device capabilities has negative implications for other communities because proposals require fundamental materials research to be translated into proof of concept technologies through devices. For example, processes such as photocatalysis require complex multi-junction cells made from high purity crystalline compounds, transferred under high vacuum conditions to make uniform thin films for efficient operation. Federal funding to academic centers working in photocatalysis has been significant (\$120M/5 years DOE Solar Fuels Hub). However, large center funding has gone to aspirational peers providing significant institutional commitment. Rutgers multi-investigator proposals are funded in photocatalysis of water splitting.

The REI and the revamped Rutgers Materials Institute will work synergistically to improve the infrastructure and resources. The materials institute focus is on advanced nanomaterials, electronic devices, and materials characterization. The maintenance and building of this infrastructure through collaborative initiatives with REI will enhance the impact of resources. For example, the financial support required for the integration of device fabrication facilities in the materials institute will benefit REI. The support for GAsheps, postdoctoral researchers, and technicians that work across the two institutes will help to create the type of intellectual environment needed for multi-disciplinary energy research.

### 3. BIOENERGY AND BIOPRODUCTS

**Motivation and Relation to Energy:** REI's bioenergy research complements its work on solar fuels, exploring alternative pathways to generating drop-in, low-carbon replacements for existing liquid fuels. It also complements REI's work on carbon capture and storage (CCS): bioenergy coupled to CCS is a major potential pathway for accelerating the removal of carbon dioxide from the atmosphere. But bioenergy research isn't only of use in the energy sector per se; fossil fuels are used for synthesizing high-value plastics as well as low-value energy products, and bioproduct synthesis may be one key pathway for breaking this additional dependence on fossil fuels.

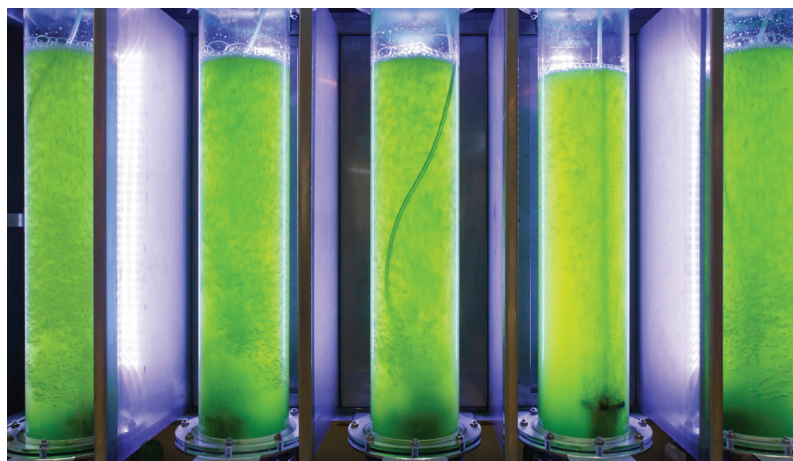
**Strengths:** REI's current strength in bioenergy and bioproducts is primarily in fundamental photosynthesis, feedstock development and in technologies relating to biomass pretreatment or conversion. Significant strength can be found in plant breeding and genomics for more traditional crops such as maize and sorghum, as well as in newer plant models for sustainable biomass such as switchgrass and duckweed as energy crops.



Microalgae, as a third-generation feedstock, also has significant critical mass of researchers in Rutgers. For the pretreatment and conversion of biomass in the process of biofuel production, research efforts in catalysis, pyrolysis, enzyme engineering, and biogas generation are also substantial. The issue of loss of biodiversity stemming from land area lost to cultivation of energy crops is an enormous potential problem on the horizon. All crops rely on the highly inefficient natural photosynthetic light capture to biomass production and overcoming this gap is a strength at Rutgers.

**Weaknesses:** There is a fundamental gap between the basic sciences in plant and algal biology and engineering aspects of the problem that are critical to making bioenergy and biomaterials available at scales that are commercially viable. Specifically, there are applied areas that are critically relevant but are presently lacking or deficient. These include research activities in Harvesting/Logistics optimization and Distillation/Refinery technology development for bioenergy and bioproducts.

**Vision for the next five years:** To galvanize more interdisciplinary research that can leverage the critical mass of expertise at Rutgers in the bioenergy area, the bioenergy and biofuels group suggests one or more **joint appointments between the School of Engineering and SEBS**. The new hire(s) should carry out research with Engineering and Plant Science and other bioenergy/bioproduct components of the REI. Another targeted approach to integrate basic researchers in the feedstock development areas with downstream applications is the recruitment of **new faculties in the Intermediate Metabolism area**, especially those working on photosynthetic organisms. This area of strategic hire could help develop more systems approach in both plants and algae by leveraging the wealth of germplasm and genomics resources/expertise that are currently at Rutgers. Coupled with additional **Synthetic Biology expertise**, knowledge gained from systems analysis of metabolic control in various feedstock candidates for bioenergy could generate novel products from the biomass or to optimize their downstream processing to biofuels, to name a few potential targets.



#### 4. CARBON NEGATIVE TECHNOLOGY

**Motivation and Relation to Energy:** Achieving international climate goals will not only require preventing CO<sub>2</sub> emissions by decarbonizing the energy system – they will also require accelerating the removal of CO<sub>2</sub> from stack gases and the atmosphere through carbon-negative technologies. The central scenario of the U.S. mid-century decarbonization scenario calls for about 0.5 billion metric tons of CO<sub>2</sub> to be removed from the atmosphere annually through such technologies in the U.S. alone by 2050. Two such technologies currently being studied by REI scientists are bioenergy coupled to carbon capture and storage (BECCS) and carbon-negative materials production. Geological storage of captured CO<sub>2</sub> is a potentially important piece of the mitigation puzzle.

**Strengths:** REI geologists are leading projects to evaluate future areas for carbon storage off the coast of the eastern US, while REI economists are assessing the costs and benefits of BECCS deployment in the northeastern U.S. With this work tied to other research threads on bioenergy and solar fuels, REI has the potential to be a global leader in this technology. Meanwhile, REI engineers have successfully invented and commercialized a CO<sub>2</sub> avoidance and utilization technology that has the potential to reduce CO<sub>2</sub> emissions of the cement and concrete industry – currently responsible for about 5% of global CO<sub>2</sub> emissions – by up to 70%. In addition, Rutgers engineers are investigating materials that utilize CO<sub>2</sub> for use for automotive parts, investment casting, lightweight packaging, agriculture, fasteners, armor and many other applications. A key to enabling this

approach is the ready availability of CO<sub>2</sub>. Scientists affiliated with Rutgers continue to develop state-of-the-art carbon capture systems that could be paired to enable extensive mineralization.

**Weaknesses:** This effort has the fewest number of researchers in the REI, but is potentially one of the most critical in reversing the effects of CO<sub>2</sub> emissions. While REI is strong in the identification of geological opportunities to bury carbon, REI research on better carbon capture technology and methods of CO<sub>2</sub> pressurization and transport are also promising directions to improve. Hiring faculty in engineering and the science fields committed to finding viable cost effective solutions where large reductions in cost are possible would be transformational, including cost-effective capture of CO<sub>2</sub> from the atmosphere.

**Vision for the next five years:** Smoke stack carbon capture and storage is not economically viable in the current economic climate without a pricing for carbon and will likely not be exploited on a global scale in the next 5 years. However, efforts at Rutgers in carbon utilization could create a large enough market demand for CO<sub>2</sub> that increases its value so as to discourage wasteful emission, as well as tax incentives. Thus, this energy initiative could lend promise for deployment in the mid-late 2020's and is an important part of any carbon mitigation strategy driven by both burial and utilization. Overcoming the huge hurdle for burial-based approaches will require several developments over the next 5 years:



1. policy and economic standards that Rutgers can help guide through the REI;
2. evaluation of storage potentiation in geological formations particularly offshore where leakage, earthquake stimulation, and political issues (Not Under My Backyard) are mitigated, a task RU is funded to do by the DOE; and
3. modeling of injection and trapping behavior of supercritical CO<sub>2</sub>, a task begun by D. Schrag at Harvard, but could be done here at Rutgers with the hire of a faculty member with expertise in geology/geophysics and civil/environmental/ petroleum engineering. In addition, we should recruit faculty who can drive utilization through materials design and the advantages that systems utilizing these materials will gain.

## 5. ENERGY ECONOMICS, ENVIRONMENT, AND POLICY SYSTEMS

**Motivation and Relation to Energy:** The decarbonization challenge isn't just a technological challenge – it's a human challenge, motivated by the human impact on the global environment, and it cannot be solved without understanding the socio-economic systems in which it takes place. REI research on energy economics, environment, and policy systems is focused on understanding the flows of energy through the human-energy system.

**Strengths:** REI has key competencies in the following areas:

- **Life Cycle Assessments:** REI faculty in the Rutgers Business School and the Rutgers EcoComplex are assessing the energy and environmental impacts of various energy resources and production processes across their life cycle.
- **Systems Analysis:** Rutgers has an opportunity to initiate a new influence-based modeling effort to include faculty in economics, statistics, and modeling to be able to assess broad-based interactions of technological, economic and cultural domains to move ideas effectively from lab to society.

- **Environmental Impacts of the Energy System:** REI faculty in SAS and SEBS are world experts on the climate, air and water impacts of various energy uses.
- **Socioeconomic Dimensions of the Energy System:** Across SAS, SEBS, the Rutgers Business School, and the Bloustein School, REI faculty are investigating the economic, social, and political dimensions that influence energy production, consumption, and its environmental impacts from a range of social scientific perspectives.
- **Energy Consumption Behavior:** REI faculty in SEBS and Bloustein study how human behavior influences energy consumption, the direct and indirect energy impacts of household and building consumption, and the factors driving shifts in energy consumption.

These key strengths in the EEPS theme provide REI a solid base for investigating the dynamics of energy transitions and the systematic impacts of energy technologies emerging from the other REI themes.

To advance this agenda EEPS teams identified three objectives to strengthen this capability:

1. increase hands on energy research and educational opportunities,
2. interdisciplinary team building and
3. energy decision-maker support.

**Weaknesses:** The Energy Economics, Environment, and Policy Systems group's main challenge is networking and making meaningful connections within the group and with the other core research themes. This is, in part, due to the geographic distribution of people across the campuses, however, with help from the REI, symposia have helped lead to an understanding of each other's research enough to align interests and then identify and find funding sources.

**Vision for the next five years:** Increase experiential energy research and educational opportunities.

This objective focuses on providing undergraduate students, graduate students and researchers the opportunity to engage in a more hands-on way with the human-energy system. This could be advanced through the establishment of:

1. living labs to study building energy use, behavior and environmental components,
2. energy studio courses where students engage a "client" and produce an analysis of an energy issue,
3. participation in a currently-being-discussed Design Institute, by adding a focus on integrating components of planning, industrial design, landscape, and architecture to design low carbon spaces and devices, and
4. an improved internship pipeline.

**Living labs around campuses and on sites in Newark, New Brunswick and Camden.** Clint Andrews has been working with a pilot in the Bloustein building and suggests that the way to go is to have a few sensors in a broad range of settings. The goal is to establish a 'smart city' test bed and support researchers and students learning curves for how to use sensors and analyze big data.

**Energy studio labs** build on the tradition in fields like landscape architecture and urban planning where students engage with a real life project. EEPS identified ideas like students developing Rutgers mitigation and adaptation plans for various campuses or working with various municipalities, businesses, or NGOs conducting various technical, economic, and social analyses of policies and solutions.

**Partnership with the discussed Design Institute** would look to provide student opportunities to learn how to design across fields (planning, industrial design, landscape, and architecture) and have a main focus on energy/sustainability. It would seek to not only educate students on design but on best practices for innovation and commercialization.



The partnerships engaged in the energy studio and design institute can help provide an opening for the development of an **expansion of the REI internship** program to include opportunities outside of Rutgers. REI could partner with **Rutgers Biomedical and Health Sciences** and the **Heldrich Center** to expand training and internship opportunities as well.

**Rutgers Business School Supply Chain Energy Management Research Opportunities:** Research currently conducted in the Supply Chain Management Department shows that manufacturing organizations use several energy sources for a variety of uses. The typical energy sources are electricity and natural gas, but these are provided by a utility supplier using its own energy resources. Energy may be produced onsite as well from solar, wind, and geothermal technologies, but is most commonly generated from the combustion of fossil fuels. Common energy uses throughout industrial sectors include lighting, heating and cooling systems, transportation, and a wide variety of process equipment. Understanding how to integrate the right energy source based on manufacturing processes requires supply chain analysis integrated with the expertise of our REI research partners. This collaboration could result in industry valuing sustainable energy solutions as part of their bottom-line production, profit and revenue goals.

The costs of energy uses are not always apparent to management personnel because many organizations allocate them to overhead usage rather than their appropriate processes. Possibly the most primary form of energy documentation is a facility's utility bill, which charges an organization based on the amount of electricity used in a billing period and the peak use each month averaged over a short time period. The research REI and the Rutgers Business can do to develop industry dashboards or scorecards could bring extreme value-add dimensions to supply chain energy management decision-making.

**Interdisciplinary Team Building:** The group identified the need to make connections within the EEPS group and with the rest of the REI themes. This is necessary to produce relevant research and compete for large interdisciplinary grants. This included an effort to build relationships over time where researchers understand the work others do and have had the opportunity to identify potential research collaborations ahead of calls for grants. Lifecycle assessment was thought to be a useful frame for engaging groups across the themes and those working in the biological and health sciences (around health impacts). Activities that have been identified that may do this would be bimonthly networking events, encouraging team development and teaching of classes, or biweekly brownbag around topics likely to lead to future funding opportunities.

**Energy Decision-Maker Support:** The EEPS and other themes are conducting cutting edge research that can inform better energy decision-making. Energy decision-makers may be businesses, homeowners and policymakers that would find state of the art and concise information useful. We identified short research briefings, potentially targeted to segments of decision-makers, could be useful to write and post on-line. For particularly relevant and timely research, briefs could be used for outreach to relevant decision-makers.

### **Overall plan for the REI**

The REI is underfunded, not only relative to its peers in other institutions, but relative to its goals as described by the members. It has been basically flat funded for over a decade, in spite of having made a major impact on the research portfolio of the university.

The REI proposes to develop a funding model that can provide:

- Fifteen graduate student and postdoc lines that rotate among the five core areas identified above. These lines would allow RU to become exceptionally competitive in recruiting the strongest talent and at the same time leverage the best intellectual capacity of faculty to develop the strongest research proposals.



- Strategic faculty hires in:
  - Integration of nanomaterials for solar energy and storage
  - Intermediate metabolism and synthetic biology for bioenergy and bioproducts
  - Joint appointments between the School of Engineering and SEBS to galvanize more interdisciplinary research in bioenergy.
- Engaging the Rutgers campuses and surrounding cities as living laboratories for
  - Studying building energy use, behavior and environmental components
  - Integrating advanced technologies and urban planning to achieve deep decarbonization
- New educational opportunities
  - Interdisciplinary undergraduate course on the Energy/Food/Water/Population Nexus
  - Greenhouse gas mitigation studios
- Internship program through collaboration with the Heldrich Center and RBHS
- Briefing paper series and other communications activities, with support through dedicated time from Rutgers communications staff, to translate our research results for policymakers and the broader community
- Interdisciplinary team building that links human system analyses into fundamental technological research
- Seminar series for each theme, building upon the successful model of the energy polar seminar series

This model will require either ICR on grants funded through the REI, or direct investment from the relevant schools and/or central administration to support the institute.

# Appendix: REI Faculty by Theme

	Catalysis	Nano	Bioenergy	Carbon Negative	Energy Systems
Amatucci, Glenn		x			
Andrews, Clint					x
Asefa, Teddy	x	x			
Bhattacharya, Debashish			x		
Birnie, Dunbar		x		x	x
Bonos, Stacy			x		
Brennan, Peggy			x		x
Broccoli, Anthony				x	x
Castner, Ed		x			
Celik, Fuat	x	x	x	x	
Chant, Robert					x
Chhowalla, Manish	x	x			
Chundawat, Shishir	x	x	x		x
Coit, David				x	
Cuite, Cara					x
Di, Rong			x		
Dismukes, Charles	x	x	x		
Fabris, Laura	x	x			
Fahrenfled, Nicole			x	x	x
Falkowski, Paul	x		x	x	x
Farris, Thomas					x
Felder, Frank				x	x
Feldman, Leonard		x			
Fennell, Donna			x		
Garfunkel, Eric	x	x			
Garofalini, Stephen		x			
Goldman, Alan	x	x			
Greenblatt, Martha	x				
Guo, Qizhong					x
Guran, Serpil			x	x	x
Hagblom, Max			x		
Hayes, Robert	x	x			
He, Huixin	x	x			
Helsel, Zane			x		
Hochman, Gal			x	x	x
Ierapetritou, Marianthi	x		x		

# Appendix: REI Faculty by Theme

	Catalysis	Nano	Bioenergy	Carbon Negative	Energy Systems
Janes, Harry			x		
Javanmard, Mehdi	x		x		
Khare, Sagar	x				
Kopp, Robert					x
Kornitas, Michael					x
Krogmann, Ute			x		
Kukor, Jerome					x
Lam, Eric			x		
Leichenko, Robin					x
Levitán, Orly			x		
Li, Jing	x	x		x	
Lun, Desmond			x		
Lyons, Kevin					x
Mazurek, Monica				x	x
Melamed, Benjamin					x
Messing, Joachim			x		
Miller, Ken				x	
Nanda, Vikas	x				
Niederman, Bob		x			
O'Carroll, Deirdre	x	x			x
Patel, Nirav					x
Piotrowiak, Piotr	x	x			
Podzorov, Vitaly		x			
Pray, Carl			x		x
Ransome, Ronald				x	
Reinfelder, Ying				x	
Riman, Rick				x	
Robock, Alan					x
Shwom, Rachael					x
Sigman, Hilary					x
Somalwar, Sunil		x			x
Specca, David			x	x	
Trachtenberg, Mike				x	
Tsilomelekis, George	x	x	x		
Wang, Honggang			x	x	x
Xu, Ming				x	x
Yee, Nathan	x				
York, Darrin	x				
Young, Lily					x
Zhang, Xumu	x				
Zhang, Desheng					x
Zhao, Yao					x