White Paper Response to Naval Surface Warfare Center-Carderock Division Broad Agency Announcement

Hydrokinetic Analysis of a Turbine-Integrated Hydrofoil

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I. Technical Summary

(1) Concept of Operation, Feasibility, and Applicability

Herein the Integrated Power Technology Corporation (hereinafter IPTC), a California S-Corp formed on July 19, 2006, presents a project in completing the design of one class of mobile structure, the Turbine-Integrated Hydrofoil, or Turbofoil®. The Turbofoil® offshore remote-controlled mobile structure, a UMV, captures energy from wind and hydrokinetic sources simultaneously, and delivers energy to central distribution locations which control configuration, maintenance and operation, and navigation of the mobile structure by accounting for wind probability/weather tracking data from satellites (i.e. DMSP, SAR, GOES), Geospatial Information System (GIS) databases (NOAA, NWS, NHC, TPC, etc.), and from sensors on the mobile structure (GPS, IMU's, fuel gauges, etc.), while relating these data points to vessel Computational Fluid Dynamics and Velocity Performance Prediction (CFD/VPP) models to determine greatest yield and/or least cost path. The patented innovation embodied in the Turbofoil® exists in the integration of a turbine coupled to a generator all within a hydrofoil reducing drag and providing lift. In delivery mode, the hydrofoil provides lift and reduces drag to an energy extracting sailing vessel with the turbine gate along the foremost edge of the hydrofoil closed. When capturing energy, the turbine gate opens to allow seawater to pass through the turbine thereby generating DC for charging batteries, hydrogen electrolysis, or anhydrous ammonia synthesis as the storage medium for carbon-free energy, energy-intensive commodities, or environmental remediation reagents.

For the military bases in the Western Pacific Basin, Guam and Subic Bay, tropical storms and hurricanes have proven a bane to their existence until now as the invention of the Turbofoil® promises to render such co-location fortuitous. IPTC recently completed a study of thirty years of NOAA hurricane tracking data finding the Western Pacific Basin, "Typhoon Alley", experiences on average 118 days per year with sustained winds greater than 45 knots. A substantial advantage of the Turbofoil® comes from exploiting higher velocity winds maximizing greatest turbine power or total stored energy over time. Because total power is cubically proportional to motive fluid velocity in a turbine, and water is ~775 times denser than air, the Turbofoil® in Typhoon Alley will capture 27 times more power compared to typical wind turbines of similar scale in 15 knots winds, availing a substantially smaller form-factor and therefore lower materials cost for equivalent energy yields.

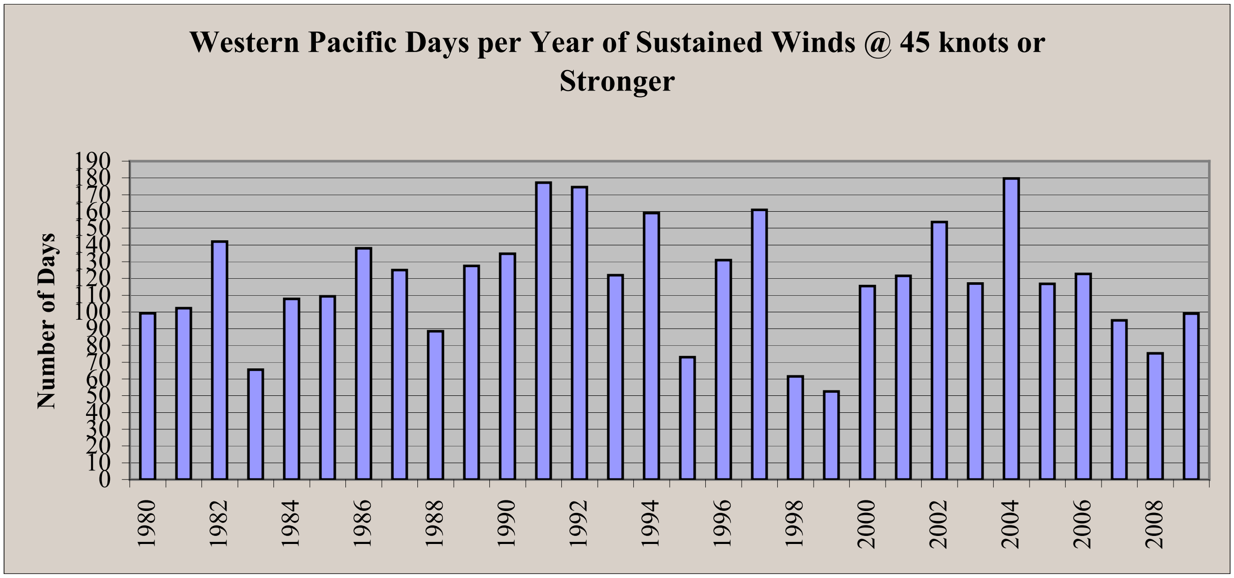

Figure 1. Thirty-year history of days with winds greater than 45 knots in the Western Pacific Basin, Source: NOAA's IBTrACS WMO: International Best Tracks Archive for Climate Stewardship -- Version: v03r02

Thus the proposed concept is a modular, distributed energy system in which numerous mobile structures harvest wind and hydrokinetic energy while being directed toward the high energy within storms. A centrally located distribution, maintenance and operation facility, a command vessel dispatches and follows a fleet of Turbofoil® equipped vessels toward the storm, and stores the recovered energy during deployment. In an estimate of any storm originating, on average, within 720 miles from this awaiting fleet, and the fleet capable of 20 knots cruising speed in approach to the storm, the fleet will engage the storm within an average of one and a half days. Accounting for this estimate of logistical inefficiency and average number of storms per year, that leaves 87 days of energy extraction on average. Given that the fleet of Turbofoil® equipped vessels will spend two-thirds of their time during these days actually capturing energy, with the other one-third spent delivering and offloading the energy to the command vessel, that leaves 58 days per year of energy extraction in 45 knots winds or stronger, about sixteen per cent of its life, or 26 hours per week on average, hence the feasibility numbers in Table 1 below.

An alternate concept of operation and configuration of the proposed energy extraction and delivery vehicle includes a less rugged, streamlined design for ordinary wind conditions, a Turbofoil® equipped vessel configured with a kite – parasail to exploit the higher altitude (up to 300m) winds of greater force than lower altitude winds even in ordinary conditions. While for the Western Pacific Basin tropical storm frequency and intensity is greatest between June and November, other locations have high-energy wind patterns during the hurricane "off-season", including high intensity winter jet wind events, "Williwaws", near Kodiak Island Alaska, and an expansive source of wind north and south of the Big Island of Hawaii. These wind patterns drift over a great expanse and both extend into deep water thereby exemplifying instances where a streamlined designed Turbofoil® attains obvious advantages over fixed wind farms confined to relatively shallow water. Thus, given these two locations, the value of a streamlined designed Turbofoil® serves a distinct advantage in the tropical storm off-season.

Table1. Energy Extractable and Profitability of a Turbofoil® equipped Vessel

	entry:		
Hydrofoil Intake Length (Meters):	10	**=Hydrofoil 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):	34.97688	**=Cubic Feet per Second (cf/s):**	1452.589
		=Cubic Meters per Second (M^3/s):	41.13306
Estimated Water Density (kg/M^3):	1.00E+03		
		= Power = (1/2MV^2)/s=J/s=Watts:	6.66E+06
Turbine Efficiency (%):	90		
Generator Efficiency (%):	90		
Mech. & Elect. Efficiency (%):	88	**=Total Efficiency (%):**	49.39704
Electrolyzer Efficiency (%):	77		
Hydrogen Compressor Efficiency (%):	90		
		=Extractable Power (W):	3.29E+06
		4.41E+03 hp	
Est. Wholesale Energy Price ($/kWh):	$0.07		
		=Dollars per Hour per Turbofoil:	$230.24
Number of Turbofoils per Vessel:	3		
		=Extractable Power (W):	**9.87E+06**
		1.32E+04 hp	
		=Dollars/Hour:	**$690.73**
		=kg of H_2 per hour	3.71E+02
		=ETA (hours) for 1 Metric Tonne H_2	2.694615
		=Dollars/kg	**$1.86**

Profitability of a Turbofoil® equipped Vessel

Crew Cost/hour ($):	$90.00
Weekly Gross Energy (kWh):	**2.57E+05**
Hours/Week in operation:	**26**
Monthly Maintenance/Docking Cost ($):	**$10,000.00**
Monthly Gross Revenue:	$77,762.50
Operating Margin:	4.66%
Monthly Profit:	**$3,625.52**
Annual:	**$43,506.22**

Amortization of the Vessel

Principal	**$4,500,000.00**
Annual interest	**7.75%**
Term (years)	10
Periods per year	12
Monthly payment	$54,004.78
Number of payments	120

Table 1. Feasibility and Profitability of a Turbofoil® equipped vessel capable of attaining true wind velocity in 45 knot sustained winds with turbine gates closed, 10 knots with turbine gates open.

(2) Anticipated Benefits

Obvious inherent advantages of the proposed distributed oceanic energy recovery system comprising one or a fleet of remote-controlled mobile structures include mitigating or circumventing prevailing new grid or fuel infrastructure renewable resources risks/costs:

• Oversubscribed grid/Curtailment losses (by storing the resource);
• Resource Intermittency (by patented weather tracking SCADA system);
• Storage feedstock scarcity (i.e ZnO, NaS battery chemistry, seawater readily available);
• Regulatory Delays (deployed in international waters under limited jurisdiction);
• Land-Use Restrictions (deployed in international waters under limited jurisdiction);
• Load Balancing/Baseload Functionality (through high-efficiency storage/delivery/dispatch);
• Installation and Maintenance Difficulty/Costs (port side manufacturing/service/distribution infrastructure already established);
• Susceptibility to Damage from Severe Weather; (rugged vessels prosper, others dock)
• Aesthetic Objections, "NIMBY“; (mobile, therefore availing deepwater, too…)
• SCADA patent invigorates floating turbine concept; (stored energy over time is cubically proportional to turbine motive fluid velocity, optimized by weather prediction)
• Substantially reduces LCOE (M&O) by enhancing total recoverability (continuous, concurrent production, storage and delivery);
• Substantially reduces M&O cost with assembly line (not field) maintenance procedures.

(3) Development and Project Timeline

By completing the design process within a period of 18 to 24 months for Phase 1, the project will validate the feasibility of one or more configurations of the proposed energy extraction and delivery vehicle. The design work completed in Phase 1 will guide applicability through prototype development in Phase 2. Phase 1 design work will further delineate the limitations in terms of true wind velocity working range in which the Turbofoil® effectively extracts energy, and determine which optimal design configuration, streamline or rugged, to prototype in Phase 2 to advance toward production.

IPTC proposes to utilize NSWC-CD's or other consultant’s expertise in developing 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 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: (a) Because of the foil support, the vertical force equilibrium is significant, requiring an additional force equilibrium equation. (b) 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. (c) Effective functioning of the hydrofoils requires a nearly upright attitude, so heel angle is effectively removed as a degree of freedom. (d) The primary objective to be maximized is power generated, rather than boat speed.

IPTC anticipates the program input will be a file of input dimensions and coefficients, and its output will be a file tabulating generated power versus 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.

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. IPTC proposes to develop a kit of relational components that will allow rapid assembly of configuration models in the environment of SolidWorks, for visualization purposes: Displacement hull component (parameters: length, beam, depth, freeboard); Turbofoil® 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.

(4) State-of-the-Art, Problem Areas

An iterative approach to CFP/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, IPTC will investigate a rugged design for tropical storms or hurricanes, whereby limiting the vessel speed to avert structural fatigue becomes the issue. The fundamental differences in the streamlined versus the rugged 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 payload container 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 rugged 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.