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TOWARDS A TRANSPARENT PHOTOVOLTAIC FILM

A TECHNOLOGICAL APPROACH WITH THE ETFE

RELATRICE
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un ringraziamento particolare va alla Professoressa Zanelli che ha
credutо in me durante tutto il mio percorso universitario

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Introduction

Sustainable architecture is a general term that describes environmentally conscious design techniques in the field of architecture.
Sustainable architecture is framed by the larger discussion on sustainability and the pressing economic and political issues of our world. In the broad context, it seeks to minimize the negative environmental impact of buildings by enhancing efficiency and moderation in the use of materials, energy, and development space.
Most simply, the idea of sustainability, or ecological design, is to ensure that our actions and decisions today do not inhibit the opportunities of future generations. This term can be used to describe an energy and ecologically conscious approach to the design of the built environment.

This definition of the sustainable architecture is a starting point which identifies the new role of the architect in our century: not only a designer, not only a constructor, not only an engineer. The new architect has to combine style, structures, territorial links, to an idea of environmental respect and to an eye on the future and on the developments that the new technologies produce.
Buildings are not more made to resist for ages, just only until you found a new better technology to improve them and their performances, like a machine that receive an upgrade of one part. This is an important point because the city, with that new rule, becomes a lab where you could experiment, change, develop, improve technologies and styles. A fluid dynamic place where architects, within the limits of laws, show their experiences and their feelings.
During my last two year in Politecnico I had the chance to know the China reality, in particular the city of Shanghai: this is an example of a flexible city, an extreme one.
To build in Shanghai you have three weeks to project and three weeks to build: the people there goes two times faster because they know to reach the West they have to run and fill the gap between these two worlds. In this economical boom they see the dark side of this run: pollution increase, traffic of vehicles goes out of control, the population increase too much and too fast, the resources won't satisfy all the population. They know this problem but for now the authorities are not able to solve it: they control the media and all the internet with a strong filter, just to not give information not approved from the government, and there's a law that increase taxes for the couple who wants more than one baby; this last decision on population

wants to control the use of territory in order to indirectly reduce the pollution and directly the consumption of the resources, just to not raise a debt too large with other countries.
The Chinese situation, similar to the Indian one, or in future for the African countries, is a big alarm for the world and the United Nations have promulgated from the '80 a document that define the guidelines for the next century to reach in order to control and prevent the collapse of the earth system. This document is the Agenda 21, which is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment. Agenda 21, the Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests were adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, on June 1992.
The full implementation of Agenda 21, the Program for Further Implementation of Agenda 21 and the Commitments to the Rio principles, were strongly reaffirmed at the World Summit on Sustainable Development held in South Africa in 2002.
Agenda 21 addresses the pressing problems of today and also aims at preparing the world for the challenges of the next century. It reflects a global consensus and political commitment at the highest level on development and environment cooperation. Its successful implementation is first and foremost the responsibility of Governments. National strategies, plans, policies and processes are crucial in achieving this. International cooperation should support and supplement such national efforts. In this context, the United Nations system has a key role to play. Other international, regional and sub regional organizations are also called upon to contribute to this effort. The broadest public participation and the active involvement of the non-governmental organizations and other groups should also be encouraged.
This is one of the most important extract from the preamble of the document, because it put the accent over the responsibilities of every nation in front of the environment cooperation, let every signed country to promote new technologies and to develop bonuses to involve people to approach the new green technologies.
In Italy for example we see a large use of incentives for new cars if the people recycle the old one, or bonus for new appliances without greenhouse gases or for solar panels integrated systems: the solar energy is one of the best solution for our country, which is one with the largest

number of sunny days along the year in Europe. This is also one of the cheapest solutions for sustainable energy, and one with the lowest impact on territory, in particular in an urban situation.
The solar energy opens different uses of the energy, from heating, to hot water or photovoltaic, and is now one of the most developed, also from big petrol companies, that see it as a future way of sustainable energy with low costs and high efficiency on the medium-long period, in order to justify the first investment.
Photovoltaic energy represents an important resource for the production of electric energy, in particular because today this fundamental power is produced by petrol, nuclear fission and hydro-electric centrals and a new clean energy like the solar could implement the offer and in certain places change the hierarchy.
Another important sustainable issue is concerning the materials and their production. One general mistake is to think that if a material is sustainable for U.S., it has to be sustainable for Italy: this is not true, because if I buy that material in a range of few km from the production, I have a sustainable product, but if I buy it from the other side of the world, it couldn't be sustainable, just only for the transportation.
The research today has the possibility to discover incredible solutions for construction and it has the potential to adapt well known natural materials with the modern requests for the sustainability and the flexibility of the buildings. Today we could use a textile as a structural element, like glass, and a glue could be more resistant than a screw or a bolt.
In this prospective, I've had the chance, here in Politecnico, to study the proprieties of a different range of materials and after a course with the professor Alessandra Zanelli, I have analyzed the tensile and I've focus my attention on ETFE, a sustainable plastic, 100% recyclable,
The production of the ETFE has made with a base of water and it's produced in thin films, thanks to his extreme thickness and his strength, that made it one of the lightest structural material. Another important point is the translucency and the elevated strength against chemical agents, so this is why today architects like Herzog & De Meuron approach this material for their projects.
The flexibility of the ETFE gives it also the possibility to integrate this film with a renewable energy system like the photovoltaic thin films, making a tensile totally sustainable and produ-

cer of elettric energy. I've started to approach this solution four years ago, when only one little firm in Germany, called Solar-Next, begun to commercialize this product. Today this technology is no more developed and my research try to make the new step that this technology needs to become accessible: when in February the magazine Elementi asked me to speak in a conference to explain my first thesis on this product, I realized that the knowledge of ETFE-Photovoltaic system is today only an idea and my wish is to arrive at the end of this thesis to demonstrate that this solution is real and could have incredible evolutions in few years, just for the fast development of photovoltaics thin films and for the optimization of the production of ETFE, reducing also the cost of the tensile.

ETFE

The ETFE is a fluorine based plastic and its systematic name is polyethylene-co-tetrafluoroethylene, because this polymer is based on the link fluorine-carbon.
Compared to glass, ETFE film is 1% the weight, transmits more light and costs 24% to 70% less to install. It's also resilient, able to bear 400 times its own weight, self-cleaning (due to its nonstick surface) and recyclable. On the other hand it is prone to punctures by sharp edges, therefore it is mostly used for roofs. In sheet form as commonly employed for architecture, it is able to stretch to three times its length without loss of elasticity. Employing heat welding, tears can be repaired with a patch or multiple sheets assembled into larger panels. This "sewing" method enables ETFE to be installed in pieces much longer and wider than glass: a strip of ETFE could be 54,90m long and 3,66m wide. When exposed to fire, it softens and shrinks away from the heat, naturally venting smoke out of a building.

History

It was originally designed around the 1970s, when DuPont, a leader producer of plastic elements, invented a fluorocarbon-based polymer to be used as an insulation material in the aeronautics industry, in order to solve the needs of a material with high corrosion resistance and strength over a wide temperature range.
DuPont did not initially care about marketing ETFE to architects: it was Stefan Lehnert, a German mechanical engineering, in his search for new sailing technologies, who saw building-material potentials in its transparency, in its self-cleaning and structural properties. In 1982, he founded Vector Foiltec, a design and manufacturing company, specializing in the use of ETFE, in Bremen, Germany. The company's first project was the roof of a small pavilion at a zoo in Arnheim, Holland. Since then, ETFE has become increasingly popular, especially in Europe, and this new polymer was widely used in office atriums, some educational buildings, medical facilities, exposition halls, and zoos across Britain and Germany. In 2000, the Eden Project, an environmental complex in Cornwall, Britain, designed by Grimshaw Architects and containing two gigantic geodesic conservatories covered in ETFE, was completed. The construction was acclaimed as an engineering marvel and created a wave of global interest.
The interesting property for architects is that the resin can be spun into a thin, durable film,

which manufacturers such as DuPont Tefzel and Asahi Glass Company, which calls its version Fluon, pack in rolls. It can be used in sheets or inflated into cushions. An example of its actual use is as pneumatic panels to cover the outside of the football stadium Allianz Arena in Germany or the Beijing National Aquatics Centre, the world's largest structure made of ETFE film (laminate).

Eden Project, 2001

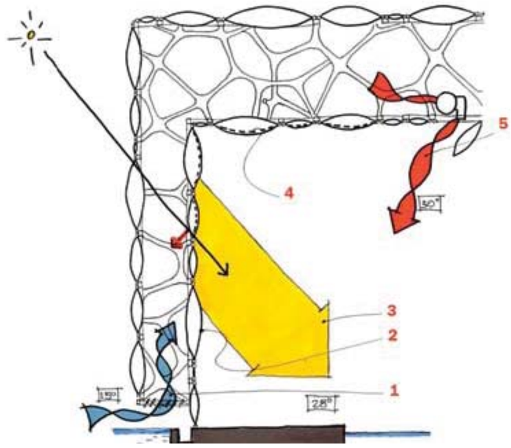
These huge geodesic-domed greenhouses, part of an environmental complex in Cornwall, England, were originally supposed to be made of glass. But ETFE gave designers, Nicholas Grimshaw & Partners, a flexible, lightweight, and durable alternative. The result was an environment capable of housing plant species from around the world in tropical rainforest -and Mediterranean-style climates. With its 30.000m2 Eden was, at the time, the world's largest ETFE project and remains a defining image of "ETFE architecture".

As the design team searched for the most effective and interesting way to enclose the planned environments the organically inspired dome-shaped biome emerged as a strong idea, with the surfaces made up of geometric shapes. Nicholas Grimshaw and Partners worked closely with Anthony Hunt Associates Ltd and Mero Plc to develop the structure and define the lengths of each steelwork section via a 3D computer model. This enabled each section of the steelwork frame to be fabricated off-site and assembled in its unique position on-site matching precisely within the steel framework.

The final architectural and structural design is hugely efficient, providing maximum strength with minimum steelwork and maximum volume with minimum surface area. The transparent hexagonal membranes transmit more light than glass and the largest biome spans more than one hundred meters without requiring internal supports - allowing complete freedom for the landscape architects and horticulturalists.

Performances

In its typical usage, two or three layers are welded together and shipped flat to the job site, where they are inflated into panels or "pillows". These cushions require semi-continuous air pressure, just to keep them stable and give them thermal properties, so most systems include thin hoses that plug into the cushions' sides. These air-supply lines connect to a computerized system that monitors the pressure within the cushions. This system can also feed air into, or eject air from, particular chambers or layers to let in more light or create more shade. In some installations, this is done automatically using light sensors.
As many projects don't call for such a complexity Architects will have to evaluate, project by project, the convenience for using ETFE. It's certainly not advised to use it for small-scale or residential projects.
Acoustics can be another drawback. The cushion system, when used on a roof, can amplify the



a constructive particular of the Olympic Pool of Beijing buildt for Games of 2008 in China: the ventilation here is controlled by the cushions of ETFE in order to optimize the performances and to control the insulation of the Watercube.

sound of rain because the tension in the cushion acts like a drum. Manufacturers have developed several noise-suppressing techniques, including layering polycarbonate sheets within ETFE cushions, but their use isn't widespread yet. Interior applications, such as walls within an office, present other sound issues. ETFE transmits more sound than glass or wood, making it not convenient for meeting rooms, or conference centres. In opposition, ETFE can be beneficial for self-contained, noisy areas like aquatic parks -sound bounces off the walls and floor and escapes through the roof.
ETFE is a thermoplastic fluoropolymer, in particular is a copolymer comprising of tetrafluoroethylene (C2F4) and ethylene (C2H4).

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It's also a balanced one that has chemical resistance and electrical properties comparable to typical fluoropolymer, such as PTFE, PFA and FEP and also is more progressive than ECTFE or PVdF with its improved mechanical strength.
Translucency of the ETFE membrane is about 95 % within the range of 400 - 600 Nm, with scattered light at a proportion of 12 % and direct light at a proportion of 88 %. For a three-layered module (upper layer 200μm, middle layer 100μm, inner layer 200μm), the degree of light transmission for vertical incidence is = 0.7. This range represents the translucency characteristics important for life (of humans, animals and plants). Compared to open air environment the dangerous UV-B and UV-C radiation (which causes burning and is carcinogenic) is considerably reduced by filtration.

u-values are as follows (depending on test procedures these values may vary considerably):
- for one-layered membranes ≈ 5.1 W/m^2K
- for two-layered membranes ≈ 3.5 W/m^2K
- for three-layered membranes ≈ 2.0 W/m^2K

- for four-layered membranes ≈ 1.5 W/m²K

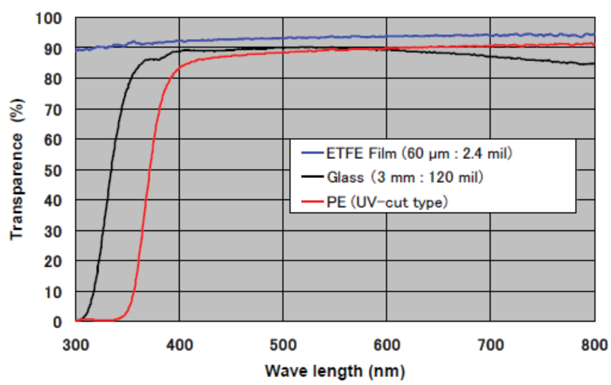
As ETFE is one of the most stable organic combinations; resistance to all environmental influences is very high. Life expectancy is far beyond 20 years if the material is used according to the specifications. As told before and according with it's life span, ETFE is self-cleaning due

GENERAL PROPERTIES OF ETFE (COMPARISON WITH PVF)

		ASTM	ETFE	PVF
Light transmittance(50 μm thickness film)	%		95	89.2
Melting temp.	˚C (˚F)		260 (500)	203 (397)
Continuous service temp.	˚C (˚F)		-100 to 150 (-148 to 302)	-70 to 100 (-94 to 212)
Oxygen Index	%	D2863	31	23
Linear thermal expansion coefficient	1/˚C	D696	$5.9X10^{-4}$	$9X10^{-4}$
Shrinkage (150˚CX30min)	%		-2 to 1	-5 to -8
Tear strength (Elmendolf)	g/25 μ m	D1922	1400 to 2400	15 to 60
Tensile strength	MPa	D638	69	44
Tensile elongation	%	D638	420	130
Tensile modulas	MPa	D638	824	1863
Volume specific resistance	Ωcm	D257	$>10^{16}$	$4X10^{13}$
Dielectric constant (10^3Hz)	-	D150	2.6	8.5
Water absorption	%	D570	0.03	<0.5
Moisture permiation (25 μ m (1 mil))	g/(m^2·24h)	E96	6	30
Acid resistance		D543	A	C
Alkari resistance		D543	A	B
Solvent resistance		D543	A	C

A: Excellent B: Fair C: Poor

High Transparence (Comparison with Others)



to its chemical composition, and will therefore retain its high translucency throughout its life. Any accumulated dirt is washed off by normal rain if the shape and the connection details are designed correctly. In climates where rainfall is minimal, or if special cleaning is required, cleaning is carried out using ecologically 'green' detergents or water, that makes this material maintenance-free. However, inspections are still recommended in order to find defects (for example damage caused by mechanical impacts of sharp objects) and to identify and repair such damage as early as possible. It is also recommended that the perimeter clamping system and the primary structure be regularly inspected (annually), however, the specific intervals need to be assessed on a project-by-project basis.
The data and all these characteristics are taken out from the main sellers of this product: all over the world we have only few producers of ETFE, because the costs of fluorine based materials is high and requires particular technologies, just to raise the chemical strength that is the most important quality. In this sense the main brands for the ETFE technology are Tefzel by DuPont, Dyneon by 3M, Norton by Saint-Gobain, Fluon by Asahi Glass Company and Neoflon by Daikin.

Accelerated Exposure Test (EYE Super UV Tester) of ETFE film (White color)

Retention of Mechanical Properties

Exposure time	0 hrs	Retention rate after 500 hrs	Retention rate after 1000 hrs
Tensile Elongation	300～400 %	95～100 %	95～100 %
Tensile strength	55～65 MPa	90～95 %	85～95 %

Change in Optical Property

Exposure time	unit	0 hrs	500 hrs	1000 hrs
Transparency at 360 nm	%	≦ 0.1	≦ 0.1	≦ 0.1
Solar reflectance	%	60～62	61～63	61～63
Colour difference ΔE*		-	-	< 0.7

Chemical Resistance of ETFE Film

Stable and inert against most chemicals

Chemicals		Temp. (℃)	Days	Retention (%) Elong.	Retention (%) Wt. Gain
Sulfuric acid	78%	121	10	100	0.1
	98%	121	10	100	0
Nitric acid	25%	100	14	100	–
	60%	120	10	100	0.7
	70%	60	60	100	–
Sodium hydroxide	10%	120	10	97	0
	50%	120	10	100	−0.3
Ammonium hydroxide	15%	66	7	98	0.1
Chlorine		90	10	94	–
Bromine		60	7	100	0.1
Sulfuric chloride		70	7	100	6.0
Carbon disulfide		100	30	98	1.0
Water		100	7	100	0

Outstanding Resistance to Weather and Ageing (1)

			Before test	After 15 years exposure test
Light transmittance	%		96	94
Tensile strength	(MD)	MPa	62.8	56.9
	(TD)	MPa	64.7	57.9
Tensile elongation	(MD)	%	420	360
	(TD)	%	440	370

Outside exposure test

Test sample : 100 μm (4 mil) thickness

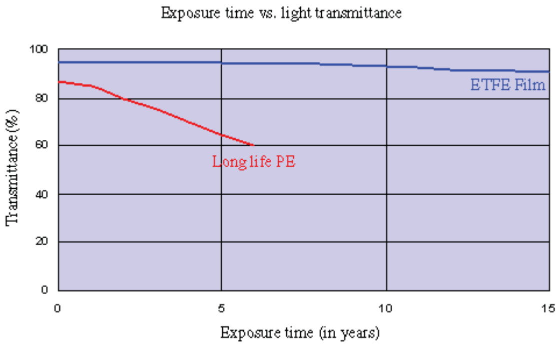
Outstanding Resistance to Weather and Ageing (2)

			Before test	After 5000 hrs exposure test
Light transmittance	%		93	93
Tensile strength	(MD)	MPa	61.8	55.9
	(TD)	MPa	57.9	63.7
Tensile elongation	(MD)	%	360	350
	(TD)	%	430	430

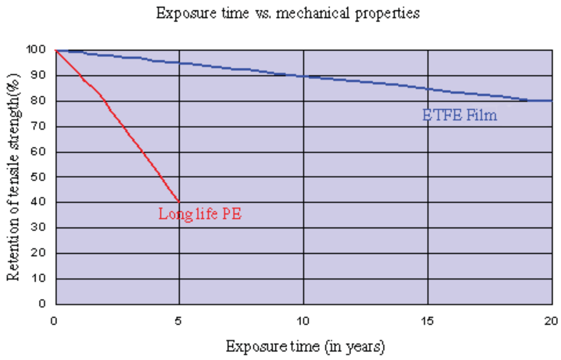
Accelerated weather test with Sunshine wether-o meter

Test sample : 100 μm (4 mil) thickness

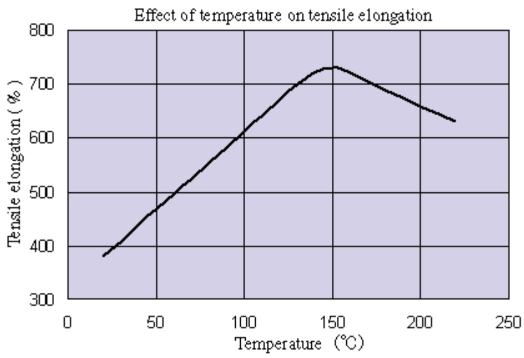
in this analysis it's possible to measure the low change of traslucency of the ETFE in spite of an improved polyethilene membrane. The chemical properties of ETFE and the low power of adhesion on its surface make possible this result



also the comparison for mechanical properties show the good performances of the ETFE membranes in spite of the others.
There's a loss of 1% by year on the retention of tensile strenght, in spite of a fast decreasing of performances of the other plastic product.



the graphic shows the effect of change of the temperature on the elongation of the ETFE membrane, until the meltin point.
The top data is raised around 150°C when the ETFE reach 700% of his elongation.



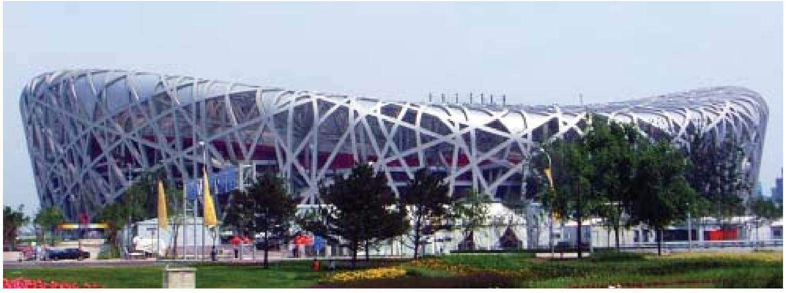
data provided by Asahi Glass Co. Ltd. Chemicals Europe

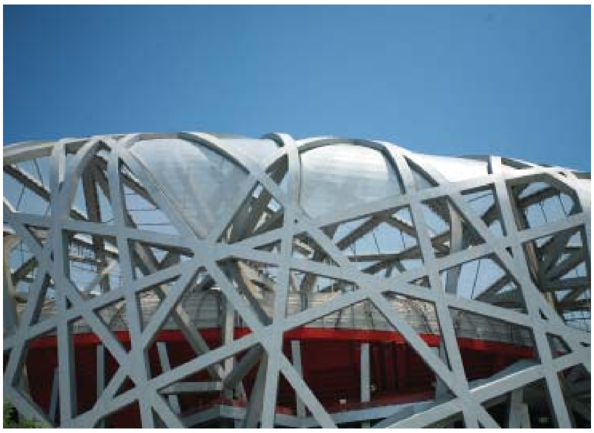
2008: the Olympic games in Beijing

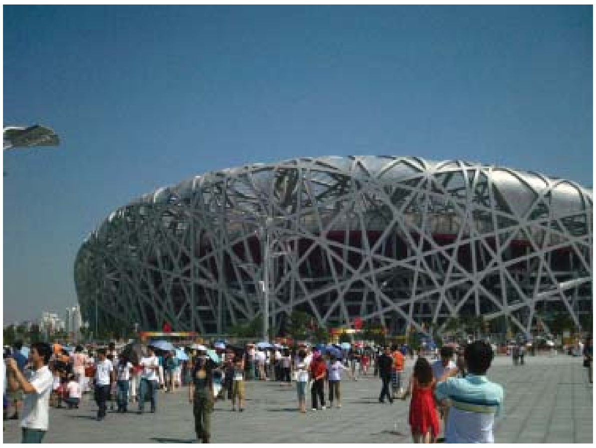
Beijing has both excellent and classical architecture but few distinguished modern buildings. Now such world famous architects as De Meuron and PTW Architects displaied their skills here. With the speeding up of China's urbanization and the challenging concept of the 2008 Olympic Games, almost all famous design consortiums from around the world have found that China is one of the few countries which provides not only imaginary space but also abundant funds for modern architecture today. Therefore, Herzog and de Meuron's "bird-nest" and PTW Architects' "water cube" are just a small part of the skills displayed by famous architects in China.

The Bird's Nest:

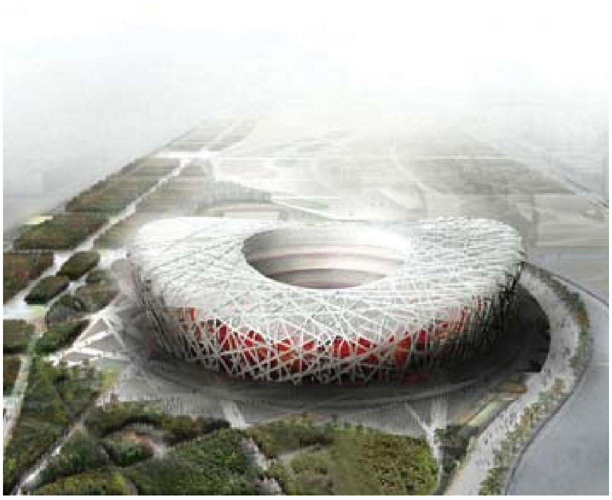
The National Stadium is commonly called the "Bird's Nest" has been praised as the "the stadium of the fourth generation", it is located inside Beijing Olympic Park, east side of northern part of middle axis of Beijing, and is the main stadium for 2008 Beijing Olympic Games. During the 2008 Olympic Games period, the "Bird's Nest" will host many competition activities, such as the opening and closing ceremony, track and field competion, men's football finals etc. It can hold 91,000 spectators, with 11000 temporary seats. After the Olympic Games, the stadium can accommodate 80,000 spectators, and host large-scale sports competitions, all kinds of routine competitions as well as non-competition events, and will also become a physical exercise and large-scale recreational and professional location for citizens in Beijing. It will also be the symbolic recreational architectural site for physical culture all over the country.
The National Stadium is jointly designed by a cooperative consortium, Herzog & De Meuron Architekten (Switzerland), Ove Arup Partnership (Australia) and China Architecture Design & Research Group. The proprietor is the National Stadium Co., which is jointly established by Beijing State-Owned Assets Management Co., Ltd. and Citic Group.
The stadium has a built-up area of 258,000 sq m and a covered area of 204,000 sq m, for main body of the building, its major axis is 332.3m, minor axis 297.3m, vertex 68.5m and nadir height 40.1m. The length of its roof opening is 185.3m and the width is 127.5m. The major structure of the stadium adopts a bending and twisty box shaped steel beam, which surrounds the red ochre colored and bowl like seating area in spoke-wise form, and also rotate, interlace in slope direction. The superface appears as a saddle shape, the places between the steel beams are covered by the transparent membrane material. The elevation, superface, suspended ceiling and interior grey steel beam regularly form the oroclinal warping lattice which seems a little untidy, the interior solid interlaced steel frame is dimly visible through the membrane material on the superface. Seen from the distance, the stadium is just like a jumbo Bird's Nest woven by the twigs.
The design proposal for the stadium is based on the use of scientific and simple space structures, novel building design, unique structure, overall unification and the perfect combination of architecture and structure, ensuring that after the completion of construction, the stadium will become both a unique and symbolic building. The membrane structure of the National

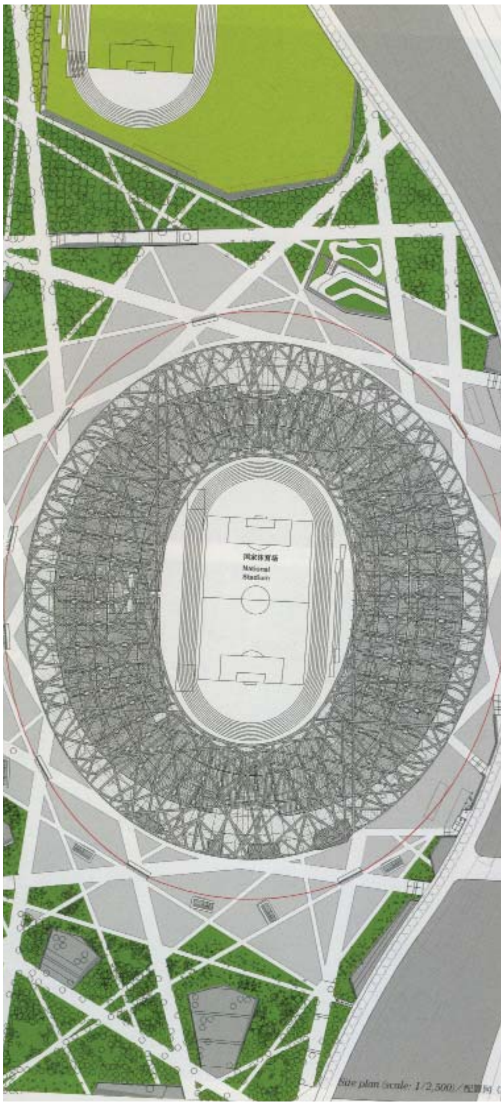




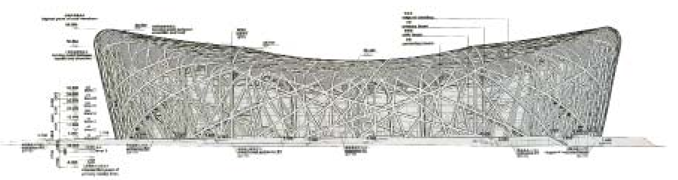
Stadium consists of a roof enclosing structure; acoustics suspended ceiling and internal ring elevation cladding membrane structure three parts. The upper chord of roof system adopts single-layer stretching membrane system as maintenance structure of roof for wind and rain resistance and sunlight shading, the transparence ETFE membrane material with the glaze point is selected and disposed on comparatively flat roof and the adjacent area between the elevation and roof. The acoustics suspended ceiling of lower chord for roof system adopts white translucence PTFE membrane system as denoise layer and sunlight shading layer at stand area, which is hung beneath the lower chord of main frame and substructure, meanwhile extends downwards from back of upper story stand, functions as screen. The elevation of the interior framework of roof opening (internal ring surface) is sealed with PTFE membrane for good waterproofing quality. The single-layer ETFE stretching membrane structure of roof consists of 1038 membrane units, with total area about 38500m2. On the roof, the drainage gutter is set up along the inside of lattice unit constituted by interwove steel beam, the ETFE membrane unit is fixed on the border of gutter after stretching. Therefore, the high precision of supporting structure for ETFE membrane unit is essential, because the ETFE membrane unit shape is very complex, especially at shoulder area, where the membrane unit and bracing member should, without exception, be made into complicated hyperboloid form.



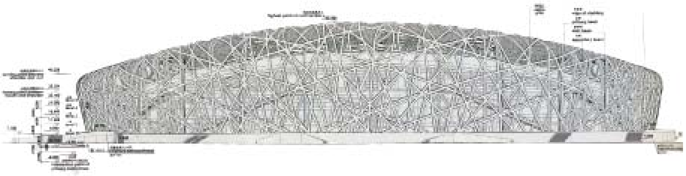
Planimetric view, sections, main fronts of the project



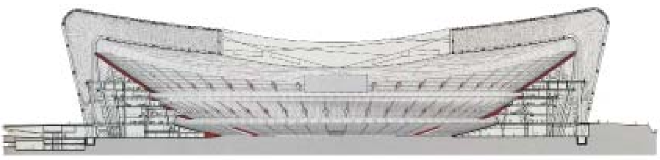
Site plan (scale: 1/2,500)



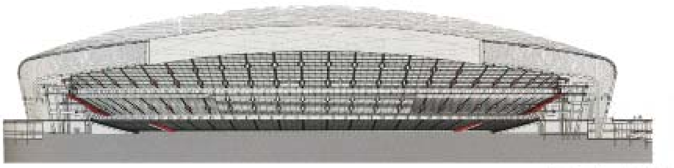
South elevation (scale: 1/2,000)



East elevation



East-west section (scale: 1/2,000)



South-north section

The Watercube

PTW + CCDI + Arup won the International Design Competition for the Beijing 2008 Games aquatic centre. The scheme will meet international standards for competition, while maximising social and economic benefits. In addition to being an aquatic competition venue for the games, the centre will provide public multi-function leisure and fitness facilities before and after the games.

The National Aquatics Centre, also known as the 'Water Cube', will be one of the most dramatic and exciting sporting venues for the Beijing Olympic Games in 2008. Enclosed within the blue bubble walls are five swimming pools, including a wave machine and rides and a restaurant, along with seating and facilities for 17 000 spectators.

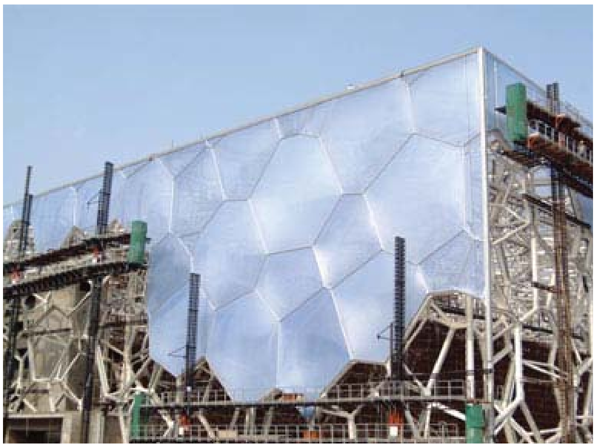
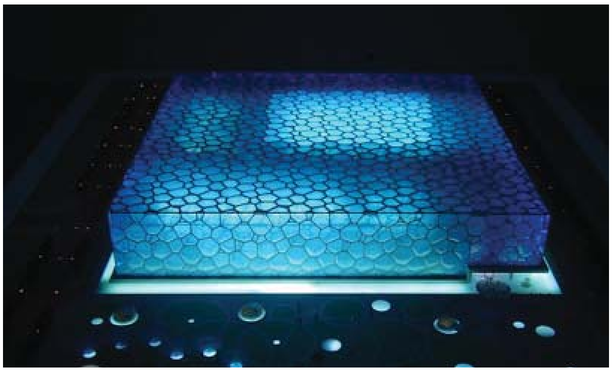
The Water Cube is located in the Olympic Green, the focal point for the Beijing Games. The design was voted as the clear winner by the people of China in a competition for their favourite design. The square shape of the Water Cube is a reflection of the Chinese symbol for Earth, while the adjacent circular form of the National Stadium represents Heaven.

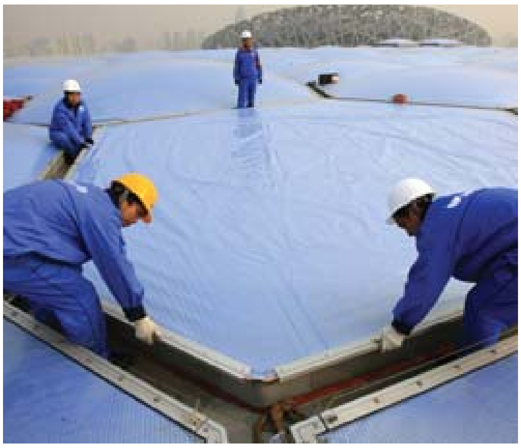
The form of the Aquatics Centre was inspired by the natural formation of soap bubbles. Arup's engineers realised that a structure based on this unique geometry would be highly repetitive and buildable while appearing organic and random. The result is a very simple regular building form, with very complex geometry in the façade which is used for beautiful effect.

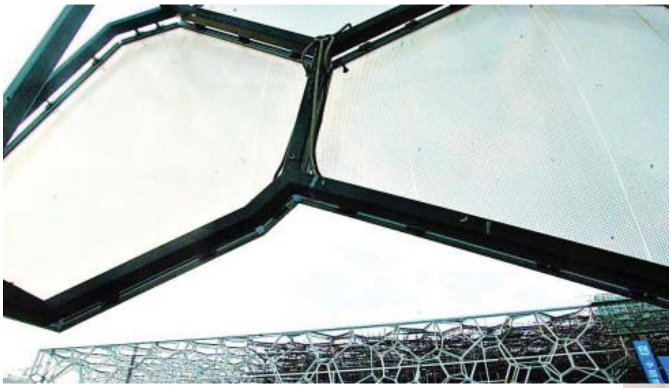
The highly sustainable structure is clad with translucent ETFE: the bubble cladding of the Aquatics Centre lets in more light than glass and thoroughly cleans itself with every rain shower. It is also a better insulator than glass, and is much more resistant to the weathering effects of sunlight.

Although it appears fragile, the skin and structural form is very robust and is ideally suited to the seismic conditions found in Beijing. In fact, it is so strong that Arup's computer models show that the structure can be placed on its end and still maintain its shape.

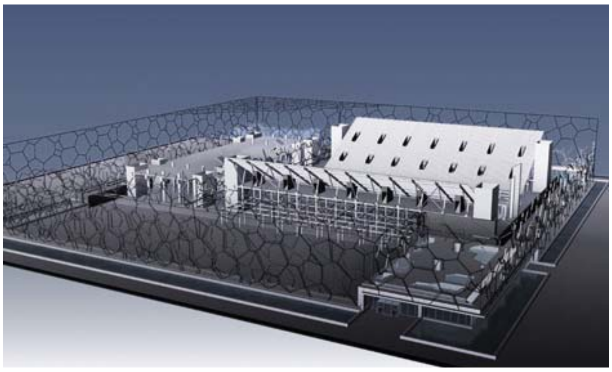
The Water Cube is specifically designed to act as a greenhouse. This allows high levels of natural daylight into the building and, as swimming pools require a lot of heating, harnesses the power of the sun to passively heat the building and pool water. Arup has estimated that this sustainable concept has the potential to reduce the energy consumption of the leisure pool hall by 30 per cent, equivalent to covering the entire roof in photovoltaic panels.








Material for an Architectural Revolution

ETFE, a fluorocarbon-based polymer, is a durable, adaptable plastic that's opening horizons for builders at the Beijing Olympics and beyond

by Elizabeth Woyke

Imagine a swimming arena made out of bubbles. Or a stadium knit from steel girders like a bird's nest. Or even an enormous tent, proudly covering over a million square feet of space. A decade ago, such buildings might have existed only in the imagination. Today, they're being built in Beijing as China's new National Stadium and National Aquatics Center and as the Khan Shatyry Entertainment Center in Astana, Kazakhstan. All thanks to innovative architects, adroit engineers—and the unusual properties of the material called ETFE.

ETFE may be about to get its moment in the architectural spotlight, but in fact, it has been around since the 1970s, when DuPont invented a fluorocarbon-based polymer, Ethylene Tetrafluoroethylene, for use as an insulation material in the aeronautics industry.

The interesting property for architects is that the resin can be spun into a thin, surprisingly durable, film, which manufacturers such as DuPont (also Asahi Glass Company, which calls its version Fluon) pack in rolls—like a sturdier version of plastic cling-wrap. It can be used in sheets or inflated into pillows, and with its incredible versatility, it has become the go-to material for those in search of an alternative to more traditional materials, such as glass.

SWEEPING EUROPE - As it happens, DuPont didn't really care about pushing ETFE to architects at all. That fell to Stefan Lehnert, a German mechanical engineering and business administration student and avid sailor, who stumbled across the material in his search for new sail technologies. Having discounted it as inappropriate for his sailing needs, he nonetheless saw building-material potential in its transparency and its self-cleaning and structural properties.

In 1982, he founded Vector Foiltec—a design and manufacturing company specializing in the use of ETFE—in Bremen, Germany, and began shopping the material around to architectural firms. The company's first project, the roof of a small pavilion at a zoo in Arnheim, Holland.

Since then, ETFE has become increasingly popular, especially in Europe. The 1990s saw it used in office atria, university buildings, medical facilities, exposition halls, and zoos across Britain and Germany. In 2000, the Eden Project, a huge environmental complex in Cornwall, Britain, containing two gigantic geodesic conservatories covered in ETFE, was unveiled. Designed by Grimshaw Architects, the construction was widely acclaimed as an engineering marvel, and created a wave of global interest.

BUBBLES AND TWIGS - With the spotlight on the Beijing Olympics, designers expect ETFE to go mainstream at last. Certainly there's no better illustration of the material's ability to turn architectural fantasy into reality than the Beijing Olympic Green, located at the north end of the central axis of Beijing City. There, less than 500 meters apart, sit the rapidly rising National Stadium and National Aquatic Center.

The two structures could not look more different. The Herzog and de Meuron-designed stadium is crafted out of woven steel and resembles a sturdy but intricate bird's nest. The Aquatics Center, nicknamed the Watercube, is refined and delicately detailed, an iridescent box covered in what appear to be bubbles. When completed later

this year, both will showcase innovative uses of ETFE. To protect spectators from rain and wind, the stadium will feature red ETFE cushions inserted in the spaces between the "twigs" of its "nest." The 750,000 square foot Watercube, the largest ETFE project ever, will be clad entirely (roof and four walls) in blue ETFE cushions.
Given the extensive size and expense (an estimated $100 million) of the Watercube project, it's surprising to note that this will be the first time that Sydney, Australia's PTW Architects have actually used the fabric. They're that confident. John Bilmon, managing director at the company, says they chose ETFE over glass and fiberglass because it satisfied the project's engineering needs. Some bubbles in the design span 30 feet without any internal framing—a distance that wouldn't be possible with other materials.
NO SHARP OBJECTS - But the ETFE system also cost less (though they wouldn't give specifics) than an equivalent traditional system, freeing up money for higher-quality filtration and water-treatment systems for the center's pools. A more traditional form of cladding would have been not only more expensive and cumbersome, says Bilmon, it would have resulted in a "…less exciting, beautiful, and functional building."
The material's appeal is manifold, and those who work with it praise its unique properties. First, it's extremely light—about 1/100 the weight of glass—and deceptively strong, able to stretch to three times its length without losing its elasticity. (Having said that, a sharp implement like a knife can puncture it—one reason it's used mostly for roofs.)
If the film does tear, it can be patched with other pieces of ETFE. When exposed to fire, it softens and shrinks away from the heat, naturally venting smoke out of a building. And it's naturally nonstick, nonporous surface, which has chemical properties similar to DuPont's other best-selling material, Teflon, is so slick that dirt, snow, and rain simply slide off.
SHAPE SHIFTER - Its light weight reduces corresponding structural costs. Edward Peck, managing director of the North American Division of Foiltec, which now has 12 offices and 250 employees worldwide, estimates that a simple, small roofing project could be 10% cheaper if ETFE were used. For larger, more complicated projects, the overall construction savings could reach 60%.
Then there's the fun factor. ETFE comes in different finishes (transparent, matte) and colors, and can be lit from within using LED lights or decorated with light projections like a giant movie screen. It can be printed with patterns by running it through a special press—something not possible with glass. It can take myriad shapes, too: Strips can be heat-welded together like fabric squares in a quilt. This "sewing" method enables ETFE to be installed in pieces much longer and wider than glass. A large glass panel might measure 10 ft. by 5 ft., whereas a strip of ETFE could be 180 feet long and 12 feet wide, with structural supports.
It also scores well on the environmentally friendly front, particularly crucial given the current call for greener building practices. The film is recyclable (simply melt and reuse), and due to its light weight, doesn't require much energy to transport. The Watercube is designed to gather heat passing through its ETFE walls and roof—energy that can be used to heat the building's water systems or expelled through vents if the building gets too hot.
HIGH MAINTENANCE - On an aesthetic level, the cushions reinforce the building's theme. Their pillowy shapes evoke a bubbles's roundness, and their triple-layered construction, which mixes layers of blue film with transparent film, gives the façade a sense of depth and shifting color. Once the games start in August, 2008, officials will be able to transform the walls into a giant TV screen showing simultaneous projections of the swimming activi-

ties taking place inside.

For all its wondrous properties, ETFE isn't an entirely perfect material. In its typical usage, two or three layers are welded together and shipped flat to the job site, where they're inflated into panels or "cushions". These cushions require semi-continuous air pressure—to keep them stable and give them thermal properties—so most systems include thin hoses that plug into the cushions' sides.

These air-supply lines connect to a computerized system that monitors the pressure within the cushions. This system can also feed air into, or eject air from, particular chambers or layers to let in more light or create more shade, meaning the ETFE cushions act as a dynamic puffer jacket for buildings. In some installations, this is done automatically using light sensors.

OVERHEARD OVERHEAD - Of course, many projects don't call for such complexity. "You have to evaluate, project by project, what the driving force is for using ETFE," says Foiltec's Peck. "Is it for architectural imagery, for transparency, for structural reasons or thermal performance?" He doesn't advise using it for small-scale or residential projects.

Acoustics can be another drawback. The cushion system, when used on a roof, can amplify the sound of rain because the tension in the cushion acts like a drum. Manufacturers have developed several noise-suppressing techniques, including layering polycarbonate sheets within ETFE cushions, but their use isn't widespread yet.

Interior applications, such as walls within an office, present other sound issues. ETFE transmits more sound than glass or wood, making it ill-suited for meeting rooms or conference centers near airports, to name one ETFE proposal that was quashed by noise concerns. Conversely, ETFE can be beneficial for self-contained, noisy areas like aquatic parks—sound bounces off the walls and floor and escapes through the roof.

JUST THE BEGINNING - But plans are already under way to address these concerns, and ETFE is already cropping up in more and more locations. Foiltec has eight projects that will be built in the U.S. next year (and more than 100 projects slated worldwide), and has just completed an atrium roof for a U.S. Federal building. Peck hopes the latter project might prove to be a turning point for ETFE in the U.S., which has been notably slow to catch on to the material's potential. ETFE was named in three of the four submissions for the Beijing National Aquatic Center, and can be seen in several proposals for the 2012 London Olympics.

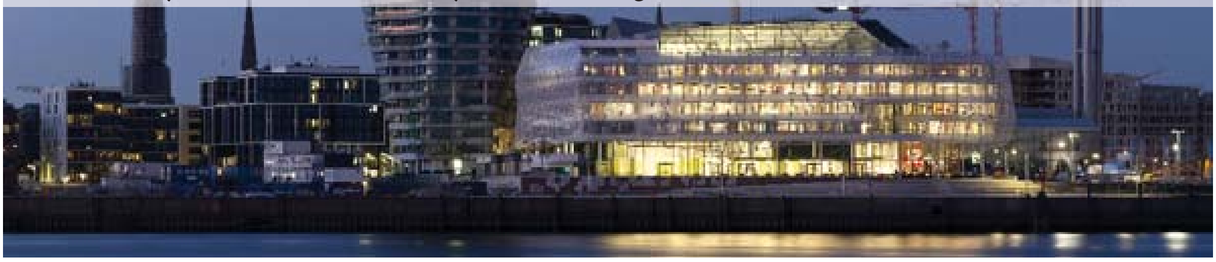
Another large ETFE project is already on the horizon: The Khan Shatyry Entertainment Center, a 1,076,000-sq.-ft. tent-shaped recreational complex in the capital of Kazakhstan, designed by London firm Foster + Partners is due for completion next year. Other top-tier architecture firms, like Skidmore, Owings & Merrill (SOM) and Gehry Partners, are said to be considering ETFE for upcoming projects.

And other innovations are still being developed. Foiltec is currently testing whether it might be possible to attach photovoltaics to ETFE panels or use an insulating "nanogel" to increase a panel's thermal properties. As Bilmon, the Watercube architect, says: "There's a new realization that the whole of the world is facing sustainability issues—and solutions like ETFE are required for the future."

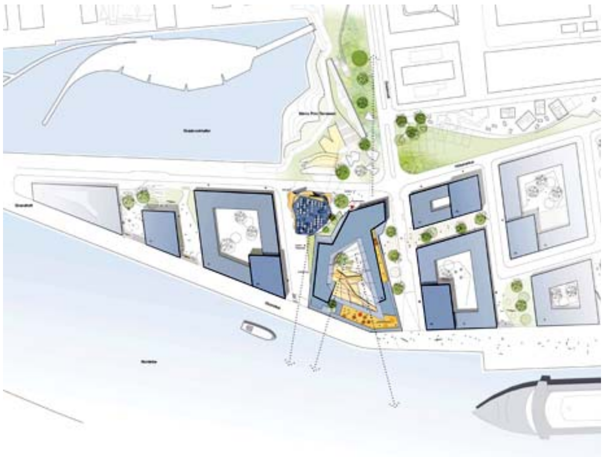
BUSINESS WEEK - April 24, 2007

Unilever Headquarter
Behnish Architekten - 2009

The new Unilever headquarter building for Germany, Austria and Switzerland is located right by the river Elbe in Hamburg's HafenCity. It marks the end of the route out of the town centre to Hamburg's new attractions: the cruise ship terminal and the promenade on Strandkai. Here Unilever's new building opens itself up to the city and its inhabitants.
The central element and heart of the design is the generous atrium, flooded by daylight, which, on the ground floor, gives passers-by the opportunity to get to know the company better while browsing in the shop stocked with Unilever products, sitting in the cafe or relaxing in the spa. The atrium is also the central location for people to meet and communicate. As in a city, bridges, ramps and stepsconnect central spaces with each other. Here people can meet, talk and enjoy the inspiring ambiance. Vibrant and communicative interaction evolves, thereby fostering a feeling of togetherness among the employees.
The workplace is no longer a separate department. The building itself reinforces the identity of the company. The building follows the principles of holistic, sustainable architecture. While implementing technologies that help save resources, the energy concept adheres to the principle of avoiding technical solutions wherever possible. The office area is cooled by means of thermally activated reinforced concrete ceilings. A single-layer ETFE film facade placed in front of the building's insulation glazing protects the daylight-optimized blinds from strong wind and other weather influences. The building's primary energy consumption during operation will be under 100 Kwh/a m². A newly developed SMD-LED system has been deployed both for the building's general lighting and for workplace lighting. This system is up to 70% more efficient than conventional halogen or metal halide lighting. The Unilever building received the newly established HafenCity EcoLabel in gold.





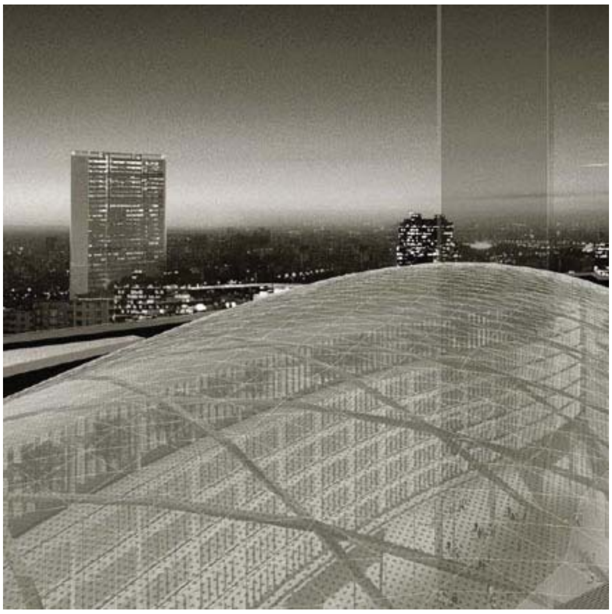




Ansicht Süden

Palazzo Lombardia
Pei Cobb Freed & Partners - 2007

This is the winning entry in an international design competition for the Lombardy Regional Government's New Seat and civic square, required to have a visible symbolic and functional presence. Significant to the design is its integration with the Pirelli Tower, which houses related regional government offices, with the urban context of Milan and with the Lombardy region. Sited in the greater Garibaldi-Repubblica urban enhancement area, close to the heart of the city, its scale relates to the surrounding neighborhood, while the tower speaks to the Pirelli building and the city. Key design principles are:
- an urban passage invites entry.
- it is a significant destination.
- there is a sequence of engaging spaces.
- animated edges give shape to public space.
- the design promotes social interaction.
- an emblematic vertical element contributes to Milan's skyline.

The building's sinuous interweaving strands recall the mountains, valleys, and rivers of the region. Their curvilinear forms are adaptable to changing functional requirements and are receptive to the region's evolving organizational structure. In addition to its headquarter functions, the building accommodates public amenities accessible to all. The central piazza, projected with curved glass roof, but realized in ETFE, recalls Milan's Galleria while linking to two secondary open spaces and a linear landscaped spine, together celebrating the natural environment, rich culture, and citizens of Lombardy.
The cover of the plaza, 3. 380 sq.m. of developement, presents a typical structural system used for glass, so it's more than hyperstatic for the ETFE, but the constructor prefer to mantain the original design of the architect to built this roof, the first time projected with a glass system. The change of materials had to be necessary for the weight of the glass panels, so the choice to contact Vector Foiltec to install ETFE, 10 times lighter than glass.




VIA ALGAROTTI
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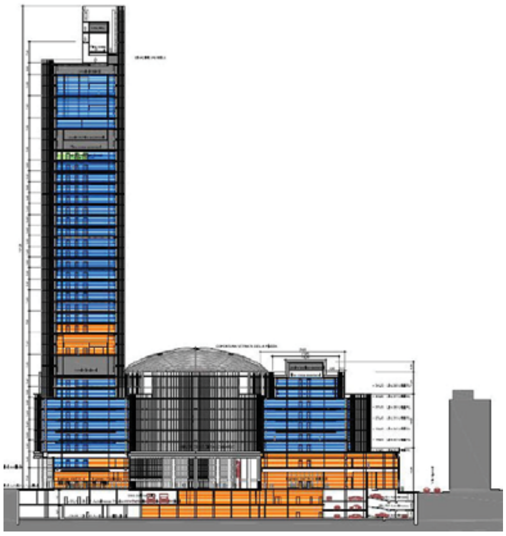
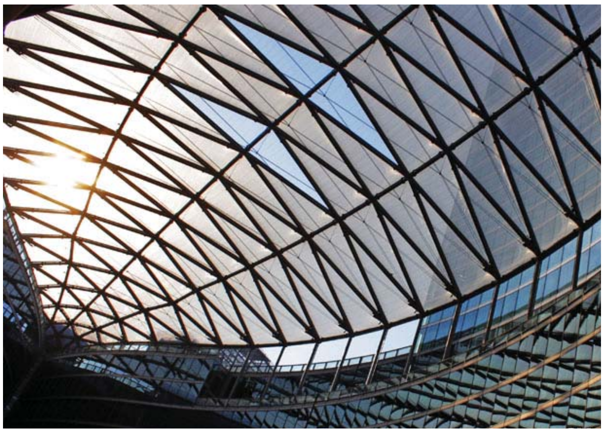
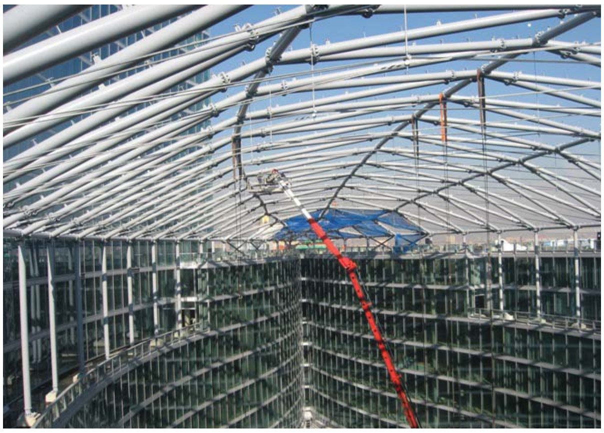




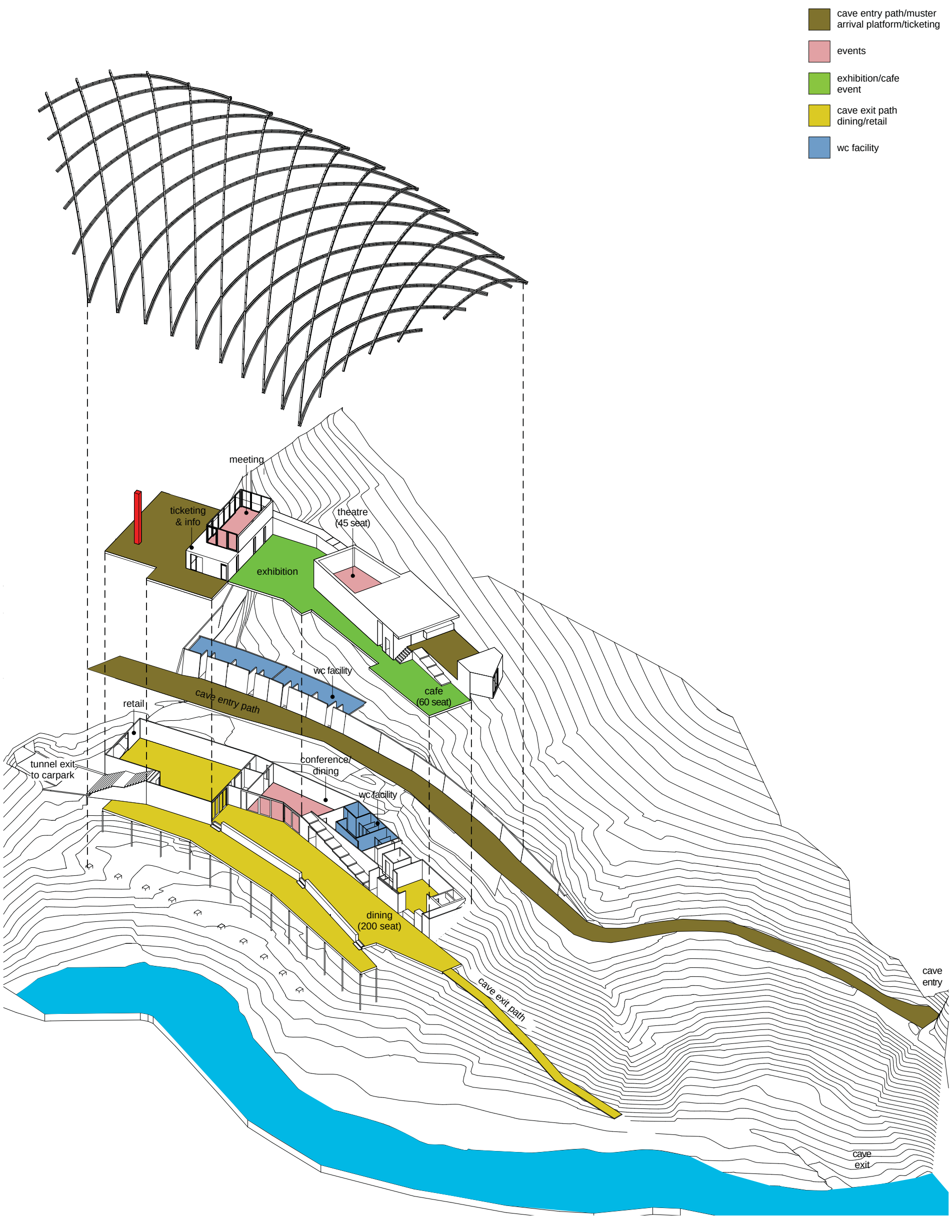





New Waitomo Caves Visitor Centre
Architecture Workshop - 2010

Sheltered below an innovative woven timber canopy, new amenities for visitors to the Waitomo Caves includes tourist gathering areas, a 250-seat dining, retail, seminar and exhibition areas as well as a café and theatre for Tourism Holdings Ltd.
The cave entrance is accessed from the car park on the upper path while a lower path returns the visitors back alongside the stream exit. Between these paths the amenities were accommodated within a simple base structure that extended the contours of the land. The form of the base is distinguished and separate from the curved geometry of the overhead canopy.
The historic caves were formed from the limestone transported by water over thousands of years, so we wanted to emphasis a connection with the Waitomo stream and the flows of water running through the caves. The canopy gridshell is aligned with the curve of the Waitomo stream. It reinforces the generating idea for this project of a simple lightweight 'sky shell' to counterpoint the subterranean cave space that is dissolved and molded out of the ground. The canopy in combination with the caves, create a positive and a negative, if you like.
The structure of the centre is internationally significant. The geometry of the canopy was described by the surface of a toroid and Radiata pine LVL (laminated veneer lumber) was prefabricated into curved (and twisted) ribs in Hunter's factory in Nelson. These timber I-beams were joined, overlapped in layers, then screwed together as they were assembled on site by Hawkins Construction. The weaving of the timber structure to create a timber net or 'gridshell' is recalled by the local hapu as a hinaki or Maori eel trap. The gridshell was calculated by Alistair Cattanach at Dunning Thornton Consultants. His analysis was peer reviewed in London by Happold Structural Engineers, who commented favourably on the strengths achieved with NZ pine LVL and an innovative soft pad connection with the over cladding.
Inflated ETFE air pillows were tethered over the gridshell structure like a tent fly. The long translucent pillows are structurally efficient in spans of 4-5m and followed the lines of the LVL ribs. The gridshell was designed to span across the existing pathways and provide some shelter in the journey to and from the caves as well as maintain a strong connection to the established Kahikatea bush.


cave entry path/muster
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events
exhibition/cafe
event
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dining/retail
wc facility
meeting
ticketing
& info
theatre
(45 seat)
exhibition
wc facility
cafe
(60 seat)
cave entry path
retail
tunnel exit
to carpark
conference/
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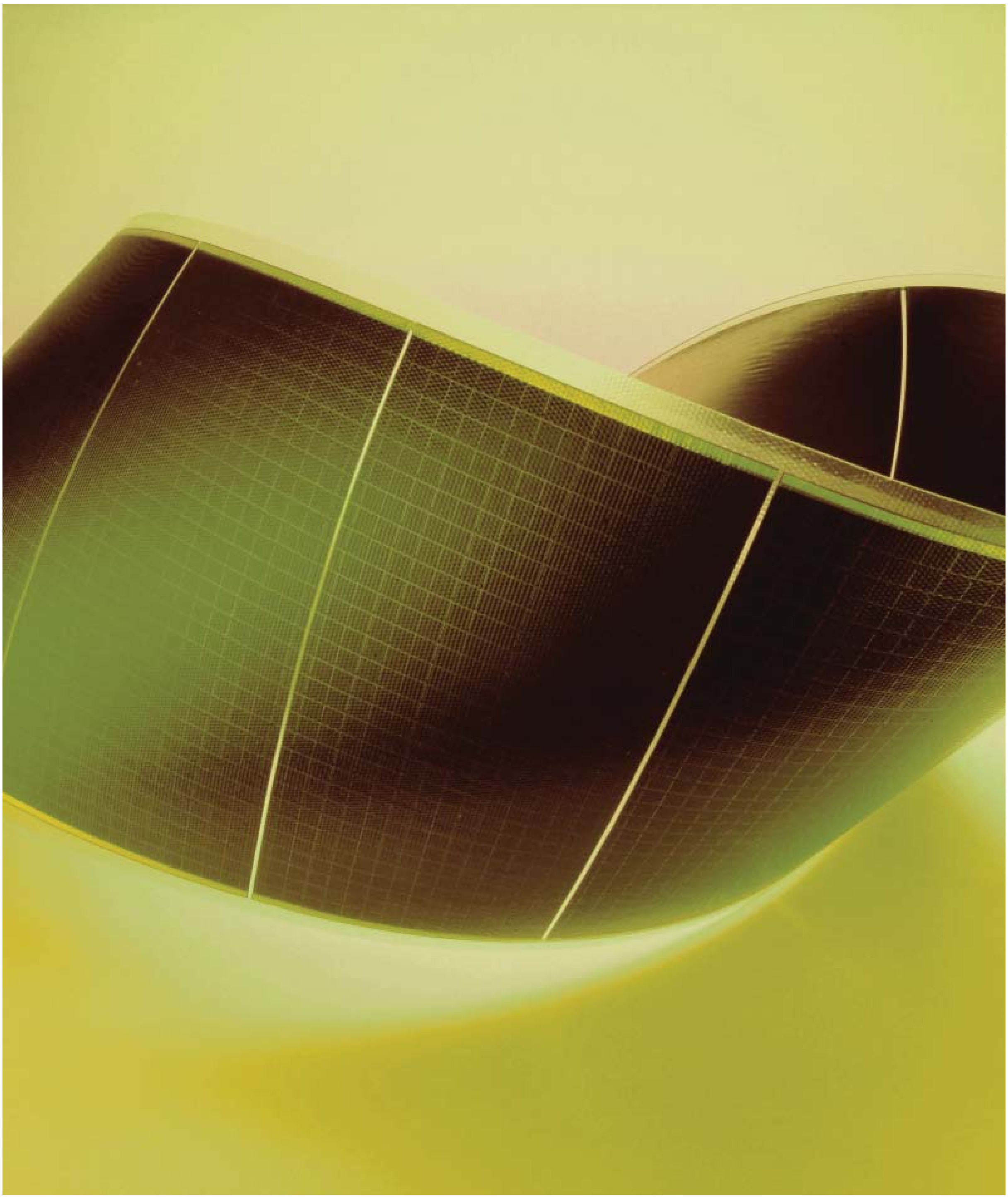


THIN

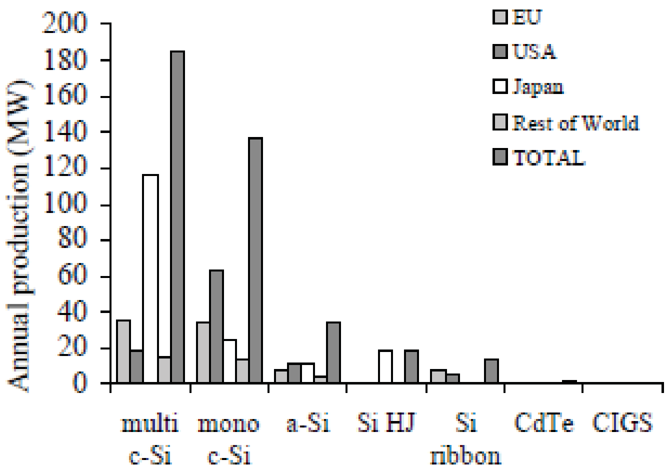
PHOTOVOLTAIC

FILMS

Photovoltaic conversion of solar energy is based on semiconductor electronics. Although materials such as GaAs, CulnSe2 and CdTe may be without any doubt valid alternatives, still today the photovoltaic market is by far dominated by silicon. About 80% of the solar-cell world PV production for terrestrial applications has its origin in mono-crystalline (c-Si) and multi-crystalline silicon (mc-Si) wafer technology. Most of the remaining 20% market is dominated by thin-silicon (amorphous, microcrystalline, nanocrystalline, etc.) and by hybrid amorphous-crystalline solar cells (a-Si, μc-Si).
Experience has induced the conviction that silicon technology must dominate the PV market for the next 10 years: the cause of this predominant position is the combination of a number of factors, such as the maturity of silicon PV technologies, the good and well-known optoelectronic properties of the material, its availability, lack of toxicity, cost, chemical stability, etc.
During 2001 a total supply of 26 000 tons of silicon reached the electronic industry, of which around 15% were used to supply the PV market. Europe is a leader in the production of crystalline ingots and wafers for PV applications, in particular in Germany where are concentrated a large number of these industries and also branches of big international groups.
Crystalline-silicon (c-Si) wafer-based technology must evolve towards lower costs by implementing new material-fabrication processes and making wafers thinner. On the other hand, silicon grown directly on low cost substrates is forced to progress in the direction of improving the optoelectronic properties of the material and its growth rate and consistently of making the cell active-layer thicker. Several efforts have been done since 1994 based on European projects dealt with different options concerning substrates (silicon ribbons, conductive and insulating ceramics) and deposition technologies (high- temperature chemical vapour deposition - CVD) and solution growth-SG: the consequence of all this is a clear convergence of two families of research lines based the first on wafers, the other on the growth of silicon onto low-cost substrates that have traditionally progressed quite independently. Synergy can come out of this mutual approximation, and may be the origin of important advances in next generation PV.
For a long while, wafer and thin-film technologies have evolved as competing options, as if the solutions to the technical problems could have come out from only one of these two research lines. In the last few years, however, new possibilities have arisen on the basis of a number of

technological approaches for the fabrication of inexpensive multi-crystalline silicon, for the growth of poly-crystalline silicon thin films on inexpensive substrates or for the deposition of high-quality microcrystalline-silicon thin films at competitive growth rates.

Present research lines in europe

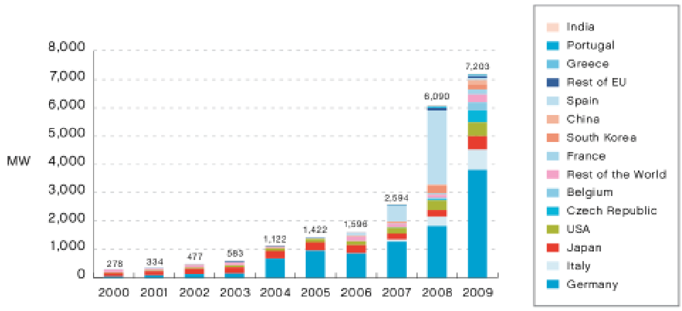


The graphic shows the market share in year 2001 among photovoltaic technologies for the different areas of the world. A rough analysis of these data reveals:

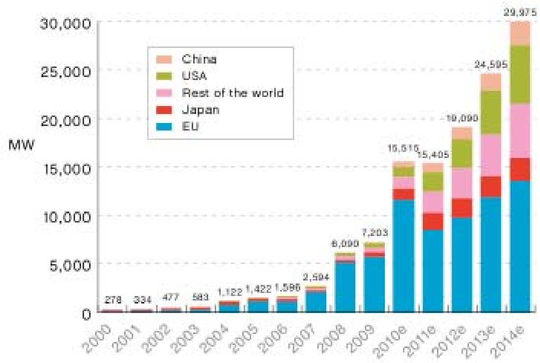
- Different priorities in the EU, the USA and Japan.
- An emerging activity on non-silicon thin film photovoltaics (CdTe and CIGS). CIGS initiatives are mainly led by European companies.
- A significant development of silicon-hetero-junction devices, focused in Japan.
- More interest for ribbon silicon in Europe and USA than in Japan and other areas.

In contrast to the well-defined and well-funded Japanese PV program, the situation in Euro-

pe is characterized by a strong diversity in national programs, some of which are individually strong, but with a high degree of fragmentation. On the other hand, a successful European Research and Technological Development strategy imposes the collaboration of a large number of public and private institutions.
In this sense in Italy CNR focus their researches on the developments of deposition of a-Si, μc-Si, SiC alloys, on Er-doped silicon thin films, on fully μc-Si thin films with very low H-content even at low temperatures, on the growth of μc-Si on plastic substrates, on optimization of c-Si/μc-Si heterojunction solar cells and on SiHJ.
So the future of photovoltaic technologies is directed to the research of the thickness of the wafer, optimizing both links, junctions and cells; in this sense I have approached the most important thin films technologies to study the possibilities and the potential for an integration inside the ETFE modules.



analysis of the world annual photovoltaic market in the last years (2000-2009)



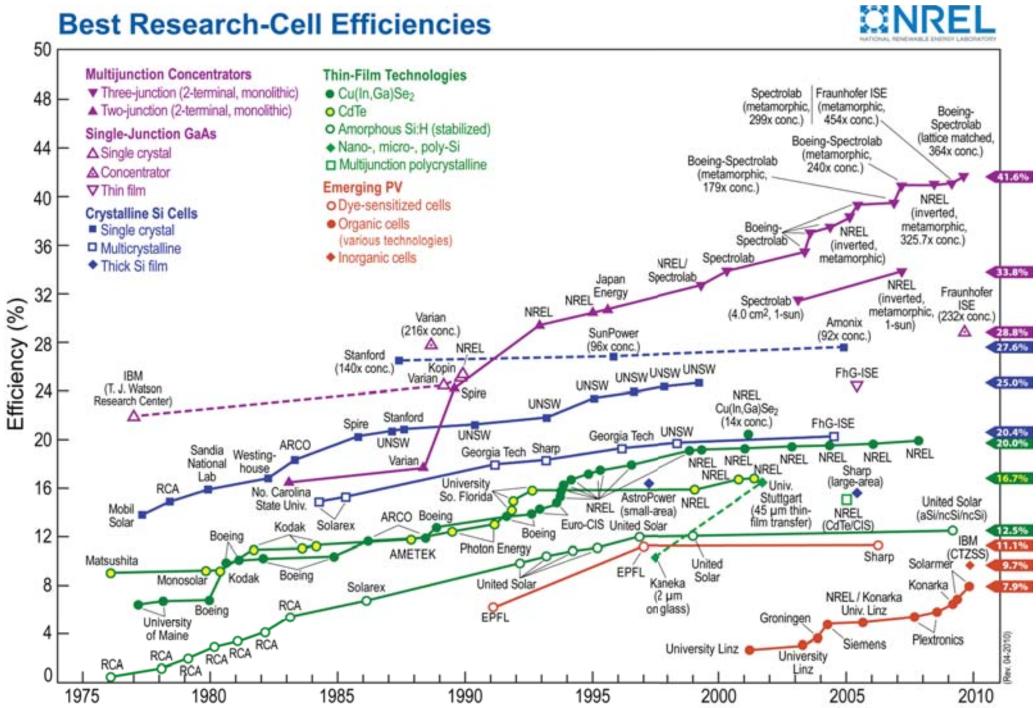
regional photovoltaic distribution from the analysis of the last years to a preview of next three years

Thin Films

Thin-film solar photovoltaic (PV) cells are an exciting product as they could also be flexible and potentially can be developed much further, providing layering characteristics and shape change alternatives. The term thin-film is derived from the method used to deposit the film, not from the thinness of the film, so the cells are deposited in very thin, consecutive layers of atoms, molecules, or ions. Thin-film cells have many advantages over their "thick-film" counterparts: they use much less material, the cell's active area is usually only 1 to 10 microns thick (thick-films typically are as much as 200 to 400 microns thick). Thin-film cells are also usually amenable to large-area fabrication and are suitable for automated, continuous production, arraying, and packaging. They can also be deposited on flexible substrates, like ETFE. Many thin-film devices are based on amorphous silicon alloys, others are usually poly-crystalline materials. The fabrication of a thin-film solar cell involves depositing a layer of semiconductor material (such as amorphous silicon, copper indium gallium diselenide, or cadmium telluride) on a low-cost substrate, such as glass, metal, or plastic. Current deposition techniques can be broadly classified into physical vapor deposition (PVD), chemical vapor deposition (CVD), electro-chemical deposition (ECD), plasma enhanced chemical vapor deposition (PECVD) or some combination of them.

Thin-film materials can be produced in either single-junction or multi-junction configurations. Multi-junction cells often referred to as stacked junction, cascade, multicolor, or tandem cells, are more complicated and expensive than single-junction cells, and should result in higher efficiencies. This concept entails combining two or more single-junction cells (the top cell being semitransparent), so that each junction converts a different portion of the solar spectrum into electricity, thus using the light more efficiently. Although a variety of semiconductor materials have appropriate energy band gaps and absorption characteristics, today technologies being developed are primarily focused on amorphous silicon (a-Si), copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe).

There is an interesting comparison to be made between thin-films and wafer technologies, when it comes to inter-cell connections. To connect wafers together, metal ribbons are attached to the cells at discrete points, while one of the main advantages of thin-film over crystalline solar cells is that the complete module can be deposited with the cell interconnections made during layers deposition. Unlike crystalline modules, thin-film modules are not plagued by problems associated with interconnecting individual cells. Individual cells of any size and number are made by scribing the sequential layers (either with a laser beam or mechanically), as they are made so that the top electrode of one cell contacts with the bottom electrode of another cell, linking them in series. While broken connections are not uncommon in wafer-based modules, it is virtually impossible for thin-film modules to open up because of inter-cell contact failure. Each individual cell is in the form of a long narrow strip, which reduces series resistance, and all cells are connected in series, with the outer metal strip being the negative terminal and the outer transparent conductor strip the positive terminal for the whole module. Since the voltages of cells in series add, the total voltage for a module can easily be adjusted by changing the scribing pattern that defines the number and size of individual cells. Width of each strip determines the current of individual cells. Thin-films exhibit contact redundancy that can be an important factor in module longevity.



Amorphous silicon

History

The last quarter century witnessed the birth, the adolescence, and the maturity of amorphous silicon (a-Si) based photovoltaic (PV) technology. As it usher in the twenty-first century, it must also meet the ever increasing energy demand while addressing environmental issues and ecological concerns. The a-Si PV technology has positioned itself as the low-cost solution to the challenge of energy, environmental, and ecology (the e-tripos).

As the a-Si photovoltaic industry still experiences unavoidable growing pains, large-volume manufacturing plants are ready to demonstrate their competiveness in the rapidly growing global market. Photovoltaics in general, and a-Si technology in particular, will undoubtedly play a significant role in providing clean, quiet, and renewable energy harvested from the inexhaustible sun. The volume of worldwide sales of a-Si modules was 34 MW in 2001, a phenomenal growth of 26% over the previous year, but only represents less than 10% of the total photovoltaic market. In the next quarter century, the most important brands expect the a-Si technology will attain a greater share of the world market.

In recent years, the feasibility of using a-Si PV for space applications has been investigated due to its high specific power (W/kg) and low cost. Nineteen months of experience on board MIR Space Station has revolutionarily uplifted the outlook for use of a-Si solar arrays for future missions in space. The a-Si photovoltaic has been identified as the enabling technology for certain applications.

Analysis and advantages

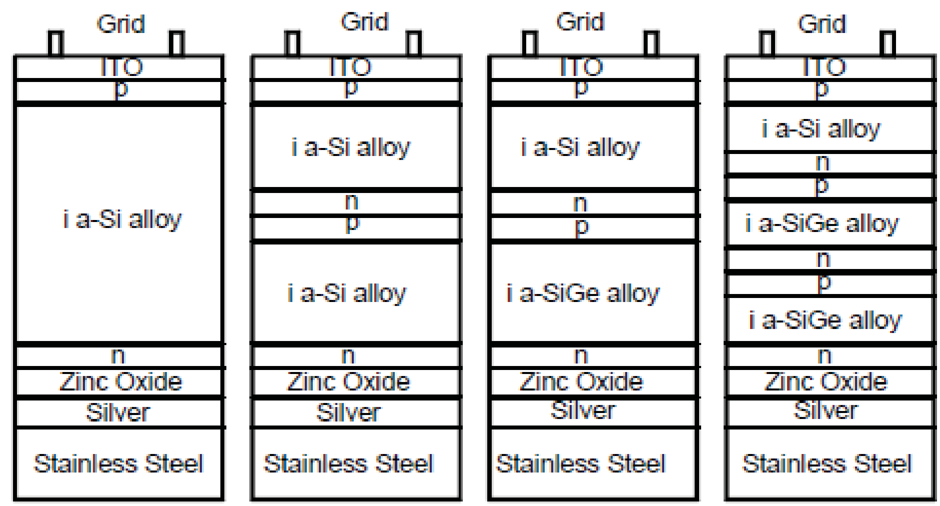
Low cost is one of the leading advantages of a-Si photovoltaic modules. Two of the major ingredients of the a-Si alloy are silicon and hydrogen. They are environmentally friendly and abundant on earth. Furthermore, a-Si alloys are characterized by a high absorption coefficient. Only a thin film ($< 1\ \mu m$) is needed to absorb the sunlight, and this leads to low material cost. Good conversion efficiency is another advantage for a-Si modules. In the laboratory, it's used the radio-frequency plasma-enhanced chemical vapor deposition method and it has been demonstrated a stable cell efficiency of 13% using a spectrum splitting triple-junction structure. In addition, low cost manufacturing is also an important requirement.

While disorder leads to a high absorption coefficient for a-Si alloys, it also creates wide band tails in the energy gap. The band tails and other structural defects in the form of weak, dangling, and strained bonds affect transport of carriers in the solar cell. Furthermore, a-Si alloys degrade upon light soaking due to the Staebler-Wronski effect (SWE). To alleviate these problems, the multi-junction approach, where more than one cell is deposited on top of another, is used. This approach allows one to use thinner cells to minimize the SWE. In addition, the multi-junction structure incorporates materials with different band gaps that increase the overall spectral response of the device and results in higher efficiency.
One way to improve the double-junction cell efficiency is to broaden the spectral response of the absorber layer. By incorporating germanium (Ge) into the bottom cell, one can reduce the band gap and enhance the long wavelength response. However, the carrier transports properties of the a-SiGe:H materials are inferior to those of the a-Si:H material. In general, a-SiGe:H solar cells exhibit lower Volts in open circuit and poorer fill-factor than the a-Si:H cells of similar thickness. On the other hand, the enhancement in junctions gives the opportunity to pass by this problem.
This dual band solution results not improved and susceptible to the SWE, since the top cell needs to be sufficiently thick to produce a current large enough to match the current from the low band gap bottom cell. This leads to the design one using a triple-junction approach. In this structure, the top cell is a-Si:H to absorb the blue photons, the middle cell uses a-SiGe:H with ~15% Ge to capture the green photons, and the bottom cell incorporates ~ 30% Ge to absorb the red photons. The textured back reflector at the bottom and the indium tin oxide (ITO) antireflection coating on the top complete the most efficient cell structure to date.

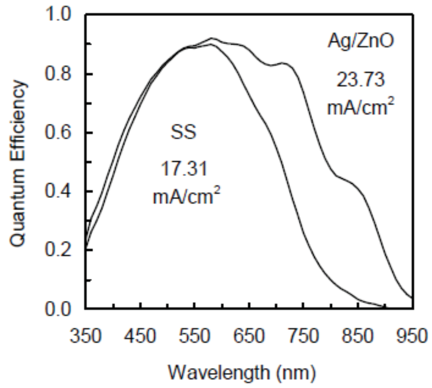
Triple junction structure

A highly reflective metal, such as aluminum or silver, is usually deposited on top of substrate to enhance its reflectivity. The most effective reflector we have used to date consists of a two-layer structure. It contains a textured Ag layer followed by a conductive ZnO layer to form the back reflector and facilitate light trapping in the solar cell.
To achieve high performance multi-junction cells, one must first consider the thickness and band gap of the component cells. For a double-junction structure, one should first evaluate the capability of the bottom cell on back-reflector and see how much current it can generate under

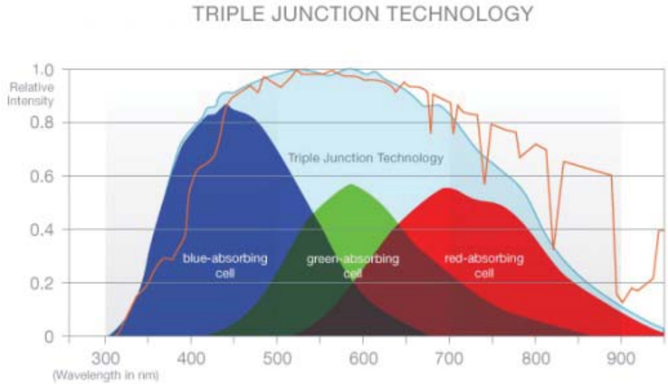
the standard spectrum. The rule of thumb is then to design the top cell to produce about half the current. During the optimization process, it is often useful to evaluate the bottom cell with a red filter to simulate its operation in a double-junction structure. Since the top cell usually uses a-Si:H and shows a good fill factor due to its small thickness and superior material quality, it is beneficial to slightly limit the double-junction current by the top cell. It is also important to keep in mind that the desired amount of current mismatch should be determined by the degradation behavior of the component cells after light soaking. A similar approach can be applied to the triple-junction structure. One should first evaluate the bottom cell on back reflector. The top cell should roughly produce one-third of the bottom-cell current, and the middle cell two thirds. Again, it is useful to evaluate the middle and bottom cells with appropriate filters to simulate their operations in a triple-junction structure.
The doped layers that flank the i layers are necessary for solar cell operations, but they are not photovoltaically active. They represent parasitic loss both electrically and optically. The p layer through which the light enters the solar cell is particularly important and should be as transparent and conductive as possible.



(a) Single - Junction (b) Same Gap Double - Junction (c) Dual Gap Double - Junction (d) Triple - Junction



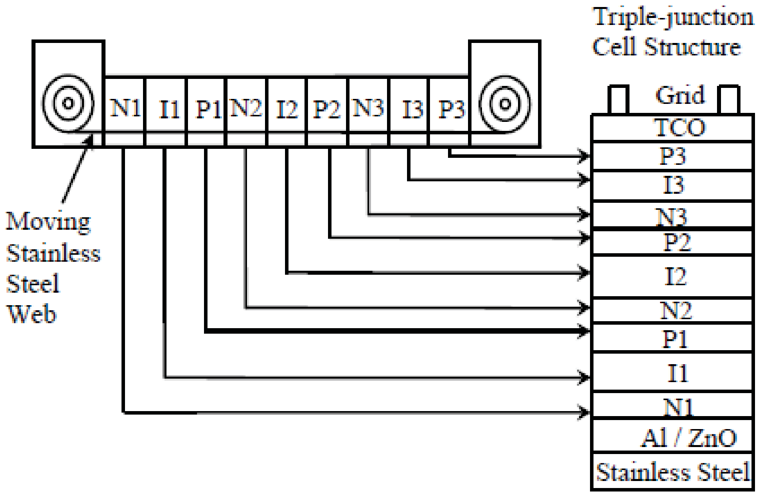
the effect of the Ag/ZnO conductive layer on the efficency of the cell

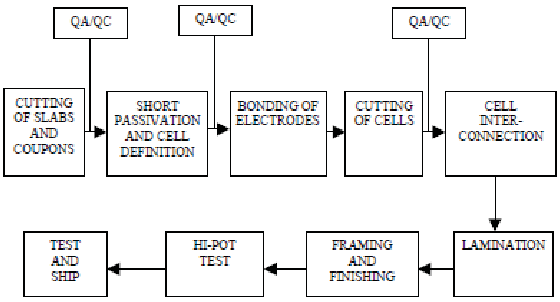


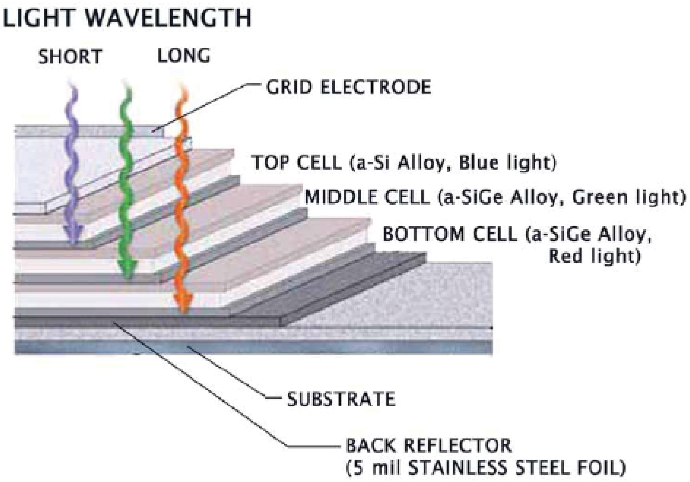
the effect of the triple junction spectrum: the catch in the three layers of different wavelenghts optimze the efficiency of the whole cell

Uni-Solar, leader in triple junction technology, has developed a microcrystalline p layer, which resulted in a significant improvement in the cell performance. In a multi-junction structure, a tunnel-junction is formed consisting of the two adjacent doped layers of the two adjacent component cells. Because the tunnel junction consists of thin doped layers, carriers can be considered to 'tunnel' through the layers. In reality, photogenerated electrons and holes recombine in the 'tunnel' junction. Thus, it is also referred to as the 'recombination' junction. However, the polarity of the tunnel junction is opposite to that of the multi-junction device. It is therefore important to minimize losses associated with the tunnel-junction.
The quality of the component cells determines the performance of the multi-junction structure. The component cells are the basic building blocks. It is convenient to evaluate and optimize each component cell separately, then integrate them into a multi-junction configuration. It is useful to evaluate the component cells under appropriate illumination conditions corresponding to their respective spectral response in a multi-junction structure.
I should point out that high quality component cells are necessary but not sufficient conditions for achieving high efficiencies. This is analogous to the fact that high quality intrinsic material is a necessary but not sufficient condition for fabricating high efficiency solar cells.

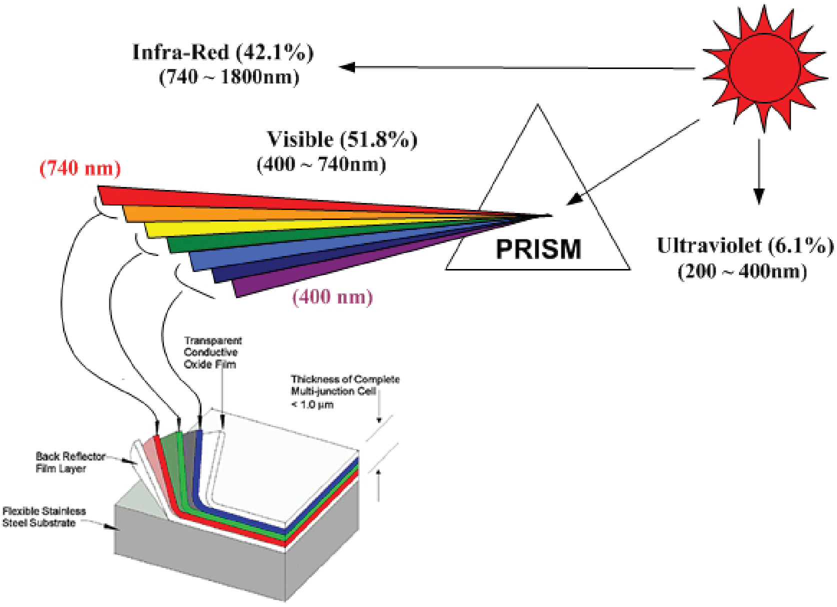
A key feature in the manufacturing technology for the production of the amorphous silicon cells is the roll-to-roll continuous deposition process. Only flexible substrates are compatible with this process. A roll of 0,12mm thick substrate goes through four consecutive roll-to-roll machines: first to wash, then to deposit the back reflector film, triple-junction structure and top conductive layer. While the width of the rolls used is fixed, there is no constraint on the length of the roll. After the four roll-to-roll processes, the coated web is then cut into a predetermined size for module fabrication.







LIGHT WAVELENGTH
SHORT
LONG
GRID ELECTRODE
TOP CELL (a-Si Alloy, Blue light)
MIDDLE CELL (a-SiGe Alloy, Green light)
BOTTOM CELL (a-SiGe Alloy, Red light)
SUBSTRATE
BACK REFLECTOR (5 mil STAINLESS STEEL FOIL)



Infra-Red (42.1%)
(740 ~ 1800nm)
Visible (51.8%)
(400 ~ 740nm)
(740 nm)
PRISM
Ultraviolet (6.1%)
(200 ~ 400nm)
(400 nm)
Transparent Conductive Oxide Film
Thickness of Complete Multi-junction Cell < 1.0 µm
Back Reflector Film Layer
Flexible Stainless Steel Substrate

Future directions

Over the last quarter century, although a-Si PV technology has emerged as a strong contender for providing quiet, clean, and renewable energy for terrestrial applications, many challenges remain, as described below. The fundamental limitation in the solar cell efficiency is in the material quality. Hydrogen dilution during film growth has been effective in improving the material quality and cell stability. Further improvement in a-SiGe:H alloy can benefit the multi-junction structure.

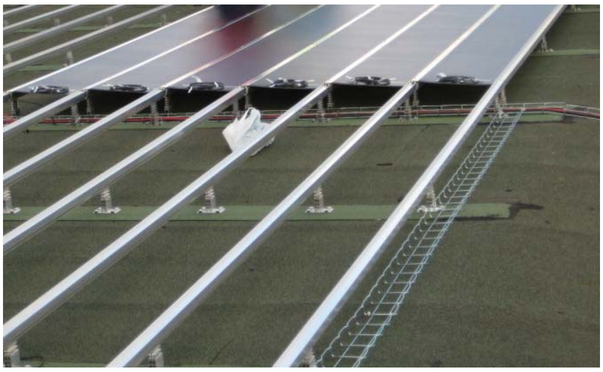
Innovative cell design and improvement in the back reflector and anti-reflex film can also have significant impact on the cell efficiency. Improvement in fundamental understanding of the SWE may shine additional light on ways to minimize or eliminate the degradation mechanism. Studying the correlation of the SWE and other properties such as micro-structural change should be helpful.

Improvement in manufacturing technology can greatly impact the module cost. Cost reduction in raw material, such as higher throughput without sacrificing the efficiency is a major issue. Use of inexpensive raw materials, encapsulation materials and processes, as well as automation for large-volume production can also significantly reduce manufacturing cost.

Coca-Cola Hellenic Bottling Company, Italy
solution for bitumen roof

Solar Integrated Technologies and investor Contour Global currently co-develop green energy solutions on four different sites of Coca-Cola bottler Hellenic using UniSolar brand flexible thin-film photovoltaics: on the site in Marcianise, the PowerTilt system is installed on the existing bitumen roof. The projects were realized into a larger energy savings program providing further benefits to Coca-Cola's efforts to further reduce its carbon footprint and increase the energy efficiency of its operations.
The decision for UniSolar brand products was made due to Coca-Cola Company's requirement of a low impact PV-installation on the rooftops of their facilities. The PowerTilt solu-

tion is light weight and though on a substructure it still adapts perfectly to the architectural design while generating high energy yields. This solution adds less than 10 kg/m² of weight.
The PowerTilt system consists of a substructure and the photovoltaic laminates bonded to an aluminum sandwich panel. The base rails of the substructure include fixation points to which the remaining structure is attached. The base rails themselves are covered by a strip of the same bitumen material as the roof, which is hot welded to the existing bitumen roof. No ballast is required for fixation or wind-load security. Due to the thermal welding of the substructure to the roofing material the waterproof roofing material is not being penetrated and thereby damaged in any way, maintaining the watertight function of the roof and its respective guarantees.
The modules are installed in rows with all cables facing to one side. The cables run in special mesh trays to guide them to the inverter station, where the direct current produced by the solar system is converted to alternating current, which can be fed into the grid or used on-site. This system in Marcianise produces 905 kWp of clean energy that contribute to the reduction of carbon footprint.



Exhibition Center, Rome, Italy
solution for curved metal roof

The project was realized under the management of Green Utility, who is also the system owner and operator. They decided, in order to obtain full architectural integration of the PV installation, to use a PV solution developed by the roofing supplier (ISCOM), which integrates seamless with the existing metal roofing. The UniSolar flexible laminates are adhered to a specially designed aluminum support, which can be simply snapped into the existing metal roofing. ISCOM's Riverclack solution is lightweight and flexible allowing perfect adaptation to the curved roof design while generating high energy yields.
The Rome exhibition center benefits from green solar electricity at predefined favorable prices with respect to current market prices and without peak tariffs, able to cover 20% of electricity consumption. Additionally no investments or maintenance costs related to PV system need to be covered and with a target of 20% electricity produced by renewable energy resources the Rome exhibition center is 12 years ahead of the 2020 goal fixed by the European Union. There is no concern about the roof integrity as the system was installed without roof penetration by simply snapping ISCOM's Riverclack solution into the segments of the existing metal roof.
The 1.5 MWp installation will produce approximately 1 800 MWhs per year of electricity, which reduced CO_2 emissions by about 981 tons per year.

Ernst Sutter AG in Bazenheid, Switzerland
solution for membrane roof

The installation of an innovative construction of Ernst Sutter AG, with a grid-connected photovoltaic, together with the use of climate neutral refrigerating agents, application of state-of-the-art control technology and district-heating of a near-by refuse incineration plant, is another milestone to complete the Minergie Frischfleischzentrum (fresh meat center). The Swiss Minergie standard focuses on improving the thermal comfort in buildings, maintaining and upgrading the value of real estate and reducing energy cost when avoiding fossil fuels like mineral-oil, gas and coal.
The undulated roof consists of sections with a length of 10 meters and 3° inclinations on which an amorphous silicon photovoltaic system was installed by Solar Integrated. The solar roof is a combination of high-end roofing membrane of Sika with integrated UniSolar PV-laminates. The main advantage of this solar roof compared to conventionally mounted systems is the low weight of only five kilogram per square meter and having no extra wind loads as it is welded

around all edges directly to the roof membrane underneath. Furthermore, it perfectly adapts to the existing roof structure and does not have any negative impact on the overall aesthetic design of the building.
Due to its low temperature coefficient, the efficiency also remains stable in summer with rising module temperatures, has no available ventilation and makes this technology ideal for its building integrated application.
The PV-installation has a size of 150kWp and produces more than 140MWh electricity per year and avoids a minimum of 70 tons of CO2 emissions, which would be otherwise produced by fossil fuels.

CIGS Photovoltaic

CIGS is the acronym of copper-indium-gallium-(di)selenide, a chemical description of one of the most developed technologies in photovoltaic systems today. From 2000 this material develop from an efficiency of the 12-13% to a tested 19-20% by the NREL, the most important solar research center in the United States.

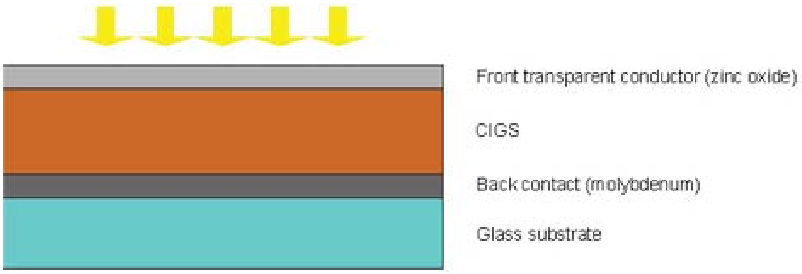
The thin flexible films today on the market made with this technology raise an afficiency of 14%, that made this thin film the direct competitor for the crystalline modules.

CIGS films can be manufactured by several different methods: the most common vacuum-based process co-evaporates or co-sputters copper, gallium, and indium,then anneals the resulting film with a selenide vapor to form the final CIGS structure. An alternative is to directly co-evaporate copper, gallium, indium and selenium onto a heated substrate. A non-vacuum-based alternative process deposits nanoparticles of the precursor materials on the substrate and then sinters them in situ. Electroplating is another low cost alternative to apply the CIGS layer.

The most important CIGS brands specifically designed thin films for utility-scale systems, engineered to reduce total-system cost, the product is electrically and mechanically optimized for utility-scale solar power systems: this solution give competitivity to this product that for the first time put on the market a PV product that cost less than 1$ by Watt.

The driving forces for CIGS are compelling: potentially high efficiency and low specific energy for production. To these we may add the broad advantageous properties of thin-film PV relative to wafer-based PV: monolithic design leading to reduced parts handling, low consumption of both direct and indirect materials, and fewer process steps.

The CIS is usually formed on a base electrode of molybdenum (Mo), chosen for its refractory nature and good electrical conductivity. Thin-film CIGS is a p-type semiconductor, and a junction is formed at the surface by deposition of a very thin layer of CdS. This creates an n-p homojunction just inside the CIGS, rather than a simple heterojunction. It is also possible to form effective junction without the use of CdS. The device is completed by deposition of a transparent conductor such as zinc oxide on top of the junction to help collect the light- generated current. Figure below shows typical C IGS solar module. In a manner similar to the definition and monolithic integration of thin-film a-Si cells, individual CIGS cells are defined and serially interconnected via three patterning steps. The first scribe (in the molybdenum - Mo) is performed by a laser beam, while the second and third scribes (to remove CIGS and separate the ZnO) can be performed mechanically or by laser. Again, metal foils are bonded to the first and last cells, and the module is encapsulated using a top cover glass laminated with encapsulant.



The most common Cross-section of an Cu(In,Ga)Se2 solar cell substrate is soda-lime glass of 1–3 mm thickness. This is coated on one side with molybdenum (Mo) that serves as metal back contact. The heterojunction is formed between the semiconductors CIGS and ZnO, separated by a thin layer of CdS and a layer of intrinsic ZnO. The CIGS is doped p-type from intrinsic defects, while the ZnO is doped n-type to a much larger extent through the incorporation of aluminum (Al). This asymmetric doping causes the space-charge region to extend much further into the CIGS than into the ZnO.

CIGS thin film record module that reach 20,9% efficiency

Development

The demonstration of laboratory-scale, thin-film CIGS solar cells reaching nearly 20% efficiency helped to launch numerous start-up companies seeking to "grab the ring"—namely, to develop a low-cost, thin-film product that performs as well as the best siliconbased modules. The entry point for many firms will be based on leaving a large gap between the champion device and the first product efficiencies; but these companies can enter commercial markets as long as their product can compete with the cost of other thinfilm PV modules. Increasing CIGS module performance to values higher than competing thin-film PV technologies could ultimately allow CIGS to achieve the lowest module costs and levelized cost of energy (LCOE) among all PV technologies. Hence, a primary challenge is to provide the science and technology needed to close the gap in efficiency between the entry-level prototype products and champion devices. A second challenge is to discover and qualify new materials and device schemes that can enhance performance, absorber bandgap and voltage, material usage, stability, yield, and process simplicity. Start-up companies have selected a multitude of processing approaches, which provides both an opportunity as well as a challenge to improve commercial module efficiency. Ultimately, we need to know at what point a chosen deposition or processing approach becomes the dominant factor for limiting product performance. Building-integrated products may provide a significant entry channel for CIGS thin-film cells, taking advantage of the demonstrated capability to manufacture flexible cells (e.g., Global Solar, DayStar, Miasole, Ascent Solar, NanoSolar, ISET, and SoloPower) and the potential to conform the film PV to building-material geometries. The absence of glass encapsulation systems drives a second high-priority development to address the inherent device sensitivity to water vapor. Developing a low-cost, flexible, transparent package for CIGS that will assure long (20-year-plus) outdoor module lifetime constitutes an enabling prerequisite for addressing this business segment.

Indium limit

The ultimate impact of CIGS PV technology may be limited by the availability of indium. Estimates vary widely, but based on what is known today about In usage and In supply, a range of 2,000–10,000 MWp of annual module production may perhaps be established as a limit. To extend these limits, it would be highly desirable to use CIGS devices with much thinner absorber layers than used today (typically, 1.4–3 microns). This would also increase manufacturing throughput because thinner layers can be deposited in less time. Implementation will require the development of thin absorber cells without a loss in efficiency, processing robustness, and module reliability. Alternatively, the family of chalcopyrite materials provides a rich set of options for engineering new absorber layers that could mimic the physical properties of CIGS needed to achieve similar remarkable efficiencies—but also add important attributes such as avoiding indium, moving to a different bandgap, increasing processing robustness, and providing a clearer path to control of properties needed.

Nanosolar solution

Nanosolar grows a thin film semiconductor using a printing and annealing process that is far faster than conventional high vacuum deposition.

Leverage recent advances in nanoscience to create high quality, highly uniform layers of nanoparticles dispersed through their proprietary CIGS ink.

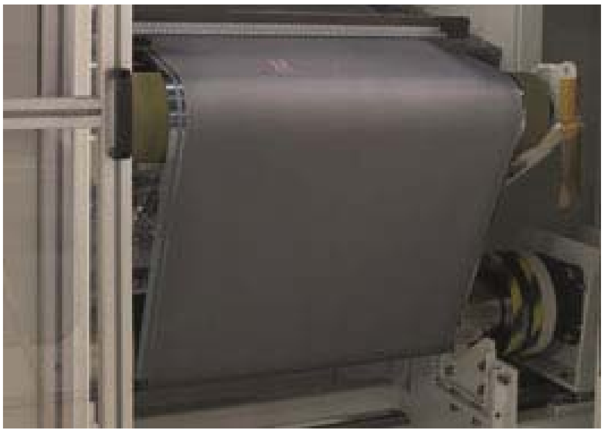
This allows to utilize equipment from the industrial printing and roll-to-roll manufacturing industries to produce solar-electric foil at high speeds, bringing the economics of printing to the world of solar PV semiconductor manufacturing.

Applying the latest in robotic manufacturing, primarily from the automotive industry, Nanosolar assembles solar cells into solar panels with high throughput and high quality. Consistency in inspections, manufacturing and on-going testing is a critical part of Nanosolar's production process.

The key point is the realization of a small base module system that it's easy to link and combine to obtain a full panel with high performances: on these modules the PV ink is deposited on a flexible substrate (the "paper"), and then nanocomponents in the ink align themselves properly via molecular self-assembly.

Nanosolar has developed a suite of in-house capabilities for creating nanostructured components based on various patented and patent-pending techniques. It uses nanostructured






components as the basis for creating printable semiconductors, printable transparent electrodes, novel forms of advanced nanocomposite solar-cell design and powerful new forms of barrier films. According to the company, leveraging recent science advances in nanostructured materials, Nanosolar has developed a proprietary ink that makes it possible to simply print the semiconductor of a high-performance solar cell. This ink is based on Nanosolar developing various proprietary forms of nanoparticles and associated organic dispersion chemistry and processing techniques suitable for delivering a semiconductor of high electronic quality.
Two advantages over earlier technologies is that a printing process is quick and also makes it easy to deposit a uniform layer of the ink, resulting in a layer with the correct ratio of elements everywhere on the substrate. Also, the ink is printed only where needed, so there is less waste of material. Last, the substrate material on which the ink is printed is much more conductive and less expensive than the stainless steel substrates that are often used in thin-film solar panels.
These solar cells successfully blend the needs for efficiency, low cost, and longevity and will be easy to install due to their flexibility and light weight. Estimates by Nanosolar of the cost of these cells fall roughly between 1/10 and 1/5 the industry standard per kilowatt.
The company implies that their solar cells can last more than 25 years by saying they “achieve a durability compatible with our 25-year warranty.” They recently commissioned a study by Black and Veatch that finds their 25-year warranty to be compatible with their module design

Cadmium telluride PV is the first thin film photovoltaic technology that has surpassed crystalline silicon PV in cheapness for a significant portion of the PV market, namely in multi-kilowatt systems.
Since inception, the dominant solar cell technology in the marketplace has been based on wafers of crystalline silicon. During the same period, the idea of developing alternative, lower cost PV technologies led to the consideration of thin films and concentrators. Thin films are based on using thinner semiconductor layers to absorb and convert sunlight: concentrators, on the idea of replacing expensive semiconductors with lenses or mirrors. Both reduce cost, in theory, by reducing the use of semiconductor material. However, both faced critical challenges.
Research in CdTe dates back to the 1950s: a simple heterojunction design evolved in which p-type CdTe was matched with n-type cadmium sulfide (CdS). The cell was completed by adding top and bottom contacts. Early leaders in CdS/CdTe cell efficiencies were GE in the 1960s and then Kodak, Monosolar, Matsushita, and AMETEK. By 1981, Kodak used close spaced sublimation (CSS) and made the first 10% cells and first multi-cell devices (12 cells, 8% efficiency, 30 cm2). Monosolar and AMETEK used electrodeposition, a popular early method. Matsushita started with screen printing but shifted in the 1990s to CSS. An important step forward occurred when cells were being scaled-up in size to make larger area products called modules. These products require higher currents than small cells and it was found that an additional layer, called a transparent conductive oxide (TCO), could facilitate the movement of current across the top of the cell (instead of a metal grid). Made more conductive for PV, tin oxide became and remains the norm in CdTe PV modules.
Professor Ting L. Chu of Southern Methodist University, made significant contributions to moving the efficiency of CdTe cells to above 15% in 1992, a critical level of success in terms of potential commercial competitiveness. This was done when he added an intervening or buffer layer to the TCO/CdS/CdTe stack and then thinned the CdS to allow more light through. Chu used resistive tin oxide as the buffer layer and then thinned the CdS from several micrometres to under half a micrometre in thickness. Thick CdS, as it was used in prior devices, blocked about 5 mA/cm2 of light, or about 20% of the light usable by a CdTe device. By removing this loss while maintaining the other properties of the device, Chu reached 15% efficiency in 1991,

the first thin film to do so, as verified at the National Renewable Energy Laboratory(NREL). Chu used CSS for depositing the CdTe. For his achievements in taking CdTe from its status as "also-ran" to a primary candidate for commercialization, some think of Ting L. Chu as the key technologist in the history of CdTe development.

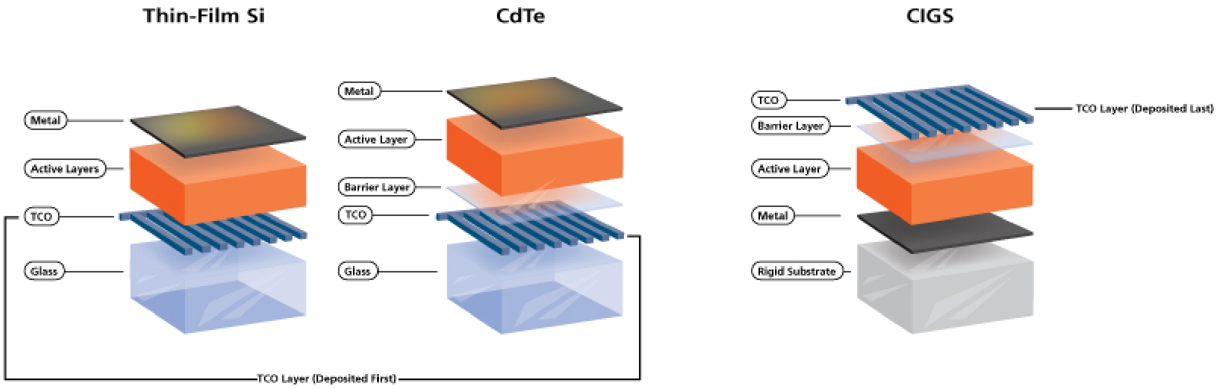
The major commercial success to emerge from the turmoil of the 1990s was Solar Cells Incorporated (SCI). Founded in 1990 as an outgrowth of a prior company, Glasstech Solar, led by inventor-entrepreneur Harold McMaster, it switched from amorphous silicon to CdTe as a better solution to the higher-cost crystalline silicon PV. McMaster championed CdTe for its high-rate, high-throughput processing. In February 1999, he sold the company to True North Partners, an investment arm of the Walton family, owners of Wal-Mart: John T. Walton joined the Board of the new company, and Mike Ahearn of True North became the CEO of the newly minted First Solar.

In its early years First Solar suffered setbacks, and initial module efficiencies were modest, about 7%. Commercial product became available in 2002. But production did not reach 25 megawatts until 2005. The company built an additional line in Perrysburg, Ohio, then four lines in Germany, supported by the substantial production incentives (about 50% of capital costs). In 2006 First Solar reached 75 MW of annual production and announced a further 16 lines in Malaysia. As of 2008, First Solar is producing at nearly half a gigawatt annual rate, and in 2006 and 2007 was among the largest PV module manufacturers in the world.

Cell efficiency

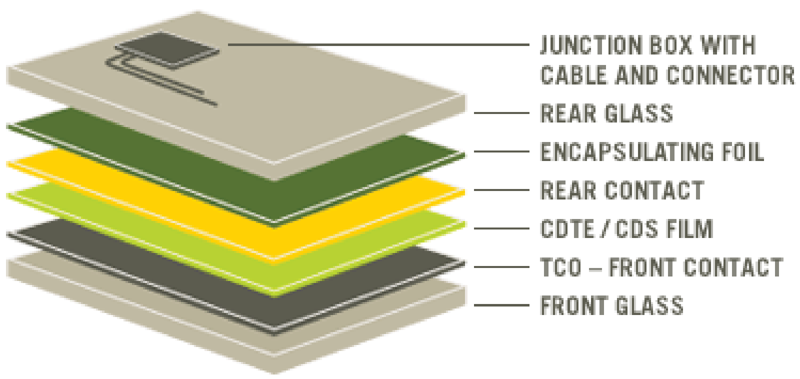
Best cell efficiency has plateaued at 16.5% since 2001. The opportunity to increase current has been almost fully exploited, but more difficult challenges associated with junction quality, with properties of CdTe and with contacting have not been as successful. However, the number of active scientists in CdTe PV was small: improved doping of CdTe and increased understanding of key processing steps are keys to progress. Since CdTe has the optimal band gap for single-junction devices, it may be expected that efficiencies close to exceeding 20% (such as already shown in CIS alloys) should be achievable in practical CdTe cells. Modules of 15% would then be possible.

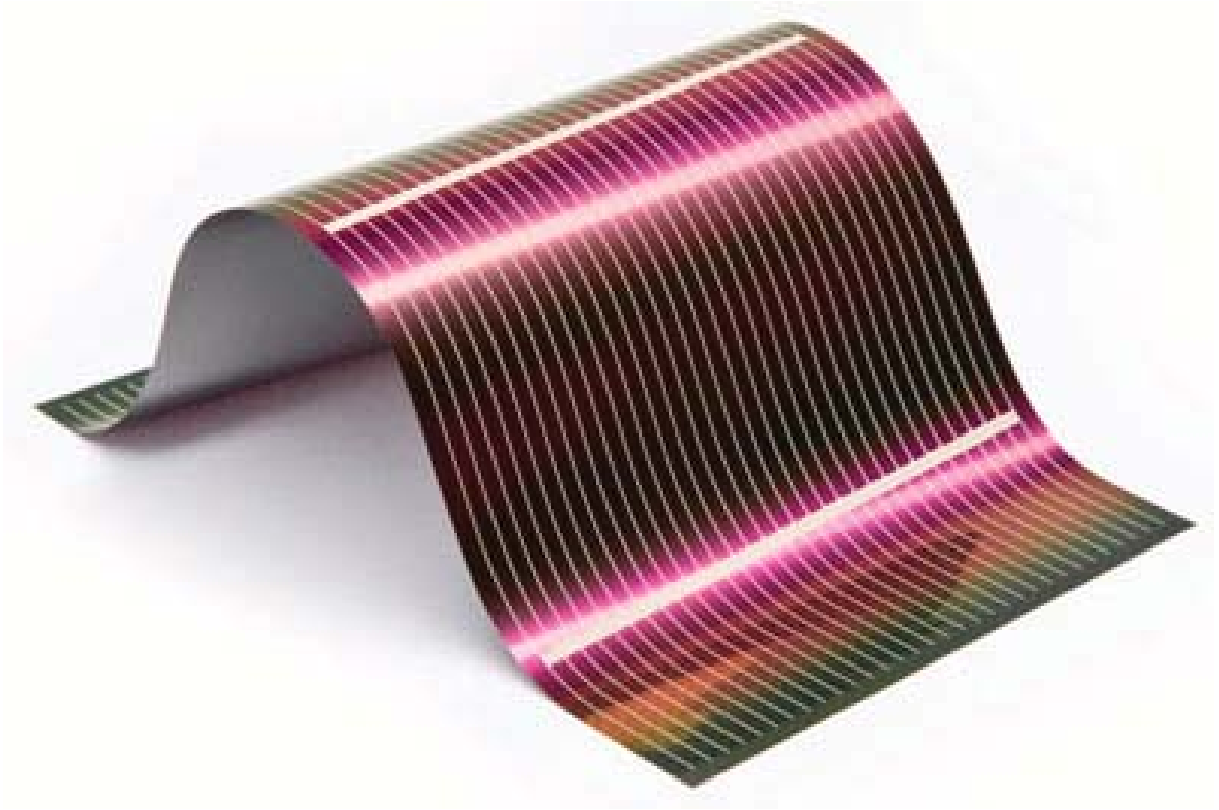
Perhaps the most subtle and least understood problem with CdTe PV is the supply of tellurium (Te): it is an element not currently used for many applications. Only a small amount, estimated to be about 800 metric tons per year, is available. According to USGS, global tellurium production in 2007 was 135 metric tons. Most of it comes as a by-product of copper, with smaller product amounts from lead and gold. One gigawatt of CdTe PV modules would require about 93 metric tons (at current efficiencies and thicknesses), so this seems like a limiting factor. However, because tellurium has had so few uses, it has not been the focus of geologic exploration. In the last decade, new supplies of tellurium-rich ores have been located, in Xinju, China. Since CdTe is now regarded as an important technology in terms of PV's future impact on global energy and environment, the issue of tellurium availability is significant. Recently, researchers have added an unusual twist – astrophysicists identify tellurium as the most abundant element in the universe with an atomic number over 40.This surpasses, heavier materials like tin, bismuth, and lead, which are common. Researchers have shown that well-known undersea ridges (which are now being evaluated for their economic recoverability) are rich in tellurium and by themselves could supply more tellurium than we could ever use for all of our global energy.



Another issue frequently mentioned, is the use and recycling of the extremely toxic metal cadmium, one of the six most toxic materials banned by European Union's RoHS regulation. According to First Solar's annual report, the CdTe solar panel is not in RoHS compliance, not listed in the exemption product list, but not currently listed in the restricted list either. So the product's future RoHS compliance status is uncertain. First Solar has a self-imposed recycling regimen that provides a deposited amount (<$0.05 a watt) that covers the costs of transport and recycling of the module at the end of its useful life. Recycling has been fully demonstrated on scrap modules although recent work has questioned the economic viability of recycling CdTe PV modules and called for producer responsibility policy to ensure all CdTe PV is recycled. In a validating test, Vasilis Fthenakis of the Brookhaven National Laboratory showed that the glass plates surrounding CdTe material sandwiched between them (as they are in all commercial modules) seal during a fire and do not allow any cadmium release. All other uses and exposures related to cadmium are minor and similar in kind and magnitude to exposures from other materials in the broader PV value chain, e.g., to toxic gases, lead solder, or solvents (most of which are not used in CdTe manufacturing)

CROSS-SECTIONAL VIEW THROUGH A MODUL





Transparent Photovoltaic Films

aSi - T

The patented transparent photovoltaic panel is sandwiched between two thin panes of glass (or ETFE) to create a one-quarter inch thick transparent panel. The panels are 7 to 12 percent efficient, typical of current PV panels. Cost will be less than one-half that of currently available PV systems when production begins. Electricity produced using these panels may potentially be cost competitive with fossil fuel based electricity.
The solar panels use a tin oxide coating on the inner surface of the glass panes to conduct current out of the cell. The cell contains titanium oxide that is coated with a photoelectric dye. The surface of the titanium oxide is rough, this provides a large radiation collection area in a relatively small panel. The combination acts like a “solar antenna” that receives solar radiation and supplies a stream of electrons that are gathered into a flow of current. The circuit is completed by the tin oxide coating on the opposite glass surface. A iodine electrolyte returns the electrons to the dye molecules.

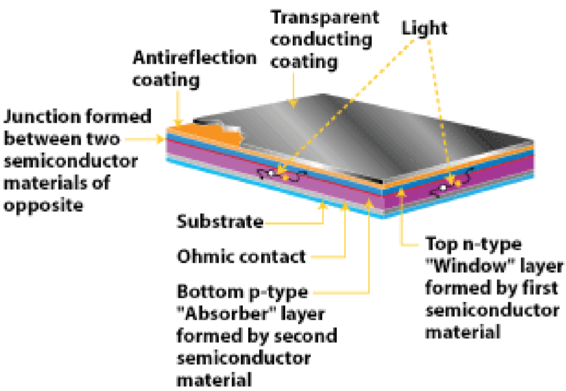
Transparent conducting films (TCFs)
TCFs for photovoltaic applications have been fabricated from both inorganic and organic materials. Inorganic films typically are made up of a layer of TCO (transparent conducting oxide), generally in the form of indium tin oxide (ITO), fluorine doped tin oxide (FTO), and doped zinc oxide. Organic films are being developed using carbon nanotube networks and graphene, which can be fabricated to be highly transparent to the infrared light, along with networks of polymers such as poly(3,4-ethylenedioxythiophene) and its derivatives.
Transparent conducting films act as a window for light to pass through to the active material beneath (where carrier generation occurs), as an ohmic contact for carrier transport out of the photovoltaic but also as transparent carrier for smd electronics used between laminated glass or light transmissive composites. Transparent materials possess bandgaps with energies corresponding to wavelengths which are shorter than the visible range (380 nm to 750 nm). As such, photons with energies below the bandgap are not collected by these materials and thus visible light passes through. However, applications such as photovoltaics may require an even broader bandgap to avoid unwanted absorption of the solar spectra.
Transparent conductive oxides (TCO) are doped metal oxides used in optoelectronic de-

vices such as flat panel displays and photovoltaics. Most of these films are fabricated with polycrystalline or amorphous microstructures. On average, these applications use electrode materials that have greater than 80% transmittance of incident light as well as conductivities higher than 103 S/cm for efficient carrier transport. The transmittance of these films, just as in any transparent material, is limited by light scattering at defects and grain boundaries. In general, TCOs for use as thin-film electrodes in solar cells should have a minimum carrier concentration on the order of 1020 cm^3 for low resistivity and a bandgap greater than 380 nm to avoid absorption of light over most of the solar spectra. Mobility in these films is limited by ionized impurity scattering and is on the order of 40 $cm^2/(V \cdot s)$.

Current transparent conducting oxides used in industry are primarily n-type conductors, meaning their primary conduction is from the flow of electrons. Suitable p-type transparent conducting oxides are still being researched.

To date, the industry standard in TCO is ITO, or tin-doped indium-oxide. This material boasts a low resistivity of ~10−4 Ω·cm and a transmittance of greater than 80%. However ITO has the drawback of being expensive. Indium, the film's primary metal, is rare, and its price fluctuates due to market demand: for this reason, doped binary compounds such as aluminum-doped zinc-oxide (AZO) and indium-doped cadmium-oxide have been proposed as alternative materials.

AZO is composed of aluminum and zinc, two common and inexpensive materials, while indium-doped cadmium oxide only uses indium in low concentrations.



The aSi-T cells are now under the first experiments and the main important technology to produce them is realized by Oerlikon and, with its production chains, it optimizes costs and time to realize aSi panels. Today they reach a 8,5% of efficiency, with a trasparency of the 25%, so a big value for an amorphous silicon panel (a double-junction layer reach approximately this value also without trasparency), that means the trasparent back reflector worksas the other, with the specifications before exposed. It's important to underline that these are lab tests, so it's going to be a little lower the efficiency, concerning climate and installation.
This solution represent a big step for the amorphous silicon developement, because on the market today we have only two technologies that are able to reach good values of efficiency with transparent modules: the other one is the organic PV, analyzed in the next chapter.

Is Organic PV the Future of Solar?

By Stephen Lacey

Massachusetts, United States - When Dr. Alan Heeger and his colleagues began experimenting with newlyfound semiconducting polymers in the 1970s, they just wanted to understand the basic physics of how electrons were set free in the materials. But they ended up making a discovery that has helped advance a new generation of solar plastics and inks. By oxidizing polyacetylene, a long-chain molecule which acts like a pigment, the researchers found the polymer to have extraordinarily high conductive properties.

"We realized it in a classic 'ah ha moment,'" says Heeger. "But then over and over again, we saw additional properties that we had not foreseen."

Eventually, Heeger and his colleagues, Alan MacDiarmind and Hideki Shirakawa, figured out that the material was not just a novelty. It had the potential to change the way we manufacture electronic devices, transistors, diodes and solar cells. These semiconducting polymers could be put in a solution and printed on a substrate – potentially creating a revolution in electronics that rivals what Gutenberg's printing press did for books 600 years earlier.

"Printing is a low-cost, high speed manufacturing process...I doubt that there's a lower-cost manufacturing for any solar technology," says Heeger.

The science community agreed. In 2000, the three researchers received the Nobel Prize in chemistry for their work. A year later Heeger co-founded Konarka, a Massachussets-based company working to commercialize organic solar PV technologies. The company has since racked up tens of millions of dollars in financing and has built a GW-scale manufacturing facility that produces "power plastic," a flexible material that can be integrated into bags, electronics, and building materials. With all this promising sounding news, one might think that the revolution in printed organic PV is underway. But that's definitely not the case. A number of technical challenges and changing market conditions have made it difficult for third-generation solar companies to ramp up production and sell products.

"Clearly the industry had a good story to tell," says technology journalist Peter Fairley. "But that story has since changed and I think things look very different today for these companies."

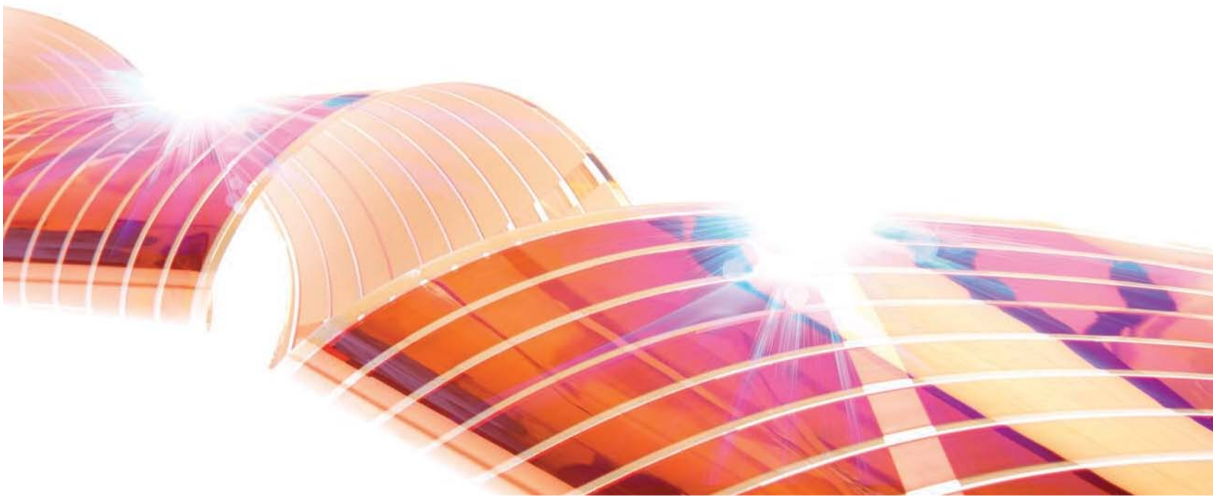
During the height of the silicon shortage between 2005 and 2007, interest in emerging third-generation solar technologies was strong. The high price of silicon made printable, non-silicon based solar products look very attractive. Never mind that they were only 4 to 5 percent efficient and lasted for only a few years: roll-to-roll printing below a dollar per watt was an attractive selling point.

Then came Cadmium Telluride thin-film producer First Solar, which said it was manufacturing 11% efficient products below a dollar per watt. It quickly steamrolled its way to the top of global module producers.

The eventual easing of the silicon shortage and the global oversupply of PV caused a roughly 30% drop in prices, making traditional PV technologies more attractive than they've ever been. This has taken some of the spotlight off the third-gen PV industry as well. Konarka may have a GW-scale manufacturing facility, but they don't appear to be shipping anywhere close to that amount of product.

"I don't believe that Konarka is producing a GW of material a year," says Fairley. "They have to find buyers and people who want a GW of their material. And that's still the number one challenge."
With such low efficiencies and short product lifetimes, third-generation PV companies are trying to find a unique niche rather than taking traditional PV head-on. Applications like portable chargers, solar clothing, solar umbrellas and roll-out awnings are the most obvious. And after that, windows and building facades are a potentially promising area. Companies are already installing small building integrated systems, but organic solar technologies need to get much more efficient in order to achieve real scale.
"In the laboratory today, people are making these organic solar cells with peak power efficiencies in the range of 6 to 8 percent. We should be able to get twice that – and that's our challenge," says Konarka's Heeger.
Success in the lab does not necessarily mean success in the market. However, these technologies have moved fairly quickly from research to reality. And if the progress continues, organic PV may someday be competitive with more traditional solar products – someday being the key word.
"It seems premature to call the technology commercialized," says Fairley. "Many of the products that we've heard about have failed to materialize."

RenewableEnergyWorld.com, 3 may 2010



Organic Photovoltaic

Solution processable organic photovoltaics (OPV) are currently being intensively investigated because this technology represents the best chance for developing a PV product in Zone II. The major advantages of using conjugated organic materials for PV units rather than inorganics are the low material and substrate costs and the ease of printing and fabrication. However, OPV devices are currently far less efficient and have shorter lifetimes than inorganic solar cells. The combination of low material and fabrication costs for OPV promises to reduce the unit cost by 10. This cost savings is based on the idea that mass production will decrease material costs and that fabrication can be performed in a reel-to-reel format onto flexible substrates. The resulting economic balance will yield a reduction in the costper-Watt for power produced from OPV devices when the device power conversion efficiency nears 10%.

Evolution

The first OPV device was fabricated by Tang at Kodak and had a power conversion efficiency of 1,1%. This first device was a bilayer stack of copper phthalocyanine as the electron donor and a perylene tetracarboxylic derivative for the electron acceptor with a standard p-n connection. This initial design was only able to deliver a low conversion efficiency because the light-induced excited states (excitons) are tightly bound in organic molecules and can only separate at donor/acceptor interfaces. Typical exciton diffusion lengths are 5–25 nm: this small exciton diffusion length places a fundamental limit on the thickness that a material layer can have since light absorbed further from the interface will not result in charge separation and photocurrent.

In the early 90s a new design for OPV active layers was developed called the bulk-heterojunction (BHJ). This layers consist of a mixture of donor and acceptor species in a mixture of a common solvent: as the solvent rapidly evaporates, phase separation occurs between the two components. The degree of phase separation is determined by the solubility of the components in the solvent, the peed with which the film dries, and the mutual solubility of components in each other.

The new BHJ design has the major advantage that the distancebetween the donor and acceptor in the layer is reduced and theprobability of charge separation approaches unity. However, the mixed film has reduced order, leading to a less charge mobility, greater trap density and island domains that do not have a charge transport pathway to either electrode. Until 2007, nearly all increases in OPV device of power efficiency came about as a result improved BHJ layer morphology. For example, Shaheen found that using a solvent with improved mutual solubility for the two components could reduce the domain size: switching from the solvent toluene to chlorobenzene improved the efficiency from 0.9% to 2.5%.

Next it was discovered that the application of thermal treatment could be used to improve the hole mobility, increase crystallinity and increase efficiency. Simultaneously, it was found that the use of high-boiling-point solvents and long solvent- soaking times could optimize the morphology through self assembly. Finally, it was found that the morphology could be optimized by using low-concentration additives, that could improve morphology either by selectively dissolving one of the components or by causing rapid crystallization of the polymer during drying. All of the thermal, solvent, and additive techniques increase the efficiency from 1% to >4%. An important research theme for the last 15 years has been the determination of the mechanism for photocurrent production in a bulk heterojunction: photons with energy above the optical band gap (Eg) are absorbed in the active layer by both the donor and acceptor materials, but since the donor polymer has a much larger absorption coefficient, the polymer typically absorbs the majority of the light. In a BHJ, the exciton has a high probability of diffusing to a donor–acceptor interface and separating into a geminate charge pair. This geminate or bound pair, also known as a charge-transfer exciton, consists of a Coulombically bound hole on the donor and electron on the acceptor. The bound charge pair can be separated into free charges at room temperature when a sufficient electric field is applied. This built-in electric field is generated by sandwiching the BHJ layer between electrodes that have differing work functions. Finally, the free charges can hop from site-to-site under the influence of the built-in field until they reach their respective electrodes. Bound charge pairs can reform from free charges. Both bound pairs and free charges can recombine.

Since 2007, a number of new record efficiencies have been reported that can be directly attributed to improved synthetic design of either the donor or acceptor.

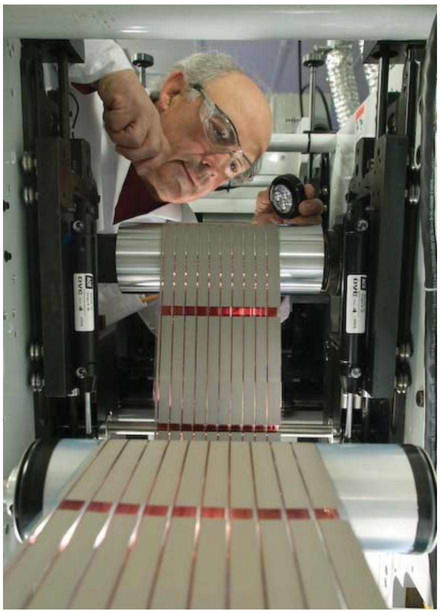
Three successful synthetic strategies can be identified. First, the short circuit current density can be increased by lowering the Eg and maintaining the polymer HOMO–fullerene LUMO spacing. The second possibility is to increase the open circuit voltage Voc by maintaining the

Eg but shifting the both the HOMO (highest occupied molecular orbital) and LUMO (singularly unoccupied molecular orbital) of the polymer down in energy. The third possibility is to increase the Voc while maintaining the Eg by raising the LUMO level of the fullerene.
Two scientists have predicted that these combined adjustments can yield power efficiencies of over 10%. A series of new co-polymer donors synthetized reach record efficiencies of 5,4%, 6,4%, and 7,9%. All of the published results used various new push–pull polymers to achieve the high efficiencies.
The domain size, crystallinity, and curing method (temperature, solvent soak, or solvent additive) can now be chosen for these mixtures. A better understanding of optical and electrical loss mechanisms has also been gained for these mixtures. But, there is still quite a lot of academic research that needs to be performed in all three of these areas. Hopefully, the scientific community will have increased access to the new low-band-gap co-polymers for morphology and device physics studies in the near future.

Production

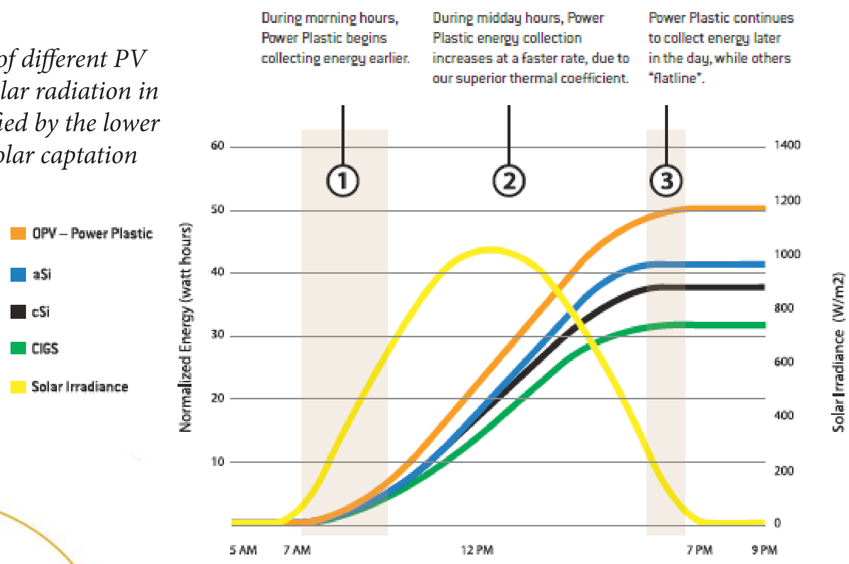
Fabrication of an OPV device involves four broad sequential steps. First, a conducting substrate with an optimized work function and surface energy is created. Second, a BHJ layer is coated onto the substrate. Next a second electrode is deposited onto the BHJ layer. Finally, the device is encapsulated in a material that protects the active layers from exposure to H2O, O2, and UV irradiation. To optimize costs of production, in order to be competitive with the other solar producers, it's used a roll-to-roll fabrication: in this sense, OPV devices can either be regular (holes move towards the substrate) or inverted (holes move away from the substrate). The direction of current flow is determined by the choice of electrode materials. One of the requirements for reel-to-reel coating is that the substrate has to be flexible so that it can be pulled through the reels. Regular devices can be fabricated onto transparent plastic foils that have been coated with a transparent conducting oxide (TCO) such as ITO, ZnO:Al or SnO2:F. Preparation of the substrate electrode requires similar steps for both device types. First the electrode must be either etched into the required shape or a resistive coating must be applied to prevent shorts where the electrodes will be externally contacted. Then the substrate material must be extensively cleaned and the electrode materials coated with a layer of material that sets the work function.

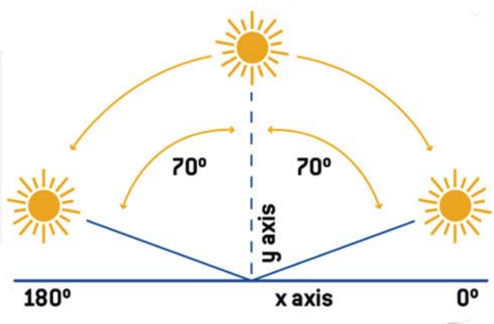
The second step is the coating of the active layer mixture. This step is performed identically for both device types. The only difference that could arise in the film comes from possible differences in morphology. Since regular and inverted devices have differing electrodes the surface energies of the prepared substrates could be different. This difference in surface energy could lead to differing surface driven formation of morphology features. If the outer surface of the substrates have differing surface energies, the coating conditions must be adjusted to achieve similar layer thickness and dry morphology. For both device types, excess solvent must be driven from the BHJ film to ensure morphological stability. Next comes the coated electrode: this is the area that requires the most innovation for both device types. In the case of a regular device, a metal electrode must be deposited. A metal is always chosen for the back electrode material because it reflects transmitted light back through the active layer and thereby increases light absorption and photocurrent. Thermal evaporation of a metal is used in a research lab for electrode deposition and it requires small device areas and high vacuum conditions that are not compatible with reel-to-reel fabrication. Solution methods have been developed for printing a 50 lm Ag wire mesh from solution onto various substrates.



The disadvantage of this technique is that the Ag mesh has reduced transparency compared to a TCO and the “windows” between the Ag wires also have to be filled with a transparent conductor to move charges to the wires and to planarize the Ag mesh. Low-temperature deposition of a transparent conducting electrode for an inverted device is even more difficult because oxides and conducting polymers have lower conductivity and are more complex materials than metals. For both device types, heat treatments must remain below 200* C to prevent damage to the BHJ material. Finally, an encapsulant material must be applied to block O2, H2O, and UV radiation from the active layer material. The requirements of the encapsulant materials are that it be transparent, flexible, durable, impermeable, and low-cost. The deposition should also not destroy any of the layers already deposited and should not require curing temperatures above 200* C, like ETFE.

graphic shows the performances of different PV technologies and their catch of solar radiation in standard contitions. This is justified by the lower graphic that shows the angle of solar captation that OPV panels have.





Future

Organic photovoltaics is a facinating subject to study. It is necessary to be familiar with optical absorption processes, charge transport, polymer morphology, recombination kinetics, the relationship between polymer structure and electronic and optical properties, the interaction between metal and organic layers, and a host of other interesting basic science themes.

The increase in the power conversion efficiency of organic photovoltaics from <2% to 7.9% in eight years is mostly due to intense and focused academic research on the basic science issues surrounding every aspect of this device type.

In the past 2–3 years several companies have started to produce OPV materials and have reported record PCEs that cannot be matched by academic groups. This is, however, not the right time for reduced governmental support of academic research in this area. In fact much more research is needed. This review article has focused on the scale-up of OPV to a reel-to-reel solution-processed and mass-produced product. Almost the entire article stresses that research must still be done on flexible transparent electrodes, solution-processable electrodes (metal or transparent), developing reel-to-reel and spray coating methods, studying polymer morphology that results from the new coating methods, developing effective transparent O2 and H2O barrier materials, and learning to make all of these technologies work together.

Largescale production and distribution of low-cost OPV modules can play an important role in greenhouse gas reduction and meeting global energy demands. These goals are urgent and need to be addressed by increased funding of basic and applied research in this area.

San Francisco MTA Transit Shelter
Konarka Technologies, Lundberg Design, 3form, Clear Channel Outdoor

In 2008 San Francisco Municipal Transportation Agency (MTA) decided to upgrade the city's urban transit shelters: it wanted to bring new technology and innovative thinking to the challenge. Its goals were both functional and aesthetic, so the shelter had to provide comfortable seats for bus passengers, look great on the street, and reflect the city's unique qualities, while the solution has to be durable enough to survive harsh urban conditions for as long as 25 years. As part of the city's extensive commitment to green technology, the new design also had to integrate the latest advances in environmental efficiency and sustainability: from solar power to recycled materials. Designers submitted dozens of different approaches, which were ultimately displayed at City Hall as models.
After the inherently long process was over, a creative approach spearheaded by Lundberg Design (and its client, Clear Channel Outdoor) won thecontest, and the contract.
A critical differentiating element of the design is its unique, red/amber undulating roof, which references the legendary hills of the city, the waves of the San Francisco Bay, and seismic waves. Embedded within this translucent roof, you'll find Konarka Power Plastic®, which enables the transit shelters to generate power and be largely self-sufficient from an energy perspective. Power generated by Power Plastic is used to fuel LED lighting at night, "NextBus" LED signage, and built-in Wi-Fi routers that provide free access to commuters.
In fact, Konarka Power Plastic panels not only power the structure, but also create new solar power for the city via two-way connections to the power grid. Ultimately, the city expects that the new transit shelters will channel an estimated 43,000 kilowatt-hours back into the grid annually. The new design transforms transit shelters from power consumers into power generators, all while providing the protection and information that travelers rely on. Plus it introduces new capabilities, such as Internet access, that enhance the overall experience: capabilities fueled by Power Plastic.
Starting with a prototype shelter on a residential section of Geary Street, new shelters are rolling out throughout the city. Of the more than 1,200 shelters of various sizes, about 300 will include solar capability fueled by Konarka Power Plastic. Some shelters are located in low light areas where any solar capability would be impractical.

The city's new transit shelters have been receiving rave reviews and awards, even at this early stage. The city launched the Geary Street prototype with a high-profile grand opening featuring the mayor and other dignitaries. Since then, it has continued to get a lot of attention from people waiting for the bus and other passersby, becoming an unlikely tourist destination.

Three advantages

The right capabilities - Power Plastic provides the flexibility, durability, and efficiency required by this unique design challenge. Available in quantity, simple to integrate, lightweight, and effective even in indirect lighting environments, and Power Plastic's organic photovoltaic technology was the clear choice for Lundberg Design.
An attractive look - As a visible element of the transit shelters, Konarka Power Plastic had to do more than perform efficiently for years, turning light into energy. It had to look great as well. Power Plastic's unique appearance combined functionality with beauty, giving a unique look to the transit shelter's distinctive canopy.
A commitment to collaboration - Konarka worked together with Lundberg Design, 3form, and others throughout the design,prototyping, and testing phases to ensure that Power Plastic was compatible with thepolycarbonate material of the canopy, and protected from the environment. Konarkamanagers and engineers provided the ability to satisfy all of the project's diversestakeholders by meeting various design, technical, and aesthetic needs.

Spherical Solar Cell

The Japanese company Kyosemi Corporation has developed a spherical solar cell called the Sphelar. Given the spherical like shape, Sphelar is capable of greater power efficiency and flexibility in applications than conventional flat solar cell panels.
The product measures 1 mm in diameter and it's a crystallization of a little silicon sphere obtained in a particular extrusion process.
Conventional flat solar cells were unable to effectively harness this indirect light. In addition, the sun takes on a many different positions according to the season and time of day, so in order to obtain a stable supply of power, there was a need to change the orientation of the solar cell by constantly following the sun. Sphelar captures light from all directions, which means it can catch reflected light and diffused light. In addition, there is no need for the superfluous operation of tracking the sun. The spherical light-receiving surfaces achieve unprecedented high generation efficiency. The Sphelar light sensitive surface is therefore able to achieve high energy efficiency. When assembled in a panel fashion, resulting modules are said to have a conversion efficiency of almost 20%.
The unique design of the Sphelar with a diameter of only 1 mm to 1.5 mm allows it to be installed in a variety of energy efficient settings. It can be placed in a parallel format or in a series. The advantage of the Sphelar is that it will not block views as some conventional flat solar cell panels have been found to do.
Sphelar is efficient from a manufacturing stand point. As opposed to conventional flat solar cell manufacturing the Sphelar has little or no waste product. The Sphelar is made by a process of melted silicon that is subjected to free fall. Whereby spheres are created naturally by the microgravity conditions. The result creates little or no waste of raw materials. This feature is cost effective and provides efficient use of the rare component silicon.
According to Kyosemi Corp. the production costs in producing Sphelar are halved as compared to the conventional production of flat solar cell panels. In addition, the Sphelar is environmentally friendly both in production and in use: the company says that unlike traditional solar cell manufacture, waste of raw materials is minimal, resulting in a dramatic reduction in production costs while preserving silicon resources.

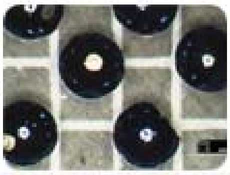
Microgravity – a key factor behind spherical solar cells.

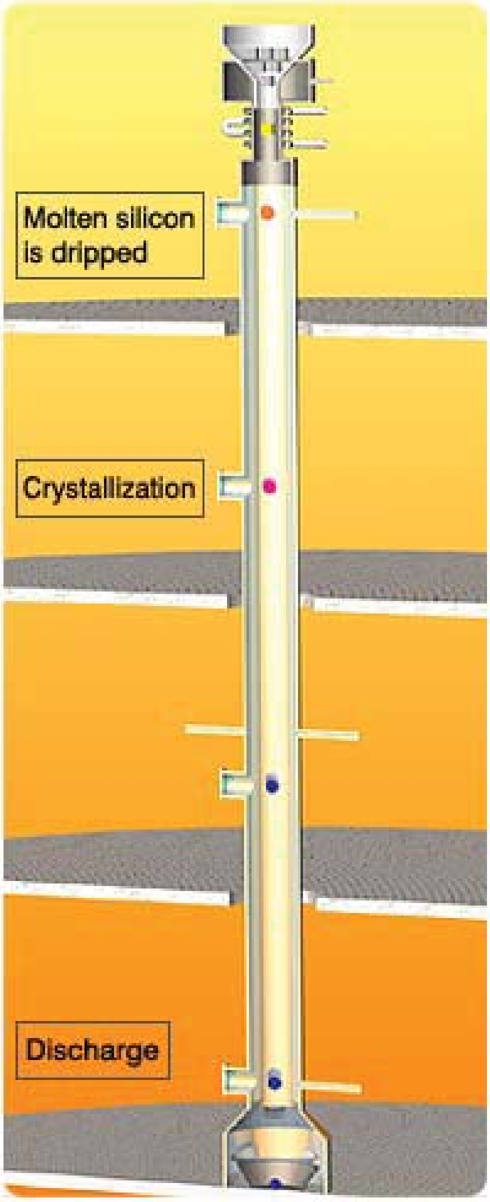
1. When molten silicon is dripped from a height of 14m,

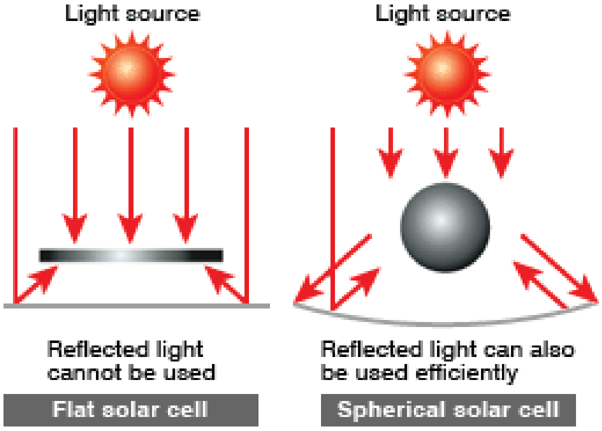
2. The surface tension causes round droplets to form, like rain drops,

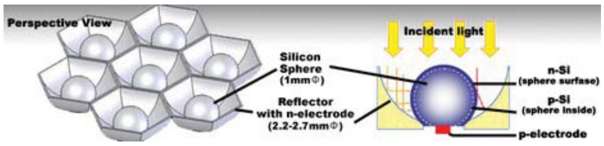
3. And under space-like conditions of microgravity for 1.5 seconds, crystallization occurs, unhindered by anything.

4. As a result, several thousand silicon single crystal spheres form naturally each second






Light source
Light source
Reflected light
cannot be used
Flat solar cell
Reflected light can also
be used efficiently
Spherical solar cell


Perspective View
Silicon
Sphere
(1mmΦ)
Reflector
with n-electrode
(2.2-2.7mmΦ)
Incident light
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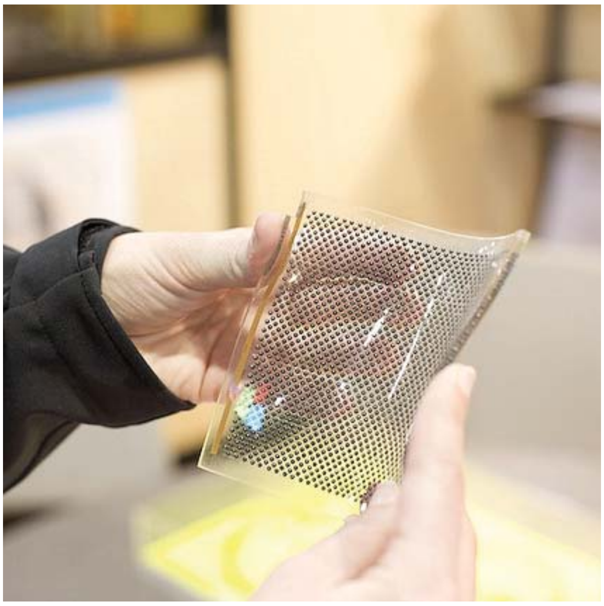
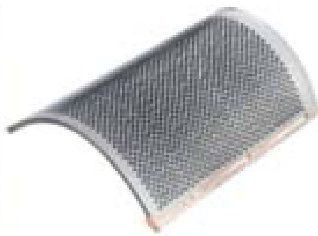
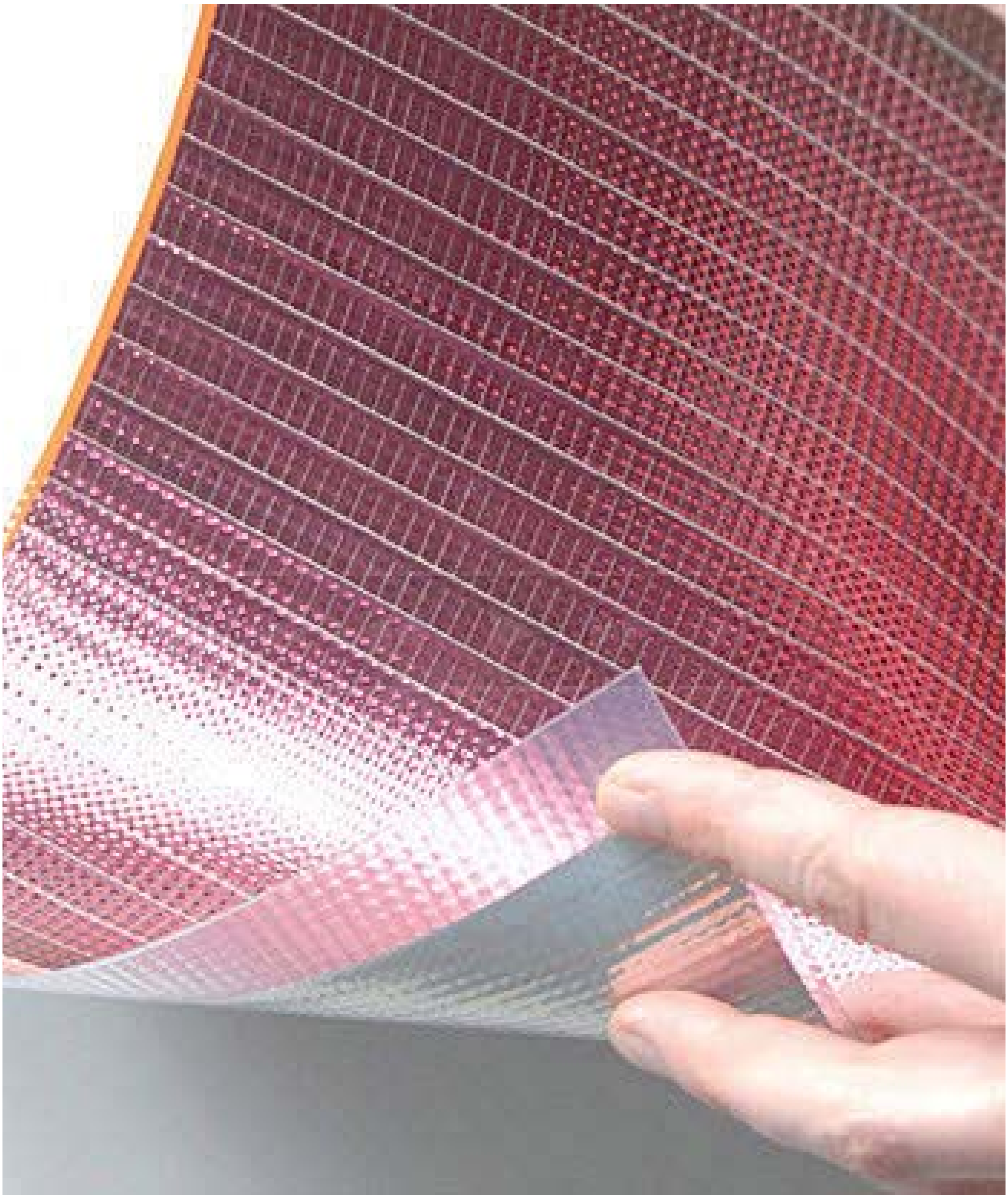
p-Si
(sphere inside)
p-electrode







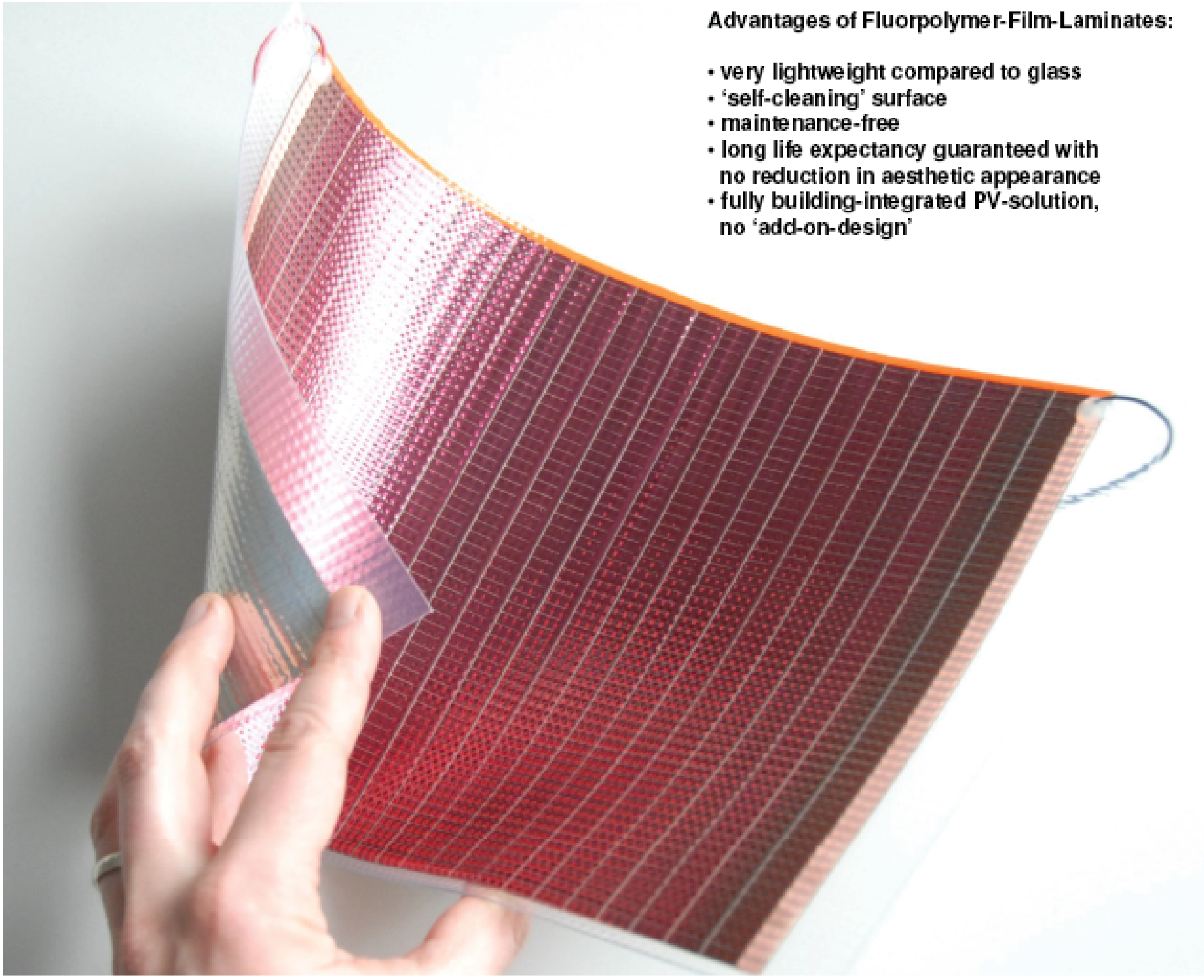
Photovoltaic Integrated ETFE

A dynamic architecture

When we think about ETFE, the first image of our mind is or a pillow or a Zaha Hadid design, because the mechanical properties of this material suggest us something flexible, adaptable, extensible and soft. This image is true for all the first architecture made with ETFE: Eden project, Allianz Arena in Munich, Bird's Nest are all flexible and not standard shape architecture.
Today we could see a developement of this image and the integration of this fluoropolymer with other technologies, open new markets and new possibility for the use of the ETFE. Photovoltaic integrated ETFE could represent an opportunity to generate a dynamic material, with a range of infinite possible use, because the flexibility combined with the generation of elettricity could represent a new step in the building construction, not only for flexible or modular shapes.
Today there's only one firm that develop a research in this kind of product, Solar Next, a branch of Hightex, but new realities are coming in this market.
Architects and customers are now orientated to efficient, dynamic and transformable buildings, not rigid or not upgradeable: the wish is to have an architecture that in the years mantain his soul, upgrading its technology in order to reach a zero impact on the environment. This is why an intagrated PV ETFE technology could represent an important solution and a strong starting point for the creation of a dynamic architecture.

advantages and disadvantages

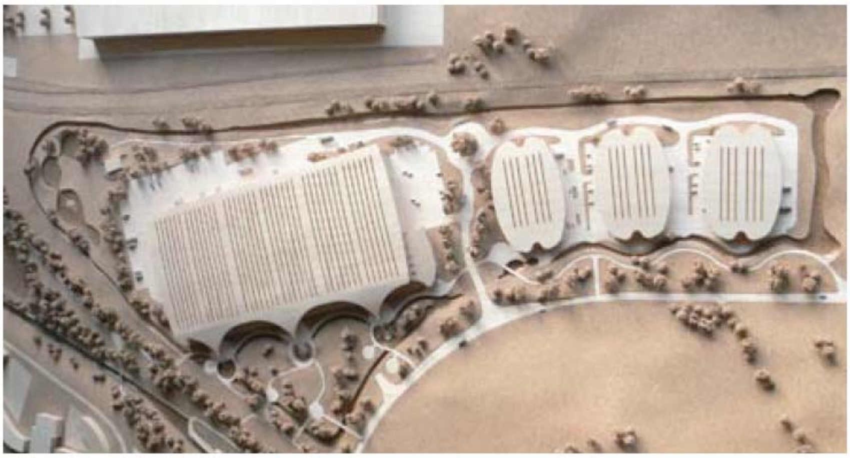
The possibility, analized in the previous chapter, to have a transparent photovoltaic film is an important point for tha integrated product, because in this sense it's possible to make the most, looking the translucency of the ETFE. Cover systems and curtain walls could be realized with a transparent PV-ETFE system, giving light and producing eletricity, with the possibility to see through, an option that only the glass could give. Another important poit is the height, because this system, comparing to glass one, is 10 times lighter, so the structural system could be easiest and lighter too: the only disadvantage concern the safety, because a thief could easily cut the ETFE.
The solution of PV-ETFE is important for the dimension of the structural system of an archi-


Advantages of Fluorpolymer-Film-Laminates:
• very lightweight compared to glass
• 'self-cleaning' surface
• maintenance-free
• long life expectancy guaranteed with no reduction in aesthetic appearance
• fully building-integrated PV-solution, no 'add-on-design'

tecture: it’s possible to use a tenso structure or an inflated one minimizing the use of aluminum or steel, optimizing the costs of the whole system. In particular this allows to reduce the costs of ETFE and PV.
The ETFE for example has in the world just five or six big producer, due to the complexity of the fluorine production, and this means that costs will rise up if the production does not cover the whole demand.
The analysis for the costs is important also for the photovoltaic films: aSi films are now quite cheaper, like CIGS (that are not performing a transparent panel for now), but Organic PV is expensive and the Sphelar is just under lab tests so it’s not evaluable in this moment.
It is certainly important to emphasize that the maintenance of the installation is virtually nothing, because the ETFE is self cleaning and solar integrated panels, with the films already described, are not so fragile like the polycrystalline type.
Combining ETFE and photovoltaic films there’s a material which could potentially be considered sustainable and producer of energy, like no other.
The low impact on environment give the chance to be one of the most important solution in architecture in the next years. The solar brands are now developing a lot their technologies, preparing to substitute petrol in the supply of eletricity, with good results and new discovers. ETFE has full developed the film and it’s applications, but it’s waiting a push to be more commercial and more diffused and known, a thing that surely could be given with the approach to the photovoltaic world.

Gazeley Logistic Warehouse
Chatterley Valley, UK,
Chetwood Architects, 2009

Gazeley's green credentials played a vital role in securing a strategic regeneration site in Staffordshire (UK). When regional development agency Advantage West Midlands (AWM), which owned the Chatterley Valley site near Newcastle-under-Lyme, Staffordshire, indicated its intention to sell, it requested the ultimate eco-friendly development and was prepared to work with the preferred developer to achieve it. Gazeley won preferred developer status in a competitive bid. The proposal for the 12.5ha distribution site will be the UK's first truly carbonpositive site, creating a tradable carbon surplus and the logistic warehouse will deliver a 33,900 sq m (365,000 sq ft) carbon neutral building. Three office and industrial units are also planned, which will be sold with a strict design code, covering buildings, landscape and amenities, in place to ensure that sustainable vision for the site is delivered in full. The site includes a variety of innovative eco-friendly technologies that will enable the buildings to achieve a BREEAM (Building Research Establishment Environmental Assessment Method) 'Excellent' rating and will use only 45% of the energy presently used by regulatorycompliant buildings.



Innovative features include rooflights made from ETFE inflated foil cushions, into which solar photovoltaic cells will be set for electricity generation; a micropower station driven by Bio-fuel will generate enough power for the park and for an additional 650 homes; and anaerobic digestors linked to the bio-fuel plant will enable power generation from organic waste materials. Vehicles arriving at the site will pass over kinetic plates that will produce electricity, which will be used to power electric buses, cars and even bicycles. The development will also pioneer close integration with surrounding residential areas. A large part of the site will be dedicated to community and environmental uses.

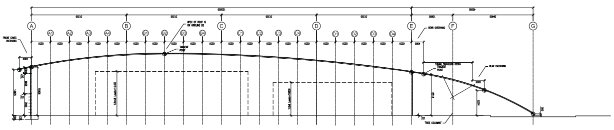
BUILDING SPECIFICATION

	Sq ft	Sq m
Warehouse	366,084	34,010
Ground Floor	5,646	524
First Floor	5,540	515
Second Floor	5,540	515
TOTAL	**382,810**	**35,564**

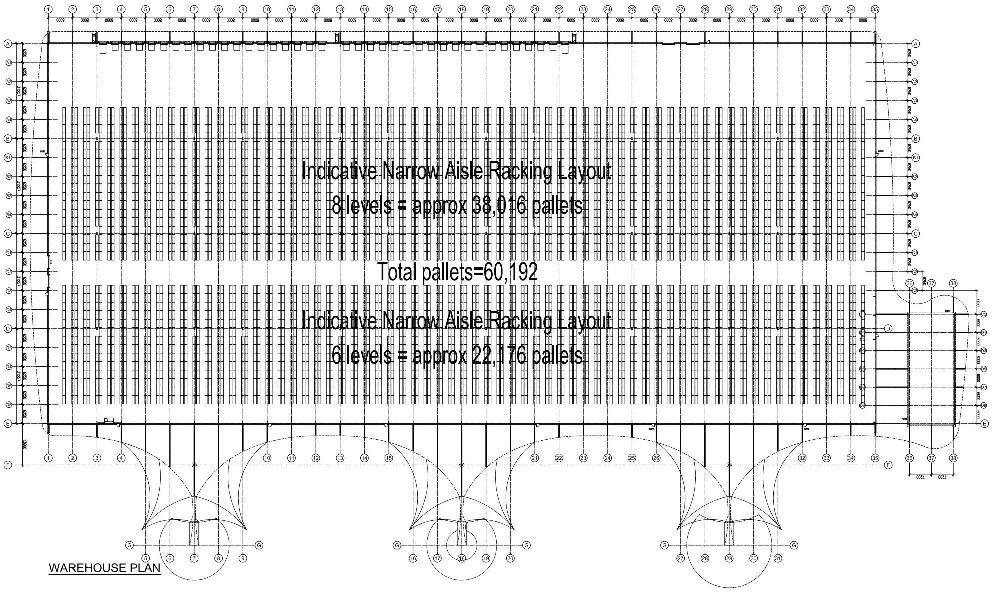
Site Area	23.9 acres
Floor Loading	50 kN/m²
Car Parking	235 spaces
HGV Parking	105 spaces
Level Access Doors	2
Dock Levellers	38
Clear Storage Height	15m

South Elevation

North Elevation



WAREHOUSE SECTION



WAREHOUSE PLAN

revisions

PRELIMINARY

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Project BLUE PLANET CHATTERLEY VALLEY, STOKE	Job Number 2668
Client GAZELEY	
Drawing Title INDICATIVE NARROW AISLE RACKING OPTION 1	Drawing Size A0
Drawn abf	Date 3/6/11
Reviewed by KL	Drawing No. 2668-104-SK03

Panels made of ETFE, have never been used on such a large scale on industrial buildings before. ETFE is a transparent foil which, like Teflon, has non-stick, selfcleaning properties. It is very light and highly resistant to tearing. As it became apparent that the material had a very long useful life – estimated to be more than 50 years – it began to be used in buildings with longer life spans.
The park at Chatterley Valley will utilise a system known as Texlon ETFE, developed by Vector Foiltec. This consists of three layers of foil, stretched over a lightweight aluminium frame and inflated with air to produce a rigid structure. Gazeley was introduced to the possibilities of ETFE by their renewable technology partner, Solarcentury. The rooflights will include solar photovoltaic laminates, provided by Uni Solar, welded into the outer cushion of the ETFE panels. The panels are the Uni Solar triple junction amorphous silicon solution and they are overlaid on the rooflights: they will generate 80mwh of power and will save 32 tonnes of CO_2 per year at the 33,900 sq m (365,000 sq ft) distribution centre.
This building represent the first coniugation between ETFE and PV aSi film, although is not integrated but overlaid, and it make this building a milestone to approach the combination of these two solutions.
The use of ETFE has several advantages over standard roofing materials. Not only is it recyclable, it uses 50 to 200 times less embodied energy in its manufacture than other transparent roofing systems, significantly reducing the building's carbon footprint. It is also 25 to 50 times lighter than the alternatives, which means that it does not need heavy support structures. It is also possible to produce ETFE with a variable skin, which can cut down on light pollution at night, while allowing plenty of natural light into the building during the day. This will reduce significantly the overall energy demand of the building. It is possible that an entire warehouse envelope could be made using PV ETFE in the future.

Solar Next

The global mission, these days, is an extensive reduction in the consumption of fossil energy without any loss in comfort or living standards. An important method to achive this is the intelligent use of current and future solar technologies. With this in mind, we are developing and optimising systems for architecture and industry to meet the high individual demands. The existing membrane technology know-how within the Hightex Group provides opportunities to combine membrane technology with solar energy related products such as photovoltaic and solar thermal. This is a most essential step towards the development of future building envelopes being highly complex and asking for an integrative approach in their handling. This range of issues is the main focus of the 'Envelope Division'. A further focal point of SolarNext rests with 'Solar Cooling', the possibility to directly convert solar generated heat into cooling energy. Within the process of a global change towards renewable energies, this technology increasingly gains importance in all moderate, sub tropic and tropic regions.

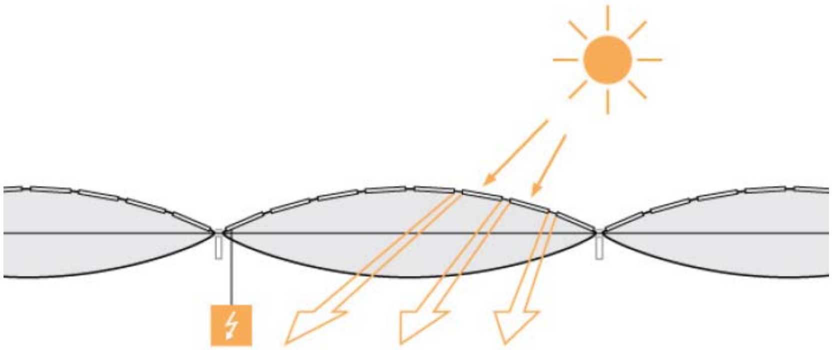
In 2006 Hightex, company pioneered in processing and application standards for high performance architectural membranes, founded in Germany a branch called Solar Next AG. The reason of this action was the will to integrate flexible photovoltaic into membrane constructions and the development of solar/thermal cooling & heating systems. This project born with a great team of engineers and managers and with the support of university research institutes, in order to achieve good results in short times and to have a direct experience results. The tests want to demonstrate the chance to put on the market this product with a convenient ratio prices/performances.

Today the highly flexible thin-film solar cell system has reached the maturity phase. Hightex with company SolarNext, is able to offer this technology integrated with membrane and foil structures on the market.
In a large-scale lamination process this coated substrate foil is encapsulated in two layers of fluorpolymer-foil. Being used in the building sector for decades, fluorpolymers have proved their value through long-term durability and a self-cleaning surface.

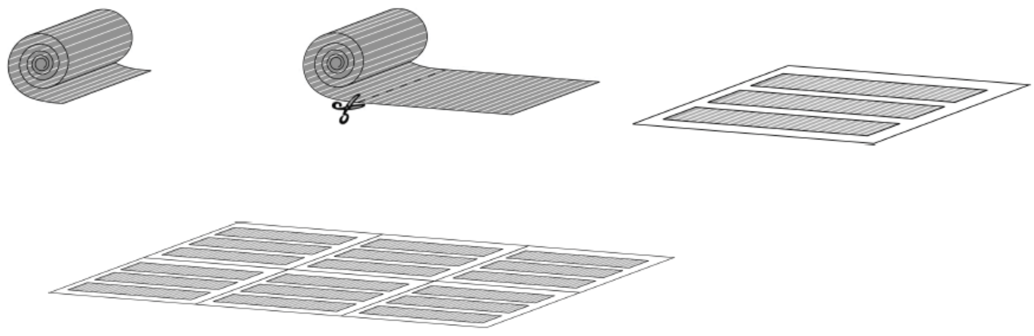

SolarNext production and administration building in Rimsting

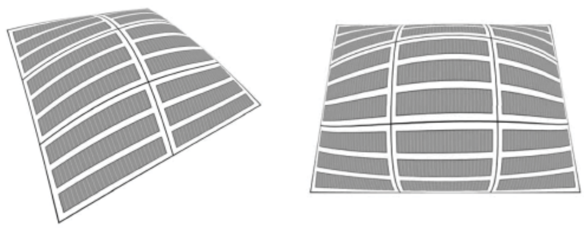
The high light transmission of the fluorpolymer-encapsulation ensures the highest energy output of the photovoltaic cells possible.
The degree of shading is dependent on the chosen membrane material. Conventional shading systems might become dispensable and therefore can be omitted. The heating up of the building due to solar irradiation and the resulting cooling loads in the summer are minimised.
PV Flexibles are produced in a roll-to-roll process in a very economical way. The width of the photovoltaic film is 30cm at a length of currently 3m maximum.

Building with membranes has become more and more popular worldwide for a number of years. PV Flexibles integrated in PTFE or PVC translucent membranes or ETFE transparent foils are highly matched for creating intelligent building envelopes and roofs.
Now, following extensive research and development carried out by Solar Next, the almost arbitrary arrangement of PV Flexibles on tensile membranes is available allowing for unlimited design possibilities.
PV Flexibles are suited for multilayer membrane cushion structures as well as large-scale, mechanically pre-stressed tensile membrane structures. Using scientifically developed joining technology PV Flexibles are assembled to large-scale membrane modules.
Wide span roofs and facades with filigree steel, wire, or wood structures can be composed to light-flooded spaces. Thereby PV Flexibles are able to provide a combination of clean energy production, integrated shading and unique architecture.

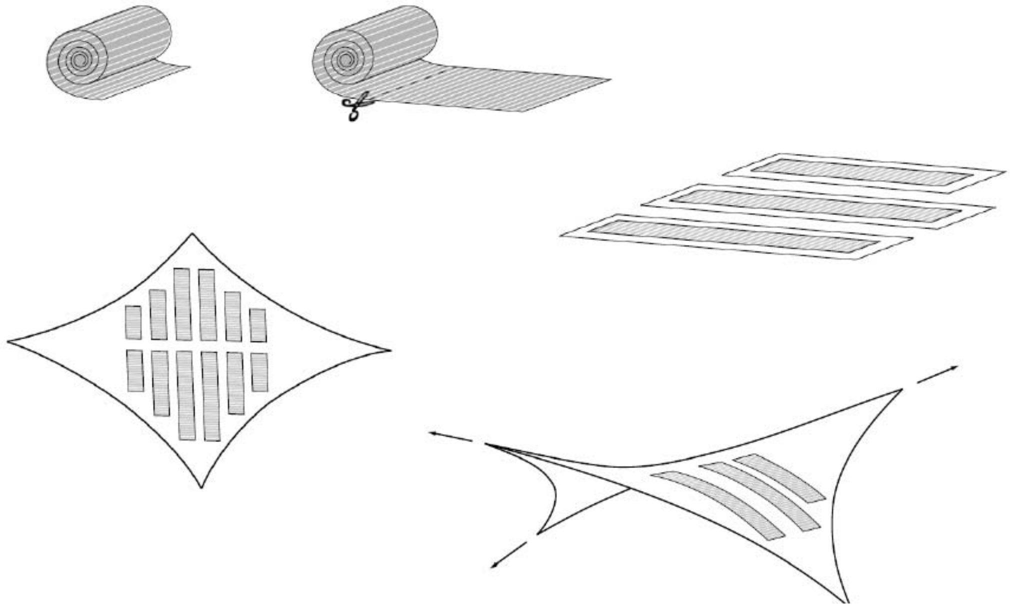


If the PV is applied to the top layer of a pneumatic cushion structure, it provides electrical power and a controlled amount of shading by a fully integrated design solution.





the two installation methods developed by Solar Next: membrane cushions and pre-stressed tensile membrane structures.

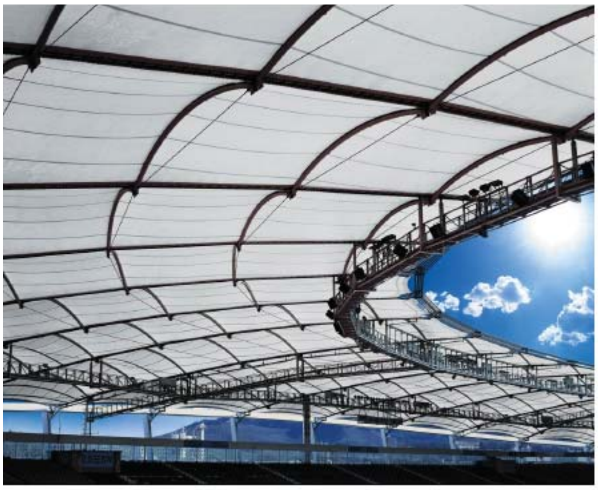


Hightex Office installation

• 2-Layer ETFE cushion, 5 m x 5 m
• Area of Top Layer: 25.7 m2
• Coverage of PV-Area: 9.3 m2 (37.4%)
• Installed Power approx. 440 Wp

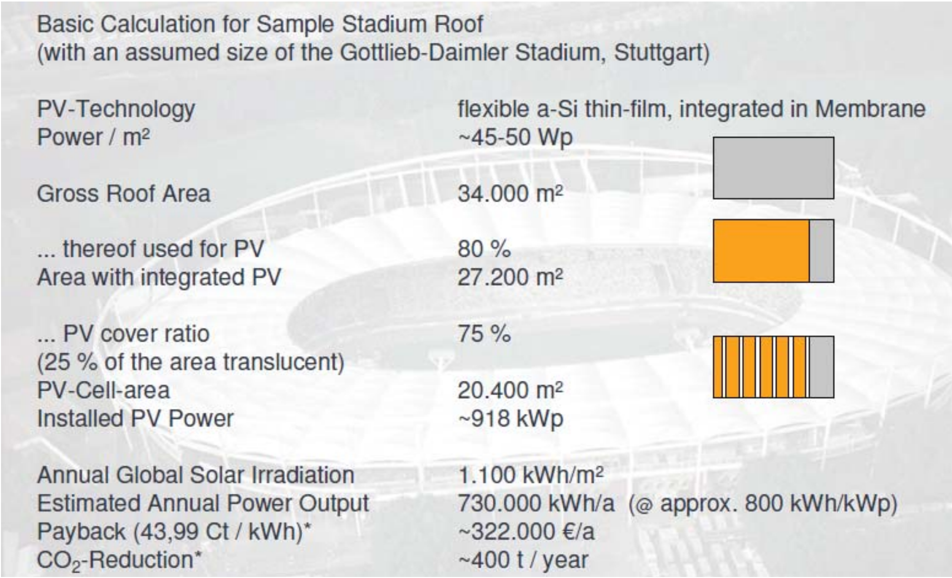
a first test with photovoltaic bonded on PTFE tensile.

Gottlieb-Daimler stadium (simulation)
Stuttgart, Germany



Gottlieb-Daimler-Stadium, Stuttgart, Germany
(Status-Quo)

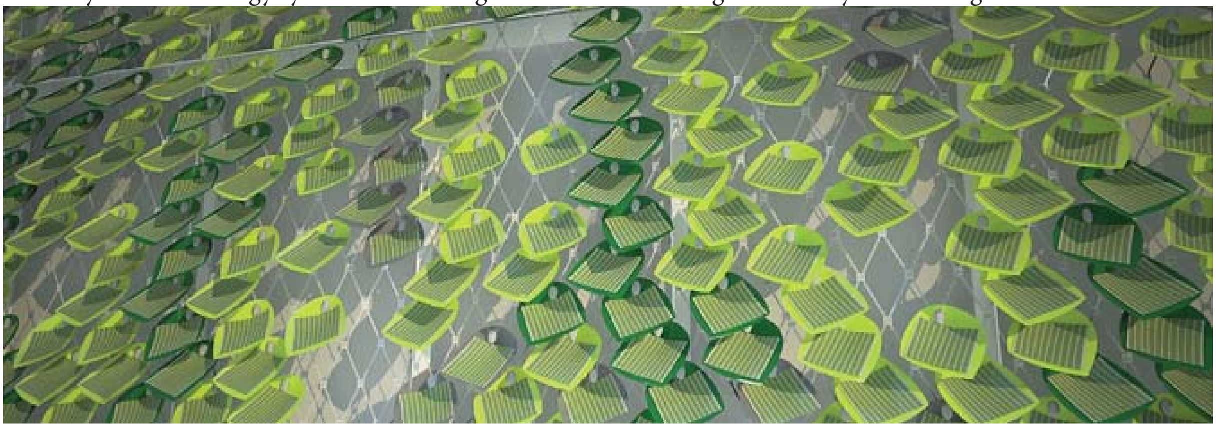
Gottlieb-Daimler-Stadium, Stuttgart, Germany
(Integrated PV, Computer Simulation)



SMIT - Sustainably Minded Interactive Technology

The SMIT project is one of the first architectonical application of the PV ETFE technology. They are developing new design solution in order to integrate the photovoltaic with new efficient and sustainable products, like ETFE, looking to balance energy production and a good design: it's important to create an useful architectural object or solution.
SMIT is a sustainable design team that offers eco-efficient solutions, education and products for sustainable modern living. SMIT combines green consultancy with sustainable product development to promote sustainability through biomimicry, the principle of basing design on natural forms, functions, and processes.
SMIT is committed to the sustainability of all our pursuits. Our multidisciplinary background and wide range of skill sets allows SMIT to work in many specialized fields that are emerging under the cultural and social umbrella that is sustainability. By actively engaging in education, product & systems design, and a green consultancy over the past 5 years, SMIT has become a recognized pioneer in the sustainable design community. SMIT's design work has been widely exhibited and published, and is included in the permanent collection of the Museum of Modern Art in New York City. SMIT is currently developing a number of projects in the USA and abroad with architects and builders that utilize the company's first product, Solar Ivy, on an architectural scale.

Solar Ivy is a solar energy system whose design reflects the natural growth of ivy on building and in nature.



Tensile Solar Structures

Tensile Solar Structures are lightweight, modular systems that provide shade, shed water and produce solar power. The systems utilize advanced thin film solar panels, and can be customized for a wide range of residential and commercial applications.

Modularity

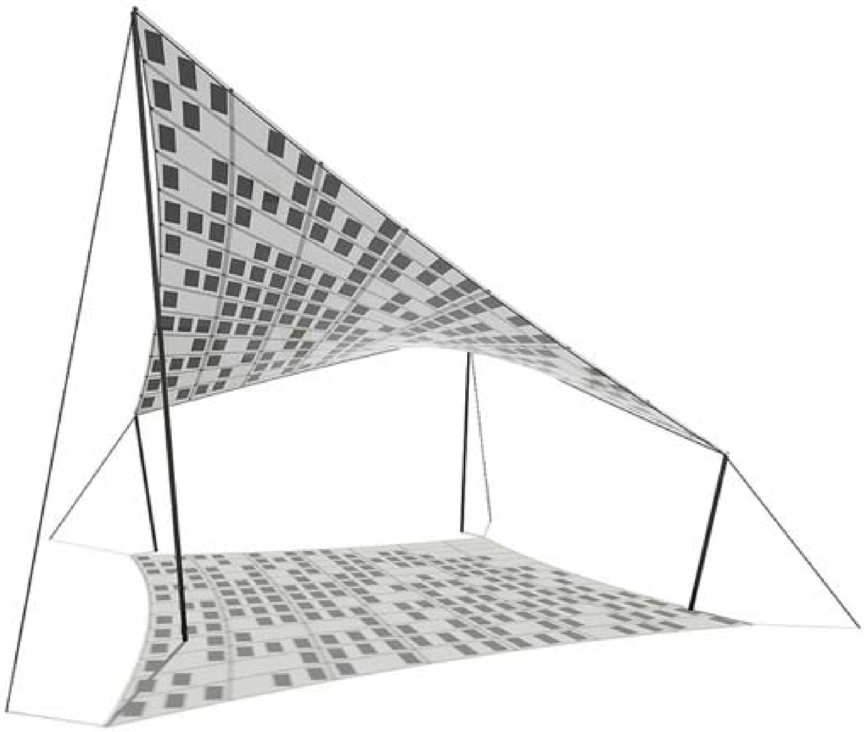
Tensile Solar Structures are assemblies of weatherproofed and structurally reinforced photovoltaic (PV) modules. They provide shade, shed water and produce solar power. Each photovoltaic module is an interchangeable part of the membrane ETFE structure; modules can easily be replaced without affecting the entire system.

Thin–Film PV

Tensile Solar is a system designed with the rapid evolution of photovoltaic technology in mind. As PV industry leaders roll out new and more efficient thin film solar panels, Tensile Solar can seamlessly integrate the latest technology. Tensile Solar can meet the financial, environmental and aesthetic demands of a wide range of projects by utilizing solar technologies with different characteristics. Organic PV is the first type of photovoltaic to be free of toxins and completely recyclable. Amorphous silicon can reach its peak performance in cloudy conditions. CIGS performs well in low light and is currently the most efficient thin film technology in direct sunlight.

Customization

Tensile Solar Structures range from small standard configurations to large scale custom structures. Standard configurations include saddle shaped canopies, point supported umbrellas and tents. Larger structures such as parking lots and public markets are developed in conjunction with designers, architects and engineers.



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