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# HDIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

# Small-Scale and Low-Profile Wind Turbines for Power Generation in an Urban Environment

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**14. ABSTRACT** The Homeland Defense and Security Information Analysis Center was asked to provide information on recent and ongoing efforts to field small-scale wind-power designs generating ≤100 kW to serve standalone electrical loads not connected to a utility distribution system or local microgrid. Sources include work from U.S. Department of Defense entities, academic scholars, and industrial/commercial products or research. Additional parameters for the inquiry include a focus on: (1) use cases in urban or urban-like environments, (2) designs with minimal profiles and space requirements (i.e., bladeless or with small blades), and (3) the ability to interface with a controllable (or "smart") grid. A short digest of key articles on small-scale wind applications is also requested. To achieve this, HDIAC researched this topic and generated a report on the findings for the various research or technologies in this area. HDIAC identified a number of recently fielded (or soon-to-prototype) designs that are relevant to the requestor's parameters, including enclosed- or confined-blade turbines, bladeless or motionless turbines, and airborne or suspended wind-capture systems.

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## TI Research

A chief service of the DoDIAC is free technical inquiry (TI) research limited to four research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. Given the limited duration of the research effort, this report is not intended to be a deep, comprehensive analysis but rather a curated compilation of relevant information to give the reader/inquirer a "head start" or direction for continued research.

# Abstract

The Homeland Defense and Security Information Analysis Center was asked to provide information on recent and ongoing efforts to field small-scale wind-power designs generating ≤100 kW to serve standalone electrical loads not connected to a utility distribution system or local microgrid. Sources include work from U.S. Department of Defense entities, academic scholars, and industrial/commercial products or research. Additional parameters for the inquiry include a focus on: (1) use cases in urban or urban-like environments, (2) designs with minimal profiles and space requirements (i.e., bladeless or with small blades), and (3) the ability to interface with a controllable (or "smart") grid. A short digest of key articles on small-scale wind applications is also requested. To achieve this, HDIAC researched this topic and generated a report on the findings for the various research or technologies in this area. HDIAC identified a number of recently fielded (or soon to prototype) designs that are relevant to the requestor's parameters, including enclosed- or confined-blade turbines, bladeless or motionless turbines, and airborne or suspended wind-capture systems.

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# 1.0 TI Request

## 1.1 Inquiry

Who is conducting research and development (R&D) on small wind-energy generation?

## 1.2 Description

The Homeland Defense & Security Information Analysis Center (HDIAC) staff was asked to provide information on recent and ongoing efforts to field small-scale wind-power generation systems that can serve standalone electrical loads not connected to a utility distribution system or local microgrid.

# 2.0 TI Response

KeyLogic and HDIAC reviewed reports from the U.S. Department of Energy (DOE), independent third-party standards groups (e.g., the Small Wind Certification Council), peer-reviewed academic journals, and energy-focused online news aggregators. HDIAC also searched the Defense Technical Information Center Research and Engineering Gateway for relevant publications from the past 3 years.

## 2.1 Background

Since the 1980s, an overwhelming majority of research efforts and commercial spending on wind-turbine technology have been directed at large, utility-scale, three-bladed, horizontal-axis wind turbines (HAWTs) perched atop very tall turbine towers. Because HAWT generation and cost efficiencies generally scale upward with size, these systems have increased dramatically in scale and power over the past 3 decades. The average "hub height" of new land-based U.S. turbines was roughly 340 ft above the ground in 2023—an 80% increase since 2000 [1]. The average land-based HAWT is rated at 3.4 MW, and offshore models outside of the United States are soon to exceed 18 MW in nameplate capacity [2]. In addition to the cost efficiencies gained from scaling, turbines have grown in size and height because air currents are strongest between 300 and 400 ft [3].

As a result of the conventional HAWT design's dominance, R&D interest in developing novel designs for small-scale wind turbines (SWTs) has lagged at the utility scale. Systems for small-scale wind generation are hampered by high production costs; a high levelized cost of electricity (LCOE) for their owners; and, until recently, a lack of demand, absent state-sponsored financial incentives [4]. (Note that DOE defines "small" wind turbines as having a nameplate capacity ≥100 kW and "micro" turbines as between 20 and 100 W. A technical standard set by the American Clean Power Association in 2021 sets the threshold for small systems at 150 kW and microsystems at 1 kW [4].) Driven by public interest in decarbonization goals, the desire to attain energy self-sufficiency, and a rapid decline in the cost of power electronic inverters, the market for SWTs has seen several years of steady growth in the United States. (Note that inverters transform a wind turbine's direct current power into alternating current [AC] power, which most U.S. consumer devices use.) By the DOE's count, more than 2.3 MW of SWT capacity were added during 2022, representing 1,745 turbines. As only project-based additions are able to be tracked by the DOE, this is certainly an undercount [5].

Like utility-scale systems, the majority of SWTs are traditional HAWTs. They are typically tower- or pole-based; sport three or four blades; and are composed of a rotor, generator/alternator, and tail. Horizontal-axis SWTs are widely used at agricultural sites, homes, remote industries (i.e., telecommunications stations), and offshore facilities. Representative models available on the open market range from capacities of 160 W (with a hub height of 9 ft; rotor diameter of 46 in) to 50 kW (hub height of 100 ft; rotor diameter of 63 ft) [6].

Recent R&D conducted by the DOE's Wind Energy Technologies Office produced performance specifications for a SWT system that is rapidly deployable to disaster response or military sites. Designed to fit within a 20-ft shipping container (i.e., half the size of standard intermodal containers), the system uses traditional three-bladed HAWT technology and has a total height of 65 ft (top-of-blade height) [7].

While horizontal-axis systems dominate the SWT market, R&D interest in vertical-axis wind turbines (VAWTs) has seen substantial growth in recent years. Of the nine SWT models certified by the International Code Council's Small Wind Certification Council (as of 2023), all but one are HAWT designs [5]. The VAWT model is equipped with both Savonius (drag type) and Darrieus (lift type) vertical blades; at a nominal capacity of 3 kW, its ground footprint has a 12-ft diameter (see Figure 1) [8]. Because VAWTs do not have to be positioned into the wind, production can be cheaper than a comparable HAWT model. On the other hand, vertical-axis models to date generate power at lower efficiency and/or capacity factors [6].

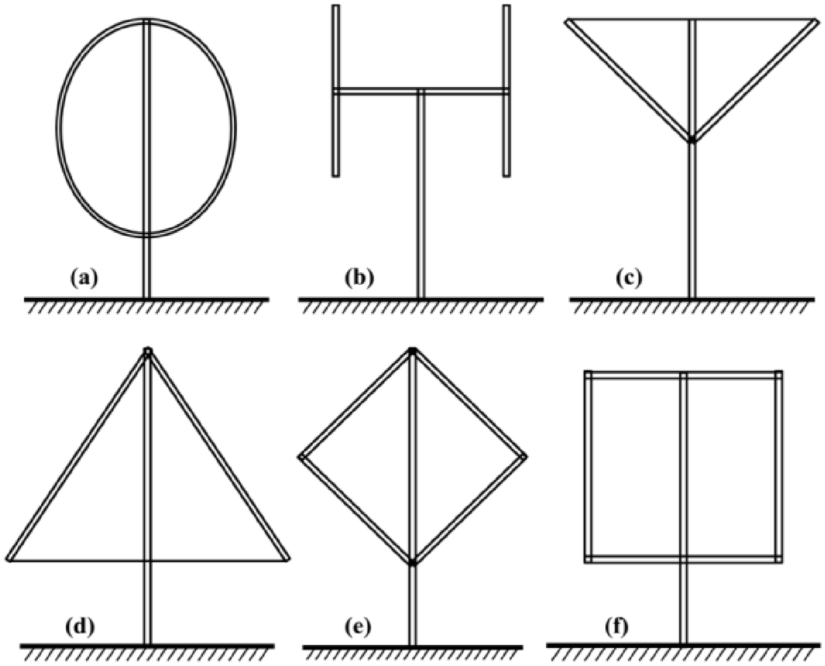


**Figure 1. Basic VAWT Configurations: (a) Full Darrieus, (b) H, (c) V, (d) Δ, (e) Diamond, and (f) Giromill [9].**

However, VAWTs are preferred for harnessing wind power in both urban and semi-urban environments, as they are better suited to an environment in which building placement results in higher turbulence (VAWTs have no yawing action), higher variable wind gusts, and lower annual mean wind speed [7, 10]. VWATs are also generally easier to maintain, as the gearbox/generator is located on the ground [11]. Savonius-type VAWT models may be most suited to DoD applications among the two. Compared to Darrieus-type models, a Savonius turbine will have a smaller ground footprint and a smaller visual signature (in absolute terms, as well as regarding blade flicker) and provide lower cost and more reliable power production, although at a lower-power coefficient [10, 12, 13]. However, in real-world trials of SWTs models (both vertical and horizontal axis) in an urban environment, researchers from the National Renewable Energy Laboratory found that actual production substantially lagged the predicted energy output [14].

Recent R&D efforts have focused on optimizing blade materials and design geometries to maximize generation rates; the addition of “augmentations” like deflector plates, nozzles, ducts, and blade curtains may also show promise to improve performance [11].

## 2.2 Emergent/Unconventional SWT Concepts

Pursuant to the TI request, the following section details three leading unconventional concepts for small-scale wind-power generation, with partiality toward bladeless or blade-confined designs.

### 2.2.1 Enclosed- or Confined-Blade Designs

Multiple types of design concepts place a housing around the turbine's rotating blades (for both horizontal and vertical axes), to boost ruggedness and/or power generation. When used in conjunction with an HAWT SWT, "guide baffles" help focus wind energy toward the blades. A similar concept is seen in CBC Wind Energy's "Hidden in Plain Sight" (HIPS) series of VAWTs. CBC's concept encloses a Savonius turbine inside a stationary enclosure that "intercepts and concentrates" wind gusts onto a high-performance rotor. As the inner portion of the enclosures can dynamically pivot, airflow is optimized, allowing for sustained rotation in a multitude of wind environments. The low profile and generic outer shape of the HIPS system allows it to blend into local infrastructures as much as possible; CBC factsheets cite a deployment time of "less than 1 hr by two people" [15].

CBC has been a previous recipient of U.S. Department of the Air Force R&D funds, routed through the Air Force Research Laboratory and AFWERX. CBC delivered its first HIPS unit to a U.S. military client in August 2024 [16].

### 2.2.2 Bladeless or Motionless Turbines

Aeromine Technologies has produced a series of "motionless" SWTs that capture wind energy by generating a low-pressure area between vertically mounted airfoils within the turbine housing, typically located on a roof. The low-pressure area accelerates air through the bottom of the unit and past a power-generation propeller. Each unit is rated at 5 kW, with Aeromine envisioning multiple units being used in a series [17]. The SWT design was validated by Sandia National Laboratories in partnership with Texas Tech University; an initial prototype was installed on a roof in Oxford (UK) in May 2024 [18, 19].

Vortex Bladeless, a Spanish start-up firm, is in the process of developing a truly "bladeless" SWT design. Its "vortex" device is a freestanding tower, subdivided into a fixed base and a longer "mast" portion that, while anchored below and jointed by a carbon rod, oscillates freely in a direction perpendicular to airflow [20]. Wind-induced movement is translated into electrical power via electromagnetic induction, obviating the need for rotating parts and a gearbox [21].

While the firm has not released capacity estimates for its prototypes, one member estimated in 2022 that a 9-ft tower could power a refrigerator, multiple telephones, and lights within an off-grid house [22]. While unproven over time, this bladeless design shows promise for delivering electrical power in a mostly sustained fashion, while displaying excellent material longevity and a relative lack of required maintenance.

### 2.2.3 Airborne or Suspended Systems

Typically referred to as airborne wind energy (AWE), these concepts range in design from balloon-based, kite- or sail-powered, to captive hard-winged drones equipped with multiple small HAWTs [23]. Designs vary as to electrical conversion and, especially, deployment altitudes. R&D efforts have been made to use a balloon to simply suspend an enclosed HAWT microturbine between 1,600 and 4,000 ft to exploit higher wind speeds [24] and to deploying a massive kite-resembling sail to 1,300 ft. Note that these systems entail a large visual signature; an AWE system at an altitude of ~350 ft can be visible up to 1.2 mi away during daylight and clear conditions [3].

SkySails Power (Germany) and Kitepower (Netherlands) have both demonstrated workable sail-based AWE systems. Kitepower's "Falcon" model has not yet made market entry, but envisions a nameplate capacity of 100 kW for a system comprising a ground station, tether, kite control unit, and kite [25]. Both system types harvest mechanical power from the constraint imposed by the tether and the large aerodynamic forces that sails and balloons are exposed to via crosswind motion [26]. While rigid aircraft-based systems pose additional challenges of nonautonomous control, the presence of onboard power allows for more predictable generation, as well as maintenance needs. In 2023, the Naval Research Laboratory funded a North Carolina-based firm, Windlift, to advance its prototype drone-based, but autonomous, turbine systems designed for flight at 200 ft [27].

## 2.3 Other Considerations

Sources reviewed indicated that connecting an SWT to a utility grid, "smart" grid system, microgrid, or other AC-based networks is unlikely to be problematic and is a well-understood task [28]. However, multiple DOE efforts are building and testing inverter designs and configurations made specifically for SWTs [29, 30].

## 2.4 Relevant Articles/Studies

A few relevant articles/studies on the R&D of small wind-energy generation are:

- “Deployable Wind Power for Defense and Disaster Response: Workshop Summary” by Houchens et al. [31]
- “An Analytical Review on the Evaluation of Wind Resource and Wind Turbine for Urban Application: Prospect and Challenge” by Tasneem et al. [12]
- “State-of-the-Art Review of Micro to Small-Scale Wind Energy Harvesting Technologies for Building Integration” by Calautit and Johnstone [11]
- “A Critical Review of Vertical Axis Wind Turbines for Urban Applications” by Kumar et al. [10]
- “CFD Assessment of Wind Energy Potential for Generic High-Rise Buildings in Close Proximity: Impact of Building Arrangement and Height” by Juan et al. [32]
- “Urban Wind Conditions and Small Wind Turbines in the Built Environment: A Review” by Anup et al. [33]
- “Deployment of Wind Turbines in the Built Environment: Risks, Lessons, and Recommended Practices” by Fields et al. [14]

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## Biography

Joel Hewett is an energy policy and national defense researcher, writer, and analyst for KeyLogic, where he applies more than 15 years of experience in assessing the utility of advancements in science and technology for furthering national aims. In his role, he supports multiple federal agencies in studies addressing energy systems and critical infrastructure protection issues. He is the author of “Resilience by Design: Microgrid Solutions for Installation Energy,” a state-of-the-art report published by the Homeland Defense & Security Information Analysis Center. Mr. Hewett holds an M.S. from the Georgia Institute of Technology in the history and sociology of technology and science, where he was the inaugural Melvin Kranzberg graduate fellow, and he earned an A.B. in literature from Davidson College, where he was a John Montgomery Belk scholar.