Overview of potential projects.

Potential Project	Area	Leading Professor
Hybrid Renewable Energy Desalination Systems	Mechanical Engineering	Lackner & Manwell
Biosolid resource recovery	Environmental Engineering	Butler
Public Perceptions and Engagement around Large-Scale Renewable Energy and Water Projects	Socio-Environmental Science	Bates
Tracking Movements of Common Terns	Environmental Science	Sievert
A biomimetic bat deterrent device for wind turbines	Mechanical Engineering	Moddarres
Evaluating portfolios of energy-water alternatives under multiple criteria	Industrial Engineering	Baker
Politics and management of groundwater sustainability in coastal aquifers	Socio-Environmental Science	Milman
Small scale coastal wind energy systems in hurricane prone regions	Civil Engineering	Arwade
Water Safety Plan development in coastal regions with decentralized water and wastewater systems	Environmental engineering	Kumpel
Assessment of offshore wind turbines on wildlife vulnerability	Environmental Science	Griffin
Impacts of energy production on fish and aquatic ecosystems	Environmental Science	Jordaan

Hybrid Renewable Energy Desalination systems

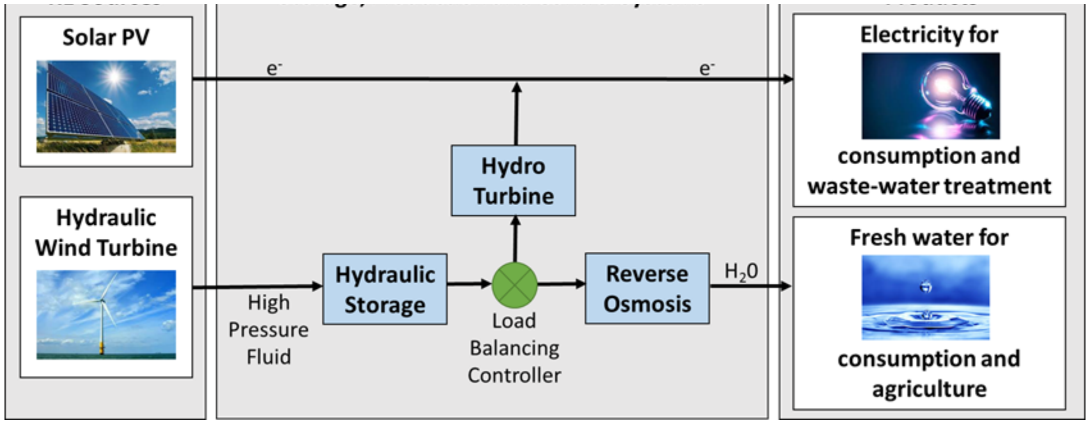
Significance. Renewable energy (RE) generation systems such as wind and solar energy are inherently "non dispatchable," meaning they produce power when the wind blows or the sun shines, rather than on-demand like fossil fuels. In many locations, fresh water supplies also vary significantly through time. Seasonal rain patterns combined with seasonal agriculture cycles can cause periods when supplies are low while demand for drinking and farming are high. The goal of the research in this project is to perform integrated system modeling and control of coupled RE–desalination–storage systems that can alleviate the electricity intermittency issue and improve the operation of both energy and water systems. Coupling of the systems offers an opportunity for improved overall performance, reliability, flexibility, and economics (Manwell & McGowan, 2008).

Theoretical Framework The objective of this project is to develop coupled numerical models for hybrid RE-desalination-storage systems that can be used for multi-criteria optimization of system configuration and performance. We will consider a system based on a hydraulic wind turbine coupled with a hydraulic accumulator–compressed air energy storage (CAES) system, Pelton wheel hydro turbine, and Reverse Osmosis (RO) desalination system (Bourouni et al., 2011; Buhagiar & Sant, 2014). Figure 4 illustrates a proposed configuration for the system model. In this system, the wind turbine directly powers a hydraulic pump creating high pressure sea water. The high pressure fluid is stored in the accumulator-CAES system. A controller can then selectively open valves to drive the sea water either through a Pelton wheel, which is a hydro turbine that generates electricity, or through an RO system to generate fresh water. A solar-PV system will also be included in the model, providing additional electricity production.

This will be the first investigation to model a hybrid system that couples a hydraulic wind turbine, storage, RO and solar power. In contrast to traditional wind turbine systems that generate electricity, this approach has a number of potential advantages, including: reduced system mass by replacing the turbine gearbox and generator with a hydraulic pump; direct storage of energy without the need for expensive

Figure 4 Model of RE-Storage-Desalination system

batteries; high pressure seawater is identical input to both electrical generation and RO systems; power generation is



decoupled from the energy source via the storage system, so power can be produced on-demand similarly to traditional generation, minimizing intermittency issues; the CAES storage system maintains a nearly constant pressure for RO operation; and when RE production levels are high, or when the storage system nears capacity, electricity can be diverted to waste-water treatment, which generally does not require on-demand power.

REU Project. In year 1, the REU student will develop a coupled numerical model for hybrid RE-desalination-storage systems using Matlab. The student will investigate appropriate models for the various components, such as wind turbines, pumps, RO systems, storage, and hydro turbines, and will model the fluid flow through the piping system to incorporate head losses. The student will review the literature for examples of related work to verify that the component models are valid. Then they will perform simulation of the system under realistic, time varying wind conditions, and adjust the control parameters in the model to control the performance. One goal will be to size a storage system and hydro turbine such that the power output can be constant indefinitely under varying wind conditions.

In year 2, the REU student will build off the model developed in year 1. The student will refine the model to include automatic control of the system behavior to optimize performance relative to some objective function. For instance, realistic load data can be incorporated as well, so that the model objective includes tracking the electric load while maximizing fresh water production. The student will use feedback control, based on system measurements to adjust the flow rates within the system and optimize performance. The student will also build a small scale experiment to test and validate the system model.

Bio-Solid Resource recovery

Significance: Solid wastes are an understudied element of the Food-Energy-Water nexus. Organic solid wastes, generally classified as biosolids, are produced from both agricultural processes and wastewater treatment cycles. Typically, they are disposed of in landfills. But, there is an opportunity to recover energy from these wastes, along with nutrients.

Theoretical Framework: Centralized municipal wastewater produces 0.25-0.33 tons of dry biosolids/million gallons of wastewater treated/day (Tchobanoglous et al. 2013), a significant fraction of which is landfilled. In addition to the production of municipal wastewater biosolids, significant biosolids are produced through agriculture and industrial processes (such as rum production in the Virgin Islands). Yet, there are a few possibilities for waste reduction. Composting and thermohydrolysis are gaining attention for energy-efficient solids reduction (Joo et al. 2015). Energy recovery can be accomplished by anaerobic digestion (AD). Fermentation yields a variety of short-chain fatty acids (SCFAs), some of which on their own have value in post-production applications (Agler et al. 2011). SCFAs are also an ideal substrate for an electricity-producing microbial fuel cell. Primary solids, waste activated sludge (WAS) and agricultural waste solids have been directly fed to microbial fuel cell (MFC) anodes (Dentel et al. 2004), but bench-scale studies have not been optimized to maximize power output.

We propose a bench-scale analysis to consider the reduction of biosolids through energy-generating pathways: pre-fermentation with an MFC; direct-feed MFC; and anaerobic digestion. We will also consider the co-reduction of solids and energy-generation with mixed organics biosolids, using waste activated sludge from municipal wastewater treatment as a template for expanding the reduction of solids to other waste streams.

REU Projects: The combination of fermentation of biosolids is new and needs validation at the bench-scale to determine viability for pilot and full scale testing. One REU student will study the profile of SCFAs using various combinations of agriculture, food, and biosolids to characterize the profile of SCFA production fermented at different hydraulic retention times. We have ready access to a variety of biosolids for this effort: UMass has a food waste collection program; and we have relationships with local community gardens (Grow Food Northampton) and local wastewater treatment plants (Amherst and Hadley, MA). Concentrations of SCFAs and gases, including methane, carbon dioxide and hydrogen will be measured with gas chromatography at the inlets and outlets of the fermenter. Understanding the relative distribution of SCFA production from these biosolid wastes in different combinations will yield useful parameters to design the pre-fermentation step of the fermentation-MFC combination.

A second REU student could evaluate the MFC portion of the process. Three continuous-flow experimental configurations will be compared for solids reduction, energy production, and viability of the end-product for agricultural application: (1) MFC fed combinations of SCFA (primarily acetate, butyrate and propionate in equal parts; (2) a MFC anode directly fed biosolids; and (3) an anaerobic digester. These configurations will be on the order of magnitude of 2-3L. The anode and cathode electrodes will be granular graphite. SCFA-MFC (configuration #1) and direct-fed MFC will feature a biological cathode reducing nitrate (a potential co-contaminant). The anode chambers in configuration #1 and 2 and the anaerobic digester in configuration #3 will be the same volume. We will characterize influent and effluent waste streams for TSS/VSS, soluble COD and total COD and total coliforms using Standard Methods (Clesceri et al. 2005). Power, current and electrochemical performance will be measured continuously. Additionally, the energy recovery will be compared. Comparison will be made by comparing electrons recovered as electrical energy per gram of carbon delivered to normalize performance between different reactor configurations. To compare the potential electrical energy achieved in the digester, heat cycle losses will be assumed for the conversion of methane to electricity. The outcome of this experiment will provide a side-by-side comparison of potential configurations for both biosolids reduction and energy recovery.

Understanding Public Perceptions, Acceptance and Engagement around Large-Scale Offshore Energy and Water infrastructure

Significance. Offshore wind power has the potential to play a significant role in transforming the world's energy economy, substantially contributing to climate change mitigation efforts. To meet ambitious U.S. and State-level targets for generating electricity from offshore wind, large infrastructure will need to be developed along coastal areas of the eastern seaboard, and specifically, off the coast of Massachusetts and Rhode Island. The development of offshore wind power in the United States is at a critical juncture, as the core challenges to *implementation* are more social and regulatory in nature, rather than technical. There is a critical need to understand the level of support for offshore wind projects in coastal communities **before** development of wind energy areas, and to uncover underlying mechanisms driving support for and opposition towards offshore wind. These issues are not well understood in new markets (such as the U.S. and the Caribbean) and remain a critical research gap; misrepresentation of these values and opinions can lead to costly delays and failures to meet targets established by the U.S. Government. Preliminary studies have shown that a primary reason for offshore wind energy opposition in the U.S. is "industrialization" of the seascape (Bates & Firestone, 2015); therefore, we seek to understand how attitudes toward offshore wind differ from attitudes towards other water-based infrastructure, such as bridges, coastal energy facilities that use water (e.g., nuclear energy), or water treatment plants.

Furthermore, we seek to understand how attitudes may change if the energy system is perceived to be adding to water quality, such as an integrated energy-water system, is neutral, or is detrimental to water quality. The linkages to water quality are particularly important to understand as this project extends to the U.S. Virgin Islands, where we seek to apply knowledge gleaned in the northeast U.S. and extend that knowledge into developing economies looking towards sustainable development of energy-water systems. This project benefits the offshore wind industry by providing an independent, well-respected and unbiased analysis of public opinion. It will lead to regional and national advances in the knowledge base of this industry for the benefit of broad stakeholder groups, including, citizens of U.S. states and territories, coastal communities, regulators, and private industry, and contribute to the reduction of the costs of offshore wind energy by providing an information base on which to develop public engagement strategies.

Theoretical framework. In this project, we will conduct qualitative interviews with targeted communities and quantitative public opinion surveys in coastal communities of Massachusetts and Rhode Island, and later in the U.S. Virgin Islands, to understand values, preferences, and underlying concerns about local offshore wind development before large-scale development is proposed in these communities. By *understanding and representing local preferences and concerns,* our research will address challenges related to *implementation of new infrastructure*. While literature exists regarding public opinion of new development on cultural landscapes, less is known about how individuals perceive coastal energy development and associated structures (e.g., Firestone, Bates and Knapp, 2015; Kempton et al., 2005; Wolsink, 2007). There has been a tendency to generalize and refer to opponents by myopic labels such as “Not in my back yard” (NIMBY) activists (Devine-Wright, 2005; Jones & Eiser, 2009), which has led to a misunderstanding of public attitudes. Furthermore, the public believes that “fair procedures produce fair outcomes” (Firestone, et al, 2012; MacCoun 2005). Consequently, when the development process is perceived as fair, that perception may lead to a higher level of acceptance of the outcome (Aitken, 2010; Frey, et al. 2004; Gallagher et al. 2008). Conversely, social distrust can be a fatal source of conflict and ultimately lead to political stalemate. Thus, creating a sense of trust and fairness may be essential for generating positive public image of offshore wind facilities that were not previously part of the landscape (Upreti and Van der Horst, 2004).

To address both substantive and procedural issues that may arise and affect implementation, we will quantify the level of support for offshore wind projects in the region, and uncover underlying mechanisms that may be instrumental in driving support for, and opposition to, new technology development and implementation. This social science research will identify key priorities that enable effective stakeholder engagement with coastal, urban and rural communities. We will emphasize those residents who are more likely to use the coastal areas and surrounding islands, as they are most likely to be vocal stakeholders in the decision-making process, as they are affected by the construction and operation of offshore wind projects due to changes to the landscape and effects on recreational activities and livelihoods from ocean-based activities. This will facilitate an informed planning process with stakeholder buy-in. Understanding the drivers of support, opposition, and underlying concerns will inform the *potential for successful implementation* of offshore wind in the United States. This project benefits the region specifically by filling informational gaps as they pertain to local project acceptance, to avoid distrust and negative public opinion as has occurred in the past. We will provide to WEA leaseholders site-specific concerns of local residents that could delay or derail projects, and ways to accommodate the concerns of the residents. We will also recommend to the leaseholders a public engagement strategy, as emerges from our research.

REU project. Conducting surveys and interviews in coastal communities is a multi-step process with numerous opportunities for students. One or two REU students will have the opportunity to work on qualitative data collection, survey design and implementation, and data analysis. For this project, students will use GIS maps to identify targeted regions to gather data; develop a semi-structured interview guide to use to interview key informants (such as local leadership or those with a vested interest, such as commercial fishers) and local residents, through targeted and opportunity sampling (with IRB approval); participate in field work to conduct in-person interviews at the coastal Massachusetts and Rhode Island field sites and in later years at sites in St. Croix on US Virgin Islands. The interviews may be one-on-one interviews or in small focus groups. The data will be analyzed using grounded theory to code the data generated from the interviews and to extract concepts contained therein (Kempton, et al., 2005; Strauss and Corbin, 1998), using software such as NVivo. These data will be utilized to make recommendations about wind development, and also to support a larger quantitative survey, by capturing issues important to coastal communities and ensuring the survey (to be conducted in following years) is asking appropriate questions. In subsequent years, one or two students will have the opportunity to participate in design, dissemination, data collection, and preliminary data analysis of quantitative survey data. Survey data may be analyzed from the Massachusetts/Rhode Island sites and the U.S. Virgin Island locations.

Tracking Movements of Common Terns in Nantucket Sound

Significance: Several wind energy facilities are currently planned for offshore Atlantic waters of the U.S.. Under Federal laws, regulatory agencies such as the Bureau of Ocean Energy Management (BOEM) and the U.S. Fish and Wildlife Service (USFWS), are required to protect populations of marine birds that

frequent these areas (O'Connell et al., 2009). There is a need to collect information on distribution and behavior (e.g., flight paths, timing) from a broad suite of birds in these areas, particularly for species of conservation concern. In addition, sea birds are an important part of the overall ecosystem, both as indicators of its health, and as a key part of the food chain.

Theoretical Framework: Studies that use telemetry to track individual birds provide spatial and temporal data on flight paths and distribution, which is needed to identify how birds use areas where wind facilities will be located. This baseline information is essential for evaluating negative interactions between birds and offshore turbines that could occur after an offshore wind facility is built. Tracking information can also be used to identify where high concentrations of birds occur and better understand factors (e.g., seasonality, food, weather) that influence their distributions, allowing regulators and managers to place future offshore wind energy facilities in areas with the lowest predicted impacts (Drewitt and Langston, 2006; O'Connell et al., 2009; Burger et al., 2011).

REU project: One or two REU students will spend two weeks in the field capturing, tagging, and monitoring common terns in Nantucket Sound. They will capture terns on their nests, band them, and attach a back-mounted VHF nanotag (See Fig. 5). The students will regularly monitor all tagged birds at their nests to confirm that each individual shows no overt physical problems, is incubating or caring for chicks normally, and has retained its nanotag. While on campus, the students will participate in developing an interactive RShiny database to explore tern detections at the Block Island tracking station relative to covariates of interest: weather (wind speed, wind direction, precipitation rate, barometric pressure, visibility), demographic (species, sex), and temporal (time of day, date, chick-rearing/post-breeding period). The students will also compare weather data with weather conditions collected by Block Island airport. Finally the individuals may participate in 2-3 boat-based tracking surveys within Block Island wind farm during peak times of tern abundance observed in the 2015-2017 dataset. This field research has been a highlight of our previous REU site.

Interconnections.

Here we briefly summarize how these projects interconnect with each other and with some of the other projects in Table 2. The Baker and Milman projects address the decision-making of communities that will be establishing portfolios of energy and water solutions, such as the components of hybrid systems, energy system design and infrastructure, water infrastructure, and environmental quality rules. Baker takes a prescriptive approach, providing decision tools, and Milman investigates the politics. In order to implement decision tools, there must be a clear understanding of stakeholder preferences (Bates), and how available alternatives impact the issues that stakeholders care about (Lackner/Manwell, Arwade, Butler, Kumpel).

One aspect that stakeholders care about is the overall environmental effects, which are also critical elements required by the regulatory process. These depend on the impacts of different components (i.e. wind or solar systems, water treatment, infrastructure) on a wide variety of species. The Griffin project ties together the ecological assessments of various taxa with technological solutions, project planning and site selection. Griffin and Sievert conduct field studies of the distribution, movements and behaviors of migratory birds to assess their vulnerability to offshore wind turbines and other infrastructure development. Jordaan conducts field studies in the US Virgin Islands to understand the positive and negative effects of energy facilities on marine organisms, and the interaction of these effects with water pollution (especially from Rum producers). This project is aimed at improving water quality of coastal environments in association with energy systems. Modarres develops technical solutions to reduce the vulnerability of species to turbines, and Bates explores the uses of marine spatial planning to site facilities in a way that reduces ecological and socio-economic effects.