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Abstract Hurricanes are viewed differently by different people. For environmentally-minded people, they are a manifestation of global warming; for potential victims living in their pathways they are a matter of evacuation and property damages; for municipality administrators, they represent a disaster planning and emergency response challenge. For most people hurricanes are viewed in these negative ways. However, for alternative-energy enthusiasts hurricanes have a silver lining resulting from their long-duration air turbulence and extreme energy in the atmosphere. A review of recent hurricanes, such as Hurricane Katrina of 2005, indicates that, although they caused casualty in the thousands and property damages in the billions of US dollars, not even a fraction of the energy contained in them were successfully extracted. This is simply because there were few means available to systematically and effectively extract the enormous energy contained in a hurricane. This leads us to develop the "hurricane chaser," which is a conceptual wind-energy harvesting vessel. With an aim to prove that most of the existing technology, including hurricane forecasting and tracking and wind-power turbines, are now mature enough, in this paper we attempt to lay down some first-level foundation works for the conceptual wind-energy harvesting vessel.

Introduction Tropical storms typically occur from June through November in those parts of the Atlantic Ocean where the surface seawater is warm. These storms are slow-moving, long-duration, and wide-span. Once the storms reach sufficient strength and wind speeds they are called hurricanes. Similar type tropical storm systems are called typhoons in the western Pacific and tropical cyclones in the Indian Ocean. The average temperature of the surface seawater in these oceans is about 60 degrees F (15.6 degrees C). Tropical storms are natural engines fueled by heat. Starting this great weather engine requires surface seawater of 80 degrees F (26.7 degrees C) or more. It also requires moist air and little wind shear—a difference in wind speed at the sea surface and aloft that can tear apart a developing hurricane. Even with all these ingredients in place, they often produce nothing more than a tropical disturbance, which is an unremarkable cluster of thunderstorms. These disturbances look very similar from day to day. Then, for reasons not fully understood, all of a sudden there is a big burst of convection and within hours a storm can grow into a tropical depression and then a hurricane. If a storm makes landfall, it is a death sentence for the hurricane as once its watery fuel supply has been cut off, the storm inevitably weakens.

In a hurricane, the heat of sun-drenched tropical sea sends warm, moist air rushing toward the frigid upper atmosphere like smoke up a chimney. As surrounding air is sucked in at the base of the storm, rotation of the Earth gives it a twist, creating a whorl of rain bands. These whiptails of thunderstorm activity are strongest near the center of the storm where they converge in a ring of rising and spinning air called the eye-wall. The eye-wall encloses a cloud-free zone. A hurricane can propel itself to an altitude of 50,000 feet (15,240 m) or more, where the rising air finally vents itself in spiraling exhaust jets of cirrus clouds. This cirrus cloud cover can be very wide. The largest ever, the 1979 Pacific typhoon Tip, sent gale-force winds across more than 650 miles (1,040 km). A hurricane can contain tremendous amount of energy in its winds. The winds of an average hurricane can easily pack some 1.5 trillion watts of power, which is equivalent to about half the world's entire electrical generating capacity in a year.

Due to their destructive force, most people view hurricanes in a negative way. However, for alternative-energy enthusiasts hurricanes have a silver lining resulting from their long-duration air turbulence and extreme energy in the atmosphere. A review of recent hurricanes, such as Hurricane Katrina of 2005 (Knabb et al, 2005), indicates that, although they caused casualty in the thousands and property damages in the billions of US dollars, not even a fraction of the energy contained in them were successfully extracted. This is simply because there were few means available to systematically and effectively extract the enormous energy contained in a hurricane. This leads us to develop the "hurricane chaser," which is a conceptual wind-energy harvesting vessel. In this paper we attempt to lay down some first-level foundation works for the conceptual wind-energy harvesting vessel. We will begin by examining a few factors that are in favor of developing this new means of harvesting energy from hurricanes.

A Record Hurricane Season 2005 was the year of the hurricane. Never before had the Atlantic seen 27 named tropical storms—so many that the list of storms had to be extended to never before used Greek letters. But what made 2005 so remarkable and unforgettable were three sister storms: Katrina, Rita, and Wilma. Never before had a hurricane caused as much economic damages as Katrina. At the end of August, Katrina killed more than a thousand people and left much of New Orleans and the neighboring coast in ruins. The damage exceeded a hundred billion dollars—the costliest natural disaster in U.S. history—and the toll in fractured lives is incalculable. In September, Rita ravaged the Gulf Coast through western Louisiana and East Texas. In October, Wilma, the most powerful of the 27 named storms, hit South Florida.

Mercifully, the winds had ebbed from 185 miles per hour (87 m/s) at sea to 120 miles per hour (54 m/s) by the time the storm hit, but it still left almost all of South Florida without power.

These three monster storms were part of a baby boom of storm activity that isn't expected to end for a decade or more. According to some researchers, the 2005 hurricane season was a continuation of the upward trend of hurricane activity that began in 1995. Because of a tropical climate shift that brought warmer waters and reduced wind shear, the Atlantic has spawned unusual numbers of hurricanes for nine of the past eleven hurricane seasons. And behind them all lurks the grim possibility that global warming is making the storms stronger.

Well-Defined Hurricane Scales Hurricane scales are used to describe the wind speed and the associated flood surge associated with a given magnitude of a hurricane. The most commonly used hurricane scale is the Saffir-Simpson Hurricane Scale, which has a 1 to 5 rating based on the hurricane's intensity. This scale is designed to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline in the landfall region. All wind speeds referenced in the scale are the 1-minute duration, mean, surface wind speed. The followings are some brief descriptions of the Saffir-Simpson Hurricane Scale:

- Category-I Hurricane: Winds 74 to 95 mph (119 to 153 km/hr). Storm surge generally is 4 to 5 ft (1.2 to 1.5 m) above normal.

- Category-II Hurricane: Winds 96 to 110 mph (154 to 177 km/hr). Storm surge is generally 6 to 8 feet (1.8 to 2.4 m) above normal.

- Category-III Hurricane: Winds 111 to 130 mph (178 to 209 km/hr). Storm surge is generally 9 to 12 ft (2.7 to 3.7 m) above normal.

- Category-IV Hurricane: Winds 131 to 155 mph (210 to 249 km/hr). Storm surge is generally 13 to 18 ft (4 to 5.5 m) above normal.

- Category-V Hurricane: Winds greater than 155 mph (249 km/hr). Storm surge is generally greater than 18 ft (5.5m) above normal.

Even though these scales are not defined for the purposes of designing a means to generate power from a hurricane, they do provide a good reference starting point for such a design.

Improvements in Forecast of Hurricanes Keeping tabs on hurricanes is the job of meteorologists and weather satellites make it easier for them to do their job well. Currently, it seems that every time there is a hurricane alarm, the satellite images of the hurricane are available everywhere. But ordinary satellite images show only the cloud tops. Besides satellites, many other instruments are used by meteorologists. Space-borne infrared sensors can reveal more detail, charting the size and shape of the warm eye while satellite radar and microwave sensors can map the rain. Hurricane hunter aircraft actually fly right into Atlantic hurricanes but can only probe conditions at altitudes of several thousand feet above the worst turbulence instead of the surface, where they really matter to people. In 2005, scientists flew a robotic aircraft straight into the maelstrom when tropical storm Ophelia was parked off the mid-Atlantic coast. The craft, called Aerosonde, swooped and circled for ten hours as low as 1,200 feet (366 m), monitoring winds and the flow of heat and moisture from the ocean into the storm. That foray was a test, but forecasters routinely probe the heart of storms with shorter lived devices called dropsondes. Released from high-flying aircraft into hurricanes and the surrounding winds, these instrument-packed tubes descend by parachute and fall from 40,000 feet (12,190 m) to splash in about 15 minutes. Along the way, they measure temperature, pressure, humidity, and wind every half second, transmitting it all back to the airplane before they hit the water.

By incorporating dropsonde data into computer models that can simulate a storm and how it is likely to evolve, researchers have sharpened their forecasts of storm tracks. Three-day forecasts of Atlantic storm positions were off by an average error of 173 miles (277 km) in 2005, down from an average of 440 miles (704 km) in the 1970s. But one-day forecasts were still wide of the mark by an average of 70 miles (112 km)—more than enough to keep coaster dwellers second-guessing the experts. The data and models still can't capture storms in enough detail to forecast all of their feints and swerves.

Storm intensity has proven even harder to forecast. Three-day wind-speed forecasts, off by an average of 23 miles per hour in the early 1990s, improved only marginally by 2005. Hurricanes regularly surprise observers with their mood shifts. In a matter of hours, a Category 5 storm (wind over 155 mph, or 69 m/s) can fade to a Category 3 (111-130 mph, or 50-58 m/s) or a mere tropical storm can explode into a killer. The state of the ocean below a storm explains some of the intensity shifts. In 1995, tropical storm Opal was inching toward Category 1 status—an entry-level hurricane—as it made its way through the western Gulf of Mexico. Then, in just 14 hours, it surged to Category 4. Satellite readings of the warm sea showed nothing unusual. But researchers discovered that the warm water layer wasn't limited to the top few yards of the ocean, as it usually is in the Gulf. Cold water at greater depths acts as a brake on hurricane intensity when the winds churn it to the surface. But Opal had strayed across a pool of warm water extending hundreds of feet down. No matter how hard the wind blew, it stirred up more warm water hurricane fuel, causing the storm to intensify. The tropical ocean is littered with these deep warm pockets, and their importance was underscored in 2005 by Katrina and Rita, which shot up to Category 5 when they passed the Loop Current. Satellites can detect surface warmth by looking for subtle bulges in the sea surface, which is something that researchers can use to work and improve intensity forecasts by 5 to 15 percent. Waves, on the other hand, can slow the winds down and blunt a storm. Whipped up by a hurricane, they can reach heights of more than a hundred feet, exerting a drag on the winds that created them.

Re-emergence of Utility-Scale Wind-Power Industry The industry that converts wind energy to electricity and other uses is, without doubt, the leading mechanically-based, renewable power source. The industry has been around for thousands of years and has been reinvented numerous times. Now the industry is facing new promise. Indication of this comes from a variety of new wind projects that were installed in the U.S. in the late '90s, including a cluster of turbines operated for a utility in southwest Texas, a wind plant of machines in Big Spring, Texas, a 10-megawatt wind plant in Northern Colorado, a number of plants in the upper mid-west, and the "re-powering" of some projects in California. Some of the projects involve foreign machines manufactured in the U.S. Successes of these projects and the news that over 2,000 megawatts of new capacity are planned for the new century in the U.S. alone give us a sense that the wind-power industry may be on the move again (McGowin et al, 2001 and Dodge, 2002).

There are two distinct market segments in the wind-power industry: utility-scale systems and small wind turbines. After 1990, the activity of manufacturing wind-power turbines shifted to Europe and Asia and only the utility-scale segment is emerging. Cooperatives and private landowners in the Netherlands, Denmark, and Germany, driven by high utility power purchase rates, have installed many utility-scaled wind turbines, first 50-kW, then 100-kW, then 200-kW, then 500-kW and now 1.5 megawatt. The installation of over 10,000 megawatts of European wind capacity has helped support a thriving private wind turbine development and manufacturing industry there. Until recently, this contrasted with the United States where low utility rates (primarily due to abundant, under-priced natural gas imported from Canada) and deregulation of the utility industry virtually strangled wind energy development. For the segment of small wind turbines, a large international market has long been predicted for small village power or "wind-hybrid" installations. Despite some promising pilot projects, the apparent interest of many countries and of many non-governmental organizations, and significant commitments from several wind turbine manufacturers and U.S. research laboratories, including Sandia National Laboratories and the National Renewable Energy Laboratory, this market segment has yet to emerge.

The reason for the re-emerge of the utility-scale wind-power industry is mainly due to cost reduction. Since the late 1970's the U.S. cost goals for wind-power systems, for both utility-scaled and smaller systems, have continued to be about $0.04 per kilowatt hour, despite inflation. Wind turbines have consistently been able to arrive at that level. By the time they get there, another reduction in the cost of non-renewable fossil fuels has taken place and the bar is lowered further. Cost per kilowatt hour figures of $0.04 or less (in 1998 dollars) are now commonly projected for advanced U.S. wind turbines in 17 mph (7.6 m/s) or better wind regimes, where capacity factors (to be defined in the following section) of over 0.40 can be achieved. That means that the wind energy cost goals of 1980--which seemed daunting or impossible at the time--have been met many times over. This fact should be remembered by those doubting the achievability of recently refigured cost goals--which are now closer to $0.025/kWh. Worldwide, there are 10 to 12 manufacturers of large, utility-scale systems, marketing 200kW to 3.0 MW systems of various configurations, including three-bladed machines with full-span pitch control and two-bladed, stall control machines with teetering hubs. The lower cost of energy from these advanced turbines is partly a result of higher efficiencies and rotor loading made possible by improved rotor design, shedding of fatigue loads provided by teetered hubs and flexible structures, and other innovations such as variable speed operation. But reduced weight and material usage and high reliability are perhaps more important factors in the cost equation. Costs of smaller systems vary widely, with installed costs from $2,000 to $3,000 per installed kilowatt. Energy costs for small turbines of $0.12 to $0.20/kWh are still the norm in the U.S. market.

The Concept of a Hurricane Chaser In a way, a hurricane chaser can be compared to building and operating a commercial fishing boat or ship. We can catch fish wherever fish live and swim: in streams, rivers, ponds, small lakes, large lakes, bays, and the open ocean. As a rule of thumb, big fish, whale included, live in large bodies of water. Therefore, we must go to the open ocean in order to harvest big fish regularly. Particularly, in order to catch whales in the open ocean safely and effectively, we must use large whale-ships. Whale-ships are designed for long voyages. To catch whales, whale-ships often move from place to place. Oils and other products from the whales are processed on board, and are carried back to port by the ship. Using this whale-ship parallel, a logical extension of the current utility-scale, offshore wind-power plants is to put these large-rotor, high-tower wind machines on vessels that can brave the largest of the ocean waves and harvest wind energy safely and effectively. We call this conceptual vessel a "hurricane chaser." The idea is to navigate a hurricane chaser along the optimum hurricane routes, similar to the way that a tall-ship in a 15th century armada followed the directions of the trade winds. This approach will drastically increase the efficiency of any wind-power turbines onboard the vessel, making the vessel a net energy harvester.

An Un-orthodox Design, Analysis, and Synthesis Paradigm When compared with a land-based wind turbine, a workable hurricane chaser will not be just a wind turbine that is onboard a barge or something that can float. It will be an engineered system that is at least one-order of magnitude more complex. It would require massive integration and interconnection between components and subsystems, feedback, and redundancy. Complexity in the system is in part due to the need to operate in harsh weather conditions and still perform predictably even when unforeseen design flaws, human error, random faults, and other disturbances, or perturbations arise. As unforeseen or unanticipated perturbations can completely disable a complex system, this complex engineered system needs to be robust and able to continuously evolve and adapt to the varied threats and opportunities realized but were difficult to predict and characterize in the beginning. As complexity alone is not sufficient to manage an engineered system under largely unpredictable scenarios, a somewhat un-orthodox paradigm for design, analysis and synthesis of engineered systems will be needed to ensure optimal operational levels when the threats or opportunities are realized.

The basic design philosophy of the hurricane chaser can be borrowed from the design of dams. Dams are used to hold back a body of water upstream and consideration of both wind and precipitation must be included in the design of these structures. Many large dams were built during the last century. In response to several dam failures during the first half of the century, all large dams in the United States are now routinely inspected. However, the design parameters to which they are built, including the Probable Maximum Precipitation (PMP), have not been significantly changed despite the fact that the maximum hydrologic event scenarios were often based upon limited or poorly understood climatic data. Instead, dam engineers world-wide have concentrated on ensuring that the water in a reservoir cannot rise to a height where it flows over the top of the main embankment. Should overtopping occur, the dam would be washed away or structurally compromised, therefore, overtopping is prevented by building a spillway, the crest of which is below the height of the top of the dam wall. Well designed and constructed spillways made more extensive and better understood climatic data unnecessary. The spillway is designed to take the maximum flow occurring during the Probable Maximum Flood (PMF) arising from the PMP over the catch-basin for the critical storm duration. Because the estimation of the PMP and the PMF are a vital part of dam design, a range of approaches have been developed (for example, see Wiesner, 1970) which do not always give the same answers. Nevertheless, there were no major dam failures in the second half of the 20th century. This is an indirect proof that the current methods of designing dams, no matter how old they are, are adequate. Although new approaches to the estimation of PMP and PMF using a storm model or radar-derived data (Austin et al, 1995) may upgrade the design standard of dams, few incentives actually exist.

Dams are stationary structures, which resists the forces of large storms passively and infrequently. In contrast, a hurricane chaser will be a moving structure that is purposely designed to stalk large storms. It will encounter large storms actively and frequently and needs to be designed with adequate safety features so that they can weather any storm conditions they will encounter. In the initial stage, however, the design paradigm for a hurricane chaser may be modeled after that of a dam with passive safety features that will protect and shut down the system in the event its design capacities are unexpectedly exceeded.

With this said, a logical beginning phase is, of course, to prove that a hurricane chaser can be a net energy harvester.

Re-Configuring a Wind Turbine for Different Wind Conditions Power generated by wind turbines is often compared with power generated by fossil-fuel plants, even though it is difficult to accurately compare the two. This is because the costs drivers of wind-power plants and fossil fuel plants are quite different. For comparison purposes, a concept termed "capacity factor" was developed. Capacity factor, simply stated, is the ratio of actual energy produced by a power plant to the energy that would be produced if it operated at rated capacity for an entire year. Capacity factors of successful wind farm operations range from 0.20 to 0.35. These can be compared with factors of more than 0.50 for fossil-fuel power plants and over 0.60 for some of the new gas turbines. Low installed-cost-per-kilowatt figures for wind turbines, however, are somewhat misleading because of the low capacity factor of wind turbines relative to coal and other fossil-fueled power plants.

The use of capacity factor is also misleading because wind has a "rubber" capacity factor that varies with the density of the wind resource. We must note that wind resource for a land-based wind turbine is constant for the life of the machine, and this resource is not subject to manipulation or cost increases. Manufacturers of land-based wind turbines, thus, optimize their machines to take advantages of local wind conditions. As a general rule, large rotor diameters paired with smaller generator can take better advantages of the wind power in most land conditions. The reason why there is more output from a relatively smaller generator in a low wind area is that the turbine will be running more hours during the year. In other words, there are economies of scale in land-based wind turbines. Larger machines are usually able to deliver electricity at a lower cost than smaller machines. The reason is that the costs of foundation, road building, electrical grid connection, plus a number of components in the turbine, such as the electronic control system, are somewhat independent of the size of the machine. The cost of foundations does not rise in proportion to the size of the machine and maintenance costs are largely independent of the size of the machine. A larger generator, of course, requires more power (i.e. strong winds) to turn at all. If a wind turbine is installed in a low wind area, it will actually maximize annual output by using a fairly small generator for a given rotor size (or a larger rotor size for a given generator). For example, the rotor diameters of a 600-kW machine may easily vary from 128 to 157 ft (39 to 48 m). The tower for such a machine can easily be 400 or 500 ft (122 to 152 m) tall. In areas where it is difficult to find sites for more than a single turbine, a large turbine with a tall tower uses the existing wind resource more efficiently. The flip side of this is that the machines will normally be located far away from population centers that consume the energy generated by the wind machines (Marsh, 2006).

Larger machines are particularly well suited for offshore wind power and it is envisioned that they will be used in hurricane chasers as well. However, these large machines must be modified so that they can generate electricity efficiently in hurricanes. The wind that a hurricane chaser will face ranges from low wind speed up to a specified design wind speed, which is 130 mph (58 m/s) for Category-3 Hurricane or 155 mph (69 m/s) for Category-4 Hurricane. In other words, the new machine to be installed on a hurricane chaser needs to have a gear-shifting mechanism that allows it to catch wind power at different, variable conditions from those faced by a land-based machine.

Defining Performance Specification and Basic Configuration of the Vessel While the wind turbine on a hurricane chaser can be re-configured from a utility-scale wind-turbine tower on land, the vessel itself has to be defined from scratch. The basic configuration and performance specification of the vessel can be developed using a set of assumed wind-tower characteristics. For example, a top wind speed of 130 mph (58 m/s), a tower that is 450 ft (137 m) tall, a rotor diameter of 130 ft (40 m), and a weight of …. With these assumed basic parameters, the task of defining the vessel's configuration will be greatly simplified.

Once a set of wind-tower characteristics is assumed, the next step is to define other parameters that are vital to the hurricane-chaser design. Estimation of these parameters is as important as the estimation of the PMP and the PMF are to the design of a dam and may include: a Design Hurricane Category and associated wind speed, wave height, hurricane-eye moving speed, pressure drop, rain intensity, the number of wind-towers, etc. A basic configuration of the hurricane chaser will hopefully emerge from an analysis of these estimations. Determination of the Design Hurricane Category must consider the balance between the historic occurrences of a hurricane in a targeted area and the capabilities of the state-of-the-art wind-power turbine. If a wind-power turbine can be modified to safely generate electricity from Category-3 hurricanes, this middle category hurricane seems to be a good starting point. Although higher category hurricanes contain more power, they also would occur less frequently.

Translating Meteorological Data into Useful Navigation Guide The primary safety feature of a hurricane chaser will be provided by always keeping it in the wakes of the hurricane. This approach seems manageable in the Atlantic Ocean as large hurricanes seem to occur sequentially or non-simultaneously within the region. However, the same can not be said of the typhoons that occur in the Pacific Ocean where two or three large hurricanes often occur simultaneously. The eye of a hurricane generally moves relatively slowly, approximately 20 mph (9 m/s), but the magnitude of the hurricane can change quickly from hour to the next. Any power increase in a hurricane will increase the speed of the wind facing a chaser that is situated in the wake of the hurricane, pushing it away from the eye of the hurricane and, thus, reducing the risk to the vessel.

An added safety feature of a hurricane chaser will be provided by a specially-designed, autonomous navigation guide. The yet-to-be-developed navigation guide will be a cyber-infrastructure that uses the real-time meteorological data, such as satellite images, hurricane wind speed predictions, etc., as the basic input and produces aids that will guide the vessel so that it can operate safely under uncertainty. The system will ensure the hurricane chaser is always positioned in optimal or appropriate operational levels during the event a hurricane takes an unexpected turn or changes in unforeseen ways. An important link between the two is an up-to-date hurricane model, which also belongs to the domain of meteorologists. Development of this cyber-infrastructure will combine advances in meteorology, engineering, and information sciences to provide unprecedented capabilities in navigation, allowing knowledge in physical, information, and human domains to be integrated.

After a path in relation to the movement of the eye of a hurricane is plotted, it will become easier for engineers to estimate the power required to navigate the hurricane chaser along that path. This will be an important step toward making the vessel a net energy harvester.

Searching for Suitable Materials Hurricane chasers are expected to be large, robust and relatively long-life structures as they need to carry tall wind-turbine towers and other heavy machineries and to operate in harsh marine environments during severe weather conditions. This requires the materials used in their construction to be strong and durable. These materials can come from conventional materials, such as steel and reinforced concrete or from more modern materials such as carbon or fiberglass, or from a combination of various materials.

No matter what kinds of materials are eventually selected, they must be modified for use in harsh marine environments. Marine environments are typically corrosive and corrosion protection techniques will be borrowed from the off-shore oil platform and ship building industries to protect the hurricane chaser vessel. Particular care will be required in selecting materials for the wind turbines as most current wind turbines are not designed to withstand harsh marine climates. The use of new or different corrosion-resistant materials in the wind turbines will need to be explored and tested.

Power Storage and Distribution Challenges One of the major challenges associated with a hurricane chaser or any other mobile power plant system is connecting the electrical power generators to an available electrical power distribution system. Stationary power plants (which include almost all current power plant technologies) are easily connected to stationary distribution systems and power lines. However, with a mobile power plant intended to move along with a storm, the storage and distribution system or at least the connection to the distribution systems must also move with the hurricane chaser. The difficulties are compounded by the fact that a tropical storm or hurricane can track for several hundred or even a thousand miles during its lifetime. In addition, the storms spend most of their existence several hundred miles from the nearest shore or land (many never even approach land).

One possible solution could include the use of a floating electrical cable that connects the hurricane chaser to some land-based or stationary connection point; something akin to a scaled up electrical extension cord. However, the practicality of dragging a several hundred mile long or longer electrical cable behind the hurricane chaser is problematic. Another more realistic solution would be to use an electrical storage device such as a rechargeable battery or fuel-cell to store the generated electrical power until the hurricane chaser could be returned to shore and discharged into the electrical grid. This approach would eliminate the need for an electrical umbilical cord to be attached to the hurricane chaser. But, in either case, additional, yet-to-be-invented technologies in electrical power distribution and storage may be required in order to overcome this electrical grid connection difficulty.

Conclusions Although hurricanes are most often viewed in a negative way, they have a silver lining as a potential alternative energy source due to their long-duration air turbulence and extreme energy in the atmosphere. However, to date not even a fraction of their energy has been successfully extracted as there have been few available means to systematically and effectively extract the enormous energy contained in a hurricane. In an effort to address this shortcoming, this paper demonstrated that existing hurricane tracking and wind-power turbine technology are now mature enough to develop a conceptual model for a wind-energy harvesting vessel called a hurricane chaser.

The hurricane chaser would be equipped with state-of-the-art wind turbines that could be navigated along the optimum hurricane routes in order to significantly increase the efficiency of the wind-power turbines and make the vessel a net energy harvester. As the system will be intentionally subjected to harsh marine environments and large storms, it will be a complex, highly engineered structure designed with passive safety features, similar in concept to a spillway on a dam, that will protect and shut down the system in the event its design capacities are unexpectedly exceeded.

In order to make the concept a reality, solutions to several challenges will need to be research and developed. First, the appropriate design storm criteria and vessel configuration will need to be determined. Next, a navigational system that incorporates real-time meteorological data as input and produces navigational aids that will guide the vessel safely in ever changing conditions will need to be developed. In addition, research into appropriate materials for the vessel and turbines that can withstand the harsh marine environment and severe storms will be required. Finally, research and development of power distribution and storage technologies will be required in order to successfully connect the hurricane chaser to the electrical power grid.

Development of the hurricane chaser will require combined contributions from the fields of meteorology, engineering, information science, material science, and others. However, if successful, the hurricane chaser has the potential to become a major supplier of alternative energy to the world's energy markets.

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