

Florida's Center for Ocean Energy Technology

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Abstract. The Center for Ocean Energy Technology (COET) at Florida Atlantic University (FAU) is a timely State of Florida initiative for the research and development of ocean current and ocean thermal energy technologies. The Center is a synergistic partnership among academic, industry, and government organizations focused on developing knowledge, understanding, infrastructure, technology, and policy towards a low-environmental-impact extraction of ocean energy. The Center is a hub that bridges the gap between concept and commercial implementation by fostering the research, design, development, implementation, testing, and commercialization of cutting-edge, clean, and innovative ocean energy technology. It brings together a broad range of unique, enabling, and accessible expertise and physical assets.

I. INTRODUCTION

Florida is faced with an energy crisis in terms of capacity, supply, cost, and stability. The state's population is expected to increase to nearly 30 million by 2030 [1], and electricity consumption has increased, on average, by 3.8% per year, yielding a predicted overall increase in electricity demand by at least 30% in the next 10 years [2] - even when energy savings are factored in. To meet this future demand, Florida must increase electricity generation capacity by nearly 17,000 Megawatts (MW). However, Florida is over 98% reliant on outside energy. Natural gas, coal and other fossil fuels comprise almost 90% of Florida's electricity-generating capacity (39% natural gas, 24% petroleum, and 23% coal) with less than 8% from nuclear power [3]. More direct petroleum-fired electricity, in absolute terms, is generated in Florida than in any other state, accounting for over 40% of national generation [4]. To meet future short-term demand, additional generating capacity is predicted to be composed of 80% natural gas, 19% coal, and 1% oil. The reliance on petroleum produced outside of the state renders Florida vulnerable to supply interruptions (caused by storms, international supply, political turmoil, etc.). The lack of supply diversity ties Florida directly to the volatile energy markets that have seen record increases in prices and, as a result, much of what consumers spend on electricity goes directly to fuel costs. Electricity costs in Florida have increased more than 50% since 2000 from \$0.08/kWh in 2000 to \$0.12/kWh.

While the momentum of fossil fuel power generation cannot be immediately turned, the state is pursuing non hydrocarbon-based energy solutions to provide Florida with energy security, price stability, and guaranteed supply. At present, in-state renewable power generation only accounts for less than 2% of capacity (including solar, biomass, landfill gas, hydroelectric,

and waste incineration). Florida's Executive Order 07-127 and recent state legislation have established very aggressive and challenging targets for greenhouse gas reduction (2000 levels by 2017, 1990 levels by 2025, and 80% of 1990 levels by 2050).

The State is pursuing energy diversity by taking advantage of its large portfolio of renewable energies. Ocean energy has great potential to provide much of Florida's energy needs. Florida is the ideal location to develop this technology. Florida is a peninsula with the longest coastline in the continental United States, nearly 1400 miles of general coastline, almost 8500 miles of tidal shoreline, and with over 70% of its population living within 10 miles of the coast. Florida also has exceptional clean renewable ocean energy resources with high base-load electricity generating potential from ocean current energy and ocean thermal energy. The Gulf Stream Current flows northward past the southern and eastern shores of Florida, funneling through the Florida Straits, and pumps in a continuous supply of warm tropical surface water which overlays colder water replenished from Northern regions.

II. CENTER VISION

Research and development (R&D) in ocean energy technology is characterized by small, disconnected, and often intentionally isolated efforts that tend to be focused on single technologies. For ocean energy technology to become commercially viable and reach its potential, coordination, communication, and immediate access to a wide range of resources are needed. The COET's vision is to be a catalyst, establishing infrastructure, proving out concepts, and undertaking necessary due diligence in system and environmental assessment, as applied to open-ocean-current and ocean thermal generation systems. The COET aims to be the national and international hub for deep-water ocean energy R&D, and to bridge the gap between concept and commercial deployment.

Because no commercially meaningful amounts of electricity are being produced from open-ocean current or thermal resources, development of the required infrastructure demands coordination, communication, and immediate access to expertise, knowledge, and testing facilities. In addition, leveraging knowledge and technology developed by the wind industry, offshore industries, and the U.S. Navy should help to

accelerate the development of needed ocean energy technology. Thus, technology-neutral centers are needed to act as catalysts and hubs that transition individual technology efforts into a coordinated, commercially-viable industry that will grow independently to help sustain economies and workforces.

Because commercial deployment of open-ocean energy generating systems will be both technically challenging and expensive, it is necessary to first test them thoroughly, although such tests can also be both demanding and expensive. Accordingly, the COET seeks to create a National Open-ocean Energy Laboratory (NOEL) to act as a national resource for this purpose, building upon the existing activities of the COET and its partner capabilities. It will establish the appropriate framework, infrastructure, expertise, workforce, policy, and knowledge base, and will carry out fundamental research in areas of significant impact to the nascent ocean-current power industry. The Center will not be a commercial entity, and will not produce, install, or operate commercial systems. Therefore, it will act as a fair and unbiased source for R&D, dedicated to the success of the industry as a whole.

The State of Florida is taking its energy crisis situation seriously, and has invested heavily in alternative energy solutions, including a total allocation of nearly \$14M to the FAU Center for Ocean Energy Technology. Initially, COET was founded through a competitive grant from the Florida State University System's Center of Excellence Program to investigate ocean-based solutions to Florida's energy crisis. More recently, the Florida State Legislature established the Florida Energy Systems Consortium, of which Florida Atlantic University is a founding member, along with Florida State University, University of Central Florida, University of Florida, and University of South Florida.

This Center is guided by the following principles:

- foster the design, development, implementation, testing, and commercialization of cutting-edge, clean, and innovative ocean current energy technologies with low environmental impact;
- provide the basis for collaboration with industry, utilities, universities, and government agencies;
- provide accessible knowledge, data, and expertise;
- develop/leverage and maintain a broad range of infrastructure to assist technology development and industry testing; and
- leverage existing technology and pursue research to shorten the time to bring technologies to market

Outcomes of the COET are:

- a facility with the infrastructure and expertise to test marine hydrokinetic and ocean thermal energy technologies;
- procedures to ensure that development of ocean energy is environmentally viable;
- broad engagement with industry, including protection of critical intellectual property (IP);
- new educational curricula integrated with COET/NOEL to attract and retain a uniquely talented workforce through horizontal transition to industry;
- balanced knowledge-based policy for industry, the environment and stakeholders; and
- ultimately stable, secure, renewable, and clean base-load energy capabilities.

III. FLORIDA'S OCEAN RESOURCE

Ocean current energy is the kinetic and potential energy available from moving water and density structures of ocean currents. The Gulf Stream Current flows northward past the southern and eastern shores of Florida, funneling through the Florida Straits, with a mass transport greater than 30 times the total freshwater river flows of the world. The ocean flow of the Gulf Stream is more energy-dense than the world's best wind power-generating sites, with a total energy flux of 25 GW [6]. The ocean current energy resource in Florida has a potential generating capacity of up to 10 GW [7], equivalent to 10 nuclear power plants – approximately one third of Florida's average electricity consumption. The Gulf Stream never stops, and its flow velocity actually increases in the summer, matching well with base-load summer-peaking energy demands. This is an annual average power density of 1.95 kW/m², with an average summer power density of 2.52 kW/m², and with peak power exceeding 8 kW/m² in the most energy dense sections of the current. On a global scale, the realizable energy is likely to be in the order of 100 to 300 GW [8]. However, this potential is anticipated to grow as more data is collected about the world's ocean currents.

To assess the Florida Current resource, nearly 2 years of ocean current measurements were collected using a bottom-mounted, upward-looking 75 kHz ADCP at a site located 3 miles to the West of the mean axis of the current. The mean current speed exceeds 1 m/s down to a depth of 150 m and, on average, decreases monotonically with depth, to a weak 0.19 m/s near the ocean bottom (at 320 m). The current speed ranged between 1 and 2 m/s (over 85% of the time) in the top 100 meters. Between 50 and 100 m, the flow exceeded 2 m/s only 3.3 and 0.06% of the time. The predominate direction of the Florida Current offshore Ft. Lauderdale ranges between 15 and 16.5°. Directional consistency is dependent on velocity, and, in the absence of velocity, or during periods of low velocity, the flow direction becomes confused. In the top 200 meters, the direction rarely turns west of due north

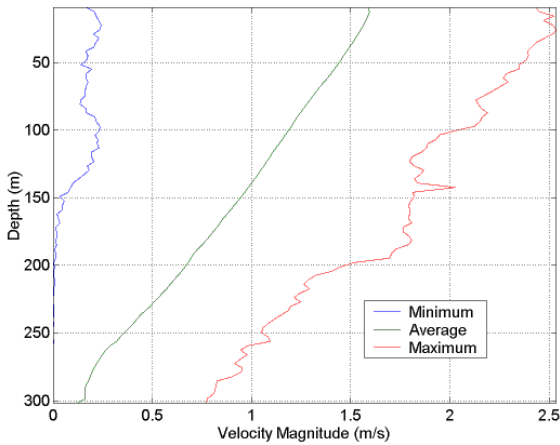


Figure 1. The maximum, average, and minimum ocean current speed measured offshore Ft. Lauderdale, FL over a period of nearly 2 years. Velocity measurements were made at 15 minute intervals using a 75 kHz ADCP.

	Direction (° True)					
	Mean	Max	Min	Std Dev	% Below 0°	% Above 20°
Surf	15.0	98.0	-47.6	6.4	1.0	16.8
50	15.4	85.3	-48.6	6.1	0.7	17.0
100	15.7	71.5	-31.7	6.5	0.8	21.0
150	16.5	106	-152	7.1	1.5	28.0
200	16.5	169	-175	10.3	3.3	31.9
250	15.5	180	-180	22.6	9.2	30.8
300	7.1	180	-180	71.7	27.7	45.4

Table 1. The mean, maximum, minimum, and variability of the current direction offshore Ft. Lauderdale, FL over a period of nearly 2 years.

Ocean thermal energy is the potential energy contained in the naturally replenished vertical temperature distribution in the ocean. As the warm upper surface layers of water are heated by the sun, deeper cold water is formed at high latitudes, and migrates to the tropical oceans. Ocean thermal gradients have the potential to provide all the world’s power, equivalent to 10,000 GW [5] (approximately 10,000 nuclear power plants, 1 GW is the approximate output power of a nuclear power plant). This prospect is very optimistic, but the statistic does highlight the massive potential.

Off the coast of Florida, lies a significant potential for ocean thermal energy. The Gulf Stream pumps in a continuous supply of tropical warm surface water that overlays colder water replenished from cooler regions. The ocean thermal energy resource in Florida can be utilized in 3 ways: (1) cold

seawater-based air-conditioning, (2) ocean thermal driven power production, and (3) thermal gradient powered desalination. Cold Seawater Based Air Conditioning (CSBAC) systems utilize the cold deep water of the ocean to act as a chiller in conventional air conditioning systems replacing energy-intensive electricity-based chillers, yielding energy savings in excess of 80%. CSBAC utilizes underwater pipe laid on the ocean floor, submersible and shore-based pumps, and on-shore heat exchangers. This technology is important to Florida, where up to 50% of the summer electricity usage is spent on conventional air-conditioning systems.

Ocean Thermal Energy Conversion/Generation (OTEC) utilizes thermodynamic cycles and a combination of electromechanical and thermoelectric systems to harness the potential energy contained in the temperature differential between the warm surface water and cold bottom water of the ocean to produce electricity (as well as other products). These massive warm and cold water sources are naturally replenished, and, through OTEC, can provide significant base-load energy to Florida. Low Pressure Flash Desalination (LPFD) utilizes the warm ocean surface water to power evaporation, and the cold deep ocean water to condense the water vapor. Large volumes of fresh water can be produced with little energy input. LPFD uses either floating structures connected to shore by pipe, or shore-based facilities drawing water through offshore pipes.

To assess the ocean thermal resource offshore South Florida, in April of 2008, the Center started performing monthly transects from near-shore to a distance of approximately 30 miles offshore (a series of 11 casts) to measure temperature, salinity, pH, and other water properties. The Northward flowing warm water from the Caribbean that overlays southward flowing cold water yields favorable waters for OTEC, in some cases, in depths of less than 200 m. The temperatures of the surface water and near-shore bottom water change throughout the year. The surface water is warmer in the summer and fall and colder in the winter and spring. The near-shore pocket of bottom cold water, located between longitude 79.90 W and 80.05 W, is larger and colder in the summer – which matches the air-conditioning demand in Florida. The maximum and minimum temperature differences measured to-date near-shore, in a water depth of 200 m (offshore in a water depth of 650 m), are 20.5 (23.25) and 15.5 (20.5) °C respectively.

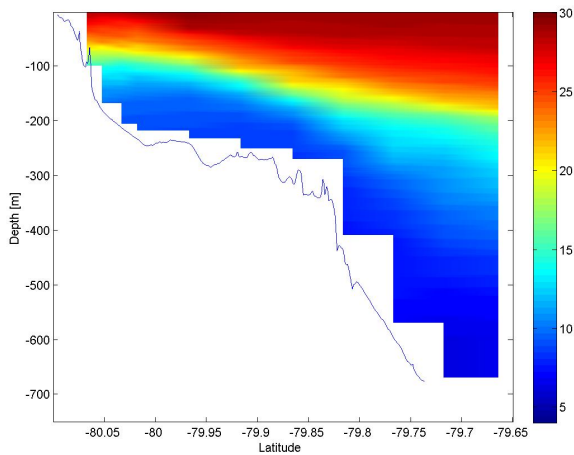


Figure 2. A West-East cross-section of the ocean temperature at Latitude 26.08 N, July 2008.

The energy production potential, considering factors such as maintenance, efficiencies, and location issues, of waters surrounding Florida, is tens of GigaWatts. It is estimated that near-term coastal installations would also save Florida several GigaWatts, achieving a greater impact if district cold water A/C is implemented, but only as a very long-term endeavor. The energy in ocean thermal gradients can also be used to power low pressure flash desalination plants to generate large volumes of sorely needed freshwater without requiring additional energy input.

IV. FACILITIES AND CAPABILITIES

The COET/NOEL and its partners have decades of experience conducting ocean science and research. The Center is located on two FAU campuses, at the Institute for Ocean and Systems Engineering (IOSE) and Harbor Branch Oceanographic Institute (HBOI). IOSE is housed on eight acres of land on the beach between the Atlantic Ocean and the Intra-Coastal waterway in Dania Beach, with valuable access to the offshore ocean environment and near-shore seawater. The Institute's 50,000 sq. ft building houses research laboratories, classrooms, faculty offices. Facilities include machine and electronic shops, significant computational capabilities, a 60ft wave/towing/flume tank and a smaller laminar flow re-circulating channel, and ocean observation systems. HBOI is situated on a 520-acre campus, located on the Indian River Lagoon, in Fort Pierce, Florida. Facilities include a 3000 sq. ft. machine shop, a well-equipped 1000 sq. ft. graphics drafting facility, a 25,000 sq. ft. fabrication/weld shop with a 50 ft tall highbay, including all updated and necessary shop fabrication tools, and various cranes (including gantries) that allow fabrication tasks of very large structures, and 2200 sq. ft. of electronics laboratory space.

The specialized facilities and equipment which include ready access to a range of ocean vessels with broad

capabilities is essential to support resource assessment and offshore testing. FAU owns and operates an advanced fleet of vessels ranging from small support vessels such as the 22' R/V Lee and the 35' R/V Ocean Power, to the 204' ship R/V Seward Johnson. To augment the fleet, FAU also has several underwater work systems capable of installation, assembly, inspection, maintenance, survey, and many other tasks. These include: two 4-person submersibles capable of operating down to 3,000 fsw, two 1-person submersibles capable of operating down to 2000 fsw, a Remotely Operated Vehicle (ROV), and several Autonomous Underwater Vehicles (AUVs) with depth ratings ranging from 300 fsw to nearly 10,000 fsw. These provide the critical ability to perform a broad range of tasks under water, and to support fully offshore operations with appropriate equipment.

Other assets include key instrumentation and diagnostic systems for measuring and assessing the environment. Among these are Acoustic Doppler Current Profilers (ADCPs), which use a high-frequency, low-power sonar to measure current velocities over a range of depths, Coastal Ocean Dynamics Application Radar (CODAR) systems that utilize high-frequency surface wave propagation to remotely measure ocean surface waves and currents, and Conductivity, Temperature, and Depth (CTD) sensor packages, which are raised and lowered through the water column to measure water properties.

A. National Open-ocean Energy Laboratory (NOEL)

Currently, only one comprehensive open-ocean testing facility exists in the world for ocean energy, the European Marine Energy Center (EMEC) located in the Orkney Islands near Scotland. EMEC was established to support ocean wave and tidal energy system development from prototype stage, to the commercial marketplace. Presently, no comprehensive commercial ocean current and ocean thermal energy testing infrastructure exists. The COET is establishing the capability, infrastructure, expertise and strategic partnership needed to develop and deploy a national test-bed facility – the National Open-ocean Energy Laboratory (NOEL) – to focus on sustained ocean current and ocean thermal energy systems. This NOEL will balance the existing EMEC facility.

NOEL will involve permanent infrastructure offshore of South Florida, in the Florida Current, to serve as an integrated, standardized testing and research range for advanced marine, hydrokinetic, and ocean thermal devices. Range activities will focus on devices, components, and systems to harness sustained open-ocean current and thermal potential and, to a lesser degree, ocean tidal and wave systems. This facility will provide capability to government agencies, technology developers, and universities for testing and evaluation of ocean energy systems, from small sub-scale systems to full scale commercial ones - Technology Readiness Levels (TRLs)

3 – 9. The range will be used to develop best practices, test protocols, and system standards, to perform environmental and ecological assessment and risk mitigation, to pursue advanced technology development and demonstration, and to facilitate education and outreach. Although the NOEL is intended to support commercial activities, it will remain impartial to any commercial interest.

The development of the NOEL is planned in three major phases, driven largely by permitting protocol. Phase one begins with installation of temporary infrastructure to support initial studies through a large-scale, fully capable, permitted testing range. The first phase will temporarily deploy stand-alone instruments to gather baseline data to guide subsequent phases and to support near-term science, environmental and resource assessment, and technology development. During the second phase, a suite of instruments will be permanently deployed that are directly connected to shore by data and low-power cables. The cables will provide a real-time control and data link to shore-side facilities, as well as, power for the instruments. Finally, a high-capacity power cable will be laid offshore, nodes will be installed to connect power generation systems, and onshore monitoring systems will be finalized, thus creating a full-scale testing range. These planned phases ensure that NOEL will support ocean current and other systems.

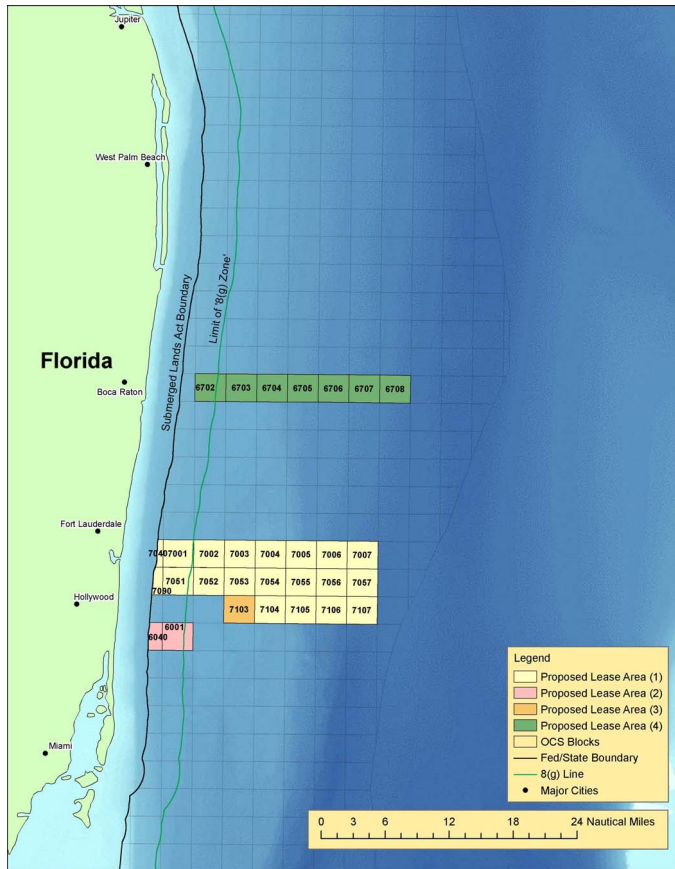


Figure 3. The proposed COET/NOEL ocean energy testing range is the yellow blocks located offshore Ft. Lauderdale. The Department of Interior’s Minerals Management Services, <http://www.mms.gov/offshore/AlternativeEnergy/Assets/PDFs/FloridaProposeLeaseColorCoded.pdf>.

Phase 1 Ocean Observing and Monitoring System

Only sparse measurements of the ocean environment exist within the proposed NOEL, most of them near shore. Thus, baseline information is needed to characterize, in detail, the spatial and temporal variability of the ocean in the range area. As part of this phase, two classes of instruments will be temporarily installed: ADCPs and CODARS. Two shore-mounted 12 MHz CODAR stations will be deployed onshore (Haulover Inlet to the south of Port Everglades and Hillsborough Inlet to the north). These installations will provide ocean-surface current measurements over the entire NOEL test range at a grid resolution of approximately 1 km, updated at 20 minute intervals. High resolution vertical velocity profiles of the Florida Current will be obtained at regular intervals from an array of cross-stream ADCPs.

The moored ADCPs and CODAR systems cannot capture small-scale horizontal spatial properties within the water column, and therefore they provide only part of the necessary hydrographic picture. Thus, at regular intervals, cross-stream vertical profiles of the salinity and temperature and the east-west vertical velocity profile will be obtained along the longitude of the moored ADCPs, using a CTD and ship-mounted downward-looking phased-array ADCP. CTD casts will be performed at each ADCP mooring, and locations between them. Detailed bathymetric, bottom type, and ecological data will also be collected with vessel-mounted and towed instruments.

Phase 2 Ocean Observing and Monitoring System

Phase 1 stand-alone temporary installations will provide the necessary observations and information for site planning, development and permitting. However, retrieval of data (and hence access to it) will necessarily be limited to periodic on-site downloads using acoustic telemetry. As well, repeated deployments, recoveries, and refurbishments would add significant costs and personnel to the project. To facilitate cost-effective operations, real-time data flow and a long-term presence will be required.

Instruments will be permanently installed onshore and offshore during Phase 2 to provide real-time data about the resource, ocean conditions, and device-specific measurements. The set of instruments on the ocean floor will be connected to a direct high-speed data and power link to shore, which is currently envisioned to be electro-optical armored cables. The data, knowledge, and understanding of the spatial and temporal characteristics of the Florida Straits, as well as, the environmental and ecological data collected in studies from Phase 1, will determine the path of the cable, type of cable(s),

locations of instruments, and methods for deployment/maintenance/recovery. The instruments will include current measuring systems such as ADCPs and surface current radars, and bottom-mounted profiling CTD systems. By judiciously locating each instrument system, a full volumetric measure of the offshore environment will be available, providing instantaneous and continuous measurement in support of resource assessment and testing. Thus, ocean energy systems can be deployed in a fully characterized environment, allowing rapid and cost-effective offshore testing for research and industrial purposes. Additional sensors will be installed such as underwater cameras and passive hydrophones for acoustic tracking to benefit the environmental scientific and education communities.

Phase 3 NOEL Testing and Evaluation Range

To facilitate in-water testing of ocean energy components and systems, Phase 3, the most ambitious phase, will involve installation of systems to create a full-scale offshore testing and evaluation range for ocean-energy systems. At present, it is envisioned that this phase will involve design and deployment of one or more power-conducting trunk lines to connect offshore turbines to the onshore power grid. To facilitate rapid standardized installation and testing of turbine systems, plug-and-play offshore underwater nodes will be specified and installed. This permanent infrastructure, including the ocean observing and monitoring system, will allow quick system deployment and recovery, real-time monitoring through the high-speed connection with the offshore systems, in-place permits, standardized measurements, onshore monitoring facilities, activated power-grid connections, access to experts and base-line data, and year-round operation in both near-shore shallow and deep-water facilities. The offshore nodes are envisioned to consist of a concrete structure on the bottom, anchored in place with both permanently moored connections and underwater-mateable power and communication connections. This will allow systems to be plugged in without requiring recovery of the mooring, acoustic modems and passive hydrophones to provide through-water communications and sound-level monitoring, and other environmental sensors to provide local water-velocity measurements. Each node anchor system will be designed to support the mooring load of a commercial-scale system.

To avoid any actual or perceived conflict with commercial development, power output from the range will be limited to 5MW, thus providing for full commercial-scale testing while avoiding commercial-scale energy production. The COET is working with Florida Power and Light Corporation, one of its partners, who own and operate the power grid in South Florida, to develop grid connection.

Designing any system to operate reliably for extended periods of time, and to produce energy (and other products) that are cost and performance-competitive with land-based equivalents involves unknown risk, and hence, unavailable risk mitigation experience. COET/NOEL will pursue both short-term and long-term R&D in areas aimed at accelerating open-ocean energy extraction, while at the same time adopting a test protocol that enables risk mitigation. These efforts will leverage existing technology with recent breakthroughs in science and engineering from offshore oil and gas industries, naval architecture, energy research, navy design, environmental knowledge, and land-based technologies. The focus is on advancing critical technology, tools, and knowledge in the areas of (1) engineering/ technology, (2) environment and ecology, and (3) policy, and economics for the unique environmental conditions and novel applications related to harnessing ocean current energy. The research described below is intended to provide a brief overview of the existing and planned research areas to address the viability and sustainability of a marine hydrokinetic and thermal energy industry.

A. Engineering Research

Materials and their protection

This effort will identify and characterize materials for various applications, will identify and design corrosion control and monitoring systems to attain required service life and performance of ocean energy structures, and will provide an information clearinghouse for engineering and technology design. Research will also include identification of best practices for protection against corrosion and bio-fouling. Research areas include (1) high strength steels, (2) Ti alloys, (3) composites, (4) corrosion resistance alloys (CRAs), and (5) protection systems, e.g. coatings and cathodic protection.

Intelligent systems

The objective of intelligent systems research is to develop techniques and sensor systems that minimize equipment failure and downtime while increasing reliability and providing maintenance optimization. This effort will: (1) develop sensor systems to monitor the health of offshore systems, (2) develop prognostic methods based on operating turbines within the test range, and (3) work with industrial partners to equip their systems with the necessary intelligent health monitoring, assessment, and prognostic systems.

Energy storage, transmission, and chemical-conversion product development

Research efforts will develop offshore processes for the production of hydrogen and other chemicals and/or fuels from seawater for ease of long-term storage and transport. This effort will: (1) study the energy transmission issues and, by integrating advances in technology, determine the most cost-effective means of energy transport for different distances

from shore, (2) develop new technologies for electrolysis of sea water, (3) review feasibility and develop technology for offshore underwater ammonia generation (or other novel energy storage chemicals that are energy carriers), high-value fuels and chemical feedstocks, and (4) develop processes and technology for generation of value-added products.

Energy transmission and grid integration

The objectives of this effort are to provide a scientific and engineering basis for transferring electrical energy harvested offshore from numerous floating power generation units to shore, with minimal losses, high reliability, and minimum adverse impact on the existing electrical power grid. Therefore, the research will be conducted to: (1) investigate novel transmission technologies, including high current DC and superconducting systems, (2) develop optimal structure for the United States Transmission Grid (USTG) to maximize reliability of service and investigate the integration of the USTG into existing power grid, (3) identify advanced fault management methods for locating and isolating faults in the USTG, and (4) provide for optimal control of the USTG and the associated power conversion systems.

Experimental turbines in a sustained ocean current

No ocean current turbines exist, or have been built, that are capable of operating in a sustained ocean current, or that have been deployed offshore in the Gulf Stream, for more than a few hours. Thus, little, if any, knowledge exists about *in-situ* performance of this technology. As well, laboratory experiments cannot replicate the long-term operating effects of real system deployment and operation. As a result, a strong level of confidence cannot be placed on existing analyses, and this research effort is intended to assess the performance of existing technology while mapping out the needed technology areas of study.

To investigate these areas, COET will design, fabricate, deploy, and operate a series of small-scale test turbines. The initial design is a 20 kW open-blade axial-flow horizontal underwater turbine, driven by a 3 m diameter 3-blade rotor. As knowledge is gained from each generation, design will iteratively progress toward a 300 kW test system. The focus of this research is to perform a technology assessment of the equipment, aimed at identifying gaps that need to be filled for commercial implementation and to investigate and collect data about potential environmental impacts, providing a better foundation for future studies.

B. Environmental and Ecological Research

Environmental and ecological research for the NOEL is needed to fully understand the open-ocean system and provide for mitigation of potentially adverse impacts resulting from ocean energy development in the Southeastern United States. Critical research will be conducted throughout all phases of the program to provide the necessary knowledge to assist State and Federal agencies to implement all phases of permitting.

Benthic Site Assessment and Mapping

In the marine environment, the development of objective, systematic and intuitively understandable habitat maps fundamental to the study and management of living natural resources, has just begun. In the southeastern United States, habitat mapping is urgently needed in areas of greatest fishery production, such as shelf-edge reefs and deep-water reefs (where there is increasing loss of habitat and fishery production, and declining biodiversity). The COET/NOEL will investigate these bottom effects using high-resolution imaging from AUVs, submersibles, and ROVs, employed to co-locate features and areas of concern.

Marine Mammal Population Assessment and Monitoring

Using a sophisticated array of hydrophones, remote listening/recording data systems, and aerial and boat-based surveys, the Center will monitor offshore marine mammal stocks in the proposed range. Information on species-specific spatial and temporal distribution will serve as a guide to predict areas and times of concentration, as well as significance for various stages in the life cycle, such as calving or mating, which may require conservation measures.

Sea Turtle Population Assessment and Monitoring

Details of migratory and diving behavior by sea turtles along Florida's coastline are not well studied, so little data exists to address impacts of offshore energy development. To address the potential impacts, data will be collected and analyzed that will: (1) detail the geographical and temporal distributions of the various sea turtle species, (2) provide baseline data on feeding grounds for the species using these deep waters, (3) identify species-specific concerns relative to placement of the turbine and cables, and (4) identify any site fidelity occurring in these waters. Vessel-based surveys will be conducted to assess population trends and to collect baseline data on life history relative to the site. Information on species-specific spatial and temporal distribution will serve as a guide to predict areas and times of concentration, as well as determine the significance of ocean energy system impacts for various stages in the life cycle.

Environmental and Physical Session Modeling and Simulation

The objectives of this effort are to develop tools for prediction of system performance, planning and anticipating environmental and climatic problems before establishing systems in the ocean, system design optimization, and mitigation of environmental impact. Modeling and simulation provides virtual realizations of real world problems. The Center will leverage and expand state-of-the-art computational tools and software to: (1) predict background conditions, including distribution of currents, temperature, and other quantities, (2) determine impacts of individual turbines on the local environment, including upwelling, downwelling, and down-stream wake, (3) estimate gross impact of several systems on the environment for various system placement

designs, and (4) investigate design modifications for mitigation of environmental impact and system optimization.

C. Economic, Policy and Standards Research Lifetime economics

The aims of this effort are to develop, implement, test, and validate detailed knowledge of full life-cycle economics analysis associated with ocean energy projects in North America, and to provide the basis for fair comparisons with other energy projects for potential investments. Variables considered are: design, fabrication, demonstration/validation, delivery, installation, maintenance, taxes, incentives, tariffs, insurance, capital investment, and other financial parameters.

Policy development

This research will assist in the development of policy based on knowledge that balances public wellbeing, stakeholders' interests, and environmental impact of business development. Keeping in mind the nature of the resource for the test and demonstration site (the Gulf Stream), there are potential global policy implications that also need to be addressed. In fact, it is very likely that these areas will be sufficiently novel so that policies and regulations must be carefully considered and analyzed to ensure unnecessary barriers to commercial development are not adopted, and while establishing necessary, safe, and environmentally-friendly practices. The Center will work with local, state, and federal government to develop and define the criteria and knowledge needed to address policy on a global scale. The COET is working closely with federal and state agencies to review criteria for early-stage policy.

Development of ocean energy system standards, best practices, and testing methodologies

The aim of this effort is to develop standardized methods and criteria to test and evaluate ocean turbine technology. The ocean energy industry is new, so that standard practices, criteria, and methodologies need to be developed to evaluate and compare technologies. The Center will work with industry and government bodies to develop an initial set of standards

that leverage existing standards in the offshore oil and gas, shipping, and the power industries.

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REFERENCES

- [1] U.S. Census Bureau, "Interim Projections of the Total Population for the United States: April 1, 2000 to July 1, 2030," 2005, <http://www.census.gov>
- [2] Florida State Legislature, "2006 Florida Energy Act," 2006, <http://www.dep.state.fl.us>
- [3] "Florida's Energy Plan," 2006, <http://www.oe.netl.doe.gov>
- [4] Energy Information Administration, "State Profiles, Oct. 2006", <http://tonto.eia.doe.gov>
- [5] Department of Energy, National Renewable Energy Laboratory, www.nrel.gov/otec/what.html
- [6] Von Arx, W.S., Stewart, H.B. and Apel, J.R., 1974, "The Florida Current as a Potential Source of Usable Energy," Proceedings of the MacArthur Workshop on the Feasibility of Extracting Usable Energy from the Florida Current.
- [7] Lissaman, P.B.S. and Radkey, R.L., 1979, "Coriolis Program: A Review of the Status of the Ocean Turbine Energy System," IEEE, 559-565
- [8] Isaacs, J.D. and Schmitt, W.R., 1980 "Ocean Energy Forms and Prospects." Science 207 (4482): 265-73