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Wind to Hydrogen using Seawater Electrolysis

Additional submitted attachment is included below.

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Why Consider Offshore Wind-to-Hydrogen Employing Seawater Electrolysis?

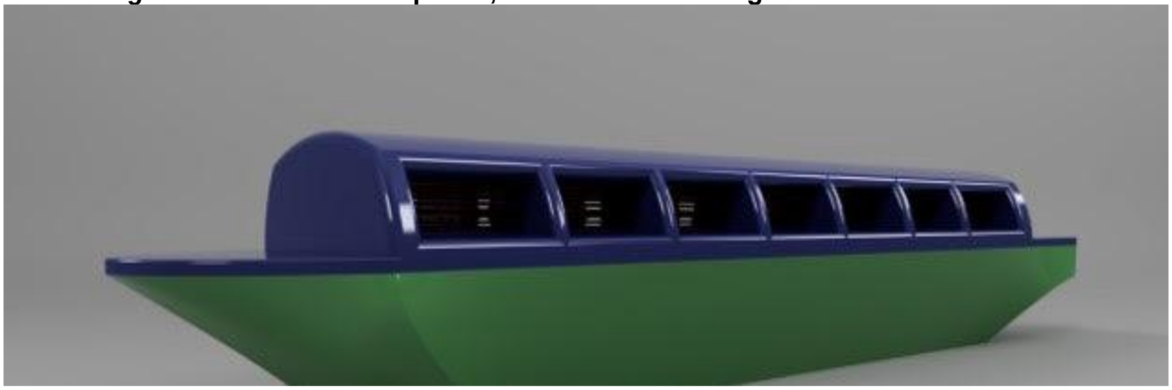
Wind-to-Hydrogen

Aeroderivative wind turbines **(Figure-1**) are presently the dominant wind-to-power technology.

Figure-1. Existing Aeroderivative Turbines

Alternative methods can recover low-velocity wind power, with on-set at 5-miles per hour, highly efficient with average wind velocities, designed for electrolytic production of hydrogen.

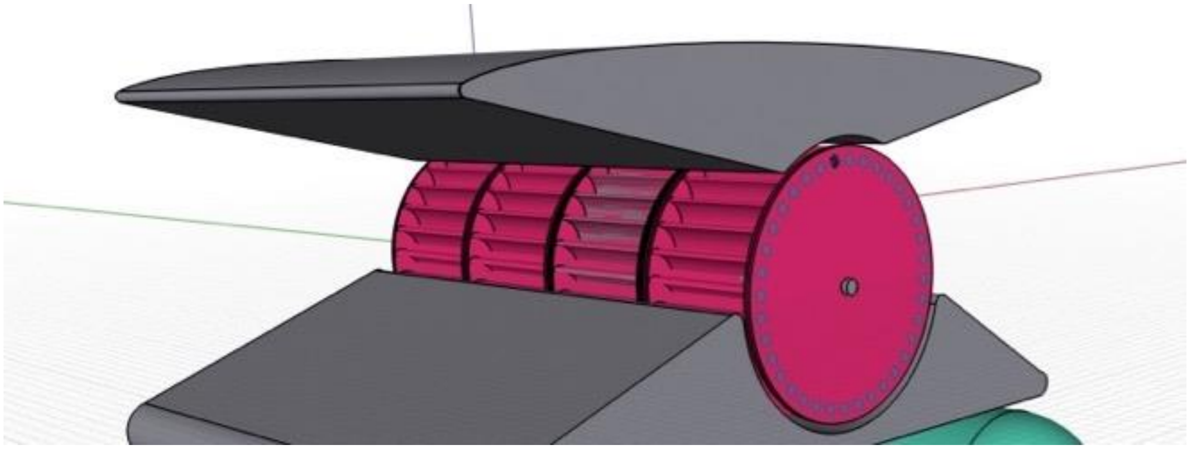
Figure-2. Container-Ship Size, 100' x 1000' Floating Offshore Wind Platform



Technical Approach

Based on Russian technology from the 1990's the horizontal wind machines were conceived to use converging-diverging nozzles to magnify wind power, increasing the momentum of low-velocity wind (**Figure-3**), while improving efficiency during average wind conditions.

Figure-3. Wind-to-Hydrogen Concept using Converging/Diverging Nozzles



- The rotor design would employ a series of magnets secured to the circumference of the turbine-wheels. The larger the diameter the turbine wheel, the greater the differential speed between rotor and stator, driving electric current generation -- Larger wheels generate current more efficiently.

- Electricity generation would be designed for direct-current (DC) output at low-voltage. Low-voltage DC current optimized for electrolytic separation of hydrogen from seawater.

- The horizontal wind turbine/nozzle/generator would be barge mounted, anchored by two cables that enable the craft to turn into the wind, or fall off the wind during storm conditions, which vessel is moved by tug to a Port for refitting and redeployment.

- Hydrogen (H_2) would be produced directly using low-voltage (high-current flow) applied to the separation of hydrogen atoms from water molecules. The optimum electrolysis technology would require some comparative evaluations.

Ultimately, the scale-up would require the development of a custom-designed permanent magnet DC-generator with magnets mounted on the outer circumference of large diameter turbine wheels, scaling-up the rotors to 100-foot diameter. A development program would modify an existing ocean-going Pacific barge (cost about $800k) designed to support a series of proof-of-concept horizontal wind turbines integrated with various state-of-the-art electrolytic methods. The horizontal turbine blades offer the potential for significant improvements using Computational Fluid Dynamics (CFD), enabling the design of stiffer blades, lightweight construction, low-cost, recyclable, and highly efficient.

Seawater Electrolysis

There are multiple emerging technologies that are applicable to seawater electrolysis. Thoughtful comparisons are needed. A very promising approach would use proven reef-restoration technology for hydrogen production, employing low-voltage electrolysis to dissociate water molecules (**Figure-4**). With the help of ions in seawater, hydrogen ions are efficiently separated as H_2, while forming calcium carbonate accretions. Developed by architect W. Hilbertz in the 1970s, this technology uses electrolysis of seawater to precipitate calcium and magnesium minerals to 'grow' a crystalline coating over artificial structures to make construction materials (Hilbertz 2012). The mineral accretions, largely aragonite ($CaCO_3$) and brucite ($Mg(OH)_2$), are very similar in chemistry and physical properties to reef limestone (Hilbertz 2012), which are primarily the remains of the aragonite skeletons of corals and green calcareous algae. "Hydrogen gas bubbles up and crystal-mineral growth begins as soon as rust on the steel is reduced by low-voltage current. The surface changes from red to black to grey, and then white as minerals grow. Accretions reach a thickness of up to 20-centimetres over 3-years. Iron and steel remain bright and shiny as long as sufficient electrical current flows to maintain cathodic protection."

Figure-4. Mineral Accretions on iron Cathode

This approach would use proven reef-forming technology, but focusing on the economic production of H_2, rather than on making artificial coral reef. Nevertheless, reef-restoration and break-water construction projects could be performed in parallel, or the formation of cement structures, such as habitat designed to increase commercial fishing, or lobster farming.
The H_2 process would use simple low-cost iron-mesh cathodes as the surface to form hydrogen. Aragonite ($CaCO_3$) and brucite ($Mg(OH)_2$) are the minerals produced. Mineral accretions have mechanical strength comparable to concrete (Hilbertz, 1979). Deposition of minerals results from alkaline conditions created at the cathode by the reduction reaction:

$\mathbf{2H_2O + 2e^- = H_2 + 2OH^-}$ precipitating calcium and magnesium minerals from seawater:

$$\mathbf{OH^- + HCO_3^- + Ca^{++} = CaCO_3 + H_2O}$$

$$\mathbf{2OH^- + Mg^{++} = Mg(OH)_2}$$

The sum of the net reactions at both electrodes is neutral with regard to hydrogen ion production. Note that the ions in seawater also serve to sequester CO_2 (in solution as HCO_3^-) as a solid in the form of the calcified mineral aragonite ($CaCO_3$).

The basic concept is that the hydrogen (bubbles) will come out of solution when formed at the iron-cathode. A shroud or containment structure is envisioned that forms an umbrella or alveolus (alveoli) of sorts formed over or around the iron-mesh cathodes. Seawater electrolysis can be accomplished in the hold, or just below sea level, or deep under the flotation vessel. Both the electrodes and the collection/containment shroud could be located at some depth, say 70-feet below the floatation vessel (about 2-atm). Compression cost may potentially be reduced relative to other electrolysis-to-hydrogen systems used for H_2.

Offshore floating wind systems, invisible beyond the horizon (**Figure-5**), could be evaluated by the Energy Commission; the federal government could provide co-funding through NREL.
For example, these activities would fit with CE-CERT's R&D objectives at the University of California Riverside, working in collaboration with Taylor Energy, a California Corporation based in Riverside, presently developing thermo-catalytic gasification methods used to convert biomass residues into pipeline-quality renewable-gases.

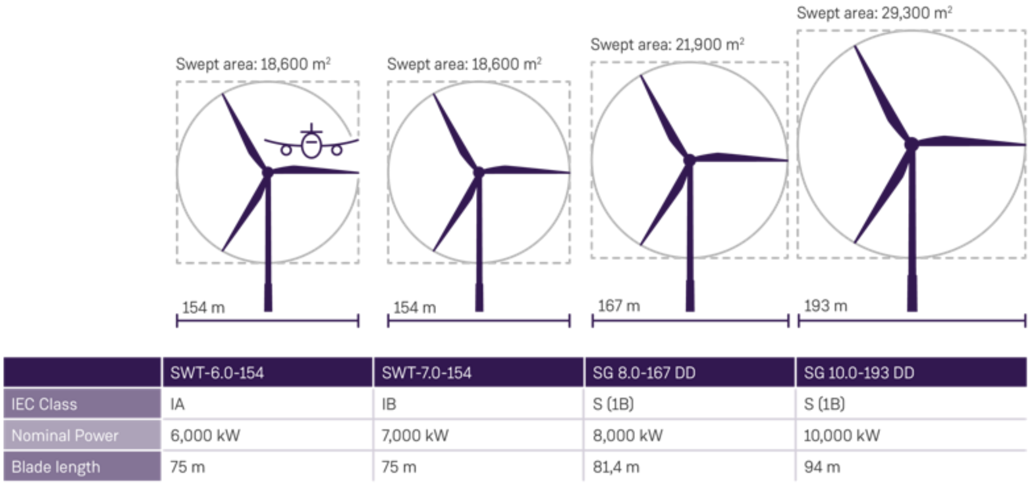
Figure-5. Invisible Beyond the Horizon: Offshore Hydrogen Production

Aeroderivative Wind Machines for Offshore Hydrogen?

Aeroderivative wind turbines (amazing scale-up success stories) are approaching their maximum economic size (10-MWe). The bigger the rotor, the slower the shaft speed; consequently, the gear box becomes more expensive than the rotor because of the step-up speed required. Alternatively, wind-machines without a gear box are costly, and very heavy, recovering power at high-torque and low-rpm. "The direct-drive generator becomes huge. Instead of the 100-ton gearbox, you have a 200-ton generator" (Polinder). Wind-power below about 9-mph is not recovered using existing aeroderivative turbines (**Figures 6, 7, 8**). The wind-tower technology seems structurally less suited to Pacific deep waters. Whereas, floating wind-power, recovering wind down to 5-mph when magnified with nozzles (that form the electric generator housing), using turbine/generators with low starting inertia, high-strength high-tech blades, with low resistance to rotation, is likely feasible in the near term.

Figure-6. Aeroderivative Wind Turbines

Figure-7. 10-MW Turbine has 94-meter diameter rotor



	SWT-6.0-154	SWT-7.0-154	SG 8.0-167 DD	SG 10.0-193 DD
IEC Class	IA	IB	S (1B)	S (1B)
Nominal Power	6,000 kW	7,000 kW	8,000 kW	10,000 kW
Blade length	75 m	75 m	81,4 m	94 m