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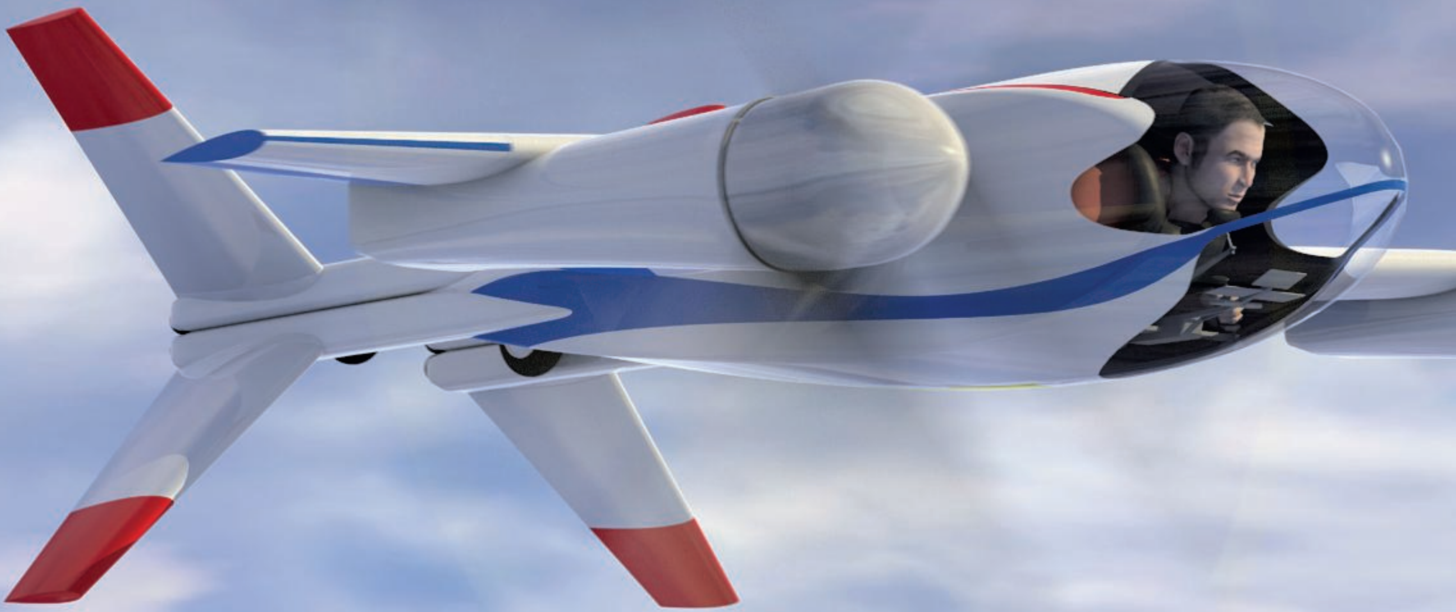


21st Century Technology Propels Electric Aircraft into the "Blue Yonder"

THE MANNED ELECTRIC AIRCRAFT INDUSTRY HAS EMERGED BY EMPLOYING HIGH-PERFORMANCE BATTERIES, FUEL CELLS, AND SOLAR PANELS, AS WELL AS USING EFFICIENT MOTORS AND LIGHT WEIGHT COMPOSITE MATERIALS FOR THE FUSELAGE.

FOR SEVERAL YEARS, all-electric power assisted gliders and hang gliders have been available. Advantages of electric aircraft include improved maneuverability due to the greater torque from electric motors, increased safety due to decreased chance of mechanical failure, less risk of explosion or fire in the event of a collision, and less noise. There will be environmental and cost benefits associated with the elimination of consumption of fossil fuels and resultant emissions.

Electric aircraft are available from several sources worldwide, as shown in *Table 1*. As with on-road vehicles, the major problem with electric aircraft is range - the best of both being 160 to 400 km (about 100 to 250 miles) in a practical manned configuration. Following are descriptions of these aircraft.

The battery and solar-panel powered Elektra One (*Fig. 1*.) is built of lightweight fiber composite structures. Maximum power is 16-20 kW, and range is more than 400 km (249 miles) with a flight time of up to more than 3 hours. Its wingspan is 8.6m, and it can carry up to a 90kg payload.

Cri-Cri (*Fig. 2*) uses composite materials instead of metal to reduce overall weight and make room for the high-energy-density lithium batteries that provide power to four brushless electric motors - two mounted back-to-back on nose pods on each side - with counter-rotating propellers. Projected performance is 30 minutes of cruise flight

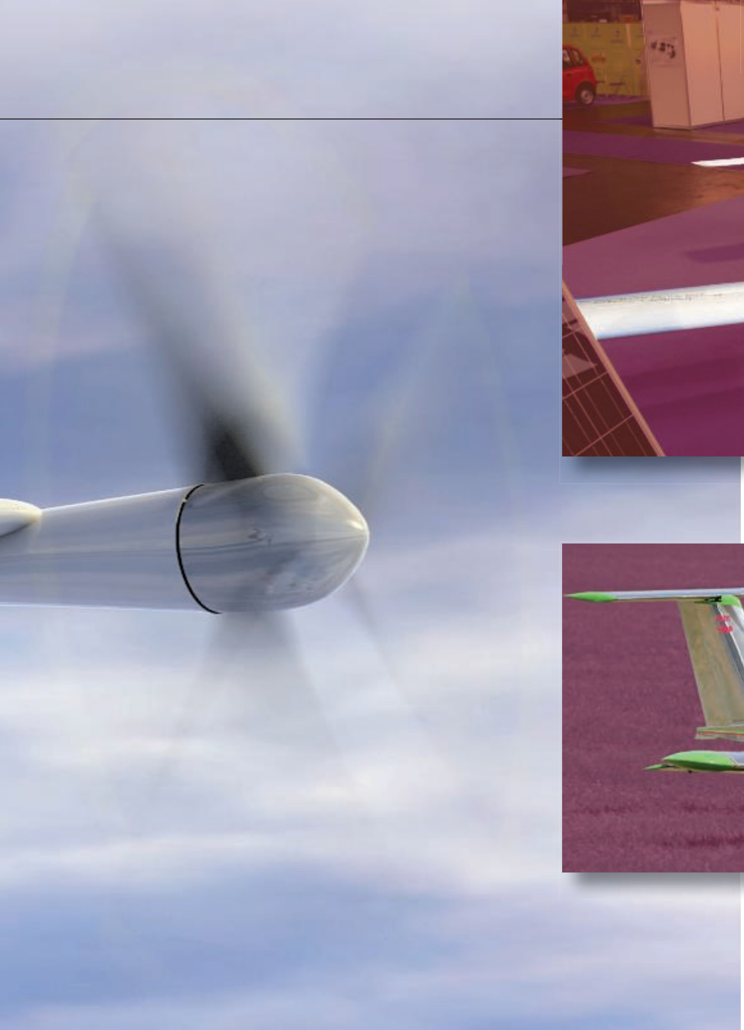


Fig. 1. Elektra One has a maximum power is 16-20 kW, and range is more than 400 km (249 miles) with a flight time of up to more than 3 hours.

Fig. 2. Cri-Cri uses composite materials instead of metal to reduce overall weight and make room for the high-energy-density lithium batteries that provide power to four brushless electric motors - two mounted back-to-back on nose pods on each side - with counter-rotating propellers.

TABLE 1. CURRENT ELECTRIC AIRCRAFT

AIRCRAFT	MANUFACTURER	COUNTRY
Elektra One	PC-Aero	Germany
Cri-Cri	EADS	France
E430	Yuneec	China (U.K.)
Sonex	Sonex Aircraft & AeroConversions	USA
Puffin	NASA	USA
Skyhawk 172	Cessna & Bye Energy	USA
Firefly	Sikorsky	USA
SkySpark	Multiple Sponsors	Italy
Fuel Cell Demo	Boeing	USA
Rapid 200-FC	ENFICA-FC	Italy & U.K.
Solar Impulse	Ecole Polytechnique Federale de Lusanne	Switzerland

at 110 km/h (68 mph); 15 minutes of full aerobatics at up to 250 km/h (155 mph); and a climb rate of approximately 5.3 m/sec (1,020 fpm.

Yuneec's E430 (*Fig. 3*) is a two seat, V tailed, composite aircraft with a high-aspect ratio wing. Take-off speed is 40 mph, cruise speed is 60 mph, and max speed is 95 mph. The company claims that the battery packs have an expected lifespan of 1500 hours and cost $7000 each, with the aircraft carrying 3-5 battery packs, giving two to two and half hours endurance. The batteries can be recharged in 3-4 hours from a 220V outlet.

Sonex Aircraft, LLC makes Sonex and Xenos models that it sells to the kit aircraft market for use with traditional internal combustion aircraft engines. The Research and Development arm of Sonex Aircraft, LLC has developed an electric propulsion system called E-Flight. A block diagram of the E-Flight system is shown in *Fig. 4a*. Here, Sonex's emphasis is on motor and controller development to provide an efficient and reliable power system

The E-Flight prototype system has been installed and flown in the company's Waiex sport aircraft (*Fig. 4b*). Initial top speeds will reach approximately 130 mph, and endurance is expected to range between 25-45 minutes or longer, depending upon power usage on each individual flight.

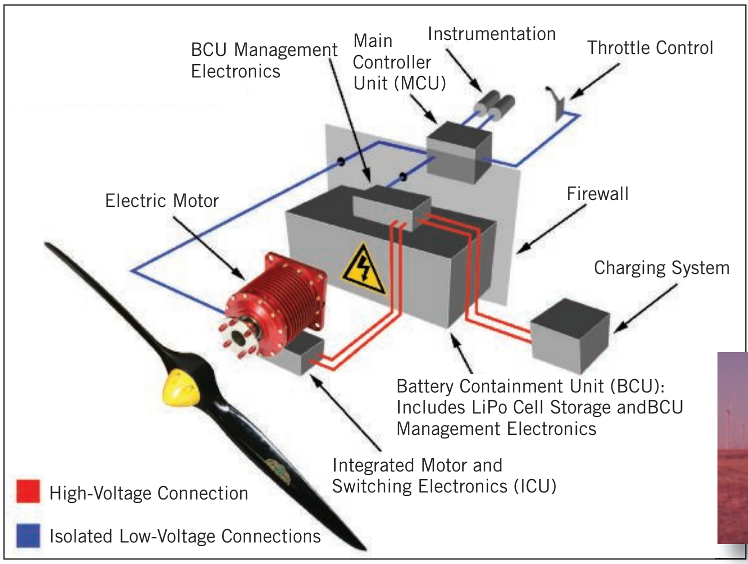
All the E-Flight system components were produced by Sonex from scratch as new technology. When it set-out to first develop and fly an electric aircraft, it quickly found out that suitable technology did not exist at the time, certainly not at acceptable cost, so the company had to focus on developing its own proprietary equipment. As a result, Sonex recently won the Lindbergh LEAP prize for Best Electric Aircraft Sub-System or Component Technology.

The Puffin is a vertical-takeoff and landing aircraft, taking off like a helicopter and flying like a plane. Just 60 horsepower gets pilot and craft airborne. It is 12-feet high with a 13.5-feet wingspan and its rotors are nearly 7.5 feet in diameter. Rather than tilting the rotors forward for horizontal flight, the whole craft, cockpit and all, pitches forward,

Fig. 3. The E430 uses three lithium polymer battery packs that allow it to fly for two hours in an "optimum cruise" with two people on board.

so the pilot flies from a prone position. During takeoff and landing, the tail splits into four legs that serve as landing gear, and flaps on the wings deploy to keep the aircraft stable as it lifts and descends. It can cruise at 150 miles per hour and sprint at more like 300 miles per hour. Its range is 50 miles, which is related to its battery density. Using carbon composite construction, the Puffin weighs less than 400 pounds including the lithium phosphate batteries. *Fig. 5a* shows the Puffin parked in its vertical position and *Fig. 5b* shows the Puffin in flight.

The original Cessna 172 Skyhawk has been the quintessential lightweight aircraft, a four-seat, single engine aircraft first built in 1956. For the new version, Cessna will insert an electric propulsion system where there now is a gas powered one (*Fig. 6*). They've joined with Bye Energy, Inc., a company that specializes in all-electric planes, to build an engine for their proof-of-concept 172 Skyhawk. The company expects to take off in their first electric model this year. The companies hope their joint venture will result in a quick and easy transition to electric propulsion.



ELECTRIC HELICOPTER

Sikorsky Innovations, the technology development organization of Sikorsky Aircraft, has officially introduced "Project Firefly," an all-electric helicopter technology demonstrator.

Chris Van Buiten, Director of Sikorsky Innovations, says, "Our objectives with Project Firefly are to provide a proof of principle concept to validate the benefits of an electrically powered rotorcraft; to develop the technologies to enable the manned flight of that technology, and to drive future development of improved, state-of-the-art 'green' technologies and practices."

In building the demonstrator (*Fig. 7*), the Innovations team replaced the legacy propulsion system of an S-300C helicopter with a high-efficiency, 142 kW (191 horsepower) electric motor and digital controller from U.S. Hybrid, coupled with a lithium ion energy storage system from GAIA. The two GAIA 135 Ah lithium polymer hold it aloft for 15 minutes. Most other electric aircraft also employ lithium polymer traction batteries of one chemistry or another because of safety and light weight, with no heavy metal casings. GAIA uses lithium iron phosphate and lithium nickel cobalt aluminum in the cathodes of its traction batteries.

Integrated sensors provide real-time aircraft health information to the helicopter pilot through a panel integrated interactive LCD monitor. Eagle Aviation Technologies, LLC, executed the custom airframe modifications and assembly of the demonstrator aircraft.

"Many of the most significant advancements in aviation have been enabled by transformations in propulsion technology. It is exciting to be at the forefront of the exploration of electric propulsion technology for rotorcraft," said Mark Miller, Vice President, Sikorsky Research & Engineering. "Through the electrical conversion, propulsion efficiency of the aircraft has been increased roughly 300 percent from baseline. Electric propulsion also inherently simplifies the complexity of the propulsion system by reducing the quantity of moving parts, increasing reliability while reducing direct operating costs."

Fig. 4a (left). The E-Flight system employs an AeroConversions brushless DC cobalt motor and controller along with a highly efficient battery and charging system.

Fig. 4b (below). The Waiex aircraft currently uses a Lithium Polymer battery that allows adequate power to fly typical light sport aircraft designs.

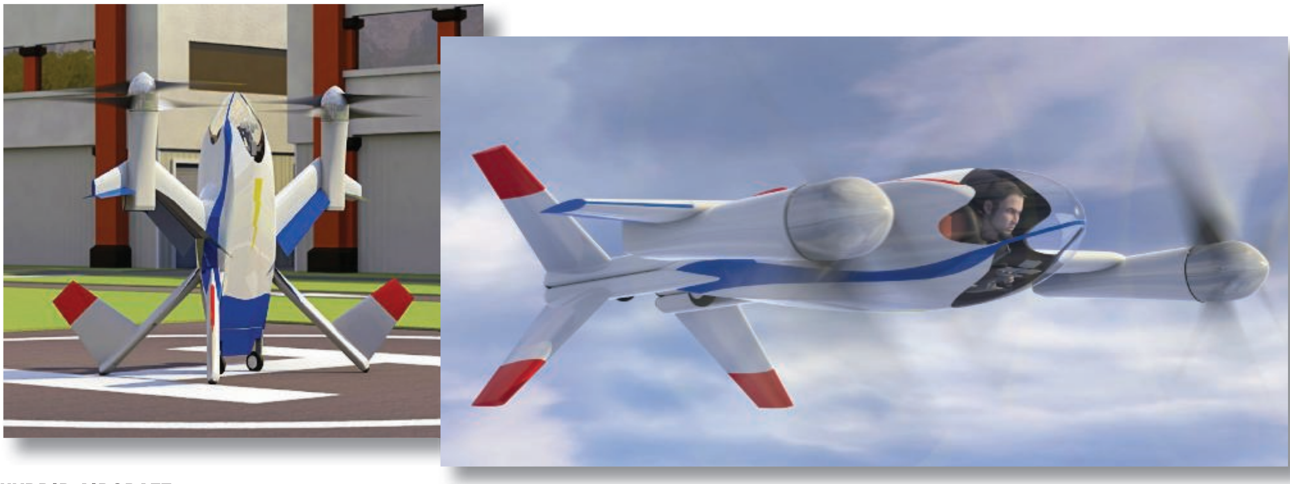


Fig. 5. The Puffin is a conceptual design developed by NASA Langley. Designed to take off and land vertically like a helicopter and fly like a plane, the craft has carbon composite construction and weighs less than 400 pounds, including the lithium phosphate batteries. The craft in shown in an artist's rendering parked in its vertical position (left) and in flight showing the pilot in the prone position (above).

HYBRID AIRCRAFT

Meanwhile, in Europe, EADS is developing a hybrid helicopter concept that uses two diesel and two lithium-ion battery packs to power electric motors on the main and tail rotors. EADS showcased this diesel-electric hybrid helicopter concept at the 2010 ILA Berlin Airshow at Berlin-Schönefeld Airport in Germany in mid 2010 and an all-electric stunt plane. It argues that fuel consumption and emissions can be considerably reduced by the hybrid propulsion technology.

In July this year, there was a symposium on these "More Electric" aircraft. Prof. Alberto Tenconi of the University of Turin is behind the Italian electric aircraft program and he has his sights on electric feeder aircraft for passenger routes. On the other hand, in the UK, Falx Air Vehicles is planning to push fuel economy further by using a hybrid-electric motor and inbuilt solar arrays in tilt rotor aircraft. The company expects its upcoming compact single and double-seater tiltrotor aircraft to use only 10 liters of fuel per hour airborne, and the quiet electric operation should see these small, light and maneuverable aircraft also act as good military stealth vehicles.

FUEL CELL AIRCRAFT

171 years ago, the fuel cell was invented in the UK, where Intelligent Energy now has its fuel cells powering experimental aircraft. As in on-road vehicles, fuel cells in aircraft are used rather like hybrids, with a sophisticated battery to manage load variations and regenerative charging. The leading aircraft manufacturers Boeing and Airbus, a subsidiary of EADS, are interested in the possibility of large passenger aircraft taking off and landing in almost total silence by using all electric mode, possibly with fuel cells involved.

The SkySpark team in Italy now plans to focus on an engine powered by hydrogen fuel cells, something used by AeroVironment in huge fixed wing unmanned surveillance aircraft that cruise the upper atmosphere. Some of the fixed

Fig. 6. Cessna will insert an electric propulsion system where there is a gas powered one in the present Skyhawk. The company expects to take off in their first electric model this year.

Fig. 7. Sikorsky's Project Firefly will include a 190 hp (142 kW) motor specifically tailored for use in rotorcraft. The battery pack consists of 300 cells, with an energy density of 0.13 kW per kilogram.

Fig. 8. SkySpark uses a hydrogen fuel cell capable of providing 65kW to power this aircraft along with a lithium polymer battery.

wing pure electric aircraft and other electric flying vehicles are now available in kit form. The SkySpark (*Fig. 8*) is a pure electric fixed wing aircraft that has reached 155 mph (300 kph) though 100 mph is more typical of such aircraft, and they have flight time of 1 to 3 hours. The SkySpark experiment is based on a two-seat Pioneer Alpi 300 powered by a 75 kW (100.5 horsepower for the nostalgic) electric motor using brushless technology and lithium polymer batteries. Supporting its development were Digisky, an Italian start-up company specializing in R&D innovative technology for aeronautical applications, and the Turin Polytechnic University.

In March 2008, Boeing Research and Technology Europe flew a fuel cell-powered modified Dimona motor-glider for 20min at its Spanish test site. Fuel Cell Demonstrator (*Fig. 9*) achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

A fuel cell is an electrochemical device that converts hydrogen directly into electricity and heat without combustion. Fuel cells are emission-free and quieter than hydrocarbon fuel-powered engines. They save fuel and are

Fig. 9. Boeing Research and Technology Europe flew a fuel cell-powered modified Dimona motor-glider for 20min at its Spanish test site. achieved straight-level flight.

cleaner for the environment. The Boeing demonstrator uses a Proton Exchange Membrane (PEM) fuel cell/lithium-ion battery hybrid system to power an electric motor, which is coupled to a conventional propeller. The fuel cell provides all power for the cruise phase of flight. During takeoff and climb, the flight segment that requires the most power, the system draws on lightweight lithium-ion batteries. The US company ended the project after that flight and would only say that the fuel cell technology would be used for other unidentified projects.

The ENFICA-FC project was intended to demonstrate the viability of manned flight in an electric aircraft that uses fuel cells as a main power supply. It is an ultra-light aircraft based on a zero-emission propulsion system (*Fig. 10*). Designated Rapid 200-FC, the aircraft completed its maiden flight on 20 May 2010. The aircraft has an entirely electric 40 kW propeller. Power is supplied to the propeller through

Fig. 10. Designated Rapid 200-FC, this electric aircraft was powered by an electric hybrid system consisting of a 20KW PEM fuel cell and a 20kW Li-Po battery.

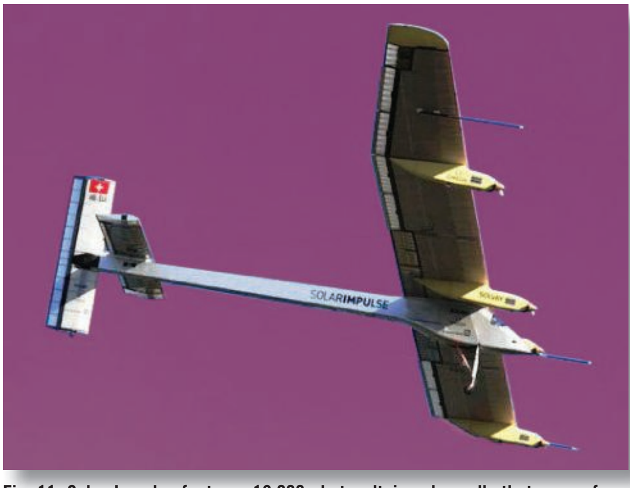


Fig. 11. Solar Impulse features 12,000 photovoltaic solar cells that power four electric motors. Under the wing are four nacelles, each having a set of lithium polymer batteries, 10 hp (7.5 kW) motor and twin-bladed propeller.

20 kW hydrogen fuel cells; gaseous hydrogen is stored at 350 bar onboard. A second source of energy consists of a set of 20 kW lithium polymer batteries that guarantee alternative or supplementary power during take off and initial climbing. The Rapid 200-FC's PEM fuel cell delivers 100-110 A at 200-240 V, plus air and water vapor emitted at environmental temperature.

This aircraft attained level flight at 700 ft and 130 kph on a partial fuel cell power setting. Further flights of the aircraft helped it establish a speed record of 135 kph for electrically powered class C aircrafts. The aircraft did show positive handling qualities and satisfactory engine performance. The plane also broke the endurance record of 45 minutes.

SOLAR AIRCRAFT

Solar Impulse (*Fig. 11*) aims to demonstrate the viability of renewable energy sources by being the first to perform a manned flight around the globe using only solar power. It has a 200-foot wingspan and features 12,000 photovoltaic solar cells bringing power to four electric motors. Under the wing are four nacelles, each with a set of lithium polymer batteries, a 10 hp (7.5 kW) motor, and a twin-bladed propeller. To keep the wing as light as possible, a customized carbon fiber honeycomb sandwich structure is used. The major design constraint of the project is the capacity of the lithium polymer batteries. Over 24 hours, in the best conditions, the power train will deliver an average of 8 hp (6 kW), roughly the power used by the Wright brothers' Flyer in 1903. As well as charge stored in the batteries, the aircraft uses the potential energy of height gained during the day for night flight. This aircraft first flew an entire diurnal solar cycle, including nearly 9 hours of night flying, in a 26-hour flight on 7-8 July 2010. Building on the experience of this prototype, a slightly larger follow-on design (HB-SIB) is planned to make circumnavigation of the globe in 20ñ25 days.

WHAT NEXT?

Certainly, the electrification of aircraft is intimately related to the electrification of land and water vehicles. They use the same or similar batteries, battery management systems and motors. Removing weight is an almost universal objective. Of interest are printed electronics and electrics from companies such as T-Ink, wireless sensors and actuators and energy harvesting as developed by the Center for Energy Harvesting Materials and Systems (CEHMS) at Virginia Tech and photovoltaic energy boosting as analyzed by IDTechEx, preferably in transparent form over the whole vehicle.

Regenerative braking in an aircraft sounds fanciful but recent studies indicate that a regenerative soaring feature is possible, whereby the propeller can be used as a turbine to recharge stored energy when the aircraft encounters an updraft. This is similar to the way the new hybrid electric motor-sailing boats will regenerate next year using their propulsion screws. An aircraft using regenerative soaring can potentially remain aloft indefinitely at high altitudes where the energy available from vertical atmospheric motion can exceed available solar power by a factor of ten or more. And remember that the pure electric Deepflight submarines of Hawkes Ocean Technologies act as aircraft underwater and have similar opportunities.

These and other electric vehicles will be shown at the IDTechEx Future of Electric Vehicles USA 2010 conference and exhibition in December (*see sidebar on page 20*).

The key to future success of electrical aircraft is the battery technology. In order for electric-powered aircraft to be successful on any scale, they will require the development of battery systems that provide increased storage density and usable life expectancy while reducing recharge time. Such battery systems could be initially expensive but come down in price as production economies of scale ramp up.

As with motor vehicles, the possibility of high-energy storage density (per unit volume and per unit mass) battery technologies will definitely enhance their use in small aircraft.