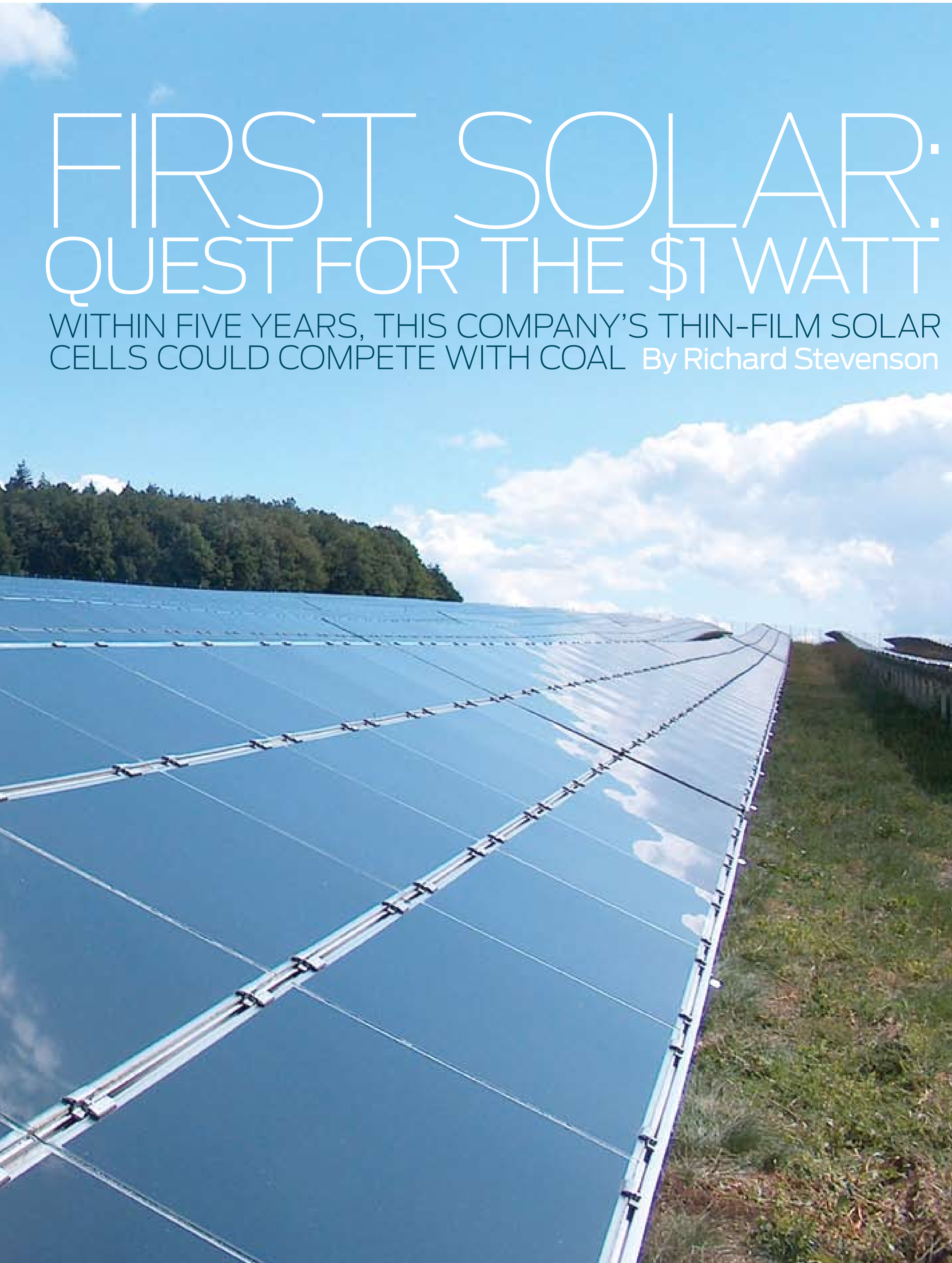
FIRST SOLAR: QUEST FOR THE $1 WATT

WITHIN FIVE YEARS, THIS COMPANY'S THIN-FILM SOLAR CELLS COULD COMPETE WITH COAL

By Richard Stevenson



IT'S EASY TO MAKE A SMALL PILE OF MONEY OFF photovoltaic cells but very hard to make a big one. The reason is one of the most fundamental in free-market economics: the larger the market you aim for, the more competitors you'll have to face.

THE HUGE SCALE of First Solar's manufacturing prowess is evident in single panels [previous spread] and in arrays like this 40-megawatt solar farm in Brandis, Germany.

IF YOU JUST WANT TO POWER a billion-dollar space probe, almost any price per watt is acceptable. If you are selling to lonely farmhouses, you just have to charge less than the cost of running a power line to the boondocks. In some parts of the world, competing with grid electricity itself may be an easy game during peak consumption hours. But if you want the off-peak market, you'll have to price your cells at about US $1 per watt. That price is called grid parity, and it's the holy grail of the photovoltaic industry. At least 80 firms around the world, from Austin to Osaka, are in the chase.

Surprisingly, at the moment no company is closer to that grail than a little start-up called First Solar, which until very recently had been known only to specialists. It's located in Tempe, Ariz., and analysts agree that it will very likely meet typical grid-parity prices in developed countries in just two to four years. It's got a multibillion-dollar order book, it's selling all the cells it can make, it's adding production capacity as fast as it can, and its stock price has rocketed from $25 to more than $250 in just 18 months.

The most tantalizing fact about First Solar? The company will not talk to reporters. At all.

The company's coyness seems to be related to the nature of its industrial secrets. These have less to do with First Solar's device—a decades-old design based on a thin film of cadmium telluride—than with the way the company manufactures it. Somehow, First Solar has scaled up the light-catching area from postage-stamp to traffic-sign dimensions. What the company does reveal is that its product has three massive cost benefits. Its active element is just a hundredth the thickness of the old standby, silicon; it is built on a glass substrate, which enables the production of large panels; and manufacturing takes just two and a half hours—about a tenth the time it takes for silicon equivalents.

Of course, it's not enough that First Solar match the costs of fossil-fuel generation on the grid; it must also maintain its economic edge over other photovoltaics. There are additional nascent technologies, including cells based on copper indium gallium diselenide (CIGS), silicon on glass, and the combination of germanium, gallium arsenide, and gallium indium phosphide. Even conventional silicon technology, which has dominated the market since its commercial launch in the 1950s, seems to have a lot of kick left in it. Currently, though, it's suffering from its own success, as an insatiable demand for silicon cells has led to a scarcity of raw material. However, if the silicon shortage disappears by the end of the decade, as expected, the sale price should drop substantially from recent levels, which have fluctuated between $3 and $4 per watt.

PREVIOUS SPREAD: GEHRLICHER SOLAR; THIS PAGE: JUWI

Right now, First Solar depends mainly on a government-subsidized program in Germany, where it has contracts worth more than $6 billion through 2012. Other markets with the same type of subsidies (known as feed-in tariffs, which spread the cost of alternative energy among all customers) include France, Italy, Spain, South Korea, and Ontario, Canada. To fill these orders, the company is undergoing a massive expansion of its manufacturing facilities that should boost annual production capacity to just over 1 gigawatt by 2009. This capacity could supply one-sixth of that year's estimated global solar-cell business, which is currently growing at 50 percent per year.

This rapid ramp-up is impressive for a company founded only in 1999, after it acquired its cadmium telluride (CdTe) technology from the purchase of Solar Cells Inc. (SCI). Cash for the launch came from the equity firm JWMA, whose president, Michael Ahearn, became First Solar's CEO and is still running the company.

First Solar began by developing its manufacturing technology at its Perrysburg, Ohio, facility. Commercial operations started in January 2002 with a 25-megawatt base plant, which began high-volume production a couple of years later. Since then the company has replicated its manufacturing line at the Ohio site, built four more lines in Germany, and begun constructing a fourth plant in Malaysia, which will bring the total number of production lines in that country to 16. Ahearn recently told investors that the first Malaysian plant has just started to produce cells and that it should be operating at full capacity by the end of next year. Line capacity has risen also, to 45 MW.

The cells are manufactured on 0.6-by-1.2-meter sheets of glass, which are cleaned and cut on an angle to produce the strong, defect-free edges required for processing. The glass has already been coated with a transparent tin oxide that provides electrical contact to the device. This starting platform is radically different from that for silicon cells, which are made from far smaller monocrystalline and polycrystalline wafers.

Next, the device layers are deposited onto the sheets. This is the stage at which First Solar's secret surely applies, says John Hardy, an analyst at American Technology Research, in Greenwich, Conn. In his view, keeping this secret is one of the main reasons that First Solar refuses to talk to the media.

Nevertheless, it is still possible to uncover some of the details of First Solar's growth process. Dieter Bonnet, a coinventor of the CdTe cell and the chairman of Solarpact, a research consortium in Germany, says that First Solar's process is just a refined version of that used by its predecessor, SCI, which released a report about its manufacturing technology in 1993. Interestingly, this document was coauthored by James Nolan, a current director of First Solar, the person responsible for designing and building prototype equipment for the pilot manufacturing line.

The report from SCI describes an elemental vapor deposition process that takes place in four chambers. Glass is placed on rollers and fed into the first chamber, where it is heated to 600 °C. Then it is transferred into the second chamber, which is full of cadmium sulfide vapor, formed by heating solid CdS to 700 °C. The vapor forms a submicrometer deposit on the glass as it moves through this cloud, after which a similar process in a third chamber adds a layer of micrometers-thick CdTe in about 40 seconds. Then a gust of nitrogen gas rapidly cools the panels to 300 °C in a fourth chamber, strengthening the material so that it can withstand hail and high winds.

The two layers—CdS and CdTe—are critical because they constitute the electronic junction that converts light into electricity. Most of the sunlight entering the glass passes through the thin CdS layer before being absorbed by the much thicker CdTe film. Here the light transfers energy to electrons in CdTe, freeing them from their normal bound state so that they can move through the material. To get them moving, however, you need an internal electric field.

In silicon cells, that field is created internally by constructing two adjacent layers with different electronic properties. One layer consists of silicon doped with small amounts of phosphorus, which has one more electron in its outer orbital than silicon does. When a phosphorus atom is inserted in place of a silicon atom, that extra electron is transferred to the crystal lattice. Because these electrons move about freely and carry a negative charge, this material is known as *n*-type silicon. *P*-type silicon, on the other hand, gets its corresponding positively charged particles from tiny amounts of boron, an element that has one less electron than silicon in its outer shell. In this case there are not enough electrons to form all the covalent bonds required, so the electrons move around to try to fill this deficiency, which is called a hole. Holes act like free, positively charged particles.

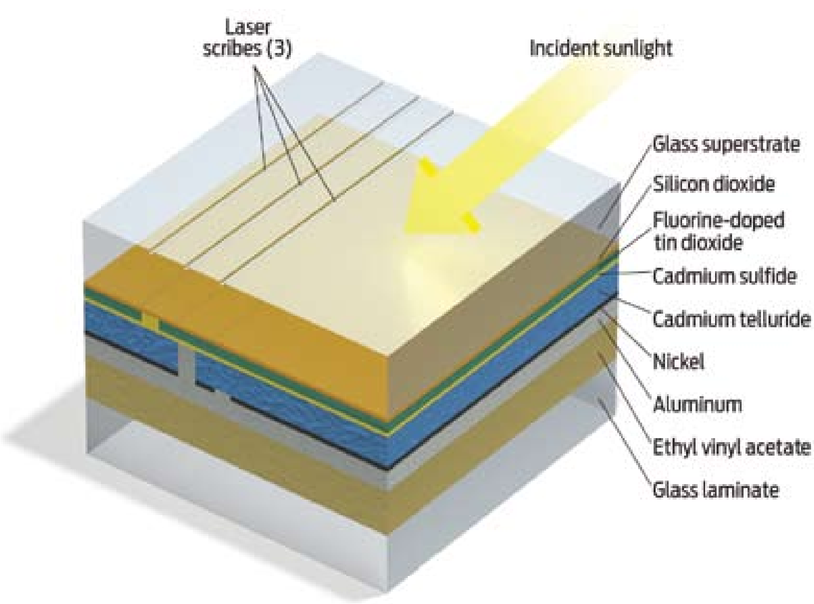
When *p*-type and *n*-type materials are placed together, they form a *p-n* junction. The electrons and holes attract one another, congregate by the interface, and leave the *p*-type and *n*-type regions with negative and positive charges, respectively, creating the required electric field.

CdTe beats silicon in this respect because it can form a *p-n* junction more simply. CdTe and CdS are made by bonding two elements with different numbers of electrons in their outer shells, and any deviation from an exact 50:50 balance between these elements produces doped material. In fact, a slight imbalance naturally occurs in both materials, and that makes it very easy to make *p*-type CdTe and *n*-type CdS. In silicon, the two halves of the junction require more steps to manufacture.

A further advantage results from the position of CdTe's absorption edge. Calculations have shown that the ideal solar cell would start absorbing sunlight at a wavelength of 910 nanometers. CdTe is close to this sweet spot, with absorption kicking in at 850 nm, while silicon starts to absorb only at 1.1 micrometers.

After forming the junction between CdTe and CdS in the four-chamber tool, First Solar heats the panels to improve the efficiency with which it converts light into electricity. Bonnet says that this process takes place in the presence of some form of chloride,

A RARE LOOK inside a First Solar plant—here, in Frankfurt/Oder, eastern Germany—gives away none of the company's secrets, which involve manufacturing very large panels. The cell structure itself is known [see diagram below]; as in all thin-film designs, the active layers are built on an inert glass wafer.
PHOTO :SVEN KAESTNER/AP PHOTO; DIAGRAM: EMILY COOPER



because it boosts efficiency, although the mechanism is not yet understood. The benefits are significant, and lab results have shown that cell efficiencies more than double as a result, to better than 10 percent.

Once the heating is over, a laser patterns the CdTe sheet into an array of smaller, rectangular solar cells connected in series. By stringing together the right number of cells, this process tailors the panel's output to produce 70-volt modules, delivering a current that ranges from 0.97 to 1.08 amperes. Finally, First Solar deposits a metal contact onto the CdTe and adds a laminate, a rear glass cover sheet, and termination wires.

Today's modules deliver up to 75 W at a conversion efficiency of 10.6 percent and have a manufacturing cost of $1.14/W. This is way below the selling price of $2.45/W, so the company enjoys a healthy profit margin. However, to compete against fossil-fuel sources on the free market and pick up a tidy profit, the company will have to get manufacturing costs down to between $0.65/W and $0.70/W. To do so, it has told investors that it needs to reduce manufacturing costs and increase conversion efficiency to 12 percent. Getting there is entirely feasible, as CdTe cells have a theoretical maximum of well over 20 percent; the National Renewable Energy Laboratory, in Golden, Colo., has already produced cells with 16.5 percent efficiency.

At first glance you might think that conversion efficiency shouldn't matter, so long as the price per watt is low enough. That argument applies only at the level of an individual module, however, not an entire installation. Because First Solar's panels are less efficient than silicon designs, they need more space to soak up enough sunlight, and that raises the cost both for real estate and installation. The company is aiming to reduce the installation costs through its recent cash purchase of the U.S. firm Turner Renewable Energy, which designs and deploys commercial solar projects.

Total cost must also reflect the expected life of the modules. First Solar says its product will last 25 years, after which the materials will be returned to the company for recycling. Besides helping the environment, recycling would provide First Solar with material, albeit after a long wait.

Cadmium is plentiful as a by-product of mining, but some critics doubt the long-term global availability of tellurium. Company president Bruce Sohn dismisses this notion. In a conference call in May he said, "We are not seeing any supply issue for tellurium. We have a couple of sources, and we have locked down our long-term contracts for raw materials. That has helped us maintain the supply as well as the price."

Although the modules would be great at providing solar electricity to homes, for the time being First Solar isn't selling to the public. Ahearn has told investors that the company is having a hard enough time supplying the demand for solar farms—some 55 percent of its business—and commercial rooftop installations. Panels for solar farms can be mounted on low-cost trellis systems. Most rooftop installations are for business premises. Such deployments could be seen as hazardous, because in a fire the panels could give off potentially fatal cadmium fumes. To fight these fears, First Solar cites an experiment done at Brookhaven National Laboratory, in Upton, N.Y., in which cells heated to 1100 °C lost just 0.04 percent of their cadmium, an insignificant amount.

More serious is the threat posed by rival thin-film technologies, which together have been receiving very high levels of investment since the silicon shortage began.

Of the alternative technologies, CIGS has been grabbing most of the headlines, thanks to its claims for maximum efficiencies of up to 20 percent. Another advantage is the ease with which CIGS can be deposited as a thin film. This technology has yet to live up to its billing, however.

"It's an awful lot of hype as opposed to a lot of reality," says Robert Castellano, president of the Information Network, based in New Tripoli, Penn. "No one has come up with a full-blown production setup, and that has soured all the venture capital and private equity companies."

He says that investors were lured by promises of simple, quick production processes for panels having an efficiency of 12 percent. In fact, though, efficiencies have been lower, and manufacturing has been delayed. Heliovolt Corp., in Austin, Texas, and Nanosolar, in San Jose, Calif., for example, have each raised over $100 million of investment but are only on the fringes of manufacture after more than five years of development.

Another thin-film technology, called amorphous silicon on glass, is already making an impact on the solar market. It has efficiencies of around 7 percent, and because it uses only tiny quantities of silicon, it has been largely unscathed by the silicon shortage. Also, because manufacturing equipment is more readily available than for CdTe technology, there is a lower barrier to entry for would-be manufacturers. "The customer can get everything from us," says Juerg Steinmann, head of marketing communications at Oerlikon Solar, in Truebbach, Switzerland. Its services are proving to be popular, and customers are currently inquiring about production systems for the manufacture of 40 MW or 60 MW per year. "Within a relatively short time we will have gigawatt factories," says Steinmann.

Oerlikon's tools produce 85-W solar panels covering 1.4 square meters, using a 0.3-µm layer of amorphous silicon that strongly absorbs visible light. However, output can be increased by nearly half with the addition of a 1.5-µm microcrystalline layer of silicon that absorbs infrared radiation too. Late last year Oerlikon introduced modified process equipment for microcrystalline growth. Even with this additional growth step, manufacturing throughput is fast, and the Swiss company contends that a manufacturer wielding its tools could make a solar module about as quickly as First Solar can. Nevertheless, the all-important cost-per-watt ratio is slightly inferior. "Today we're looking at $1.50 per watt, and by 2010 our goal is going to be $0.70 per watt," says Steinmann.

The idea of using more than one material to capture a higher proportion of the sun's radiation has also been pursued by Emcore Corp. This Albuquerque-based company uses layers of germanium, gallium arsenide, and gallium indium phosphide to manufacture cells that are roughly three times as efficient as First Solar's. But the production costs are astronomical because the technique requires relatively slow growth rates and because deposition occurs on small germanium substrates. Even so, these drawbacks did not prevent Emcore from enjoying success in its initial target market, aerospace applications, in which high efficiency and reliability are paramount.

The high cell costs can be offset in terrestrial solar-cell systems that use large lenses or mirrors to focus sunlight by a factor of several hundred, boosting conversion efficiency to almost 40 percent. But this strategy makes sense in only 10 to 20 percent of the world market. "Where we play is in the very sunny, high-solar-resource areas, where it's also very warm," says David Danzilio, the company's vice president in charge of photovoltaics. For that reason, sales of Emcore's product are unlikely to take much of a bite out of sales of First Solar's systems, which can be used in all climates.

All this means is that in the short term, First Solar's main competition will continue to come from conventional silicon cells. This mature technology is unlikely to deliver any major hike in efficiency from today's figure of around 16 percent, but if the silicon shortage disappears in a year or two, lower material costs will propel a major reduction in the cost-per-watt figure. "However, even if polysilicon came down in price significantly, First Solar could cut their prices and still see the same margins that the traditional module makers do," says Hardy of American Technology Research. "It would definitely hurt them on pricing, but they would still be extremely profitable at lower prices."

With no strong challenger in sight, First Solar is well placed to continue its quest for grid parity. Getting there would substantially reduce greenhouse-gas emissions. That achievement would be a great legacy and would make a really great story, but will First Solar be willing to tell it? ❑

TO PROBE FURTHER Solar Cells Inc. describes the details of its elemental vapor process in its 1993 report "Fabrication of Stable Large-Area Thin-Film CdTe Photovoltaic Modules," which is available at http://www.osti.gov/bridge/product.biblio.jsp?osti_id=10181903.

Get information about inverted triple-junction technology in "High-Efficiency GaInP/GaAs/InGaAs Triple-Junction Solar Cells Grown Inverted With a Metamorphic Bottom Junction," Applied Physics Letters, *91 023502, 2007.*

For comparisons between CdTe and CIGS manufacturing, see Michael Powalla and Dieter Bonnet's paper "Thin-Film Solar Cells Based on the Polycrystalline Compound Semiconductors CIS and CdTe" published in Advances in OptoElectronics, *2007, available free of charge at http://www.hindawi.com/GetArticle.aspx?doi=10.1155/2007/97545.*