Completion of the Design of the Turbine-Integrated Hydrofoil Project Narrative

a. Identification and Significance of the Opportunity, and Technical Approach

Present day wind energy installations require improved reliability, predictability, management, performance, and cost reduction in order to optimally integrate into the national energy infrastructure. Offshore wind resources offer burgeoning opportunities but face regulatory delays, installation and maintenance difficulty, susceptibility to damage from severe weather, and aesthetic objections. The success of the proposed project necessitates optimal control through cohesive integration of established weather tracking means into the control system of an innovative apparatus, thus providing means of prediction of available transmission capacity in advance, crucial to assuring grid reliability and achieving maximum benefit of offshore wind resources. This project strives to improve management of particularly offshore wind energy generation as well as exemplify practical application of energy storage such as compressed hydrogen or metal hydride technologies to achieve a more efficient integration of wind energy into the national energy infrastructure. Intrinsic to the approach of the proposed project exists improved communications and control of distributed wind energy gathering systems. As remote control from a central distribution and service facility with means to track weather conditions guides plural unmanned vehicles towards maximal wind, an inherent benefit arises in the form of reliable user-friendly prediction of wind resource availability along with control and aggregation of advanced energy storage for wind, from the proposed vehicle-to-grid via the central distribution and service facility.

A concise detailed description ensues. Successful completion of all phases of this project will achieve the goal of overcoming existing limitations of prior art oceanic hydrokinetic and pneumatic power generation systems foremost through integration into a singular generation and delivery system the ability to extract power from free-flowing seawater while simultaneously exploiting wind energy. A turbine and generator assembly electrically coupled through switch mode DC regulation means powers a hydrogen electrolyzer Membrane/Alkaline Electrode Assembly (MEA) with both assemblies integrated within a hydrofoil, in one embodiment mounted on a gimbal, affixed to the hull of a sailing vessel. This novel turbine-integrated hydrofoil enables the turbine to optimally respond to wind and water direction, facilitating guidance and stability of the vessel, and cooling of the MEA's electrodes. Through implementing a system to control vessel velocity given input parameters such as wind velocity, seawater current velocity, vessel mass and drag affecting actual velocity of the vessel, and feedback of generator output voltages; this enables the present invention to extract optimal energy from both pneumatic and hydrokinetic sources. Controlling the drag also facilitates maintaining overall stability and guidance of the vessel. At the highest level, remote control (SCADA/point-to-point CDMA) from a central control, distribution, and service facility with means to track weather (National Weather Service Geographical Information System, GIS) continuously samples and stores such variables as position (GPS), velocity, acceleration, weight, and level of vessel; velocity of motive fluids; armature voltages; fuel tank fullness; electrolyzer temperature; and energy efficiency. Thus, the energy extraction and delivery vehicle does not require a large scale of infrastructure new capital investment and therefore greatly diminishes the environmental impact while attaining a positive net energy earlier upon implementation.

Optimizing energy efficiency in the control of all processes including drag, ballast depth, vessel stability and velocity, and electrolysis of water in an integrated control loop, and including an outer loop of remote control based on wind velocity probability prediction data positions the present invention as desirable for implementation in gathering energy for emerging power conveyance systems, especially hydrogen fuel and fuel cell technology, thereby achieving more efficient integration of wind energy into the existing electric power grid.

b. Anticipated Public Benefits

Completing the design of the vehicle, a remote-controlled sailing vessel equipped with a turbine-integrated hydrofoil, will provide a vital first step in meeting the objectives of improved wind resource management. By utilizing the National Weather Service Geographical Information System, GIS wind prediction and tracking technologies; and through its novel exploitation of wind and hydropower resources in a concurrent energy extraction and delivery process, the completed vehicle design will expedite installation and facilitate maintenance, eliminate regulatory and aesthetic objections, diminish the environmental impact compared to typical offshore wind farms while attaining a positive net energy earlier upon implementation, and prosper from severe weather conditions. A remote-controlled mobile vehicle innately avails rapid deployment into optimal locations, continuously adapting to maximal oceanic wind resources. Success of Phase I of the herein proposed project will usher environmentally friendly exploitation of presently undeveloped yet immense sources of energy, the many GigaWatt-Hours of energy expelled in tropical storms and hurricanes.

Not only will the National Weather Service continue to serve in emergency preparedness, but henceforth will increasingly contribute in grid capacity availability prediction. Whereas tropical storms and hurricanes heretofore appeared only as a bane to coastal communities, the industry predicated upon harnessing the energy from these storms will now present economic growth opportunities for these communities. In the public sector, the National Weather Service, the National Oceanic and Atmospheric Administration, the DOE, and utilities regulators will foster cooperative arrangements through entities implementing this system with the public utility operators, and other private stakeholders in the renewable energy market including those promoting hydrogen fuel, supporting the Hydrogen Fuel Initiative (HFI), fuel cell manufacturers, and even public works contractors and shipbuilders. As the successful implementation of this product calls upon many scientific disciplines such as Computational Fluid Dynamics; Thermodynamics, Electrochemistry; Catalysis; Engineering Statics, Dynamics, and Strength of Materials; Material Science; Meteorology and Earth Sciences; Satellite Radar Telemetry; Communications; Control Theory; Power Supply Design; Electromagnetism; and Power Distribution, members of academia will find many applied research areas for improvements upon and optimization of the original system design.

c. Technical Objectives

The Principal Investigator and key persons will complete the design in Phase I and complete prototype development in Phase II of a new invention that overcomes the aforementioned limitations of existing offshore wind resource development projects. By completing the design process, the project will validate the feasibility of one or more configurations of the proposed energy extraction and delivery vehicle. In all configurations, remote control based on GIS/GPS/SCADA remains at the highest level of integration into the complete system. The design work completed in Phase I will guide applicability through prototype development in Phase II. Phase I design work will further delineate the limitations in terms of true wind velocity working range in which the invention effectively extracts energy, and determine which optimal design configuration to prototype to advance toward production. An iterative approach to Computational Fluid Dynamics, CFD and aerodynamic/hydrodynamic Velocity Performance Prediction, VPP, will preliminarily determine if typical wind velocity statistics and models for the majority of present proposed offshore wind farms, in the range of twelve to twenty knots, yields a favorable return of investment in net energy and financial terms, and thus validate a streamlined design for ordinary wind conditions. Whether or not the streamlined design proves viable in the majority of offshore proposed sites, the PI will investigate a ruggedized design for faring higher wind velocities, such as those typical of tropical storms or hurricanes, whereby limiting the vessel speed to avert structural fatigue becomes the issue. The fundamental differences in the streamlined versus the ruggedized configuration portend the dimensions and mass of the hull, mast, and appendages including the hydrofoil, turbine gate area, DC generator power capacity and mass, and output tank mass and volume, all of which in turn affect the overall drag of the vessel. Thus, an iterative approach solving and optimizing for extractable energy, utilizing CFD to determine the drag and therefore vessel velocity relative to true wind speed converges upon an optimal design given true wind velocity ranges. Structural integrity at high wind speeds will predominate the design criterion of the ruggedized vehicle whereas profitability at moderate wind speeds predominate the design criterion of the streamlined vehicle. Essentially the streamlined design requires meeting a minimum vessel to true wind velocity ratio criterion to meet profitability, whereas the rugged design requires sustaining a maximum profitability vessel velocity given maximum wind velocity and survival without any mechanical fatigue, electrical breakdown or thermal overstress.

The work in integrating the established wind speed prediction and tracking means will demonstrate practicability of the concept to other wind energy systems. Concurrent to the determination of optimal choice of streamlined or rugged configuration, development of the higher level SCADA remote control communication system will proceed along with design of the overall electrolyzer including the DC voltage regulators that couple the generator output to the MEA’s. Emulation of a functional higher level SCADA protocol on an emulation platform will validate the Phase I success of this aspect of the design process. Where complete system software functionality remains unfinished, a design specification will document remaining work required.

Aside from the results of a feasibility study reporting structural analysis, velocity prediction and net energy furnished from the optimal design configuration, the final deliverables will comprise a bill-of-materials and electrical, mechanical and wiring diagram design database for the energy extraction and delivery vehicle. The PI will specify no less than 90% of the items to include within in the final production bill-of-materials, of which no greater than 25% of the items will qualify as subject to change. The PI will also prepare a preliminary design validation test suite plan to enact for the prototype development of Phase II.

d. Phase I Work Plan

One may track the progress of design, feasibility study and integration of SCADA remote control into the system by first dividing the project into system component categories: Vessel structure; electrical power system; electrochemical processing and storage; Control and Communication. Figures 1 and 2 depict the majority of the components comprising the complete vehicle.

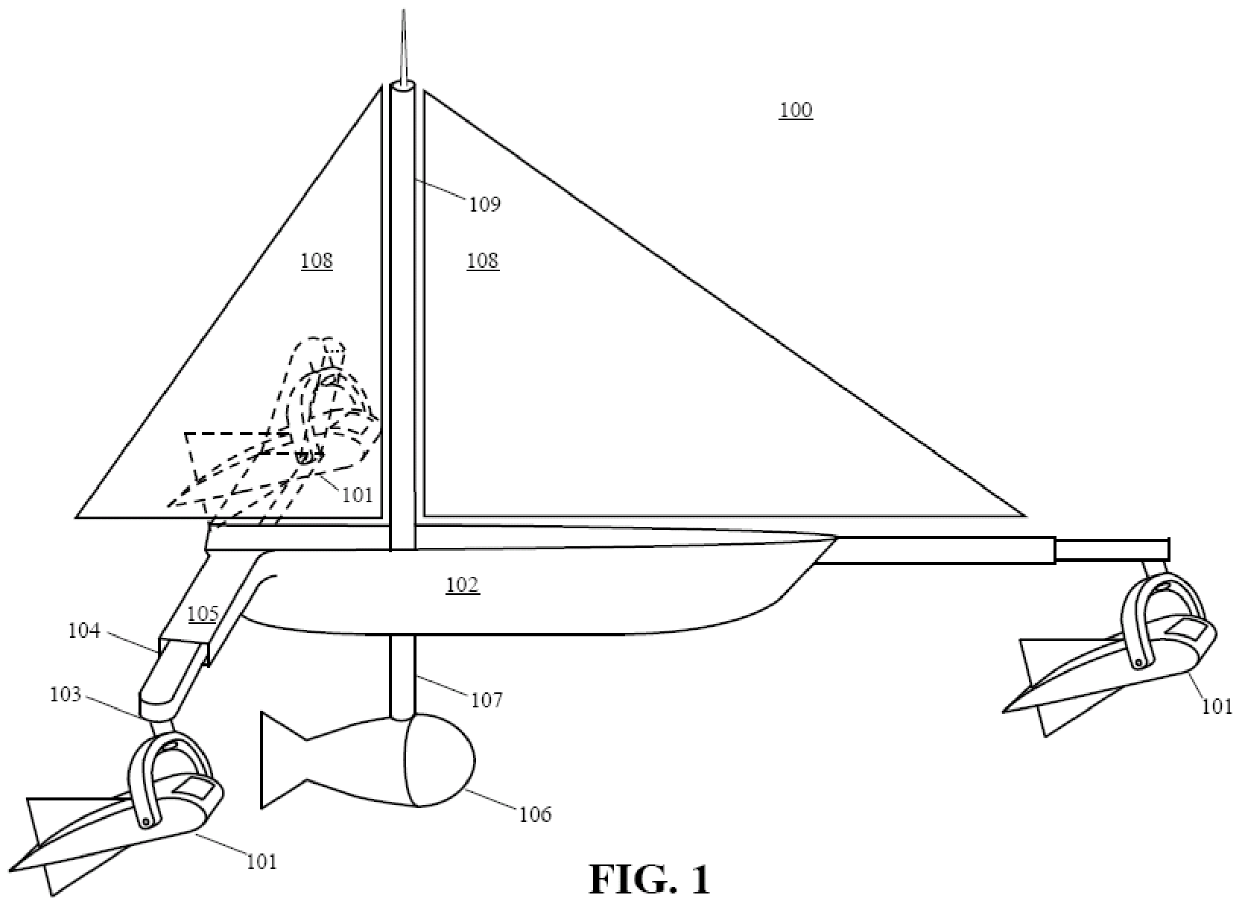

FIG. 1

Here Figure 1 illustrates a general perspective view of a vessel 100 implementing an exemplary energy extraction and delivery apparatus. Figure 1 depicts three turbine-integrated hydrofoils 101 engaged in the direction of the vessel 100 though the final configuration may implement any number of a plurality of turbine-integrated hydrofoils 101. The turbine-integrated hydrofoils 101 couple to the vessel 100 through corresponding beams 105 affixed to the hull 102 of the vessel 100. The beam 105 terminates at the gimbal mounting means 103 with the length of beam 105 extending to varying distances from the vessel's center of gravity through variable extension means 104 depending upon the velocity and stability of the vessel 100. Below the waterline, the output fuel tank 106 affixes to the hull 102 through variable extension means 107 which varies the draft of the output fuel tank 106 by varying extension length depending upon vessel velocity and stability, and mass of the output fuel tank 106 affected by fullness thereby providing ballast. Sails 108 provide the ordinary means of extracting energy from offshore wind sources. Because the hydrofoils 101 enhance vessel stability, the sails 108, while not necessarily drawn to scale in Figure 1, may significantly exceed the typical area of a sail for a vessel of a given hull size as depicted in Figure 1. Furthermore, implementation of any area and material type for the sail 108 not explicitly addressed herein may result after the iterative CFD/VPP design process. The mainmast 109 affixes the sail 108 employing means typically practiced in the art, though once again, due to the additional stabilizing effect provided by the hydrofoil 101, the mainmast 109 may significantly exceed the typical height of a mainmast 109 for a vessel of a given hull size as depicted in Figure 1. Figure 1 portrays a single hull 102 although the prototype vessel form for a rugged configuration very likely will implement a multi-hull structure without the torpedo ballast 106, variable draft means 107, beam 105, the variable extender 104 or the gimbal mounting 103. In this case, the PI will reserve study into quantifying the cost/reward advantage of any components omitted from the optimal prototype at some time beyond the scope of the first phase of this development project, given less-constrained design resources. For instance, preliminary analysis has shown that that given existing hydrogen compression techniques, the prototype design will likely not implement a ballast 106 containing output fuel until technology for compression at or above 10,000psi becomes prevalent and cost effective.

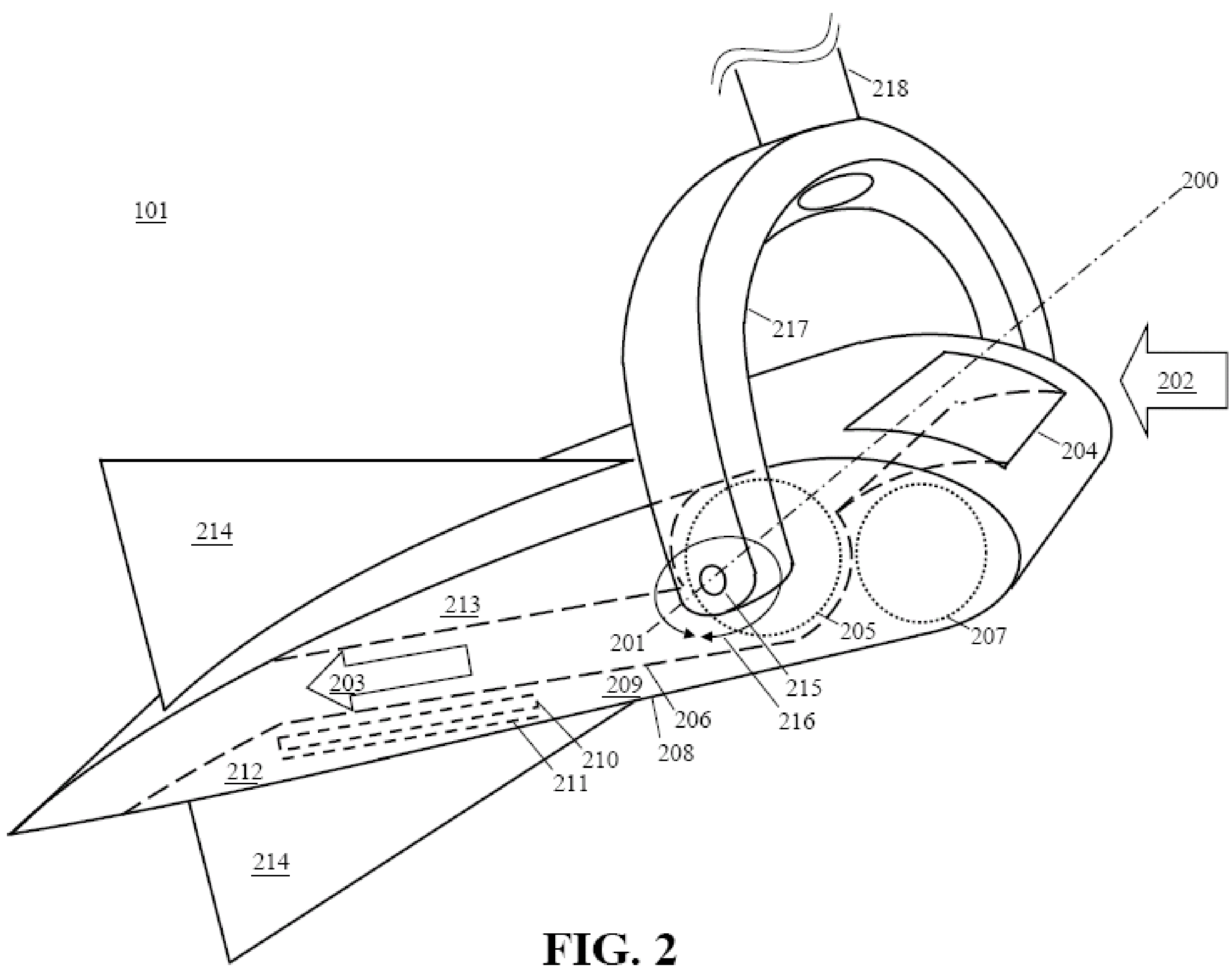

FIG. 2

Figure 2 shows the streamline 202 of the free-flowing motive fluid entering the gate 204 of the turbine-integrated hydrofoil 101, proceeding through the outline of the fluid coupler means

205, and changing in pressure and velocity as indicated by the streamline 203 in the draft section of the turbine of different size and shape than the entering streamline 202. As stated in the previous paragraph describing Figure 1, the initial design effort will likely forego implementation of the gimbal mounting means 215, 217, 218 until which time the PI has more design resources available. Thus, the hydrofoil will likely assume a fixed pitch not rotating as depicted by arrow 216. In the preferred embodiment, the fluid coupler means 205 entails a cross-flow impeller design. As the flow passes through the fluid coupler means 205, it impinges upon the lower surface 206 of the draft section of the turbine whereupon the gate 209 for coolant flow to the electrolyzer may be found. One electrode 211 of plural electrodes and the electrolyzer membrane and/or alkali 210 are shown and further comprise temperature sensors not shown which in part determine the openness of the electrolyzer gate 209. By flowing from the input gate in area 209 through the exit gate in area 212, the motive fluid of the turbine may serve as electrolyte as well as forced convection cooling fluid for the electrolyzer membrane 210 and electrodes 211. Although Figure 2 omits detail of both the turbine gate 204 and the electrolyzer coolant gate 209 on lower surface 206, one may assume these exist as continuously adjustable, simple louvered mechanisms facilitating minimization of drag after fuel tanks have filled during delivery to the distribution center. Hydrogen gas output from the electrolyzer becomes sequestered in a storage tank 207 or in the area 213. The hydrogen gas further enhances buoyancy of the overall hydrofoil 101. The openness of the electrolyzer gate 209 and the turbine gate 204 affects the overall drag of the hydrofoil 101, and thus besides electrolyzer membrane 210 and electrode 211 temperature, the drag, stability, and velocity of the vessel 100 represent input variables into the control algorithm for opening the electrolyzer gate 209 and turbine gate 204. The balance of components of the hydrofoil 101 such as the external fins and surface 208 will provide topic of analysis in the CFD/VPP design process.

Because all of these components function interactively in unison, concurrent development will facilitate immediate response to required change in one component affecting the functionality of another in another category. The aforementioned iterative CFD/VPP design analysis work best illustrates this point. As vessel velocity directly influences turbine power and DC generator capacity which influences the choice of process and storage means volumes and masses, all of which ultimately feed back to influence drag. Tables 1 and 2 portray two situations, Table 1, a streamlined vessel design operating in ordinary conditions, assuming the vessel attains a velocity of approximately 20 knots; Table 2, a rugged design operating in severe weather assuming the vessel attains a velocity of 35 knots, roughly half the true wind velocity.

Table 1A: Energy Extractable with a Turbine-Integrated Hydrofoil Streamlined Vessel

Turbofoil Intake Length (Meters):	10	= Turbofoil Intake Length (feet):	32.80833
Intake Height (Inches):	9	= Intake Area (Square Feet):	24.60625
		= Intake Area (Square Meters):	2.286005
Average Flow Rate (Miles/Hour):	23	= Meters/Second (M/S):	10.28196
Average Flow Rate (Knots):	19.9868	= Cubic Feet per Second (CF/S):	830.0508
Water Density (Kg/M^3):	1.00E+03	= Cubic Meters per Second (M^3/S):	23.5046
		= Power = (1/2MV^2)/S = Watts:	1.24E+06

Turbine Efficiency (%):	90		
Generator Efficiency (%):	90		
Mech. & Elect. Efficiency (%):	88	= Total Efficiency (%):	54.8856
Electrolyzer Efficiency (1) (%):	77		
		= Extractable Watts (w/ efficiencies):	6.82E+05
Wholesale (2) Price ($/KWHr):	$0.07	=H.P.:	9.14E+02
		= Dollars/Kg	$1.86
		Dollars per Hour per Turbofoil:	$47.73
Number of Turbofoils per Vessel:	3		
		= Extractable Watts (w/ efficiencies):	**2.05E+06**
		=H.P.:	2.74E+03
		Dollars/Hour:	**$143.20**
		Kg of H2 per hour (1)	7.69E+01
		ETA (hours) for 1 Metric Ton H2(1)	12.99731

note 1: Electrolyzer actual voltage accounted for in the efficiency estimate

note 2: 7 cents per kilowatthour represents rough estimate according to EIA year 2000 records

Table 1B: Profitability of a Turbine-Integrated Hydrofoil Streamlined Vessel

Crew Cost/hour ($):	$80.00		
Hours/Week in operation:	144	Weekly Gross KWHrs:	2.95E+05
Monthly Maintenance/Docking Cost ($):	$5,000.00		
Monthly Gross Revenue:	$89,289.98		
		Operating Margin:	9.05%
Monthly Profit:	$8,081.23	Annual:	$96,974.77
Amortization of the Vessel			
Principal	$3,000,000.00		
Annual interest	10.00%		
Term (years)	30		
Periods per year	12		
Start date	5/1/09		
Monthly payment	$26,327.15		
No. of payments	360		

Table 2A: Energy Extractable with a Turbine-Integrated Hydrofoil Rugged Vessel

Turbofoil Intake Length (Meters):	10	= Turbofoil Intake Length (feet):	32.80833
Intake Height (Inches):	9	= Intake Area (Square Feet):	24.60625
		= Intake Area (Square Meters):	2.286005
Average Flow Rate (Miles/Hour):	40.25	= Meters/Second (M/S):	17.99343
Average Flow Rate (Knots):	34.9769	= Cubic Feet per Second (CF/S):	1452.589
Water Density (Kg/M^3):	1.00E+03	= Cubic Meters per Second (M^3/S):	41.13306
		= Power = (1/2MV^2)/S = Watts:	6.66E+06
Turbine Efficiency (%):	90		
Generator Efficiency (%):	90		
Mech. & Elect. Efficiency (%):	88	= Total Efficiency (%):	54.8856
Electrolyzer Efficiency (1) (%):	77		
		= Extractable Watts (w/ efficiencies):	3.65E+06
Wholesale (2) Price ($/KWHr):	$0.04	=H.P.:	4.90E+03
		= Dollars/Kg	$1.06
		Dollars per Hour per Turbofoil:	$146.19
Number of Turbofoils per Vessel:	3		
		= Extractable Watts (w/ efficiencies):	**1.10E+07**
		=H.P.:	1.47E+04
		Dollars/Hour:	**$438.56**
		Kg of H2 per hour (1)	4.12E+02
		ETA (hours) for 1 Metric Ton H2(1)	2.425154

note 1: Electrolyzer actual voltage accounted for in the efficiency estimate

note 2: 4 cents per kilowatthour represents low estimated DOE FY 2006 Wind Energy Target

Table 2B: Profitability of a Turbine-Integrated Hydrofoil Rugged Vessel

Crew Cost/hour ($):	$80.00		
Hours/Week operation, annual average(1)	28	Weekly Gross KWHrs:	3.07E+05
Monthly Maintenance/Docking Cost ($):	$5,000.00		
Monthly Gross Revenue:	$53,170.94		
		Operating Margin:	22.84%
Monthly Profit:	$12,144.59	Annual:	$145,735.14

note (1): annual average, season lasts 6 months; gathers energy only 1/3 of the time in season

Amortization of the Vessel	
Principal	$3,000,000.00
Annual interest	10.00%
Term (years)	30
Periods per year	12
Start date	5/1/09
Monthly payment	$26,327.15
No. of payments	360

Tables 1 and 2 illustrate an estimated energy and financial feasibility model. Two striking differences appear in the two design and implementation paradigms represented by the data in these two sets of tables. While the example in Table 1 for the streamlined design paradigm meets the 2005 DOE new hydrogen cost goal, this number tops the wind energy estimated wholesale price. In addition, the Table 1 profit margin may not present a compelling enough case for further development in this design paradigm. In contrast, Table 2 predicts healthy margins for a renewable energy source while operating in an economy of historically low wholesale energy prices. The technical information demonstrated in these tables show configuration directions diverging especially in regard to the capacity of the DC generator. A 1000 horsepower generator will clearly serve any one Turbofoil on the streamlined designed vessel; whereas the rugged design demands a much more bulky 5000 horsepower generator for each of the Turbofoils in order to continuously generate 11MW during a tropical storm. One last point in regards to the quantitative data from above tables that the PI has considered since developing these spreadsheet models, the inefficiency incurred from the losses of the storage means, whether compressor power, cryogenic, physiochemical mechanism, or any thermodynamic losses must at least meet the DOE 2003, 94% compression efficiency target for the above macro models to maintain accuracy. Obviously, the efficiency cost will drive that design decision, taking priority over volume as hull size offset by hydrofoil lift costs less.

The PI must specify hydrogen storage means early in the project to attain a mass value for CFD/VPP work. While the PI finishes this work early, and as it appears the optimal design comprises Kevlar reinforced wrapping of 316 stainless steel tanks with contents at 3600psi, the design flow permits flexibility in allowing the meeting of specific technological milestones to warrant later design change. For example, the present perceived optimal tank configuration achieves a tank-to-payload weight ratio of somewhere between 13-to-1 to 25-to-1; whereas a survey of advanced hydride technology favors Lithium Alanate, $LiAlH_4$, with a present day vessel-to-payload weight ration of about 25-to-1 but with less appealing charge/discharge characteristics than established compressed gas techniques. The PI will expend some, albeit minimal efforts exploring cryogenics for liquid H_2 storage due to present day reports of cryogenics incurring more cost, near 30% in terms of energy efficiency.

While the above two tables provide less favorable evidence supporting streamlined design development, the below two offshore wind maps display two locations that could attain a consistently favorable margin for this technology.

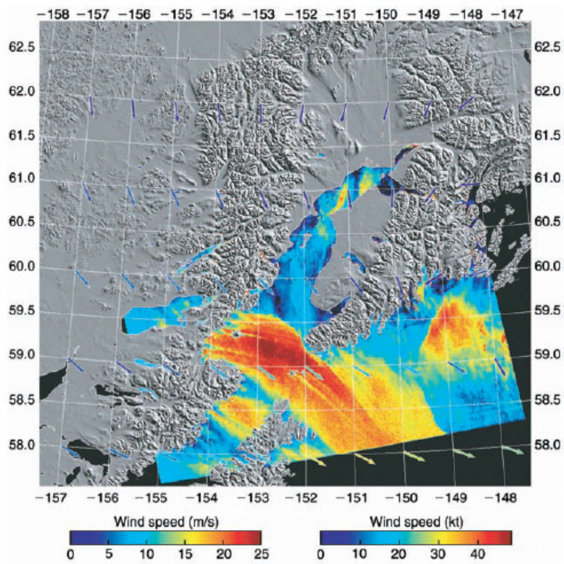

Figure 3. Radarsat-1 SAR wind speed image near Kodiak Island, Alaska.

Figure 3 above, taken from the Johns Hopkins Applied Physics Laboratory paper entitled: Ocean Wind Field Mapping from Synthetic Aperture Radar and Its Application to Research and Applied Problems, illustrates a seasonal wind resource usually near Kodiak Island Alaska for which a vessel of streamlined design would profitably regularly serve the wind energy market, even if the design barely achieves a minimal 50% vessel to true wind velocity ratio. As these jet wind patterns drift along the coast over the windy season, a turbine-integrated hydrofoil in deeper water attains obvious advantages over fixed farms over relatively shallow water.

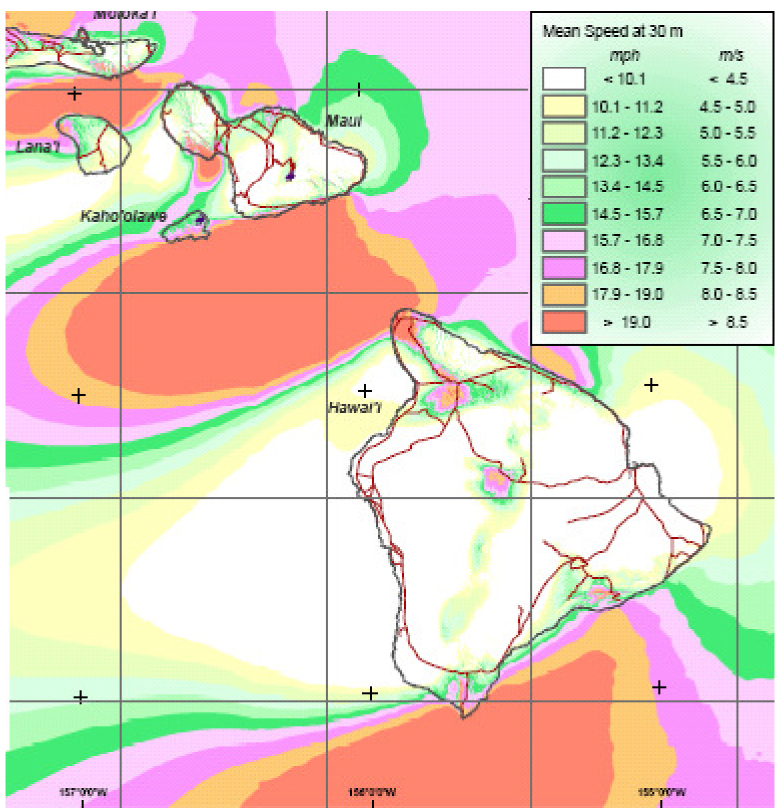

Figure 4 above, (http://www.awstruewind.com/inner/windmaps/Hawaii.htm) shows an expansive source of wind north and south of the Big Island of Hawaii. The one to the north covers approximately 2500 square miles and both extend into deep water and as such exemplify more instances where a turbine-integrated hydrofoil better serves the need for offshore wind exploitation. The Hawaiian resource appears somewhat less in magnitude compared to the Alaskan Jet wind phenomena of Figure 3, thereby suggesting a niche for a more streamlined designed vessel. Thus, given the two wind maps above, the value of streamlined designed turbine-integrated hydrofoils serve a distinct advantage in the tropical storm off-season, and therefore deserve full design consideration and characterization before deciding an optimal design approach. The CFD/VPP portion of the design effort will best characterize these two design paradigms and henceforth direct any marketing activity related to either design approach.

Performance analysis software development

AeroHydro, Inc. (Consultant) proposes to develop combined aerodynamic/hydrodynamic performance simulation software, to support quantitative evaluation of the technical and economic feasibility of the proposed vehicle and support system.

This software will be similar in concept and level of modeling detail to the Velocity Prediction Programs (VPP's) that are widely used for performance prediction, optimization and handicapping of sailing yachts. A VPP takes as inputs:

- the leading dimensions of the vessel (including its sails and appendages),
- hydrodynamic coefficients characterizing the hull resistance components, and
- aerodynamic coefficients characterizing the available sail forces,

and solves for equilibrium of the forces and moments, simultaneously optimizing multiple control settings, including sail trim, reefing (sail span) and heading angle with respect to the wind direction. This numerical solution furnishes a prediction of the optimal performance of the vessel as a function of wind speed and heading.

The primary differences in this project from a conventional sailboat VPP are:

(1) Because of the foil support, the vertical force equilibrium is significant, requiring an additional force equilibrium equation.

(2) The turbine power generation will have associated drag components that enter the horizontal force equilibrium equations. These drag components will be estimated by energy and momentum conservation principles.

(3) Effective functioning of the hydrofoils requires a nearly upright attitude, so heel angle is effectively removed as a degree of freedom.

(4) The primary objective to be maximized is power generated, rather than boat speed.

We anticipate the program input will be a file of input dimensions and coefficients, and its output will be a file tabulating generated power vs. wind speed, along with the accompanying sailing angles, velocities and control settings.

Note, the contemplated simulation program does NOT address the larger questions of optimal routing through weather systems, or optimization of configuration choices to maximize system performance, but it does provide an essential foundation for those types of analysis.

The simulation program will be built on the foundation of AeroHydro's proprietary RGKernel library. Relevant software components already available in RGKernel include dynamic arrays, vector analysis, solution of simultaneous nonlinear equations, and optimization procedures.

Anticipated level of effort on this topic is 20-25 days.

Proposed CAD modeling component

It is desirable for various purposes to visualize candidate configurations. This need ranges from detection of interferences between components, to preparation of marketing presentations for attracting investment capital.

AeroHydro proposes to develop a kit of relational components that will allow rapid assembly of configuration models in the environment of MultiSurf, for visualization purposes:

Displacement hull component (parameters: length, beam, depth, freeboard)
Turbo-foil component (parameters: length, span, thickness, camber, intake area)
Sail component (parameters: height, chord, trim angle)

Each of these components would be located in relationship to a point, and sized according to its parameters. Thus with a very short sequence of modeling operations and component loads, a visual model can be assembled with varying numbers and positions of hulls, foils, and sails.

Anticipated level of effort on this topic is 5 days.

In view of all these design variables, electronic design of the DC regulator for the MEA and all the mechanical and electromechanical design may immediately proceed as this system component quickly scales to any configuration change of the other system component categories. Reuse of design techniques disclosed in a prior patent granted to the PI involving local feedback to regulate shunt or separately excited field coil current thus averting turbine impeller mechanical fatigue given a constant electrical load and in this instance, for reducing drag and generator thermal stress, allows quick implementation of DC generator design. Figure 5 below shows the schematic. Note that DC regulator for the MEA occupies block 724 of Figure 5 and presents a constant electrical load to the power generation system, thus leaving the theoretical equivalent of line regulation, here turbine output, as the control input variable in the system.

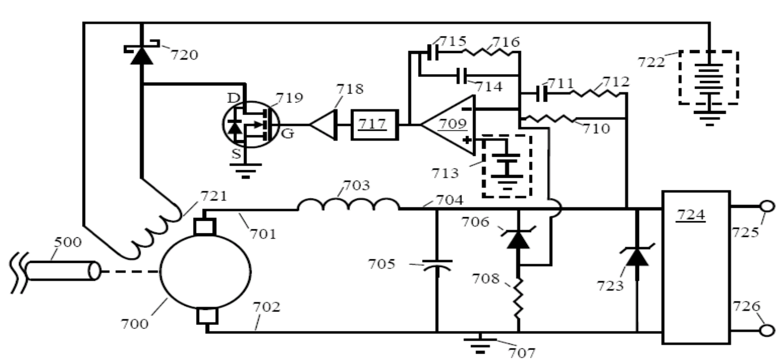

FIG. 5

Figure 6 shows a preliminary draft top-level control algorithm for both the local control loop and the SCADA/GIS/GPS remote control system. Choices of high-bandwidth control input accessory sensors such as motion video depend upon physical layer of choice, i.e. SCADA point-to-point UHF or else CDMA. Early milestones will consist of SCADA configuration, cost and functionality analysis, and top-level control functional description. As top-level software integration typically tends to occur towards the end of the development of the design cycle, a high-level emulation system will function upon completion of Phase I, with completing final software integration comprising a considerable portion of the prototype development in Phase II.

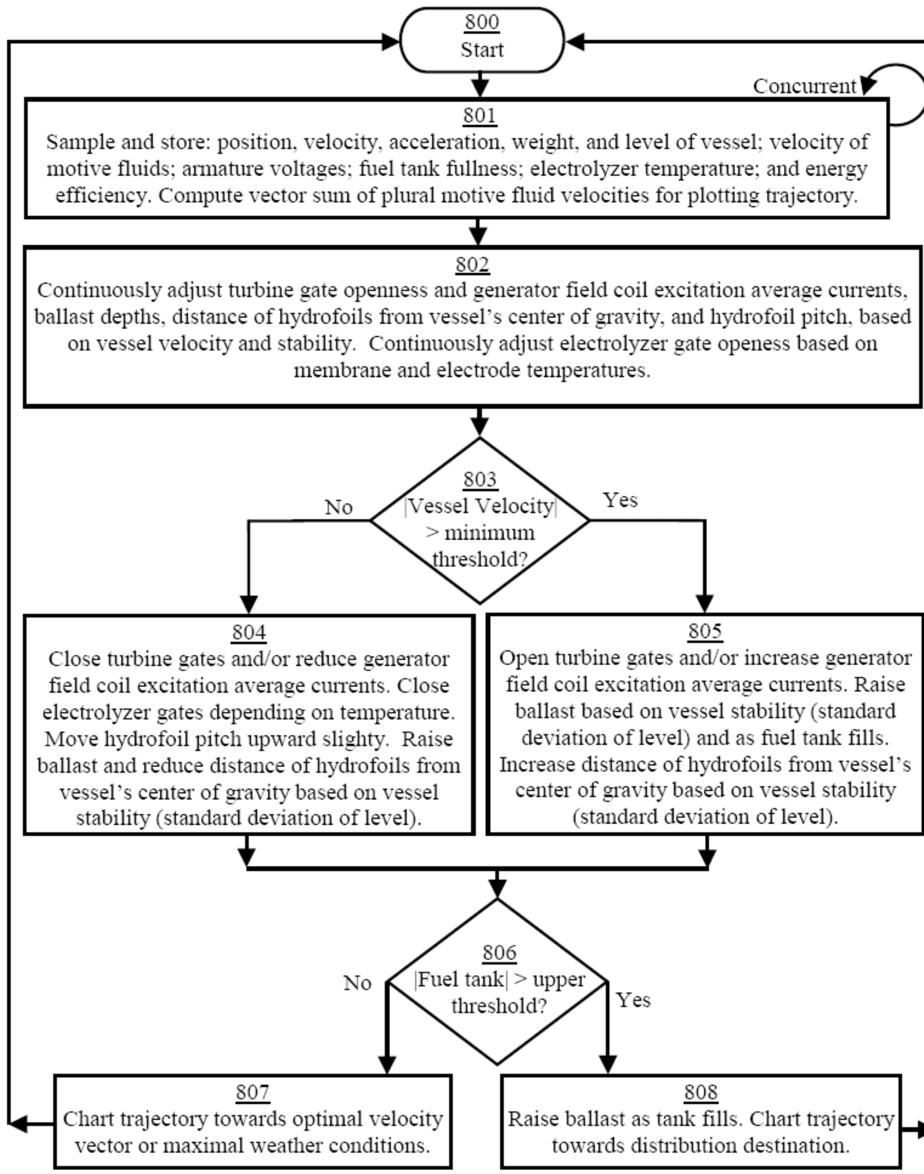

FIG. 6

Figure 6 as shown does not delineate which control algorithm functions locally or within both the local control loop and the SCADA/GIS/GPS remote control system. Such delineation exemplifies the early milestone goal of control system configuration and functionality analysis. The specification of integration of the VPP analysis software with the GIS component into the SCADA system to enable analysis of optimal route through weather systems will also demarcate an early milestone.

GIS -- GPS SCADA Integration

An integrated geospatial information system (GIS) database and satellite global positioning systems (GPS) data feeds enable controlling the navigation of the hydrofoil vessel. The GPS control systems will include integrated real-time streaming weather data so as to provide the optimal geodetic navigation path into a maximal wind system to gain the largest capacity for return.

Proposed Approach

Advanced Spatial Meridians (Consultant) proposes to develop an integrated GIS-GPS system that is used to control the hydrofoil vessel using satellite technology based TCP-IP network solution. This solution would involve developing supervisory control and data acquisition (SCADA) system that interfaces with a geospatial database containing both navigational mapping data and real-time weather data. The project would also involve the development of algorithms that integrate the on-board vessel sensor data with the weather and GIS data. The system would be controlled using a human machine interface (HMI) solution developed as a user-friendly graphic user interface (GUI). The HMI GUI would be developed as both a desktop and web based application to enable a variety of control options for systems controls, operation and maintenance functions.

The SCADA/HMI systems would be integrated with the vessel through a series of clustered servers hosting the server side functions communicating with the client side GPS control application running on the hydrofoils. The on-board application would be fed the parameters delivered from the aerodynamic/hydrodynamic performance simulation software models, the on-board sensor data and integrate the real-time weather and environmental data and determine an optimal routing through weather systems. Additionally, a server-side optimization algorithm will be developed to access configuration variable assessment and present choices to the HMI to maximize the SCADA system performance.

The system would be developed using client server technologies with servers hosting and controlling the GIS – GPS databases, running computational algorithms on client provided data feeds. The HMI would be developed as a server-side application with secure remote client control application connection.

SCADA system includes input/output signal hardware, controllers, HMI (Human Machine Interface), networks, communication, and software.

The hydrofoil CAD component model would be integrated into the HMI to allow for real-time visualization in a 3D virtual reality simulation. This tool would be used to fine tune, test and calibrate the SCADA navigation systems.

This development effort would be accomplished, wherever feasible, using Open Source standards and software to minimize the software licensing fees and constraints.

Deliverables

The project deliverables will include a mid-level systems design guide report consisting of an executive summary, detailed report, supporting drawings, tables and figures.

The design guide would include a number of sections detailing the architectural tiers of the system, process controls, HMI Visualization interfaces, data analysis and supervisory servers, data storage, network communications layers, all hardware, SCADA object tags definition, software development definitions and overall systems integration plans.

The estimated time for completion to plan and develop the design guide would be approximately 50 hours.

The design guide data would be compiled into a final report including supporting diagrams and drawings. This effort is expect to take approximately 14 hours.

Performance Schedule

Table 3 below depicts the estimated timeline for completion of all the aforementioned tasks as evidenced by arrival to their respective milestones.

Table 3 DESIGN MILESTONES	
COMPONENT & CATEGORY:	NUMBER OF WEEKS
Control and Communication:	
Specify Control I/O for Local and Remote Loop (PI,1,2)	2
Specify/Integrate Radio/Antenna and PLC for SCADA (PI)	3
SCADA Software Design and Documentation (2)	1.5
Specify and Design System Electromechanical Actuators (PI)	10
Vessel Structure:	
VPP Software modification for this project (1)	5
MultiSurf CAD Software modification for this project (1)	1
Iterative CFD/VPP Vessel CAD (PI)	5
Initial Structural Integrity Analysis (PI)	5
Electrical Power System (PI):	
Specify and Design DC Generator	1.5
Specify and Design DC Regulator for MEA	1.5
Specify and Design Auxiliary Power for Control/SCADA/Radio	2
Specify and Design Electromechanical Actuators Power	5

Electrochemical Processing and Storage (PI):	
Analyze & Specify Membrane/Alkaline Electrode Assembly	3
Analyze & Specify Output Storage (Tank/Cryogenic/Hydride)	1
Analyze & Specify Compressor/Storage System Power Efficiency	1
(PI): Principal Investigator; (1): AeroHydro, Inc.; (2): Advanced Spatial Meridians (Consultant)	

Because the success of the project focuses upon the PI coordinating a tight, limited member team effort with the tasks, for the most part, in parallel, this table does not attempt to display task dependencies in a Pert or Gant project management style. The effort in terms of time commitment sum to nine months full time for the PI the committed amount of time of the respective consultants per their above proposed work plans.

e. Related Research

The prior research of others most relevant to this project includes the cited references in the funding opportunity announcement for the topic 4 Wind Energy Reliability and Cost Reduction; subtopic a. Smart Wind Grid Integration Systems, particularly ANEMOS, an integrated software short term wind modeling system. Several utilities of the European Union have planned implementing ANEMOS system installations for on-line operation at onshore and offshore wind farms for local/regional/national wind prediction. The project proposed herein will bring the United States up to competitive stature in this area of research. The aforementioned Johns Hopkins Applied Physics Laboratory work and paper has demonstrated that through the National Oceanic and Atmospheric Administration, the United States has unrealized human resources able to bring the nation back to technological leadership, with this Turbine-Integrated Hydrofoil serving as catalyst to this success due to its inherent advantages in exploitation of offshore wind. The United States can further gain technological leadership due to the fact that the Patent Cooperation Treaty nations could potentially become excluded from making, using, selling, or importing any system that infringes upon the claims of the pending patent for the Turbine-Integrated Hydrofoil.

The Wind and Hydropower Technologies Program of the EERE, in their Wind Energy Multi Year Program Plan for 2005-2010, published November 2004, on page 18 of the Technical Challenges section states, "In the area of offshore development, technological challenges include issues such as combined wind, wave and ice loading, geotechnical design issues (foundations, floating platforms, anchoring, and shifting ocean floor dynamics), and offshore transmission and interconnection issues." This statement very well emphasizes the key advantages to the Turbine-Integrated Hydrofoil system.

In the category of Electrochemical Processing and Storage, the PI has already invested substantial research related to storage techniques such as referencing the work with Lithium Alanate to which this paper previously alluded. In addition, alkaline electrolysis technologies appear to achieve the efficiencies required to realize the energy and profitability forecasted in Tables 1 and 2. However, much research and development must proceed in order for successful completion of Phase I of the proposed project. While alkaline electrolysis affords the highest efficiency of electrolysis methods, without a membrane of some sort, the high vibration environment in which the Turbine-Integrated Hydrofoil operates likely decreases the purity of hydrogen with oxygen and chlorine gas contaminants given seawater as the electrolyte. The PI will inquire into product price and delivery date quotes at other corporations and research institutes undergoing fledging research projects in the area of alkaline membrane electrolysis techniques. Detailed summaries for the following projects can be found in the 2005 DOE Hydrogen Program Annual Progress Report (APR) as referenced. The premiere research institute in this area, Sandia National Laboratory (Albuquerque, NM) investigates polymer membranes and higher efficiency electrocatalysts for alkaline electrolysis systems [APR IV.H.6 p.353]. The most established corporation, Teledyne Energy Systems (Hunt Valley, MD), conducts research in two areas of value to the Turbine-Integrated Hydrofoil, novel membrane and electrocatalyst materials for low-temperature alkaline electrolysis to achieve higher efficiencies and better system integration and also, advanced high-pressure alkaline electrolysis, targeting part reduction and system design to enable low-cost manufacturing [APR IV.H.5 p. 348]. Analytic Power, LLC (Woburn, MA) now engages in the most intriguing project as far as fit in the Turbine-Integrated Hydrofoil along the lines of high-pressure electrolysis and compression, a system for integrated electrochemical hydrogen compression for water electrolysis, [APR XI.2 p. 1330]. The PI will thoroughly inquire into any opportunity of cooperative efforts to further the development of the Turbine-Integrated Hydrofoil along with all these research projects.

The December 2005 Report to Congress, (ESECS EE-3060), Solar and Wind Technologies for Hydrogen Production, Table 2.3b Wind Energy R&D Focus Areas lists three areas that this very project, the Turbine-Integrated Hydrofoil, addresses quite succinctly. In the focus area of Offshore Turbine Technology, the DOE states "…the large available offshore wind resource and its proximity to coastal load centers make it attractive for development." Further down in that focus area, the DOE further claims, "DOE is working on developing turbines and technologies for both shallow and transitional depth applications." Obviously, the proposed Turbine-Integrated Hydrofoil project not only develops turbines and technologies for both shallow and transitional depth applications, but the proposed Turbine Integrated-Hydrofoil also readily exploits wind energy over deep water. In the Distributed Wind Technologies focus area, the DOE asserts, "Distributed wind technologies could be collocated at hydrogen generation stations in either grid-connected or off-grid applications." This statement also concisely describes how the Turbine-Integrated Hydrofoil project proposes, in combination with mature Fuel Cell/Inverter technologies, to improve grid reliability, per the solicited topic and subtopic for the grant. Finally, in the Emerging Markets focus area, four months after the PI applied for the Turbine-Integrated Hydrofoil patent, the DOE predicts: "…Although wind turbines have not been optimized to produce hydrogen, wind turbines and electrolyzers could be collocated, sharing controllers and power conditioning systems. Additionally, the turbine could be designed to operate at power levels that match the load demands of the electrolyzer…" Note that the PI also applied for the **U.S. Patent 7,088,012** entitled **Transverse Hydroelectric Generator**, in December 2004, a year before this DOE Report to Congress. Claim 1 of this patent clearly applies the concept of the turbine operating at power levels that match load demands of the electrolyzer, in this instance for a wave energy converter, thus rendering the concept to wind turbines non-novel, obvious in view of **U.S. Patent 7,088,012**.

In section 2.4, Electrolysis Recommendations, of the aforementioned December 2005 DOE Report to Congress, two of the three recommendations apply directly to the technology to which the Turbine Integrated-Hydrofoil project in Phase I and Phase II concentrates, namely, (2) continuing work on systems integration and optimization of wind turbine and electrolyzer systems, and (3) conducting limited demonstrations of renewable-energy electrolysis systems when research targets in technology roadmaps have been verified. To further exemplify this point, in that same report, Table 2.2, Electrolytic Hydrogen Production Barriers addresses Renewable Integration: "Development of integrated renewable electrolysis systems is needed, including optimization of power conversion and other system components from renewable electricity to provide high-efficiency, low-cost integrated renewable hydrogen production."

The PI's previous work resulting in two patents for Wave Energy Conversion, **U.S. Patent 6,956,300,** and **U.S. Patent 7,088,012** has already proven of practical value in contributing to this resultant research. As previously stated, the **U.S. Patent 7,088,012** entitled **Transverse Hydroelectric Generator** claims local feedback of generator armature voltages to regulate shunt or separately excited field coil currents to avert turbine impeller mechanical fatigue given a constant electrical load has applied in this instance, and additionally to reducing drag and generator thermal stress, of value to the technology in this proposed project. Furthermore, the PI's two latest pending patents, U.S. Patent Application 11/549,586 filed October 13, 2006 entitled **Pulse Width Modulation Sequence Generating a Near Critical Damped Step Response**, and U.S. Patent Application 11/555,128 filed October 31, 2006 entitled **Pulse Width Modulation Sequence Maintaining Maximally Flat Voltage during Current Transients** apply particularly well to any voltage or current regulated switch mode power supply such as the DC regulator for electrolysis. In addition, this technology is not limited in application to merely DC regulation. This technology may be applied to control of any second or higher order system mathematically analogous to pulsed control and requiring near critical damped step response or requiring a fixed output set-point in response to a transient load. Any electrical, mechanical or electromechanical system under the mathematical analogue of pulsed open loop control may especially benefit from the technology in these patent applications whereby without this technology, open loop control could result in a characteristically under damped step response or result in unacceptable output instability thus rendering such a topology undesirable and the cost benefits and ease of implementation of such open loop topology unrealizable.

f. Principal Investigator and other Key Personnel

The principal investigator brings his expertise in practical and theoretical aspects of power supply design and energy conversion that has resulted in six *pro se* patents and pending patents, several of which as cited in the above Related Research section. His diverse background also includes applied Fuzzy Logic Control design experience and patents in telecommunications, along with a strong emphasis in LAN design. Most applicably, he has worked independently within small teams on projects of broad scope and significant depth to achieve technical success in start-up business environments.

John Letcher combines an extraordinary scientific, mathematical, and engineering background with an intense love of sailing. Through his publications and design achievements, he has attained international standing as a leading authority on the technical design, hydrodynamics, and aerodynamics of sailing yachts and the foundations of geometric modeling. He has perhaps gained most renown as Senior Scientist for the design team that developed *Stars & Stripes*, winner of the 1987 America's Cup. His corporation AeroHydro has used MultiSurf and Relational Geometry, as the basis for a Navy SBIR to develop techniques for gridding and panelization for CFD analysis. He holds patents for Relational Geometry, a valued feature of the software in use for this project.

Mike Cicali will be the project manager and key contributor for the GIS -GPS portion of the project. Mike has a unique set of skills evolving over 16 years of developing and applying geospatial information systems technologies to solving real world problems in a wide variety of scientific and technological disciplines. This unique, diverse experience base will enable the integration of the turbine-integrated hydrofoil design data and the AeroHydro modeling work to develop the best overall solution.

g. Facilities/Equipment

The principal investigator and his consultants will work from their home offices substantially in design work, requiring no laboratory access for Phase I. Aside from software licenses from Aerohydro, Inc. for their MultiSurf simulation package; the Solidworks mechanical CAE product, Office Premium version with its COSMOSworks and COSMOSmotions toolkits for structural and dynamic analysis; and only a software emulation/development package for the SCADA PLC (Programmable Logic Controller), vendor as of now unspecified; this project requires no other capital investment.