CLEAN ENERGY TRENDS 2003

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WITH CLINT WILDER

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CLEAN EDGE
THE CLEAN-TECH MARKET AUTHORITY

INTRODUCTION

It is, at once, an exciting and confounding time for clean energy.

In a world buffeted by the challenges of national security, global climate change, and sluggish economies, clean-energy technologies such as solar, wind, and hydrogen-based fuel cells offer a compelling array of benefits to individuals and nations alike. These benefits include energy security, stabilized energy costs, reduced emissions and public health risks, and the creation of millions of jobs.

While most industries, especially in the technology sector, are seeing sluggish or negative growth, many clean-energy technologies are experiencing double-digit annual growth rates.

But building a clean-energy future is filled with equal parts promise and pitfalls, particularly in the United States, where government commitments to clean-energy development over the past three decades have been tepid at best, frustrating companies seeking a sustained, orderly market to fuel their growth. The hundreds of early-stage companies offering breakthrough technologies that could dramatically lower the cost of clean energy represent unparalleled potential in this arena, but many have been stymied by the recent economic downturn. Many early-stage companies will likely wither on the vine for want of consistent policies and sufficient capital.

This represents a lost opportunity. Industry, regulators, investors, and other key players must take critical steps to ensure that these emerging technologies can reach their full potential and become integrated into the existing energy infrastructure. Support from these constituents will help develop and sustain a diverse portfolio of energy resources that will be far less susceptible to economic, environmental, or political disruption and that will help guarantee ongoing technological and market competitiveness.

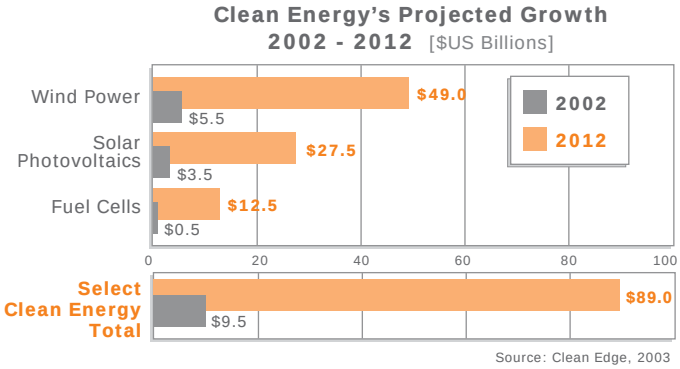
CONTINUING MARKET GROWTH

Such gloom notwithstanding, market indicators demonstrate that many clean-energy technologies are on the rise, and a confluence of forces is making clean energy one of the few bright spots in an otherwise bleak economy.

While most industries, especially in the technology sector, are seeing sluggish or negative growth, many clean-energy technologies are experiencing double-digit annual growth rates. We believe that solar power, wind power, and fuel cells will continue to exhibit aggressive annual growth for the foreseeable future.

According to Clean Edge research, solar photovoltaics (PV) (including modules, system components, and installation) will grow from a $3.5 billion global industry in 2002 to more than $27.5 billion by 2012. Wind power will expand from $5.5 billion in 2002 to approximately $49 billion in 2012. And fuel cells for mobile, stationary, and portable applications will grow from $500 million to $12.5 billion over the next decade.

Combined, these high-growth technologies will grow by nearly an order of magnitude – from just under $10 billion today to $89 billion by 2012 – offering significant economic opportunities for companies, investors, and governments pursuing clean-energy goals.



Clean energy is growing in both size and scale. In 2002, more than 6,500 megawatts (MW) of wind-power generating capacity was installed around the globe. This represents the equivalent of more than six large-scale nuclear or fossil-fueled power plants. In many regions, wind power is now cost-competitive with conventional utility-scale power sources. And solar photovoltaics, with more than 500 MW shipped in 2002, continues to see a decline in costs. Some manufacturers now sell solar modules for $2.50 per peak watt wholesale, compared to around $6 just a decade earlier. Clean Edge foresees further decreases in costs as the solar industry scales into a mature manufacturing base and breakthrough PV-manufacturing technologies enter the market.

VENTURE CAPITAL INVESTMENTS

Venture capital investments in clean energy, while trending downwards with the rest of the market, have grown as a percentage of the total venture market. Overall venture investments in US companies totaled $21 billion in 2002, down from $41 billion in 2001 and a high of $103 billion in 2000. Amid this significant decline, clean-energy venture investments fared better, and now represent a larger percentage of total VC activity than ever before. In 2002, venture investments in US-based clean-energy companies equaled $488 million, compared to $774 million in 2001 and just over $1 billion in 2000. Clean energy now accounts for 2.3% of total VC activity, compared to 0.7% just three years ago.

Table 1: Clean Energy Private Equity Investments in US Based Companies as Percent of Total

YEAR	TOTAL VENTURE INVESTMENTS (US$ BILLIONS)	ENERGY TECHNOLOGY INVESTMENTS (US$ MILLIONS)	ENERGY TECHNOLOGY PERCENTAGE OF VENTURE TOTAL
1998	$22	$204	0.9%
1999	$59	$442	0.7%
2000	$103	$1200	1.2%
2001	$41	$774	1.9%
2002	$21	$488	2.3%

Source: PricewaterhouseCoopers/Venture Economics/National Venture Capital Association Money Tree™ Survey, Nth Power, and Clean Edge, Inc.

Table 2: Select North American Clean-Energy Equity Investments in 2002

COMPANY	DESCRIPTION	FUNDING (US$ MILLIONS)	INVESTORS
Green Mountain Energy	Retail provider of green energy from wind, biomass, geothermal, and solar	$24.0	BP America; Maverick Capital; Nuon; Wyly Family Interest
Konarka Technologies	Developer of flexible, polymer, and nanoparticle-based photovoltaic technology	$13.5	Ardesta LLC; ChevronTexaco; Draper Fisher Jurvetson; Eastman Chemical; NextGen Partners; Zero Stage Capital
Polyfuel, Inc.	Developer of direct methanol fuel cells	$15.6	Chrysalix Energy L.P.; Intel Capital; Mayfield Fund; Technology Partners; Ventures West
SatCon Technology Corporation	Power and energy management products	$4.1	General Atomics
STM Power	Onsite electricity and cogeneration systems	$2.7	Alliant Energy; Hydrogenics

Source: Cleantech Venture Network and Clean Edge, Inc.

Large corporations are investing, too. General Electric Co. last year acquired Enron Wind to establish GE Wind Energy, now the largest wind turbine manufacturer in the US. BP Solar is rolling out Home Solutions, an ambitious and aggressive effort to create mass markets for residential solar PV systems in the US and Europe. Japan-based Sharp Electronics Corp. has doubled its output of solar PV modules over the past two years. Meanwhile, Ballard Power Systems, BASF, Duke Energy, Mitsubishi Corp., Shell Hydrogen, and others have joined forces as limited partners in Chrysalix Energy Management, a venture fund focused on hydrogen and fuel cell investments. And ChevronTexaco continues to invest in clean technology through its Technology Ventures group as well as through its holdings in Energy Conversion Devices.

Despite the growing interest in clean energy, investors in publicly traded clean-energy companies have fared poorly over the past year. (See Table 3 on following page.) Most clean-energy stocks traded on North American exchanges are significantly off their 52-week highs, with many trading below their initial public offering prices. While these stocks are likely to remain volatile amid the uncertainty of war, unstable government commitments, and other externalities, we believe that several will prove to be valuable long-term investments.

HARNESSING PUBLIC POLICY

Increasingly, governments around the world are recognizing that their global competitiveness and future economic growth rest in part on their investments in clean-energy technology. For many, it has as much to do with economic vitality and job creation as with energy production and security.

Japan and the European Union have been among the most aggressive players, implementing a variety of policies and initiatives to grow their burgeoning clean-tech industries. Much of the growth of clean energy in Europe and Japan comes at the expense of the United States. For example, while solar PV and wind power were first

Table 3: Select Clean-Technology Stocks (All Figures for End of Session 1/31/2003)

TICKER	NAME	LAST ($US)	52-WEEK RANGE ($US)	MARKET CAP ($US MILLIONS)
ACPW	ACTIVE POWER	1.55	1.10 — 5.58	64.5
APWR	ASTROPOWER INC	6.75	6.12 — 28.53	146.9
BLDP	BALLARD PWR SYS	10.54	6.66 — 33.59	1,105.0
ENER	ENERGY CONV DEV	10.27	7.21 — 25.73	224.9
ESLR	EVERGREEN SOLAR	1.21	0.44 — 3.58	13.7
FCEL	FUELCELL ENERGY	5.79	4.54 — 18.65	227.7
HPOW	H POWER CORP	3.85	1.75 — 15.45	41.5
HYGS	HYDROGENICS CP	4.40	2.77 — 8.30	214.2
ITRI	ITRON INC	15.95	12.53 — 36.50	321.8
MKTY	MECHANICAL TECH	2.02	0.70 — 3.85	71.9
MCEL	MILLENNIUM CELL	2.13	1.60 — 5.19	61.8
PLUG	PLUG POWER INC	5.13	3.39 — 12.58	260.9
PRTN	PROTON ENERGY	3.14	1.92 — 7.90	104.9
UQM	UQM TECHNOLOGIES	3.35	1.55 — 5.75	63.1M

Source: Clean Edge, Inc.: www.cleanedge.com/CEindex.php

commercialized in the US, they are now the domains of other countries: Japan has become the leading producer of solar PV modules, while Denmark and Germany rule the wind turbine world.

In the US, government leadership on clean energy has come not from the White House or Congress but at the state and local levels. California has implemented and oversees a range of innovative and high-impact programs, including a statewide

Table 4: Select State Renewable Portfolio Standards

STATE	GOAL	TARGET DATE	NOTES
CALIFORNIA	20%	2017	Signed in late 2002, this is currently the most ambitious target of any state, and covers the largest population base.
MASSACHUSETTS	4%	2009	The state's RPS permits the use of solar, wind, ocean thermal, wave, and fuel cells using renewable fuels, landfill gas, and "low emission" biomass.
NEVADA	15%	2013	Passed in June, 2001, Nevada's RPS requires that at least 5% of the state's total energy must come from solar projects in this sun-rich land.
TEXAS	2880 MW (approx. 3%)	2009	Texas's RPS, while not as ambitious as some, has been remarkably successful. Signed by then Governor George W. Bush in 1999, the policy has helped Texas lead the nation in new wind farm development.

Source: Clean Edge, Inc.

renewable portfolio standard (RPS), fuel-cell research and development centers, and progressive rebates and incentives. The city of San Francisco has embarked on an ambitious program to install solar PV systems, including on the roof of its convention center. Michigan, under Gov. John Engler, recently launched a roughly $50 million NextEnergy program that would make that state a leading developer of fuel cells for the transportation sector. Gov. George E. Pataki of New York recently announced a bold plan calling for 25% of the state's energy to come from renewable sources by 2010. Government-supported clean-energy incubators from California to Connecticut are helping to grow new companies.

More than a dozen US states now have renewable portfolio standards mandating that a portion of the state's overall electricity purchases come from renewable sources such as geothermal, solar, and wind. Such policies are having a salutary impact on the growth of clean energy in the US. And RPS are not limited to states: several nations are implementing similar policies, including Japan (targeting 3% renewable energy by 2010) and the entire European Union (targeting 20% renewables by 2010). The US does not yet have a national RPS.

FIVE TRENDS TO WATCH

How will clean-energy markets develop in the coming years? Here is how Clean Edge analysts view the landscape.

1. CLEAN ENERGY GETS CENTRALIZED

While "distributed generation" has received considerable attention in the media and has been widely touted by industry insiders, an equally important revolution is taking place in utility-scale renewable energy systems. Clean energy is not just going distributed and small, it's increasingly becoming centralized and big.

Consider wind turbines. More than 6,500 MW of new wind energy came online during 2002, roughly the same amount as the year before, according to the American Wind Energy Association. Much of that new capacity can be found on utility-scale wind farms, such as Germany's land-based Sintfeld Wind Farm (104 MW), the King Mountain Wind Ranch in Texas (278 MW); and Denmark's 160 MW offshore Horns Rev installation.

That's just for starters. Wind turbine manufacturers are coming forth with larger and more advanced turbines to fuel further development. While most large turbines have been designed to produce 2 MW or less of power, companies like GE Wind Energy and Enercon (see profile below) are testing wind turbines in the 3.5 MW to 4.5 MW range. Such turbines' rotors approach a football field in diameter and are geared toward large-scale offshore wind farms taking root around the globe.

Companies like GE Wind Energy and Enercon are testing wind turbines in the 3.5 MW to 4.5 MW range

It's not just wind that's coming on strong. If the folks at EnviroMission Ltd. are successful, Australia will host the world's first large-scale solar tower – at one kilometer (3,280 feet) high, it would be the tallest artificial structure on Earth. Harnessing thermal solar technology – in which the sun's rays heat water that produces steam to run turbines – it will generate enough electricity to supply more than 200,000 people, according to its creators. Several US energy utilities are developing less ambitious but still impressive solar thermal arrays. These efforts join ongoing utility-scale projects around the world to harness such renewable energy resources as geothermal, hydroelectricity, and landfill gas.

Centralized renewables have their limits. Many projects, for example, are facing opposition from NIMBY ("not in my backyard") groups concerned about the prospect of, say, wind turbines blocking their views. And centralized technologies still rely upon the electricity grid, which in many places is highly stressed and vulnerable to outages. Nonetheless, we believe that centralized renewable companies and projects will continue strong growth in lockstep with their decentralized brethren, as both private and

publicly owned utilities come to appreciate the value of a diverse portfolio of energy sources – not just in fuel source and technology, but size.

2002 Top Headlines

Australia to Host World's First Solar Tower

BP and ChevronTexaco Team Up on Dutch Wind Farm

GE Acquires Enron Wind

FPL Energy Increases Wind Portfolio

Shell WindEnergy Adds 61.5 MW to its US Portfolio

Siemens to Build 300 MW Windpower Plant in South Korea

Sierra Pacific Signs 50 MW Solar Power Contract

TXU Energy & Cielo Announce 240 MW Wind Project

Select Companies to Watch

Duke Solar
www.dukesolar.com

Enercon
www.enercon.de

FPL
www.fpl.com

GE Wind Energy
www.gepower.com/dhtml/wind/en_us

Vestas
www.vestas.com

Profile:
Enercon

Location
Frankfurt, Germany
www.enercon.de

Founded
1984

Employees
800

Technology
Wind turbines, including the world's largest, a 4.5-megawatt behemoth called the E-112 in Magdeburg, Germany that can power 15,000 homes. Its rotor blades are 52 meters long.

The Buzz
With a 34% market share, Enercon is the runaway wind energy market leader in Germany, the world's biggest wind power market, with more than 12 gigawatts installed. Enercon blew past Denmark's Vestas as the German market leader last year, and is poised for continued growth as Germany continues to invest in wind and other renewables while it aims to shut down all its nuclear power plants by 2020.

Brain Trust
Enercon founder Aloys Wobben is considered one of the world's leading wind power pioneers. He received the European Wind Energy Congress's top award in 1995.

Bankrollers
Wobben and his management team have the cash to keep Enercon humming, and have invested in other companies as well. Privately held Enercon has estimated annual revenue of 900 million euros (US$934 million).

Our Take
Bigger-is-better looks like a wind turbine trend. The largest US wind player, GE Wind Energy, said in December that it's testing a 3.6MW monster for offshore use. Enercon, with its dominance of the German market, can afford to think big and bet that huge centralized wind generation will prove cost-effective.

2. HYDROGEN FROM SOLAR, WIND, AND BIOMASS

Most hydrogen produced in the world today comes from the reformation of gasoline, methane, and natural gas or from electrolysis, powered by grid-based electricity, which typically comes from fossil fuels. In addition to producing hydrogen, however, these processes generate greenhouse gases and are based on finite resources. Such technologies are the basis of President Bush's FreedomFuels program announced in his 2003 State of the Union address, which proposes research to produce hydrogen from sources that include coal and nuclear power.

But using fossil fuels to power fuel cells is not very clean. The Holy Grail is the production of hydrogen from water, fueled by renewable energy sources such as wind, solar, and biomass. While these technologies have not yet proven cost-effective on a large scale, they are being targeted by some of the most exciting R&D efforts in the energy field today.

The Holy Grail is the production of hydrogen from renewable energy sources such as wind, solar, and biomass

Honda is the biggest commercial name in the hydrogen-from-renewables space, operating a solar-powered hydrogen production facility in southern California for its fuel-cell vehicles (see profile below). Another potential breakthrough in hydrogen production efficiency and cost-effectiveness occurred last year at Japan's Research Institute of Innovative Technology for the Earth in (appropriately enough) Kyoto Prefecture. Institute scientists developed a silicon-based photocatalyst said to use sunlight to extract hydrogen from water 30 times more efficiently than traditional titanium oxide-based technology.

The recent growth in offshore wind farms for electricity generation gives hydrogen advocates hope that wind turbines could be used to power electrolyzers to produce hydrogen from water. A few wind turbine makers, notably Anglesey Wind & Energy Ltd. in the U.K., have deployed this technology in limited use, and Japan's Environment Ministry recently announced a program to research and develop wind-based hydrogen electrolysis.

Arguably the most innovative hydrogen-production developments are occurring in the biomass arena. In joint research with the National Renewable Energy Lab and other groups, University of California-Berkeley scientist Tasios Melis has successfully produced hydrogen from algae over a sustained period and founded a company, Melis Energy, to commercialize that patent-pending technology. University of Wisconsin researchers have produced hydrogen efficiently from a glucose solution. And a research team in Georgia completed a 100-hour process of extracting hydrogen from peanut shells, with the valuable concomitant result of sequestering carbon; startup firm Eprida is seeking to commercialize that technology.

Like most clean-energy startups, such firms face an uphill battle to garner funding, particularly with large-scale deployment of hydrogen production still several years out. And the low cost of fossil fuels – still subsidized by the US government – will present renewables-based hydrogen technologies with further competitive challenges. But we believe this is a key area to watch as hydrogen and fuel cells generate increased attention and developers see more opportunities for stationary and mobile applications.

2002 Top Headlines

Japanese Researchers Develop Hydrogen-Producing Photocatalyst

Scientists Turn Algae Into Hydrogen Gas, Discover Renewable Fuel Source

Researchers Turn Waste Into Hydrogen

Algae: Power Plant of the Future?

Tohoku University Professor Produces Hydrogen from the Sunlight

Spoonful of Sugar Could be Right Medicine for Cars

Penn State Engineers Boost Hydrogen Production from Fermentation

Biomass Hydrogen Conversion Breaks 100-Hour Operational Run

Select Companies to Watch

Honda
www.hondanews.com/forms/enviro

Proton Energy
www.protonenergy.com

Melis Energy
www.melisenergy.com

Northern Power
www.northernpower.com

Virent Energy Systems
www.virent.com

Profile:
Honda's Solar-Powered Hydrogen Fuel Cell Refueling Station

Location
Torrance, California
www.hondanews.com/forms/enviro/

Founded
2001

Employees
Approximately 50 of Honda's 1,000-member R&D staff in the US work on the project full-time or part-time

Technology
8-kilowatt PV array powers a 3,600-psi compressor for hydrogen, producing 4 gallons per day — about enough for one car's daily use.

The Buzz
This is the first solar-powered hydrogen production from an auto company, and Honda is advancing its commitment, installing second-generation equipment in early 2003 that recharges fuel cells more efficiently. In December 2002, the city of Los Angeles took delivery on the first of five Honda FCX fuel cell cars it will lease this year; they'll refuel at this station and other (non solar) hydrogen fueling stations in southern California. Honda plans to lease about 30 FCX cars in California and Japan during the next two to three years.

Brain Trust
Ben Knight, VP of Automotive Engineering, Honda R&D–Americas. A 26-year Honda R&D veteran, Knight's in charge of all of the company's US environmental vehicle efforts including low-emission gasoline, hybrid, and fuel cell. He represents Honda in the California Fuel Cell Partnership.

Bankrollers
Honda R&D obviously has deep pockets, but won't disclose funding for this project.

Our Take
For vehicles, you can't get more renewable than fuel cells using hydrogen produced from the sun. Honda's name and commitment gives great visibility — and viability — to this part of the hydrogen infrastructure. Along with rival Toyota, Honda continues to outdistance US and European automakers in clean-powered cars. Mass deployment of solar-powered hydrogen fuel cells is years away, but it's likely to happen much sooner if oil prices rise sharply. Honda has taken the lead position here.

3. US DEVELOPS WEAPONS OF MASS SALVATION

One of the great, untold stories of America's homeland security efforts is the degree to which the US defense establishment has funneled money to support clean energy technologies. And while it may seem ironic that solar panels, fuel cells, and other clean, green technologies may be deployed to protect America's oil interests, it is not without precedent: For nearly a half-century, defense spending has been a boon to furthering development of technologies that have improved the lives of those in the civilian world, including sowing the seeds of today's Internet.

Consider transistors. In the 1950s, the Department of Defense, needing a lightweight electronic replacement for vacuum tubes for the development of new weapons for the Cold War, made a significant investment in transistors. At the time, transistors cost $20 apiece. Within ten years, they had dropped to 25¢ to 30¢ each, paving the way for today's microprocessors.

Now, those same economies of scale could be brought to bear on clean energy. "Federal government budgets for research and development and procurement represent a significant – and growing – niche market and resource for emerging energy technologies," according to Green Strategies (www.greenstrategies.com), a Washington, D.C.-based business and public policy consulting firm specializing in energy and environmental matters. It cites the departments of Energy and Defense as the leading players at the federal level, though funds for clean-energy technologies can be found in agencies as diverse as NASA and the Department of State.

Defense spending has been a boon to furthering development of technologies that have improved the lives of those in the civilian world

At the Pentagon, "increased concern over the logistical burden and tactical implications of fuel supply for traditional internal combustion engine vehicles has resulted in new directions, priorities, and initiatives throughout DOD," says Green Strategies. One key Pentagon program is the Army's Objective Force Warrior program, which aims to make soldiers in the field lighter, more mobile – and more lethal. The program envisions soldiers wearing an "ultra-lightweight, multi-functional protective combat ensemble and stealth technology [that] will enhance survivability," according to one Pentagon document. "Hybrid fuel cell and advanced rechargeable batteries would supply the soldier's power needs for at least 72 hours."

Fuel cells are high on DOD's agenda, based on the sheer number of programs being offered. One program offers rebates for installing fuel-cell systems at military facilities; another aims to see fuel-cell systems power residential facilities on military bases. "DOD will certainly become an early and very large-scale purchaser of fuel cell systems," says Green Strategies.

And companies are responding. Mechanical Technology (see profile below) and weapons maker Alliant Techsystems Inc. are developing a portable fuel cell about the

size of a laptop-computer battery for an infantry weapon the US Army plans to start using in 2009. Acumentrics has developed a tubular solid oxide fuel cell that will be integrated into a series of fuel-cell stacks developed by defense contractor General Dynamics.

It's not exactly an all-out assault on fossil fuels, but the Pentagon's growing interest in a greener, cleaner – and deadlier – military force will lead it to command increasing forays into the previously foreign territory of clean technology.

2002 Top Headlines

Air Products to Install Hydrogen Infrastructure Into a Submarine

Electric Fuel Corp. to Supply US Army

German Navy Launches Fuel Cell Submarine

GM to Sell Fuel Cells For Emergency Backup

Mechanical Technology, Other Fuel Cell Developers, Counting on R&D Boost from Military

MesoFuel Reforms Surrogate Military Fuel into Hydrogen

United States Navy to Deploy Largest Federal Solar Electric System

Select Companies to Watch

Acumentrics
www.acumentrics.com

Air Products
www.airproducts.com

Mechanical Technology
www.mtimicrofuelcells.com

MesoFuel
www.MesoFuel.com

Plug Power
www.plugpower.com

Profile:
MTI Microfuel Cells

Location
Albany, New York
www.mtimicrofuelcells.com

Founded
2001

Employees
50

Technology
Methanol-based fuel cells for portable electronic devices. MTI Micro's current prototype includes a replaceable methanol fuel cartridge and is half the size of a 2001 version.

The Buzz
Harris Corp. tapped MTI in November 2002 to develop micro fuel cell prototypes for its Falcon II tactical radios for the military, and that could be the deal that vaults MTI from an R&D outfit (it has two patents and 30 pending) to a product deliverer. The prototypes, to be delivered early this year to Harris' RF Communications unit, will be an important test for fuel cells as battery replacements for the Army's Soldier of the Future initiative. MTI is also developing fuel cells for wireless scanners and other handheld devices from Intermec.

Brain Trust
Chairman and CEO William Acker specializes in early tech development; he joined MTI in 2000 from Plug Power, another fuel cell company. He's the current president of the IEEE. Board members include David Peet, global head of fuel cells for DuPont; former US Secretary of Defense William Perry; and Jeong Kim, former Group President of the Optical Networking Group at Lucent Technologies.

Bankrollers
MTI is a subsidiary of Mechanical Technology Inc. (NASDAQ: MKTY), which had revenue of $4.2 million and a loss from continuing operations of $15.8 million in the first nine months of 2002. DuPont has a supplier/partner relationship with MTI Micro and owns a 6% stake in the company.

Our Take
Watch the Harris deal closely; its success is a big test not only for military applications of fuel cells, but also for MTI's ability to commercialize its methanol-based technology. MTI is seeking more big OEM partners beyond DuPont this year with an eye toward full-scale commercialization in 2004.

4. SOLAR PV BREAKS THROUGH PRICE BARRIER

Advancements in photovoltaics technology and manufacturing are likely to make subsidy-free solar PV a reality by the end of this decade. While PV is now cost-competitive with conventional power sources in many off-grid applications, the goal of affordable, abundant energy from the sun has remained elusive. Simply put, PV has remained a pricey, niche market. Most grid-connected applications still require significant subsidies and tax incentives to be affordable by end users – and even then PV installations can take years to break even. But the price differential between conventional energy sources and solar are declining as manufacturers deploy new technologies and exploit economies of scale with larger production lines.

The drive towards higher efficiency and lower costs has been steady over the past three decades, but has only recently reached an inflection point

In 2002, just over 500 MW of solar modules were shipped globally, compared with 60 MW a decade ago. Meanwhile, wholesale PV module prices dropped from around $6 per peak watt to approximately $3 and the average per-watt cost of an installed system dropped from around $16 to under $10. Still, it will take a concerted effort by industry, government, and investors to bring PV to cost-competitive scale.

This is starting to happen. Established manufacturers, emerging start-ups, and multinationals have their sights set on low-cost, high-efficiency PV. Many are aiming for module pricing of $1 per peak watt, and installed systems of $3 per watt. At these prices, electricity from solar would cost around 8 to12 cents per kilowatt-hour, competitive with typical grid-based energy prices. Clean Edge predicts that this would enable the global solar industry to reach 10,000 MW in annual shipments globally, a 20-fold increase over current levels.

The drive towards higher efficiency and lower costs has only recently reached an inflection point. An impressive array of new technologies that create low-cost, high-efficiency solar-collecting materials on a variety of materials, or substrates, are emerging from government, university, and private-sector laboratories. While not all will emerge as winners in the PV marketplace, we expect that several technologies will find markets in specific applications – from rooftop solar modules to more specialized applications, such as solar-collecting textiles. Many of these technologies look beyond traditional silicon as their principal material to more exotic substances: copper, gallium, indium, titanium, and others. There are even efforts to grow organic solar cells from a variety of materials.

In addition to making solar cells cheaper, the industry will need to find ways to reduce the costs of the rest of the system needed to convert sunlight into electricity, including inverters and energy conditioners. Equally important, the PV industry will need to develop turnkey solutions to ensure inexpensive, “plug-and-play” installation.

To fulfill solar's potential will require continued technological innovation, favorable economies of scale from ramped-up manufacturing, cost improvements across the balance of system and installation, and supportive and consistent government policy. Meeting these challenges will mean cheap and abundant solar power without subsidies by the end of the decade.

2002 Top Headlines

PowerLight Starts Around-Clock Production of Panels

US Group Makes Cheap Plastic Solar Energy Cells

ECD Ovonics Says Solar Sheets Will Compete with Utilities

Honda Develops New Solar Cell

Shell Solar Restructures to Improve Competitive Position

Canadian Firm Says Set to Slash Solar-Power Costs

Sharp Corporation to Charge Up Solar Module Business in US

Kyocera to Further Boost Solar Panel Output by 70%

Select Companies to Watch

AstroPower
www.astropower.com

Konarka Technologies
www.konarkatech.com

NanoSolar
www.nanosolar.com

Unisolar
uni-solar.com

Xantrex
www.xantrex.com

Profile:
Konarka Technologies

Location
Lowell, Massachusetts
www.konarkatech.com

Founded
2001

Employees
25

Technology
Polymer-based photovoltaic solar cells

The Buzz
Cheaper, smaller, more versatile, and faster to build than traditional PVs, Konarka's cells are built on lightweight polymers rather than silicon or glass. That opens the door to a host of small-scale consumer, industrial, and military applications. In October 2002, Konarka landed top honors in the first National Clean Energy Venture Competition sponsored by Bechtel Corp. and the National Renewable Energy Lab.

Brain Trust
President and CEO Bill Beckenbaugh (Sanmina-SCI, Hadco, Motorola, Lucent); COO Paul Wormser (Advanced Energy, solar subsidiaries of Exxon and Mobil); VP of R&D Russell Gaudiana (Polaroid). 2000 Nobel laureate in chemistry Alan J. Heeger is a director.

Bankrollers
Konarka landed one of the biggest cleantech funding bonanzas of 2002, closing a Round B pool of $13.5 million in October. Round leader Draper Fisher Jurvetson was joined by Round A leader Zero Stage Capital, as well as Ardesta LLC, NextGen Partners, and corporate investors ChevronTexaco and Eastman Ventures. Draper director Raj Atluru joined Konarka's board.

Key Customers
The US Army's soldier research center in Natick, Mass.

Our Take
Slashing the cost of PV manufacturing has been an industry quest for decades, and Konarka's titanium dioxide polymers could be a big breakthrough. The company claims it may be able to price cells at roughly half the cost of silicon-and-glass-based PVs. Konarka's blue-ribbon investors are clearly confident in the firm's potential, though Konarka still must prove itself in manufacturing technology, which it will consider licensing. Its first factory-floor pilot system is slated to start rolling later this year.

5. OPTIMIZING THE GRID

A great deal of clean-energy technology has focused on distributed generation (DG) – technologies, like solar PV and fuel cells, that produce power near where it is needed, as opposed to generating it in centralized power plants, where it is sent by wire to substations and distributed to individual homes and businesses. Some of the motivation for DG comes from the stresses and bottlenecks experienced throughout the grid – at least in developed countries.

But what if we could make the existing grid work so much more efficiently that it could reduce the need for additional power plants or costly redundant systems designed to work "just in case" of peak demand? That's the vision of a growing corps of researchers and companies working on grid optimization, a term that describes a wide range of technologies that help utilities and energy users to better understand and analyze exactly what's going on in a complex energy system on a real-time basis, then makes changes to optimize the system for maximum cost-effectiveness.

In addition to improving the efficiency of conventional energy technologies, grid-optimization technologies could also improve the performance and cost of renewable energy systems

The benefits of optimization can be significant. Grid optimization can defer the building of additional generation, transmission, and distribution capacity, reduce generation reserve margins, better use existing electric system assets, reduce financial risk for electric system investments, decrease risks of outages, and increase overall grid security. "Grid optimization is the key to creating a system that's much more efficient, effective, reliable, secure, and clean," says Steven Hauser, Director, Energy Programs, at the federal government's Pacific Northwest National Lab (PNNL).

Hauser is at the hub of a growing collaboration among government and industry to develop and implement a variety of technologies and services, from real-time pricing to "grid-friendly" chips. Included are large info-tech firms (notably IBM and Cisco Systems), large energy companies (Alstom and Sempra Energy Solutions, for example), as well as a passel of smaller newcomers. In 2003, a group of these firms formed the Consortium for Electric Infrastructure to Support a Digital Society.

In addition to improving the efficiency of conventional energy technologies, grid-optimization technologies also could improve the performance and cost of renewable energy systems. Take solar photovoltaics, for example. A PV system produces low-voltage DC current. To connect it to the grid requires running it through an inverter to pump it up to 120 volts. In many cases, that 120-volt energy is run back through transformers that power devices (such as laptop computers and anything else that has a plastic "brick" as part of the power cord) that require only 2 or 3 volts of DC power.

That's a waste of energy and equipment. Smart software and related technology could automatically send solar-generated DC power directly to DC appliances, thereby improving renewables' efficiencies and reducing their costs.

The benefits are potentially enormous. PNNL calculates that if optimization technologies can defer about 55 gigawatts of electricity by 2020 – just 5% of the total forecasted grid capacity – it would yield present value savings of more than $45 billion. A modest 25% reduction in electricity outages could yield another $15 billion in benefits.

We believe such eye-popping numbers will propel both innovators and investors into this space, allowing dirty plants to be retired and construction of new plants to be deferred. Given that the cleanest energy plant is the one that you don't have to build, grid-optimization represents the ultimate clean-energy play.

2002 Top Headlines

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Profile:
Optimal Technologies

Location
Calgary, Alberta and Benicia, California
www.otii.com

Founded
2000

Employees
17

Technology
Software and related services to optimize the efficiency of power generation, transmission, and usage.

The Buzz
Optimal got a big boost in October 2002 when chosen to work with the California Energy Commission's distributed energy resource (DER) planning project for Silicon Valley. One of the largest DER efforts to date, the project — sparked by the state's infamous rolling blackouts of 2000-01 — will use Optimal's AEMPFAST software to optimize and analyze different transmission and distribution scenarios for the region. The results of this effort could be applied to grid optimization worldwide.

Brain Trust
Founder, chairman, and CEO Roland Schoettle has 25 years' experience in high-tech business development and is a frequent speaker at industry events.

Bankrollers
Law Investments; founder Schoettle

Key Customers
State of California, National Renewable Energy Laboratory

Our Take
Optimal is well-positioned at the confluence of energy efficiency and infrastructure security, two areas of high interest in the energy arena. One study of homeland security calls grid optimization "one of the four pillars of self-healing infrastructure." The theoretical benefits are obvious. But the big challenge for Optimal — and for the whole sector — will be making the leap from R&D to widespread commercial use. Progress in Optimal's Silicon Valley project will help immensely.

ABOUT CLEAN EDGE

Clean Edge, Inc., based in the San Francisco Bay Area, is a leading research and consulting firm that helps companies, investors, and policymakers understand and profit from clean technologies. Through its business consulting services, research reports, and industry events, Clean Edge's mission is to catalyze the development of clean-tech companies and markets. Founded in 2000 by environmental and high-tech business pioneers Joel Makower and Ron Pernick, Clean Edge and its network of partners and affiliates offer unparalleled insight and market intelligence on clean energy, transportation, and materials.

To keep abreast of the latest clean-tech developments, track clean-tech stocks, read industry reports, or sign-up for CLEANWATCH, our free twice-monthly newsletter, visit www.cleanedge.com. To contact Clean Edge, email us at info@cleanedge.com or call 510.465.3600.

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Clint Wilder, contributing editor for Clean Edge, is a veteran award-winning technology and business journalist. Most recently he was editor-at-large and columnist for *Optimize* magazine, CMP Media's monthly journal for high-level business technology executives. As editor-at-large and columnist for *Information Week* before that, he won the 2002 American Society of Business Publication Editors gold award for best feature series, as well as numerous CMP editorial awards. A frequent speaker and panelist at industry events, Wilder also worked as a writer and editor at *Corporate Computing* and *Computerworld*.

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Connecticut Clean Energy Fund (www.ctcleanenergy.com) promotes the best interests of Connecticut citizens by investing in enterprises and initiatives that will help make the state an international leader in the development, production, and use of energy from clean and renewable sources. The fund is expected to aggregate over $100 million for investments in a range of clean-energy technologies and initiatives.

Environmental Entrepreneurs (E2) (www.e2.org) is a national community of business people who believe in protecting the environment while building economic prosperity. Working with the Natural Resources Defense Council, E2 serves to champion good environmental policy that takes a reasoned, economically sound approach. E2 works at both the state and national levels through its bipartisan efforts.

Nth Power (www.nthpower.com) is a leading venture capital firm dedicated exclusively to high potential investments resulting from the restructuring of the global energy industry. Nth Power currently manages over $250 million invested in more than 20 companies. And nearly 10 years after its formation, Nth Power continues to provide Energy, Vision and Capital to entrepreneurs seeking to take advantage of the high-growth potential that this expanding market now offers.

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