The Emerging Alternate Energy Consensus

by Alan S. Brown

It is hard to imagine that polar opposites Al Gore and T. Boone Pickens agree on anything, but when it comes to energy, they do.

Gore, a former vice president and presidential candidate, now campaigns for green energy and cutbacks in greenhouse emissions. Pickens, a conservative billionaire oilman and corporate raider, financed the "Swift Boat" commercials that helped sink John Kerry's presidential campaign four years ago.

Yet both men believe America must invest in alternate energy sources, and we must do it now rather than later.

In a widely publicized speech in July, Gore called for the United States to generate all of its electrical energy from renewable resources—hydropower, wind, solar, and geothermal energy—within 20 years. Pickens says that America must build enough wind generators to replace one-third of our oil imports within the next 10 years.

A May 2008 report from the U.S. Department of Energy's office of energy efficiency and renewable energy (EERE) lent their cause credence. It stated that the United States may be able to generate 20 percent of its total electrical demand—300,000 Megawatts per year—from wind by 2030. EERE also believes that geothermal energy could eventually meet 10 to 20 percent of the nation's electrical demand.

Skeptics often discount governmental reports because civil servants are not betting their own money. Yet private investors have begun to channel greenbacks into green energy. Last year in California alone, venture capitalists poured $654 million into 33 solar-power companies, up from $253 million and 16 firms in 2006, according to energy analyst Cleantech Group.

Pickens himself is pumping $10 billion of his own money into the world's largest wind farm, a four-gigawatt project on 150,000 acres in the Texas panhandle. He is not alone. Wind energy accounted for an astonishing 35 percent of all new U.S. generating capacity in 2007. It now accounts for 1.6 percent of total U.S. nameplate generating capacity and one percent of output (because wind generators do not operate at peak power all the time). Texas, the heart and soul of the American oil industry, now leads the nation in wind capacity as well.

America is rethinking how it generates energy. Once, coal would have been the automatic answer for electrical power, because the U.S. has enormous coal reserves. Yet it has become increasingly difficult for utilities to build new coal-powered generating plants because of concern over greenhouse gases and such conventional pollutants as mercury, heavy metals, and sulfuric acid. The dearth of new coal-based capacity is one reason why wind accounted for such a high percentage of new electrical capacity in 2007.

Nuclear power has also attracted adherents. President George Bush and presidential candidate John McCain believe that nuclear plants will reduce America's dependence on foreign energy. Leading greens, such as Gaia theorist James Lovelock, Greenpeace cofounder Patrick Moore, and former Friends of the Earth chairman Hugh Montefiore, like the fact that nuclear plants do not release greenhouse emissions. Yet questions about community safety and nuclear waste disposal keep the permitting process long and arduous.

Spurred by environmental concerns and soaring oil and gas prices, the public is demanding new energy options. Renewable energy—wind, solar, and geothermal—has attracted enormous media attention and developed impressive political momentum. But are the technologies ready for prime time? As is often the case in engineering, it all depends on how we define future requirements.

THE THREAT

When it comes to America's energy future, Gore and Pickens have very different takes on what is at stake. For Gore, the environment is paramount. He argues that greenhouse gases (primarily carbon dioxide) generated by combustion and other human activities are warming Earth's atmosphere and oceans and changing its climate in unexpected ways.

Many scientific societies echo his concern. The American Meteorological Society, the American Geophysical Union, the American Association for the Advancement of Science (AAAS), and the National Academy of Sciences have all

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found compelling evidence that humans are at least partially responsible for climate change. The 2007 fourth report by the Intergovernmental Panel on Climate Change found "unequivocal" evidence of human-driven global warming. Written by 600 scientists and unanimously approved by 113 government-appointed delegates, the report found that the amount of CO_2 entering the atmosphere is 1.3 times more than just 20 years ago, the atmosphere is warming 0.13ºC every decade, and the sea is rising about 3.1 cm each decade.

How will climate change play out? Scientists see evidence of unsettling trends. These include mass extinctions of animals and plants, changes in rainfall that affect farmland fertility, increased desertification, glacial and polar icecap melting, and rising seas. Some warn that America could lose its most productive farmland or that rising seas will sweep over coastal lowlands and saltwater tides will poison inland vegetation.

The 25 turbines on this British wind farm produce up to 90 megawatts.
Photo: Siemens AG

In Gore's world, CO_2 emissions threaten global security by depriving the world of productive farmland, overwhelming fragile coastal nations, and nurturing nihilistic violence among people who believe that they have no future.

Pickens sees a more traditional threat to national security. He argues that America is addicted to foreign oil. In 1970, the U.S. imported 24 percent of its oil. Today, it imports 70 percent of the 21 million barrels it uses each day. At $110/barrel (in August 2008), America's oil addiction would cost $570 billion in 2008. Pickens estimates that the U.S. will pay $10 trillion for oil imports over the next ten years, which he describes as "the greatest transfer of wealth in the history of mankind." Much of that money will flow to nations such as Saudi Arabia, Iran, Venezuela, and Russia, whose interests do not always coincide with ours.

Why not produce more oil? Pickens says we cannot drill ourselves out of this crisis. He argues that world oil production peaked in 2005. "Despite growing demand and an unprecedented increase in prices, oil production has fallen over the last three years," he writes on his website (*www.pickensplan.com*). "Oil is getting more expensive to produce, harder to find, and there just isn't enough of it to keep up with demand." What he does not mention is that unlike the past, the U.S. and other developed nations must now compete with China, India, and other emerging economies for this limited supply of oil.

Pickens' plan is twofold. He calls the U.S. the "Saudi Arabia of wind energy" and says that the Great Plains has more wind energy potential than any other region on the globe. Wind farms stretching from North Dakota to the Texas panhandle could supply 20 percent of U.S. electrical demand at a cost of $1 trillion—plus another $200 billion for a network to transmit energy to market. Compared with $10 trillion for oil imports, building a new industry that improves energy security while creating jobs and wealth sounds like a bargain.

Of course, America uses hardly any oil to produce electricity. Its generators run primarily on coal (50 percent of output), natural gas (22 percent), and nuclear fuel (20 percent). Pickens has this covered too. He expects wind energy to replace gas generators, which cost more to run than coal. This will enable the nation to divert natural gas to power vehicles.

This is not as far-fetched as it sounds. There are more than seven million natural gas vehicles in the world. According to the California Energy Commission, natural gas vehicles emit 23% less greenhouse gas than diesels and 30% less than gasoline vehicles. Moreover, domestic natural gas reserves are twice those of petroleum. (Pickens, incidentally, has been shifting his investments to natural gas from oil since 1997.)

Pickens and Gore represent two very different views of America's energy problem. The latter believes that environmental changes could cause massive global disruptions. Pickens thinks dependence on foreign oil could leave the United States vulnerable to political pressure or sudden runups in price if terrorists or war disrupt production at major oilfields.

Yet they both favor development of alternate energy sources. They join many analysts who argue that we should invest more now to provide energy security in the future. Spurred by concerns about global climate change and $4-per-gallon gasoline, policymakers are finally listening. And despite numerous technical challenges, alternate energy is making significant inroads today.

Wind is the poster child for this new generation of energy technology.

WIND

Wind power is today's alternate energy star. Aside from hydroelectric power, which has been around since the earliest days of electrical generation, wind is by far the largest source of renewable power. It accounts for roughly one percent of production.

Moreover, wind energy is growing rapidly, according to a May 2008 study released by Dr. Ryan Wiser, *California Gamma '94*, and Mark Bolinger of Lawrence Berkeley National Laboratory. In 2007, the United States invested $9 billion in 5.3 gigawatts (GW) of new wind power, more than double the previous record. This boosted total U.S. capacity by 46 percent, to nearly 17 GW.

Wind accounted for roughly four percent of all new capacity in 2004, 12 percent in 2005, 19 percent in 2006, and 35 percent in 2007. Wiser and Bolinger expect wind producers to add more than 5 GW of new capacity in 2008. They also point to another 225 GW of wind projects on the books. While they warn that investors are not likely to build all of this capacity, the wind total is still twice as high as the projection for the next largest natural resource, natural gas.

Such rapid growth has made the U.S. the world's second largest wind producer after Germany. Several small U.S. utilities generate more than 10 percent of their retail sales from wind, and one mid-sized utility, Xcel Energy, produces more than nine percent. Yet other countries use far more wind in their power mix. Denmark, for example, produced roughly 20 percent of its electrical energy from wind in 2007, followed by Spain (12 percent), Portugal (nine percent), Germany (seven percent), and Greece (four percent).

Wind generators have grown in size and sophistication. In 1996, the average utility-scale wind turbine sat on a 130-foot tower and produced 0.55 MW. Ten years later, the most common turbine stood twice as high, had a composite rotor large enough to sweep a football field, and produced 1.5 MW of power. By 2007, more than 40 percent of all new turbines were larger than 1.5 MW, and most manufacturers had either introduced or were developing units in the 3-5 MW range.

Not only have individual generators grown larger, but so have the wind projects themselves. In the year 2007, the size of the average commercial project nearly doubled to 120 MW. The more power produced in one place, the lower the per-watt cost of connecting to the electrical grid. Moreover, governmental incentives have enabled large wind farms to sell power for 2.5-5.5 cents/kilowatt-hour, which makes wind among the lowest cost of all energy sources.

The surge in wind capacity lends credence to the department of energy's call for producing 20 percent of the nation's electrical energy from wind by 2030. Yet the goal remains ambitious. Although there is certainly enough wind available, wind producers would have to add 280 GW of new capacity, or about 13 GW per year over each of the next 22 years, to get there. This is roughly 250 percent of wind's current breakneck rate of expansion.

To get there, wind proponents are banking on incremental improvements in technology. Today's wind systems are far more sophisticated than even ten years ago. Rising 200 to 350 feet above the ground, they consist of three-bladed rotors 230 to 265 feet in diameter attached to turbine generators and gearboxes. Aided by sensors and sophisticated controls, the rotors swing to face the wind, and the blades optimize their angle of attack for both low- and high-speed winds. Engineers have developed new types of drivetrains to handle wind's wide swings in torque, which are nothing like the constant rated power typically fed to steam or hydroelectric generators. According to Wiser and Bolinger, such improvements have helped boost the wind capacity factor, the percentage of nameplate capacity producing energy, to 36 percent in 2005, from 22 percent only seven years earlier.

Improving wind turbines further will not be easy. Clearly, the larger the rotor, the more wind energy a turbine can capture. Yet larger rotors are not only more costly, but their weight and speed produce huge loads that require more robust towers, mounting hardware, and drivetrains.

The department of energy sees several possible solutions. On one hand, it is funding work on engineering composites that passively twist the blade in high winds to reduce the load transferred to the turbine structure. Other researchers are working on active controls that sense rotor loads and prevent their transfer to the rest of the structure.

Mirrors in Arizona focus sunlight on a 25 kilowatt Stirling heat engine.
Photo: U.S. Department of Energy

Gearbox reliability remains a problem. According to a report from the Stockholm Institute of Technology in Sweden, gearboxes were the leading cause of wind-turbine breakdown, accounting for 19 percent of failures in Sweden and 32 percent in Finland. One German manufacturer, Enercon GmbH, developed a direct-drive system that eliminated the gearbox entirely, while others are simplifying gearbox stages. Clipper Windpower, a California startup, has developed a fundamentally new gearbox design that divides mechanical power among four generators, dramatically decreasing the load on any individual component. Other innovators are replacing turbine rotor copper windings with rare-earth magnets to boost energy density and reduce weight.

There is still room for some major advances. American Superconductor Corp., a developer of high-temperature superconducting (HTS) wires, is teaming with generator manufacturer TECO-Westinghouse Motor Co. to apply HTS wires to direct drive wind generators. HTS wires are so much lighter than copper windings, the partners believe that they can build a 10 MW generator that weighs only 132 metric tons. It would have nearly seven times the output of General Electric Company's industry-standard 1.5 MW wind turbine but weigh only 31 metric tons more. The National Institute of Science and Technology's advanced technology program is funding half of the 30-month project's $6.8 million budget.

SUN

Solar technology feels like it has been around forever. Solar cells broke into public consciousness nearly 50 years ago, when they were used to power Telstar and many of the first satellites, and have been a staple of science fair projects for nearly as long. Yet for five decades, the dream of free and limitless power from the sun has been tantalizingly out of reach. Thanks to innovative technologies, this may be ready to change.

Solar's problem has always been cost. Silicon is used to manufacture 90 percent of the world's commercial photovoltaic cells, and it is expensive. A recent global shortage that pitted solar cell manufacturers against electronics producers only drove the cost higher. Also, because silicon wafers are relatively poor light absorbers, silicon solar cells must be thick to catch more light. The large, thick wafers are fragile, which makes them difficult to handle at each stage of the manufacturing process.

Photovoltaics are made by semiconductor processes similar to those used to make integrated circuits, but with one key difference—the ability of semiconductor processes to shrink electronics drives costs down when producers harvest more chips from a single wafer. Unfortunately, the same processes have little effect on photovoltaic economics because solar cells require large areas to catch the sun's rays.

However, semiconductor technology may hold the solution to many of silicon's limitations. Semiconductors are typically made from thin films, layers of materials measured in micrometer or even nanometer thicknesses deposited over silicon. During the past decade, solar cell manufacturers have begun to build photovoltaic cells from thin films over non-silicon substrates.

The new approach relies on thin films of cadmium telluride or copper indium gallium selenide (CIGS). CIGS, in particular, has caught the attention of investors over the past year. CIGS solar cells are 12-13 percent efficient. This is not quite as good as industry-standard multicrystalline (11-17 percent) or monocrystalline (14-17 percent) silicon wafers. But CIGS cells have one overriding advantage: they cost far less to manufacture.

This is because developers can forget silicon and deposit them on glass or metal substrates. Initially, engineers did this using high-vacuum deposition processes pioneered by the semiconductor industry. More recently though, several companies have developed technologies that let them "print" CIGS films on continuously moving rolls of plastic or aluminum foil.

The new roll-to-roll technology resembles a press printing a newspaper, and it is fast and cheap. It is also complicated. Nanosolar Inc. of San Jose, CA, for example, starts with a nanoparticle ink, an organic molecule bonded to copper, indium, gallium, and selenium atoms in the right proportions to form CIGS. It claims it can print the ink onto a roll of aluminum foil (which acts as the electrode) running at hundreds of feet per minute and then convert the ink into a true CIGS layer.

Nanosolar claims that eliminating costly silicon wafers and slow vacuum deposition steps will enable it to drive down the cost of solar panels to $1 per watt and still turn a profit. The most cost-effective silicon solar cells cost about three times as much. At $1/watt, CIGS cells could compete with coal or any other type of power, especially in the sunny Southwest.

Claims like these have attracted attention. In 2006, Nanosolar raised $75 million from investors, plus $25 million in governmental subsidies, followed in 2007 by a $20 million DOE solar America initiative award. CIGS developer DayStar Technologies Inc. raised $77 million from venture capitalists and $70 million from a public offering in 2007. A third CIGS developer, HelioVolt Corp., nailed down $101 million in 2007. Nanosolar and HelioVolt are just two of the 33 Californian solar-power companies that received $654 million from investors in 2007.

Of course, investors placed bad bets during the dot.com boom and also on mortgage-backed securities recently. While several CIGS companies already sell commercial products, it will probably take several years before they prove they can scale their processes reliably enough to drive prices. If they get close to $1/watt, photovoltaics could become part of the nation's power mix.

Yet photovoltaics are not the only solar game in town. Concentrating solar power uses mirrors like magnifying

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glasses to focus sunlight to as much as 10,000 times its initial intensity. This is hot enough to heat water, oil, or molten salts to 400ºC, so they can produce steam for conventional turbines or to power Stirling heat engines. Unlike electrical energy produced by photovoltaics (or wind for that matter), thermal energy is easy to store so generating plants can run night and day. Moreover, the National Renewable Energy Laboratory states that the U.S. has the potential for nearly 7,000 GW of solar thermal power.

The U.S. already has nine solar electric generating stations operating. Built during 1985-90, they produce from 14 MW to 80 MW, but they are expensive to operate.

A 2008 study by Bernadette Del Chiaro of the Environment California Research & Policy Center and Sarah Payne and Tony Dutzik of the Frontier Group identifies advances in concentrators and fluids that promise to improve efficiency. They estimate the cost of solar thermal plants to be 14-16 cents/kilowatt-hour.

Although expensive by today's standards, this cost is competitive with operational costs of coal-fired power plants that must capture and store all carbon emissions. The solar cost is also competitive with those for new nuclear power plants, though the companies building those plants dispute the figures. Still, depending on how the government treats carbon emissions in the future, solar thermal could play a role in the nation's energy mix.

The Geysers geothermal project produces 750 megawatts of electricity, enough to power all of San Francisco, located 72 miles to the south. Photo: U.S. Department of Energy

EARTH

Geothermal energy is perhaps the most under-appreciated potential source of electrical power. The technology takes advantage of temperatures of the Earth's interior, which exceed 7,200 ºF. A fraction of this geothermal energy appears on the surface as geysers and hot springs. Far more remains underground, trapped no more than a mile or two beneath the surface. Proponents of geothermal energy hope to tap that reservoir to heat buildings directly or to drive heat exchangers or generators to produce electricity.

Not only is most geothermal energy renewable and continuously available (unlike solar cells and wind), but the United States has it in abundance. A 2006 report by the National Renewable Energy Laboratory estimated that America has enough geothermal energy within two miles of the surface to supply the nation with 30,000 years of energy at current rates of consumption. The report, "Geothermal–The Energy Under Our Feet," adds that "the recovery of even a very small percentage of this heat would make a large difference to the nation's energy supplies."

A more detailed 2007 study by the Geothermal Energy Association, "An Assessment of Geothermal Resource Development Needs in the Western United States," calls geothermal "an underestimated, under-reported, under-explored, and under-studied natural resource." Author Daniel Fleischmann estimated that the U.S. could tap 150 GW of generating capacity in the near term. If it all came online by 2015, he wrote, it would provide half the new energy needed by the 13 western states.

This is quite a turnaround from the last U.S. Geological Survey estimate of geothermal resources in 1978, which estimated total U.S. resources at 150 GW worth of power. According to Fleischmann, USGS underestimated the technology's potential because it only considered conventional hydrothermal reservoirs shallower than 1.8 miles with water temperatures greater than 300 ºF.

A lot has changed since 1978. Geologists know more about what lies under the Earth's crust. Engineers have developed better ways to use subsurface water to heat buildings, dry crops and lumber, and warm greenhouses and aquaculture systems. They have also invented new technologies that produce electricity from water as low as 162.5 ºF, as well as extract heat more efficiently from higher temperature resources.

More importantly, though, engineers now believe they can create geothermal resources to order. "Think of it as engineering a downhole heat exchanger," explains Ed Wall, who heads the geothermal energy program for DOE's office of energy efficiency and renewable energy.

Geothermal resources require three things, Wall explains: heat (where molten rock has breached the Earth's upper crust and warmed the rock around it); water from rainfall or runoff; and permeability so water can flow through the rock and be heated. Only about one in five wells finds all three in the same location. Since the cost of drilling is about 10 percent of total project cost, the uncertainty of success puts a damper on many potential projects.

The thinking behind enhanced geothermal systems, says Wall, is to find hot spots and add the permeability or water that nature failed to provide. Conceptually, this is not very different from what oil companies already do when they drill a well and then pump liquids down to fracture the surrounding rock to make it easier for oil to escape.

Of course, concept is not execution. The petroleum industry has enormous experience modeling geological formations, drilling wells 10,000 to 15,000 feet deep or deeper, creating fractures that tap the hidden liquid, and managing the flow through a system of wells. But oil geologists work with sedimentary rock, not the igneous or metamorphic rock where geothermal reservoirs are found.

The difference in rock means the emerging industry will have to develop new types of tools to fracture the rock and model the resulting network of fractures so managers can optimize the power they produce from the resource. Geothermal drilling and pumping often involve significantly greater temperatures and pressures than oil drilling, as well as caustic fluids that quickly rust away the most dependable pumps, valves, and sensors.

However, Wall remains optimistic. The problem is not so much technology as economics. Asked why geothermal energy was not developed earlier, his answer consists of two words: "Cheap energy."

Those days of cheap energy may be over. Perhaps oil production has peaked. Even if it has not, it may not be able to catch up to explosive demand in rapidly growing economies like China, India, and Brazil. Even if it did, unlimited use of energy could well create a climate crisis. No matter whether we look at it from the point of view of a Texas oilman or an environmentalist, something has to change.

That is why, in the end, alternate energy is not just about economics. It is about security, both environmental and national. It is why many state governments now mandate that utilities buy a fixed percentage of power from alternate energy producers—why green companies are able to profit by selling the renewable energy credits they earn through production—and why the federal government has traditionally provided production tax credits for renewable energy producers.

It is also why, in the end, the nation will resolve the infrastructure issues that keep it from connecting to remote wind farms, solar arrays, and geothermal energy sources. A new kind of grid is needed to integrate these types of energy sources, especially because the ones that deliver power when the wind is blowing or the sun is shining do nothing when it is calm or cloudy.

It will happen because when people as different as Mr. Gore and Mr. Pickens agree, a national consensus about alternative energy must be emerging.

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