The Case for 50% efficient solar cells…

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Good afternoon.

Today, I am going to talk to you about solar powered aircraft. What value are they, and what is the key technology hurdle to making them ubiquitous, surrogate satellites — a 50% efficient solar cell at reasonable cost.

First, some background.

More than one third of the world's population (more than two billion people) live a subsistence lifestyle today without access to any electricity. Further, another two billion people in the world exist on less than 100 watts of electricity per capita. By comparison, the large economies of Japan and France use more than 800 watts of electricity per capita, and the United States uses nearly 1500 watts of electricity per capita.

Several forecasts of electrical generation growth have concluded that world electricity demand will roughly double in the next 20-25 years, and possibly triple by 2050. This electrical generation growth will occur primarily in the rapidly developing and growing economies in Asia and in Latin America..

In 2000, world electrical generation is composed of the following:

Coal: 36.5%
Natural Gas: 16.7%
Oil: 9.5%
Hydroelectric: 21.3%
Nuclear: 16.0%

Generating one million kWhr of electricity produces about 150 tons of carbon from a natural gas-fired plant, 265 tons of carbon from a coal-fired plant, but essentially none from a nuclear or hydroelectric plant.
{James A. Lake, PhD President American Nuclear Society}

World demand for oil was 75 mbpd for 1999, and is projected to average 76 mbpd for 2000. There has been no increase in reserves from 1999 to 2000, . 2001 is projected to have world demand exceed production by its 4th quarter, by amount that exceeds reserve production capacity, and with little promise of increasing capacity at the rate demand will increase in the future.

Costs, political, and environmental issues limit the growth of either nuclear or hydroelectric power plants. Natural gas, like oil, is in an equilibrium of supply and demand, and will probably begin to drop in production rates over the next few years.

{According to Norwegian Energy Ltd.,}

Coal will likely fill the energy shortfall for developing, and developed nations, lacking an overt effort to provide alternative sources. A shift to coal, along with the increase in demand for energy, will accelerate the world's production of carbon-based, "greenhouse" gases and aerosols over the next century.

Each day more solar energy falls to the Earth than the total amount of energy the planet's 6.1 billion inhabitants would consume in 27 years.

{National Renewable Energy Laboratory}

While you think about that stuff, I'd like to show you a short news clip about a solar airplane that was developed by NASA and their ERAST Alliance, to familiarize you with the concept.

(show video of ABC news – 2.5 minutes)

Let me expound on what a Solar Powered Aircraft could do.

Imagine an aircraft being launched from New Mexico in late spring, flying across the Gulf of Mexico, the Caribbean, and the Atlantic to the West Coast of Africa. There it loiters in the stratosphere, monitoring storms that move across Africa, checking for the development of a rotational flow, which signifies a HURRICANE.

For five months, on into October, it waits and watches. When a hurricane is detected, the aircraft then tracks above it, dropping sensors to measure barometric pressure, winds, and ocean temperatures; measuring directly temperature and humidity of effluents, and accurately determining the true eye weeks before it is visible to satellites. Its information is relayed by satellite back to weather trackers in the US. Using this improved accuracy of data and location, the NOAA forecasters enhance their models and reduce the error of the prediction of storm path by 50 to 75%. What value could this be?

Imagine an aircraft that could continuously circumnavigate the globe in the tropics… or else hold a single station… for months at a time, looking at the interface between the troposphere and stratosphere. An airplane that flies so slowly and whose performance is so predictable that it can detect vertical air movements on the order of a centimeter per second. This aircraft could allow researchers to more accurately model the transfer of aerosols and gases from one layer of the atmosphere to the other, and better predict our influence on such things as the ozone layer. What value could this be?

Imagine an aircraft that could act as a 12-mile high tower, providing wireless communication service almost instantaneously to the developing countries of the tropics. Linking the thousands of islands of the Southern Pacific, linking urban, farming, and mining communities across Africa and South America… providing the communication links critical to the development of these nations with almost no current infrastructure. What value could this be?

Imagine an aircraft that flies over the storm-prone countries of the tropics, providing status on countries before and after disasters, determining if a disaster has occurred, locating isolated refugees, assisting relief planners in rapidly providing aid… providing emergency communications. What value could this be?

Imagine an aircraft that could fly science instruments reliably to 100,000 feet, or even 150,000 feet, and then return them safely to the launch point. Flying subsonically, so as not to destroy the chemistry of the samples, higher than any other aircraft has flown. What value could this be?

Imagine all these potential missions by an aircraft that consumes no fuels, no oxygen, and creates no pollution whatsoever, using only the “power in its shadow”. An airplane with no pilot. An airplane that lands slower than a bicycle. A large, friendly giant that is little more threatening to a commercial aircraft than a cloud. This is a solar powered aircraft.

{Skip?}

Let me give you a brief Technology Primer (alternatively give cost comparisons)

To fly for extreme duration requires the highest possible specific energy. Solar energy is the highest specific energy one can get — essentially infinite. However, current solar-electric systems do not offer a high specific power.

To fly high requires a high specific power, or a slow flyer. [At 60,000 feet, the atmosphere is approximately one-tenth as dense as it is at sea level. An aircraft at this altitude will need nearly four times the power required at sea level. At 100,000 feet, the atmosphere is only about 1/100 as dense as sea level, and the same aircraft would require ten times as much power to maintain level flight. At 150,000 feet, the atmosphere is about 1/700 th as dense as sea level, and requires about 27 times as much power to fly.]

Therefore, it is obvious a long-duration, high-flying aircraft must be large and light — a slow flyer, optimized for maximum wing area and minimum drag.

To fly overnight, however, the sun's energy must be stored. Such a "battery" must be extremely light, and efficient as possible. The energy storage system most promising today is an electrolyzer and fuel cell combination — a system that uses electric power to convert water to hydrogen and oxygen by electrolysis, stores the gases, and then recombines them to produce electricity when needed.

These are the fundamental issues to consider in the design of solar aircraft.

The aircraft that you have seen has proven the concept of operation – the aerodynamics, the structures, the command and control. However, with the technologies currently available, it is limited to operation in the sunny side of the year. To operate at the winter solstice at temperate latitudes will require a

dramatic increase in the efficiency of the photovoltaic cells, which convert sunlight into electricity.

To operate an aircraft like the Helios, with a 250 pound payload, year-round at 25 degrees of latitude (Miami, Brownsville Texas, Taiwan, for example) requires cells of over 30% effective efficiency. Spectrolab is projecting achieving this level in 3 years, using multi-junction cells.

However, to reach the latitudes of New York, Southern Europe, all of Mainland China, and most of South America, would require cells of approximately 50% efficiency.

Likewise, when looking to the Ultra-High Altitude science missions, replacing sounding rockets that give 6 minutes of data at 150,000 feet with a solar plane that could provide multiple hours of persistence at 150,000 feet, also requires solar cells of this perceived practical limit to photovoltaic efficiency.

There are several more issues that need to be overcome with the high-efficiency hurdle — cost, brittleness, and weight.

Cost: Currently, the types of cells that produce the high efficiencies — multi-junction cells — are quite expensive, costing hundreds of dollars per peak watt. A goal for being cost effective on a solar plane is less than $50 per peak watt, ideally $25. Some of the cost is labor, and will be driven down by automation

once the cells are in high-volume production, instead of laboratory oddities. The other part of the cost is in materials, which are dominated by the cost of the germanium backplane (which, incidentally, also blocks the absorption of albedo from the rear of the cell, and reduces effective efficiency).

Brittleness is a function of the germanium also. For installation on a flexing surface, such as an airplane wing of thin-film material, some flexibility is required. Making the germanium thicker, to increase ruggedness, makes it more stiff and less tolerant to flexing of the wing.

The germanium is also much heavier than silicon. Increasing its thickness for ruggedness also increases the weight. To achieve the performances predicted, it is desired to reach an overall aircraft weight of 0.6 pounds per squarefoot of wing area. To achieve this low wingloading, it is desired to reduce the solar array weight to below 1/4 psf, and ideally to 1/8 psf (approximately that of the Pathfinder silicon array as flown).

An effort to replace the germanium backplane with silicon would reduce cost, increase ruggedness, reduce weight, and provide for a bifaciality, which could then permit an increase in effective efficiency of 5 percentage points. Some solar cell manufacturers believe this may be achievable, but none have any significant IRAD efforts aimed at achieving this “hybrid, multi-junction” cell. NASA could team with NREL and DOE to invest in developing such a cell for the future. Not only would it permit a deployment of a fleet of solar aircraft, that would replace much of the 100,000 Kg of commercial communication satellites

launched into GEO orbit each year, but a super high efficiency cell would allow many other applications of improved solar cells.

The most obvious transfer of the technology would be to satellites, many of which are approaching 30 KW in total power. Super-high efficiency cells would reduce the size of the array,and also the structure that is required to deploy and support the array in space, downsizing the total launch package.

The Sunraycer car we built for GM and Hughes averaged 42 miles an hour over a 2000 mile race across Australia with cells averaging less than 19% efficiency. With cells of 50% efficiency, it could have averaged roughly 65 mph. In normal driving, with trips of a few hours, allowing stored energy to be used, such a car could compete with any on the road today in performance (in sunny areas).

Solar power plants are highly modular. They can be placed anywhere as a self-contained system, with or without energy storage (witness call boxes on highways). In a developing world, having modest size arrays that produce substantial power (40 to 50 watts per sft), would have a synergistic effect on economies, education, and create a basis for non-polluting energy systems (the island of Niihau, in Hawaii, has used solar power for communications and computing for several decades – the system is run and maintained by native Hawaiians). They also would lend themselves to augmenting grid power in countries like the US, because their smaller size would be much less obtrusive

and more maintainable in an urban or suburban environment. Use of these cells with 100 to one concentrators could crack the magic, $1 per watt barrier and make solar cell installations competitive with natural gas plants, even before considering infrastructure and fuel costs.

While the amount of non-renewable energy consumption to launch satellites is a small part of the global demand, there is a secondary effect on the environment from rocket launches, which is disproportionate in its impact on the ozone layer for the amount of fuel consumed. I have heard it said by a scientist within NASA that the space shuttle boosters contribute 1% of the annual global chlorofluorocarbon pollution of the upper atmosphere on each launch. Considering the total impact of launches to geo-synchronous orbit by other large rockets is shocking. We can't keep burning holes in the atmosphere without answering for it.

My challenge to NIAC is:
Multi-junctioned, silicon-backed solar cells of 50% target, effective efficiency (bifacial), areal array weights of 1/8 of a pound psf (without cover glasses, which aren't needed in the atmosphere), and costs of $25 per peak watt (AM-0).

Obviously, this is the tiniest step toward solving a formidable energy and environmental problem that I alluded to at the start of my talk. But, it is a step in

the right direction. Maybe it is an idea whose time has come. And, as Goethe said,

“Once one is committed, all kinds of events will occur to help you on your path,

Whatever you can do, or dream you can, begin it.

Boldness has genius and power and magic in it.”

Cost comparison

Some of you asked about the cost benefit of solar UAV's for doing science or disaster relief missions. I'd like to leave you with some approximate numbers for your reflection.

In terms of life cycle cost, or total cost of ownership per flight hour,

U-2 $6,000 / flt-hr

Commercial jets $4,000 to 8,000 per flight-hr, depending on size

UAV's in military (all, per General Israel, 1995) $2,000 /flt-hr

Light aircraft $200 - $800 per flight-hr

Pointer UAV $400 - $500 /flt-hr

Helios (deployed in large numbers as commercial telecom platform)

$30/flt-hr

Why is the Helios cheaper?

No Fuel costs

Extreme duration: low ground ops costs

Extreme reliability / low maintenance

Low moving parts count

High level of redundancy

Low temperatures in subsystems

Fewer people to fly… up to 10 aircraft monitored by one pilot