The New Age of Photo

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SILICON IS THE KEY

The mainstay of photovoltaic technology is crystalline silicon in various forms that produce an electrical current when exposed to sunlight. Photovoltaic arrays consist of panels made of silicon wafers (1, photo above) or of a thin film of amorphous silicon (2, courtesy of United Solar Ovonic). The newer thin-film technology shows up in flat panels, as roofing slates, and in flexible sheets that can be applied to metal roofing (photo facing page). Photo this page: Scott Gibson.

Increased efficiency and better incentives are driving builders and homeowners alike to a cleaner source of electricity

BY SCOTT GIBSON

Solar-generated electricity represents just a tiny fraction of the power consumed by U.S. households, and to Paul Kopper, that sounds like a big opportunity. The Michigan airline pilot turned developer is putting the finishing touches on plans for a 42-lot subdivision in which every house comes with its own photovoltaic roof.

Kopper envisions tight, well-insulated houses ranging in size from 1800 sq. ft. to 3000 sq. ft. with geothermal heating and cooling and roof shingles that make electricity. Even in Michigan, not the sunniest of states, the roof will give homeowners a measure of energy independence they've never had before.

Kopper is among the 15,000 or so builders and homeowners who this year will take advantage of state subsidies, federal

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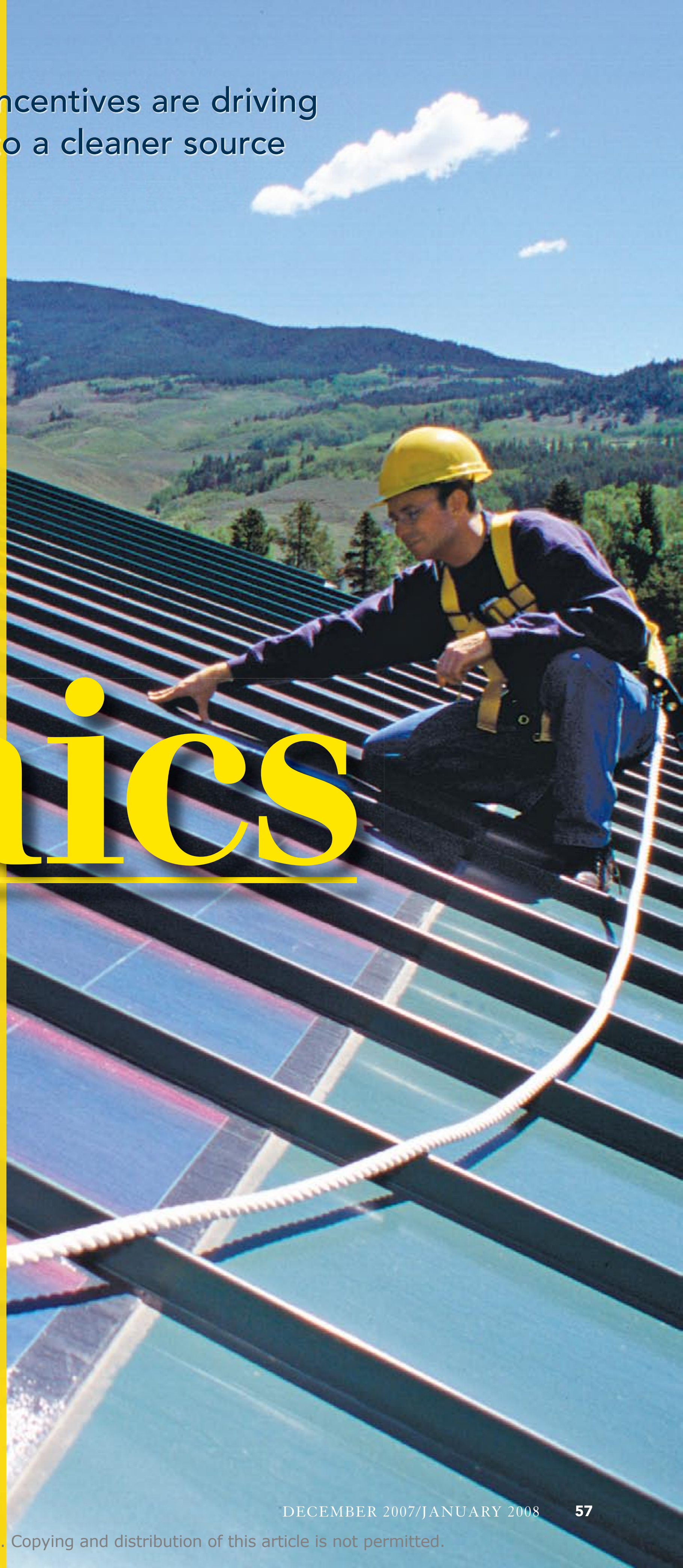

tax credits, and steadily improving technology to turn south-facing roofs into electricity-generating stations. Most will remain tied to their local electric utilities, generating some but not all the power they need. And while the systems remain expensive, manufacturers say annual sales are growing at a double-digit clip as solar modules become more sophisticated and more efficient.

How do these things work?

A photovoltaic cell is a deceptively simple device with no moving parts that generates electricity directly from sunlight. Although there are now a variety of types, almost all of them are based on silicon, an abundant element found all over the globe. When sunlight strikes high-grade silicon that has been arranged in a photovoltaic cell, electrons break free to create electrical current.

Silicon is made into solar cells in several ways. The two most common are to slice crystalline silicon into thin wafers and encapsulate it inside a glass-and-polymer sandwich; or to apply an amorphous film (also known as thin film) to a substrate.

Researchers also are able to coax electricity from a variety of materials other than silicon. These newer compounds prom-

During the country's first

TRIED-AND-TRUE METHODS

Arrays of flat panels **(1)** are probably the most familiar. To maximize annual energy production, they should face the sun as directly as possible, roughly south or a little west of south and in the northern hemisphere tilted at an angle that approximates the latitude of the site. That is, panels on a house built at 28° north should be tilted upward at 28°; panels on houses at 44° north should be tipped at 44°. Flat panels also can be mounted in an array **(2)** that tracks the sun as it moves across the sky, which boosts efficiency, but adds cost and complexity to the initial setup. Flat panels are typical for retrofits because they can be mounted on top of an existing roof. They might not be pretty, but flat panels tend to shed snow quickly, can be installed quickly and added to later, and are adjustable for sun angle.

ise to be more efficient, but for the time being, silicon in one form or another is still king.

Photovoltaic devices date from the 1950s, but the efficiency of cells—the amount of power they generate as a percentage of solar potential—has risen steadily. The highest efficiencies come from monocrystalline silicon (silicon sliced from a single grown crystal). For commercially available residential systems, that's about 18% or a little better. The efficiency of most crystalline-silicon cells is closer to the midteens, while the efficiency of thin-film products is lower, roughly 10% or less.

If those numbers seem awfully low, consider that the overall efficiencies have more than tripled over the past 30 years. In fact, researchers can make cells that are 40% or more efficient, but they're not economically feasible for mass production, at least not yet. Still, the future holds some tantalizing possibilities for both greater efficiency and lower costs (sidebar p. 63).

Efficiencies directly affect the amount of square footage required to generate a given amount of power. But that's not how you'll go shopping for a PV system. What most of us would be looking at is the rated capacity, or output, of a solar cell or panel—that is, how much juice the system can produce. Output is measured in watts, but numbers can be deceiving (sidebar facing page).

Grid-tied systems are more popular today

During the country's first solar boom, which took place in the 1970s and early '80s, the majority of residential photovoltaic systems were off the grid, meaning they supplied all the electrical power the system consumed. These stand-alone systems were installed on houses or devices where utility power wasn't available or was too expensive. But in the past five years, grid-tied systems have taken over as photovoltaics have moved from remote cabins and island retreats to upscale suburbia.

It's not an insignificant development. Grid-tied systems are based on something called net metering, which allows houses to draw on utility power when it's needed and to sell power to the utility when the system produces a surplus. Grid-tied systems typically have no battery backup, making them less complicated to install and operate. Even though homeowners remain tethered to their local utilities, they don't have to worry about running short of power or about calculating precisely how much electricity they will consume.

With an off-the-grid system, every electron counts, not only in regard to how much power the system can produce but also in how the electricity is allocated. If the electrical load is greater than the PV modules can produce, power is drawn from a bank of batteries, an integral part of an off-the-grid system.

Both systems need an inverter, which changes the direct current produced by photovoltaic cells into alternating current, as well as other sundry pieces of equipment.

As grid-tied systems become more prevalent, they're also getting bigger. Industry experts say average systems have grown from less than 2kw a few years ago to 4kw or more today.

For those of us who aren't electrical engineers, what do those numbers really mean? For a variety of reasons, there is no single answer. Mike Taylor of the Solar Electric Power Association says that in Arizona, a 5kw system could produce between 8000kwh (kilowatt-hours) and 9000kwh of electricity per year, roughly what the average American household

Drawings: Toby Welles/WowHouse.net

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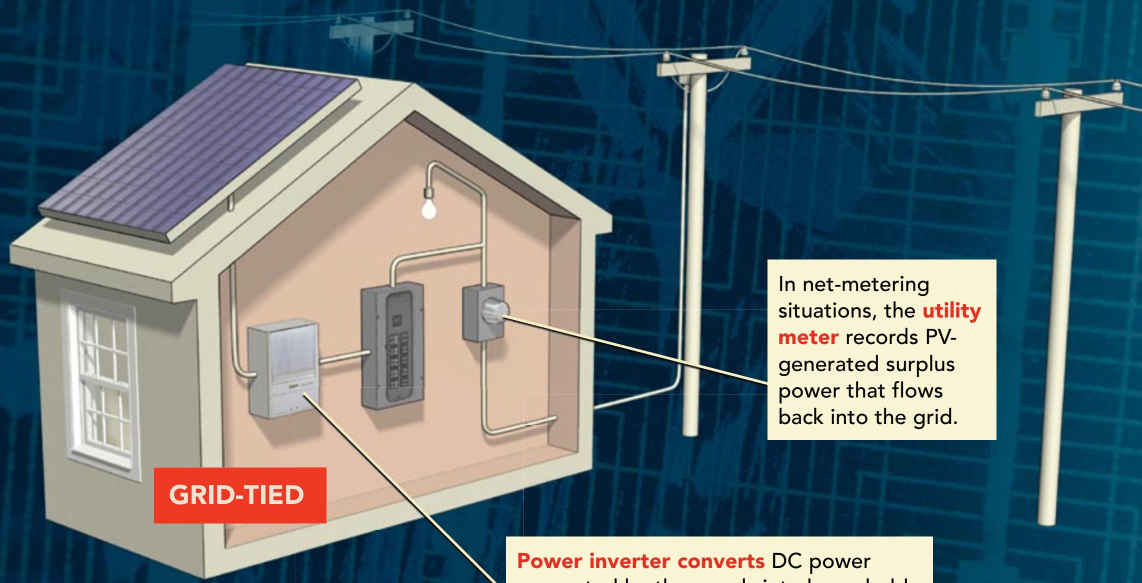
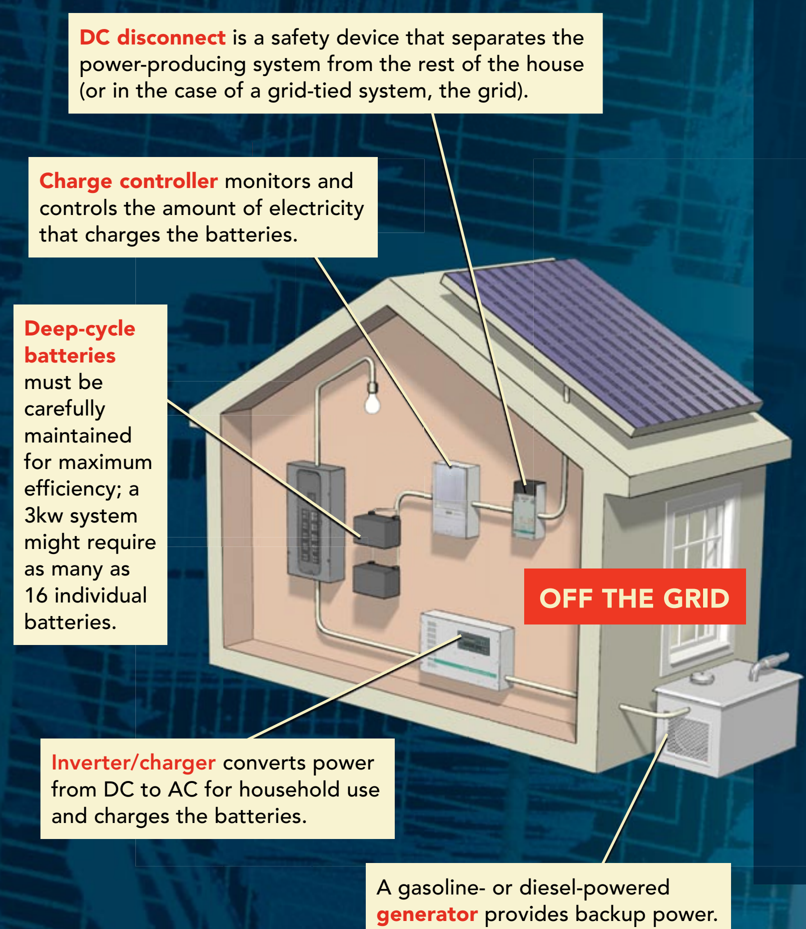




GRID-TIED OR OFF THE GRID?

Up to a point, there's not much difference between a PV system connected to the grid and a stand-alone off-the-grid system. That point is at the inverter, which changes the DC power to AC that you can use. Beyond that, they diverge quickly. An off-the-grid system must be more robust to handle an entire household's demands for electricity and have batteries to store the electricity at night or when it's cloudy. Many off-the-grid PV customers (and some grid-tied as well) have a backup generator for emergencies. A self-contained 3kw system costs about $30,000. Warranties typically run for 25 years; well-maintained batteries should last for 10 to 15 years.

Real power vs. rated power

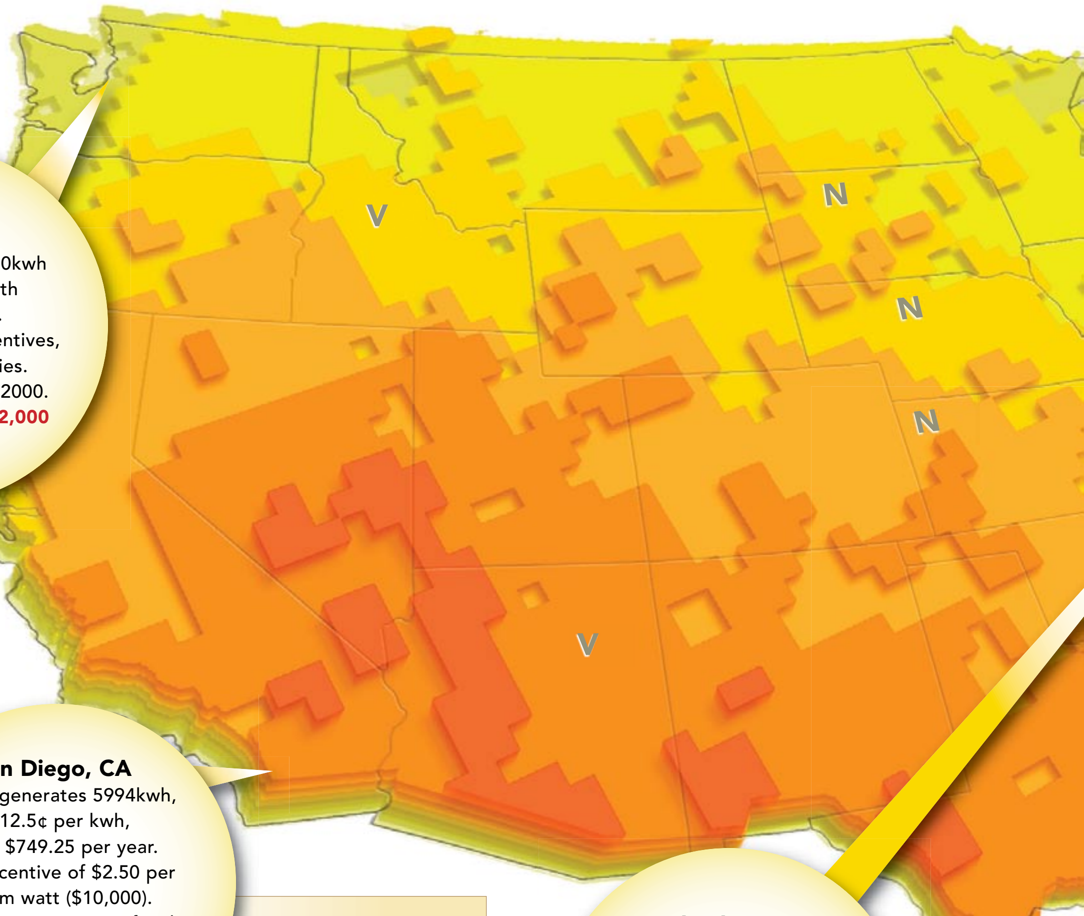
Photovoltaic cells are designed to produce a stated amount of electricity—but that's what you get only under ideal circumstances, what the industry calls "standard test conditions."

As explained by Bob Reedy of the Florida Solar Energy Center at the University of Central Florida, a variety of factors can lower that number:

- **Solar potential at the site.** Output is calculated on the assumption that the sun is providing 1000w of potential per square meter. In areas that don't get that much, power output is lower. Additionally, local weather conditions and latitude also affect how much sunlight the cells get (see pp. 60-61). Good designers take seasonal and daily fluctuations of sunlight into account.
- **System efficiency.** Some energy is invariably lost in the process. An inverter, for example, typically loses roughly 5%, although more-efficient inverters are on the horizon.
- **Operating temperature.** Most cells perform better when they're cool. They lose between 0.4% and 0.5% of their efficiency per degree Celsius above the standard test condition of 25°C. On a hot roof, that can amount to a 15% loss, one reason that thin-film cells attached directly to a roof deck are likely to produce less power than flat panels with an airspace beneath them.

WHERE'S THE BEST POWER POTENTIAL?

Depending on where you live, a 4kw photovoltaic system with an initial cost of $36,000 could end up costing a lot less. Federal and state incentives can reduce the cost by as much as half. The remainder returns in the form of electricity, which depends on location and solar exposure. In a net-metering situation, as a utility's rates increase, power supplied by the PV system becomes more valuable. To show the effects of these variables, we chose five locations around the country. Each was modeled with a 4kw system installed to maximize production; an estimated system cost of $36,000 is based on the national average cost of $9 per watt (installed). Data from the National Renewable Energy Lab's (NREL) PVWATTS calculator and the Database of State Incentives for Renewables & Efficiency (DSIRE; see sources) was used to construct each.



Seattle, WA
System generates 3880kwh at 6¢ per kwh, worth $248.32 per year.
Maximum of $2000 incentives, paid by state's utilities.
Federal tax credit of $2000.
Total system cost: $32,000

San Diego, CA
System generates 5994kwh, at 12.5¢ per kwh, worth $749.25 per year.
State incentive of $2.50 per system watt ($10,000).
Property-tax exemption for the value of the system.
Federal tax credit of $2000.
Total system cost: $24,000

The California Solar Initiative approved $3.2 billion in rebates for solar power over the next 11 years.

Columbia, MO
System generates 5282kwh at 7¢ per kwh, worth $369.74 per year.
$2000 state rebate ($500-per-kw system).
Federal tax credit up to $2000 for purchase of system.
Total system cost: $32,000

Net metering

V= States that allow net metering in some but not all areas

N= States that don't allow net metering

kwh/m²/day

4-4.5 | 4.5-5 | 5-5.5 | 5.5-6 | 6-6.5 | 6.5-7

Map indicates an annual average of daily solar-radiation potential for a south-facing flat photovoltaic array, mounted at an angle equal to its latitude. Data courtesy of National Renewable Energy Laboratory.

consumes. In rainy Seattle, the same system might generate between 5000kwh and 6000kwh per year.

Brad Collins, executive director of the American Solar Energy Society, guesses that an average residential system produces roughly 60% of a household's energy needs. "It's like most things," he says. "To try to get that last 20% or the last 10% becomes very expensive. Most people are happy to accommodate half or a little more than half of their electric needs with their own system."

Costs are still high, but PV takes the guesswork out of energy bills

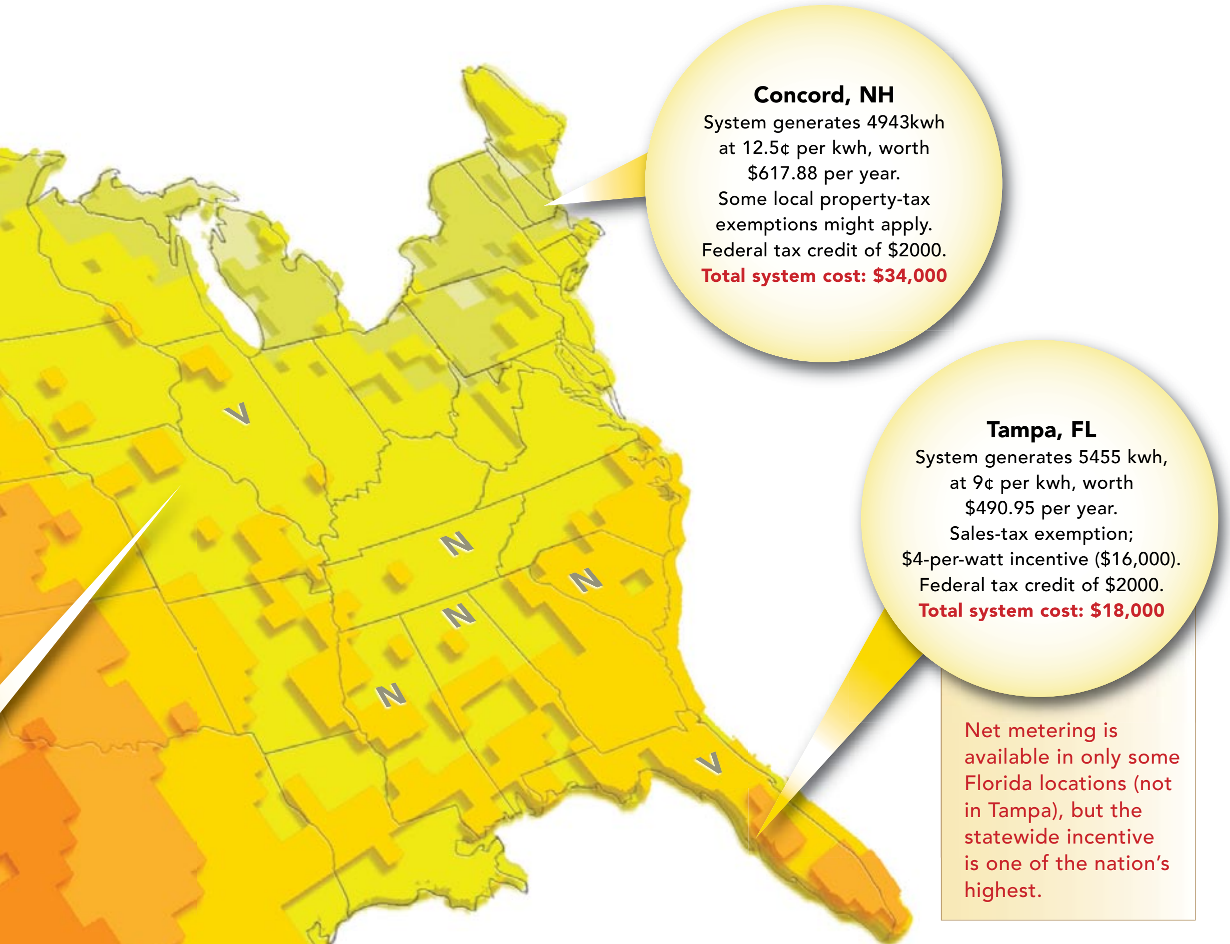
Americans lost interest in solar power during the 1980s as energy costs declined and federal subsidies ended. Now energy costs are rising and looking more uncertain than ever. Both federal and state governments are again offering incentives that make photovoltaics more attractive.

Most visibly, the state of California has embarked on an ambitious 10-year, $3.3-billion program to put PV panels on 1 million roofs by 2016. The goal is to create 3000 megawatts of new solar-generated electricity by 2017. PV panels are even showing up in some big-box stores. The Home Depot, for example, now offers a 10w solar panel called the GTO/Mighty Mule for $239. The 23-in. by 15-in. panel is intended to charge 12v batteries for a gate opener.

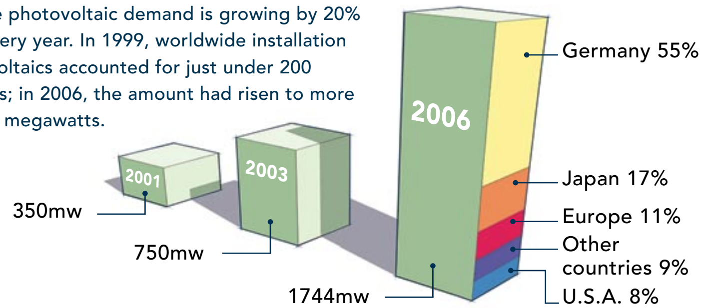
Federal help comes in the form of a $2000 tax credit, but state rebates can be significantly more. Photovoltaics tend to be a stronger draw in states that are giving away more money. (For a state-by-state list of rebates, see "Web Resources," p. 63.)

"The markets in the states that are the most vibrant are the markets that have (a) renewable-energy portfolio standards and (b) renewable-energy portfolio standards that have significant solar incentives," says Collins. "What you see in those states is that once they've established those incentives over the course of a very few years, they generally increase those incentives, mostly by extending the duration and the percentage of renewable energy they want to have as part of their electrical system."

Chart, facing page: Dan Thornton



According to solar-research company SolarBuzz Inc., worldwide photovoltaic demand is growing by 20% to 25% every year. In 1999, worldwide installation of photovoltaics accounted for just under 200 megawatts; in 2006, the amount had risen to more than 1700 megawatts.



Incentives help to overcome one simple fact about photovoltaic systems: They cost a lot of money to install. Cost per installed watt is the industry benchmark for tracking prices. Before rebates and incentives, that number averages somewhere between $8 and $10 per watt, meaning that a 3kw system would cost about $30,000 but generate only a portion of an average household's needs. Rebates can knock that number in half—provided you live in the right state (California, New Jersey, Colorado, or Maryland, for instance).

Bob Reedy, executive director of the Florida Solar Energy Center, argues that the price per kilowatt hour of electricity is a more accurate way of measuring costs. That's how our utility power bills are calculated. Translating cost per installed watt to cost per kilowatt hour, however, isn't necessarily straightforward. Photovoltaic performance can vary in relation to geography, latitude, weather, shade, and temperature. "If you express cents per kilowatt hour, it's implicit that you've factored in all of those things," Reedy says. A simple cost-per-watt calculation doesn't.

In rough terms, according to Reedy, if you buy a $10-per-watt system (before rebates), it works out to be 35¢ per kwh in an "average" location. That's higher than utility rates in many states, but it's competitive in other areas, especially during times of peak demand.

Taking the guesswork out of electricity costs is one of the big benefits of installing PV. The rest of the country will just have to wait and see what happens as some sources of energy are tapped out and others take their place. Prices are unlikely to go down, but the cost of PV-generated power is stable over the 20- to 25-year life span of the system. Maintenance costs are low.

"One of the big drivers for people who put PV on their houses is they know what their utility bill is going to be, at least for whatever percentage of it they're going to satisfy with what's on the roof," says Collins. "They're much more immune to volatility in electric rates than the guy next door."

In addition, rolling the cost of a PV system into a mortgage can mean almost instant payback. "If your energy savings and production

Would you rent your electricity?

Faced with many potential customers who balk at the high price tag of a photovoltaic system, the marketplace could be coming to the rescue. At least two new companies are trying to build the necessary customer base that will allow them to provide photovoltaic equipment to residential and commercial customers in exchange for a rental fee.

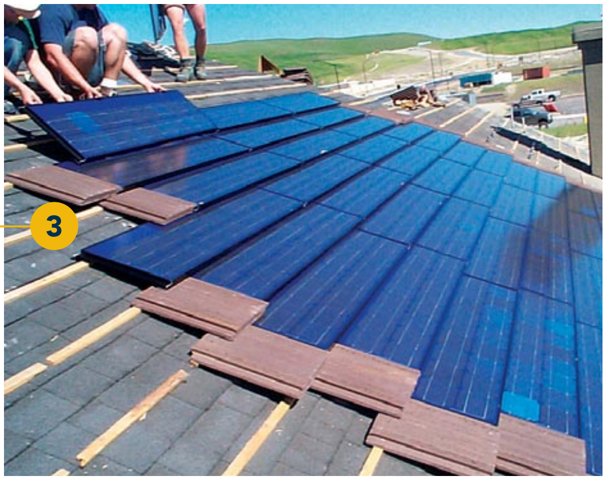
Citizenre **(www.citizenre.com)** and Recurrent Energy **(www.recurrentenergy.com)** have both launched campaigns to attract customers who want solar power but can't foot the big bill. Pursuing both residential and commercial interests, Citizenre is offering to install a system in exchange for a modest deposit and a monthly charge for the electricity produced, based on local utility rates. For instance, for signing a 25-year contract and paying a $500 deposit, a Citizenre customer would then pay a locked-in rate, say 12¢ per kwh, to Citizenre for the power their system produces. Recurrent Energy is pursuing businesses exclusively at this time.

While neither company officially has opened its doors, unofficial estimates put their starts within the next year.

1

A growing number of building-integrated photovoltaic products (called BIPV in the business) allow designers to disguise the systems in the roof itself. They can be either crystalline-silicon or thin-film versions. Sunslates from Atlantis Energy Systems (www.atlantisenergy.org), Kyocera's MyGen Meridian (www.kyocerasolar.com), and SunTiles from SunPower Corp. (www.sunpowercorp.com) all are examples of crystalline-silicon roofing products. Sunslates **(1, 2)** are installed over a grid of 2x2 sleepers and 1x4 nailers that rest on the roof (photos courtesy of Atlantis Energy Systems). The manufacturer says they can be installed by roofers and electricians.

General Electric (www.gepower.com) takes a slightly different approach with its Roof Integrated Modules, which are designed to be compatible with tile roofing **(3)**. A standard panel is just over 58 in. long and 17½ in. wide. Designed for quick installation, panels overlap along upper and lower edges and interlock at the ends. Different sizes are available to fit cement tile from different manufacturers.



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"People still don't know

of electricity exceeds what you would pay on your mortgage, then the cost per kilowatt hour is almost irrelevant," says Mike Taylor of the Solar Electric Power Association. "You're getting a return on your investment."

Buying photovoltaics is also more than a dollars-and-cents equation. As sustainable building picks up steam and global warming looms as a more widely accepted threat, making your own electricity becomes a social contribution. "Most people who buy photovoltaic systems are trying to do the right thing," says Cécile Warner, principal engineer at the National Renewable Energy Laboratory in Golden, Colo.

Without energy-efficient designs, PV doesn't make much sense

Because of the high initial cost of photovoltaics, reducing the electrical load in the house is key. Builders and homeowners already have quite a bag of tricks for accomplishing that. There are products designed to reduce electrical consumption—compact fluorescent lightbulbs, for example, and Energy Star-rated appliances—as well as building techniques that lower energy needs. Devices that use a lot of electricity, such as electrical-resistance heating, aren't the best choices in PV-powered homes.

2

The best candidates for PV systems are houses that have been designed from the ground up with conservation in mind. Passive-solar designs, tight building envelopes, and up-to-date insulation all contribute to lower energy needs and stretch PV-generated electricity that much farther. In that respect, the solar industry is still waging an uphill fight.

"Most people are fundamentally energy illiterate," Collins says. "Energy illiteracy is to my mind the single biggest barrier to getting people to understand how their individual behavior affects energy and how they can affect energy decisions, from the utility to their politicians, by understanding not only where energy comes from but also the environmental consequences of those sources of energy. We need to stop burning things to create our energy. That's 19th-century

very much about solar and even those who do still think of it as hot water, like it used to be back in the ’70s—just pipes on top of the roof.”

Marc Cortez, Sharp Electronics

Peering into the future

Researchers are studying a variety of non-silicon-based photovoltaic panels that promise cheaper manufacturing and more-flexible applications. At the Wake Forest University Center for Nanotechnology and Molecular Materials, scientists have created plastic solar cells with an efficiency of more than 6%. That’s not much compared to the 18% or 20% efficiency of some commercially available crystalline-silicon cells, but it’s double the efficiency of plastic cells just two years ago.

In New Zealand, researchers are developing colored dyes made from titanium oxide, an abundant and nontoxic mineral. They hope eventually to produce solar cells at about one-tenth the cost of silicon-based products.

In the United States, manufacturers are experimenting with thin films made of copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe) that could one day be cheaper than silicon cells and just as efficient.

Cécile Warner, principal engineer and a 28-year veteran of the National Renewable Energy Laboratory, thinks that thin-film technology will take over eventually, but not for a decade or more. Over the next five to 10 years, she expects ongoing improvements in silicon-based cells.

One breakthrough, says Brad Collins of the American Solar Energy Society, would be the development of materials that shed more than one electron when struck by a light photon. That would boost efficiency by “an order of magnitude.”

“Once that happens,” he says, “at the residential level, it will be the cheapest form of electricity you have. All we need to do is put the money behind it. There’s a large body of scientists who say 10 years and a billion dollars, or a hundred million dollars a year for 10 years, and you could have it to a point where it could be a demonstration technology and not just in somebody’s lab.”

technology that’s been subsidized with massive amounts of federal money for decades.”

Marc Cortez, marketing director for Sharp Electronics’s solar-energy group, says the new-home market has been slow to adopt solar. Most growth has been in the commercial market, and residential retrofits are still the heart and soul of the business. That, however, could change as builders in a slow housing market look for ways to compete and as Washington ponders broader incentives and the possibility of renewable-energy requirements. “I have my challenge ahead,” Cortez says. “It’s safe to say that most people still don’t know very much about solar, and even those who do still think of it as hot water, like it used to be back in the ’70s—just pipes on top of the roof.”

That wouldn’t be Paul Kopper, remarkable not because he’s planning a photovoltaic-powered community but because he’s doing that in Michigan, far from traditional solar strongholds. Kopper admits it could take twice the number of panels in Michigan to get the same amount of electricity as it would in, say, California.

“But once the project goes and it’s seen that it works here in Michigan, we will change the mind-set of America, one community at a time,” he says. “How would you like to have a house to live in where your heating and cooling and electricity were free?” □

Scott Gibson is a contributing editor. Photos courtesy of the National Renewable Energy Laboratory, except where noted.

WEB RESOURCES

There are a variety of information sources on the Web for anyone wanting to learn more about photovoltaics. While by no means complete, the following list will get you started.

www.nrel.gov
Home of the National Renewable Energy Laboratory, part of the U.S. Department of Energy. Excellent source of general information on all kinds of renewable energy, including PV. For design help, check www.nrel.gov/homer for somewhat geeky software or http://rredc.nrel.gov/solar/codes_algs/PVWATTS/ for something a little less complicated.

www.dsireusa.org
From North Carolina State University, the most comprehensive database of state and utility incentives for renewable energy.

www.ases.org
Home of the American Solar Energy Society.

www.findsolar.com
A site where you can track down a local solar contractor and use an interactive calculator that produces recommendations for PV systems along with projected costs and paybacks.

www.irecusa.org
Home of the Interstate Renewable Energy Council; includes an extensive list of links for other renewable-energy sites.

www.solardecathlon.org
Site of a global college-team competition in solar design that took place in October in Washington, D.C. Check FineHomebuilding.com for coverage of this year’s Solar Decathlon.