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Architectural Integration of PV in Norwegian Office Buildings

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ABSTRACT

The report looks into present available photovoltaics for building integration. With a look to architectural trends in office building design and the challenges and opportunities that offers for the photovoltaic industry, the report moves on to investigate the present and evolving photovoltaic materials. These materials have physical features that may be regarded as design criteria for new building elements. With basis in architectural needs, one may sample the material characteristics of photovoltaics in the development process of new products. A case study is also looked into, illustrating the potential for architectural integration and energy production.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Energy	Energi
GROUP 2	Building Technology	Byggteknikk
SELECTED BY AUTHOR	Photovoltaics	Solceller
	Architecture	Arkitektur

1 Table of content

2 Introduction

Smartbuild is a six-year strategic research programme performed in collaboration between SINTEF and the Norwegian University of Science and Technology, NTNU. The project aims at strengthening Norwegian research, education, and industry by developing new knowledge, integrated solutions, environmentally improved building technologies and user consciousness. The scope of the project is solutions in a 2020 perspective.

According to the IEA World Energy Outlook 2003, the world energy consumption is expected to increase by 58 percent from 2001 to 2025. In the same period, the consumption of electricity is expected to increase by 78 percent, not far from a doubling of the present consumption level. Of this, renewable sources are expected to continue to generate about one fifth. Photovoltaics count for only a fragment of this, with hydropower facilities being the major part. The importance of further developing also the smaller renewable sources of electricity generation is, however, none the less due to this fact. The photovoltaic market is seeing an incredible growth, with 30-35 % annual increases in production and sales in recent years, making it one of the most rapidly developing energy technologies at present.

The long term aim of the subtask 2.4 BIPV is assisting a broader use of PV in buildings. The project is focusing on large commercial buildings – with special focus on office buildings. The project also focuses on the challenges PV has to deal with in their development as architectural and technical objects.

There are several reasons for choosing office buildings. First, they have large budgets, both for construction, service and maintenance. These budgets may be evaluated in a life cycle perspective, redirecting resources from service and maintenance to initial investments for an overall improved economical and ecological profile. The size of the budgets may also give room for education on new solutions and state of the art practice, giving these projects an advantage that smaller projects seldom benefit from.

Second, the complexity of design for large projects already has much to earn on integrated design with the different professions involved, and has project management budgets to manage a holistic approach. With many professions and a vast number of components, system security and reliability becomes vital. PV is complex, but not overly complicated, and requires little service after installation. This gives it a good position in terms of being used as part of a larger system.

Last, the impact of large, successful projects is higher than for that of small buildings. Large projects seem to attract higher interest from architects, engineers and the general public. Further, large projects are often initiated by serial developers and involve a large staff. Thus, the transferability of achieved knowledge is larger. Big buildings usually have large numbers of users that through conscious design can get significant improvements of their working environment. Large buildings obviously also have more area for PV integration.

The second part of the work described in this report, looks into the very characteristics of PV materials and products in search of new and improved architectural integration concepts for the targeted building types in light of existing and emerging PV technologies.

3 Office building design trends and PV challenges

3.1 Evolving office buildings

The role of PV in future office buildings
High profile buildings are made to bee seen and recognized as a symbol. They are seeking attention and are using the architectural language to get it, both by use of shape, size and materials or effects like position in the landscape or contrast to existing environment. PV has a strong potential here, also as a carrier of environmental values commonly accepted. Looking at some of these high profile projects, it is evident that the choice of materials is essential to the image, and that the instant catching of the eye of the spectator has been well planned. Promoting PV to cutting edge architects may have a great impact on the general profession.

Thinking new on where to use PV also comprises low profile space. How many square meters of stone paved streets and squares are there in the world? How many gas stations and parking facilities? How many airports with enormous roofs? Can PV be used for giving sense to space we think of as unimportant, for beautification and further utilization of spaces we think of as ugly but necessary?

Ownership & facilities
Successful green buildings have relatively low life-cycle costs, provide healthy, safe and inspiring work environments and communicate a valuable philosophy. Many companies insist on, and pay well for facilities in such buildings, giving the building owners an advantage in the real estate market. Along with all its technical and environmental advantages, PV can be one of the most expressive technologies in terms of flaunting an environmentally conscious building profile. This is an asset that helps promote the building to its prospective tenants. This means that knowledge on PV must reach not only the companies that will use the buildings but also their real estate developers.

In the increasingly competitive and global markets, companies spend much effort on their image. The modern, holistic company profile is comprised by its physical, aesthetical, and cultural capital. The two latter are becoming progressively more important, as they can transform and relate to the market with more ease, and thus better communicate a company’s values. Many companies change locations on a regular basis, as an incentive for corporate culture change or as a part of restructuring. Thus they need a range of facilities that support their environmental profile or technology that can transform the physical profile of new locations with a poor environmental profile.

This nomadic corporate culture is likely to embrace technology for retrofitting that has a relatively short payback time or can be transferred to new locations, leased or sold as a second hand product. PV systems still have relatively long payback periods, but increasing production is lowering prices. Simpler systems for retrofitting, with “click-on” features and long lifetimes, make them feasible for moving or reselling. Today’s companies need facilities that sustain their core activities, and support activities are increasingly outsourced to make the companies more focused and agile.

New interpretations of program and the organisation of work
The shift of companies from building owner to building user is streamlining companies, giving new structures in office buildings in terms of technical infrastructure and the service organisation. Business can take place everywhere; it's the employees that need service. So service must be available everywhere business can take place.

Micro-urbanism, with building sectors referred to as neighbourhoods, streets, squares, and public facilities, is one example of the new internal structuring. The common areas are often used to express a building's "green" profile, and larger installations often appear here. This separation between "public" and "private" is often elaborated in the façade. The openness of the public domain is often articulated with large glass surfaces, which again create a need for shading. PV is often used as solar protection in arrays playing with daylight through shadow patterns, colour, and materiality. Although PV is presently a relatively expensive material, its value can extend beyond power production. Building integration and symbiosis with building service is lowering the excessive cost of PV to more acceptable levels. The perception of what building integration comprises, widens constantly. Increasing decoration of public buildings with art and light installations also opens up for a more expressive use of functional components of buildings. Here PV has a large potential to be explored.

Space planning has evolved from the rigid structural grids and the transformable "typical plan" to modules of complex geometry, often in three dimensions, that create unexpected interior and exterior environments. The move towards more chaotic space structures evolves from aspirations to stimulate creativity and knowledge flow in the organisation through random social interaction. Large structures are necessarily depending on modularity, and the new, more complex modules can introduce natural breaks between work zones for these activities. This can also introduce new aesthetical themes for facades and interiors, as different demands in terms of façade integrated service for the interiors form new design parameters. The hype towards complex module geometry and three-dimensional surfaces offer many challenges to the PV-industry that mainly produce flat, rectangular modules.

3.2 New materials and technologies
Although the aesthetics of architecture is interpreted in relation to its use, the exterior and interior of large buildings have complex relations and, to some extent, become separate projects. The built structure and underlying service facilities is designed to adapt to its content and not vice versa, as work methods, users, owners, and the exterior environment is constantly changing. A building may be redefined and restructured several times during its lifetime and modern commercial rental buildings usually maintain their initial internal structure for only 5-10 years. The concept of honest facades thus becomes somewhat hollow in a lifetime perspective. This makes way for new structures that incorporate change as an elementary function and aesthetical ideal. Interactivity, mobility, and layers along with new materials and technology meet in future facades. PV is a natural part of this development, and the material still faces many unexplored conceptual opportunities, both in terms of aesthetics and in system development.

Modern office building envelopes have tasks beyond climatic protection, and provide an increasing number of services to the interior climate. The active envelope changes its properties according to interior preferences and exterior conditions. It supplies fresh air, regulates temperature and lighting, and generates electricity. This organic understanding of the facades is supported by technology increasingly inspired by nature. With a holistic understanding of the service facilities, the by-products earlier regarded as problems become valuable resources. An example is the excess heat from PV that should be transported away to maintain high power production in the cells. This energy may be used for pre-heating ventilation air or water or for enhancing natural air flow systems.

Safety is becoming increasingly important in office and industry facilities, and buildings are becoming more and more automated with electronic security measures and dependant of a minimum access to power to maintain its basic safety operations. The attention on security of basic energy supply is increased through a number of recent electric blackouts in large urban areas several places in the world. In this context, PV stands out as an elegant solution to sustaining security measures, as systems can operate independent of the general electricity network.

3.3 Resource supply and consumption

Green building design is driven partly by energy efficiency and other cost savings. It also helps businesses attract the best employees, since these buildings can make for very attractive workplaces. Green buildings provide fresh air, some connection to nature, daylighting, personal control over the workspace and greater comfort. Comfort factors are thoughtfully considered in an effort to create a more hospitable work place. There is now proof that green buildings reduce life-cycle costs and improve staff productivity. Attracting and keeping the best and brightest employees requires office space that supports an employee’s personal best and communicates a common philosophy. Today’s knowledge workers need a work environment that inspires and motivates. Enlightened businesses are insisting on, and paying premium rents for, space in high-performance green buildings. In soft markets, vacancy rates for these buildings are lower. In strong markets they command significant premiums. While most green buildings are low-rise structures, some high-rises have incorporated these benefits. The single largest issue is “demand development.” Currently, interest is largely from the high-end of the market.

A growing global issue

The impact of sustainability – a growing global issue for all construction – on office buildings is just beginning. Sustainable or green construction broadens the energy conservation movement – originally spurred by the Energy Embargo of the 1970s – into a more comprehensive approach. Europe is far more conscious of sustainable design than elsewhere, fostered by higher cost of energy and governmental policies aimed at conservation. Office buildings using solar shading, day-lighting and even landscaped roofs are more common in Europe. The green building concept of double-skin exterior walls – used for many European office buildings – is taking root worldwide. This energy-saving feature remains difficult to justify in the American commercial market. The stereotypical image of U.S. office construction is short-term, first-cost focused, while European development is more life-cycle, environmentally focused. A short-term economic horizon makes it difficult for speculative development to embrace some first-cost-intensive, sustainable solutions, like double-glazed facades, because there is no corresponding return on the income side. But environmental considerations are increasingly being adopted and more projects are using features such as passive solar shading and solar glazing.

Barriers and approaches for success
The architects are often the responsible party for introducing PV in a project, and must often sell it to their clients. They must overcome both their own and their client's associations to cabin architecture and the first feeble attempts at building integration, presumptions about price levels and technical complexity. Obtaining the initial competence is expensive and can be a barrier, especially to small architectural offices and smaller projects. PV is therefore often introduced late in the design process and as an engineering application, not as a design tool from the start of the project. It is a paradox that PV is a relatively expensive building material, but still often is hidden away, without using its aesthetical potential. Many PV concepts are quite rigid and with numerous similar products, challenging the architects in terms of finding exiting use of existing modules, bending the boundaries of system design.

The challenge of penetrating the market goes out to both architects and product developers: PV must be addressed from the language of architecture, using the system requirements as design tools and with early integration with conceptual development. PV must be investigated further on its aesthetical potential in terms of light qualities, like shadow patterns, colours, transparency and effects, and materiality issues, such as weight, surfaces and dimensions. Issues concerning detailing, system design and placement must also be investigated along with product development and re-thinking. Architects need broad conceptual possibilities along with a broad product range to choose from. Better compatibility between different products and systems will simplify the design processes further.

4 Present BIPV concepts and products

The trend for PV in the built environment is going towards a more aesthetically integrated line of design. PV modules are made to resemble existing building materials, like roof tiles, or be fitted in an element system where the PV is seen as an integral part of a surface. The modern elements are also given the function of standard building elements, so that they can be a part of the building envelope, and thus lower the excess cost of installing PV.

PV is no longer a new material on the market, although it is developing all the time and offering new product variations. Customers are not accepting lower aesthetical quality for their buildings, demanding more of the material. Poor aesthetical quality in a PV installation can neutralize the green image effect and disrupt the built environment.

Use of PV can be somewhat conflicting with other intentions in architecture. The orientation of cells in the facade requires a dialog between power generation and the need for light, view and solar heating. Giving PV different assignments in the building envelope is one way to approach the issue. In whatever way PV is used, the important issue is whether PV is adding quality to the aesthetics of a building or not and whether it's a technical and/or economical asset.

The following section shows a range of possibilities with present products available for:

- Roof installation

- Installation in glass
- Installation as solar shading
- Installation in facades
- Installation over exterior parking
- Installation as free standing sculptural elements

4.1 Roofs

The presently most successful PV products for office/larger buildings are modules for roof mounting, and the wide range of products are well tested and are widely used. Roofs often offer simple surfaces for mounting PV, and traditionally with the cheaper range of mounting methods. On the other hand, the roof mounted PV quite often offers no additional quality to the building, making it more vulnerable to be “budgeted” away, as the investment still is high and with long payback times.

The roof is generally the surfaces with the least conflicting needs in terms of relations between the exterior and interior of a building. Usually, the roof also has the most exposed orientation of all the building facades towards the sun. The most common principles for roof integration can be grouped under the following categories:
- Free standing modules w/optimal tilt
- Modules for integration in tilted roofs
- Modules for integration in flat roofs

Free standing modules w/optimal tilt

The first mounting concepts for roofs comprised products that were installed on top of a completed roof. These non-integrated modules can easily be retrofitted and give good effect as they get optimal orientation towards the sun. The modules however, are applications with no further assignment in the building than power production, and even with light constructions and relatively simple detailing; the modules are expensive compared to building integrated devices. In terms of aesthetics, the free standing modules may appear as an element of chaos and should be considered carefully in terms of organization and visibility. One of the main problems for this method of applying PV is the need to penetrate the roof to mount the system. As the risk of water leaking into the roof construction is high, this may lead to problems with insurance and warranty of the roof. A different solution is a ballasted roof mounting system. This method eliminates fixing directly into the roof, but is regarded as unfit for areas of high wind speed and seismic activity. The roof construction must also be checked for load bearing abilities.

Present product lines offer more possibilities for integration. But roofs are also becoming more complex for large buildings. Many technical applications, like ventilation facilities, are now being placed on the roof. This means that the roof surface is more fragmented and is subject to more complicated lighting conditions, demanding more flexibility from PV elements.

Modules for integration in tilted roofs
Product groups in this category:
- Traditional modules: Relatively large and somewhat rigid units that can give elegant surfaces on roofs with simple geometry. Using big units can also reduce the total cost of the installation.
- Individual slates: A very good product for integration on residential houses, where they have similar aesthetics as normal roof tiles. They are also ideal for somewhat fragmented surfaces and for integration of small surfaces of PV in a larger surface.
- Multi-tile shingles: A larger version of the previous product, where several slates are put together into a module. The shingles imitate a fragmented surface and reduce the technical installations.
- Standing seam metal roofing panels: Many buildings have metal sheet roofs with the same finish as this product. It is easily integrated an offer an elegant finish. The system is ideal for large roofs with different size and geometry of its surfaces as well as for simple roofs

Modules for integration in flat roofs

Flat roofs offer a challenge when it comes to PV, as water and electric components are a hazard. But with extra consideration for this problem in the design of the products, this can be avoided. These products give way to a new utilization of surfaces that earlier was reserved for free standing modules. They become part of the weather skin of the building and thus save material costs for the project. Self shading is avoided and gives a higher possible density of PV on the surface along with a better appearance. The roof should be designed to avoid standing water and snow and would need some service in terms of removing pollution like dust, dirt and leaves. The modules are also becoming tougher, so that personnel can move over surfaces without harming the modules.

4.2 Glazing

PV integrated in glazing for atriums, skylights and in double facades is increasingly popular as it can give interesting light qualities and offer shading to the interior. Since PV must be encapsulated in glass or plastic to let light through to the cells, they may easily be incorporated in glass solutions in skylights and atriums by using glass or plastic on the back as well. In this way, the PV becomes a visible element both in the interior and the exterior. The elements can have amorphous or crystalline cells. Amorphous elements will be evenly translucent and have a brownish colour, giving even shading conditions. Crystalline elements will have solid cells and full transparency between the cells. This might cause glare, but also offer great possibilities in creating exciting patterns of light and shadow. The glass on which the PV is mounted can be coloured or treated in a number of ways, like acid frosted or printed. The elements of a larger surface may have different density of the cells, creating an illusion of clouds or the shade of trees. The use of PV glazing in a larger glass surface can give the surface an understandable scale and a more exiting detailing of its translucency. Since use of glass is very popular in many modern buildings, a means for giving it value and different qualities is welcome. Increased use of coloured glass and printing is a sign of this. PV can offer a range of possibilities in terms of giving the glass surfaces expression and scale. In addition, the PV offers shading from excess sunlight which can be a nuisance.

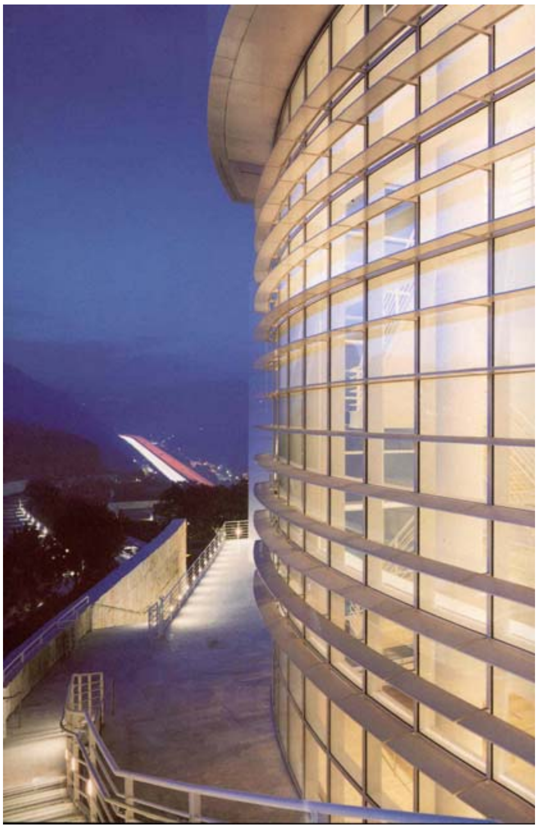
Installation in windows must be carefully evaluated in terms of the need for daylight. If the use of PV in windows cause more use of electric lighting, the installation may be of little use. For areas where light is needed but view is of insignificance or even unwanted, PV is ideal. On large glass surfaces, PV can be integrated in a portion of the area, offering light, view and shading in one solution. There are also windows where only some parts are fitted with PV.

4.3 Shading devices

Solar shading devices with PV integrated in glazing have become popular. Some of these products offer certain mobility within the module for better adjustment to the sun. Using PV as solar shading is a logical response to regulating the solar conditions to the south. Mobile shading PV elements can give better control of the workplace environment. Integration with control systems may offer increased comfort to the work place along with dynamical facades, thus integrating intelligent façade structures further.

Sun shading with PV should be subdivided in traditional and modern building style, as the range of products preferred by the two are somewhat different and the electric yield is of rather different proportions in a masonry building with few windows than for the usually abundantly glazed modern buildings.

In a dense urban situation, retrofitting with PV solar shading can be difficult, as a facade can have a number of solar conditions. PV might only be feasible in a few areas, but the facade demands a consequent detailing. The PV elements must be integrated in such a way that standard products and PV versions appear in a similar way. This may apply to products such as window shutters and blinds that may be fitted on both new and old buildings from an aesthetical point of view. Pollution is a hazard to PV installations, requiring some easy but regular maintenance.



Unlike shutters and rolling blinds, the Venetian blinds offer individual adjustment of view versus shading. This makes them very popular in office situations, as people have different need for light during a day. Venetian PV blinds should be externally fitted, and can handle building volumes of many shapes and finishes. They can also be fitted inside window solutions to lessen the strain from wind, allowing lighter structures.

Fixed sun shading devices are very interesting places for fitting PV. Being a solid platform for mounting PV along with having an ideal tilt towards the sun, makes south oriented elements well suited. Low maintenance due to low user contact is also a plus.

4.4 Solid walls

PV has also been successfully integrated in walls, although this is demanding in the modern, more fragmented expressions of office/larger buildings, as the walls of these buildings often have large proportions of window area.

The elements are usually made to fit in an industrial module facade and tend to have relatively similar proportions and materiality. Most module systems can offer insulated modules that become part of the wall and with equal features as regular wall modules without PV.

Wall elements can harvest both electricity and heat from the sun. The dark surface of PV can get very hot during operation, lowering its effectiveness. With a hybrid element, the PV is cooled down by extracting heat that can be used in the building. Thermal insulation of the building can be placed inside the installations in the module.

PV in double facades can give many advantages. If the double facade is used for ventilation, the excess heat from the PV can help pre heat the air.

The PV can also have the function of sun shading or articulation of the facade.

4.5 On site installations

PV installations on the site, for instance as a sculpture, as shading over parking or in light shafts for underlying space is an approach that receives increasing attention.

Presently, vast areas are reserved for transport and connected facilities. Climate may call for protection from sun, especially in passive situations, like waiting facilities or parking spaces. Also, the site gets a less deserted appearance with a defining structure. The constructions are usually relatively simple and large. Often, they can be easily fitted with PV, giving the structure further tasks than shading and eventually an extra income.

In train- or bus stations of remote areas, PV can supply power for lighting, ticket and information systems as well as automation and safety.

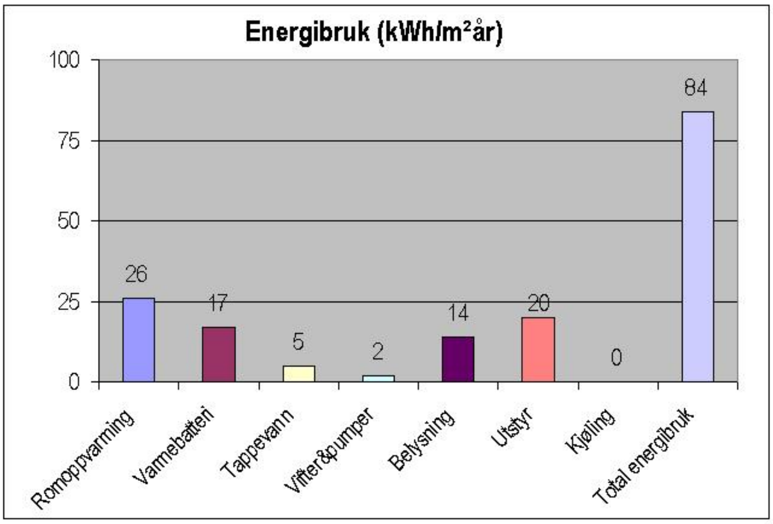
For parking facilities, PV can supply power for lighting, security cameras, charging flat batteries etc and running parking meters and information systems. In the future, PV charging stations for electrical cars may be common, in addition to a number of possible remote applications.

In many respects, installing PV as a sculptural element or as a landscape installation may prove to be the cheapest if the building requires very special, difficult aesthetical measures. If the building is relatively new, changing of components may prove to be bad resource economy and finding sufficient area with qualities for PV installation may be difficult. For most projects, the critical factor for its economy is the amount of acclimatised space, and buildings are becoming increasingly dense. This means smaller surfaces unassigned to tasks, which again means that fitting of PV can be difficult. The site usually has some excess space in addition to the built space. In many cases, this space can be fitted with sculptural elements that also can produce power. This can be a way to connect the landscape to the building and invite people out into the green. Sculptures may also be pleasing to the eye from the interior, increasing the mental area of space.

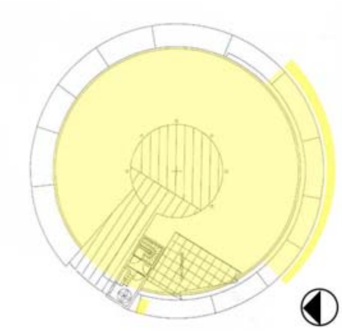
5 Case Pynten

This section is looking into how traditional building integrated photovoltaics (BIPV) can contribute to lowering the need for purchased electric energy, increasing security of supply and most of all looking into how BIPV can add architectural qualities to the building.

Pynten is an office building project that will be built in Nydalen in Oslo, an office and industry area with good infrastructural connections. The site has an exposed situation with view to all directions and the green river park “Akerselva” to the east. The building has a circular plan of three floors and two basement levels and will have a total floor area of about 4200 m² containing 114 work places.



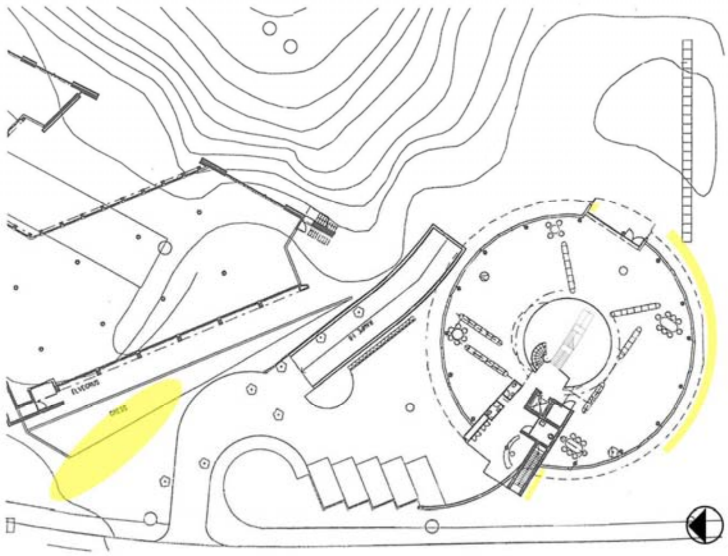
The building is aiming at a very good environmental profile, and energy use is expected to be merely 84 kW/m² per year. Average energy consumption in similar buildings is at least 250 kW/m² per year. In the Pynten building, lighting and equipment annually requires 34 kW/m². The annual total solar radiation on a horizontal surface in Oslo is 950 kWh/m^2. This means that in order to cover the entire electricity need in the building, a PV area of around 1000 m^2 is needed.



Plan roof

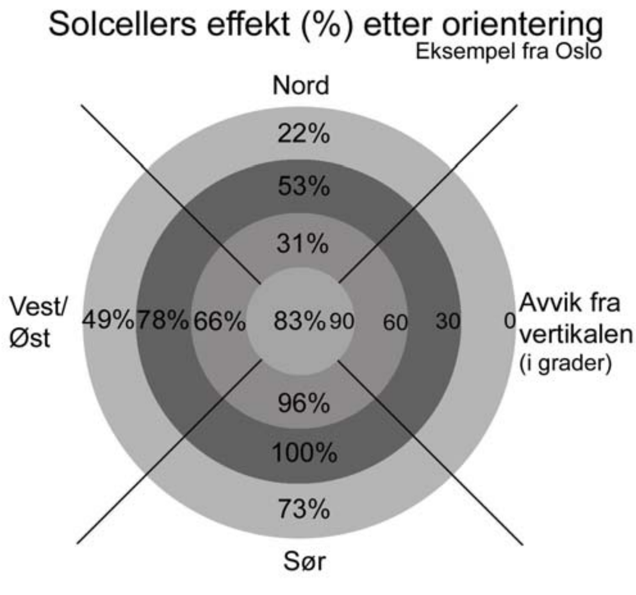
Plan second floor

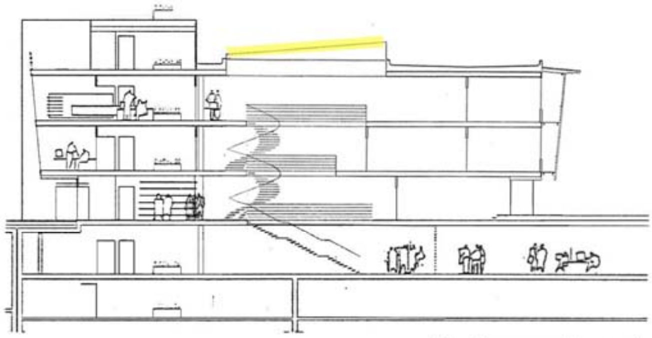
Plan first floor



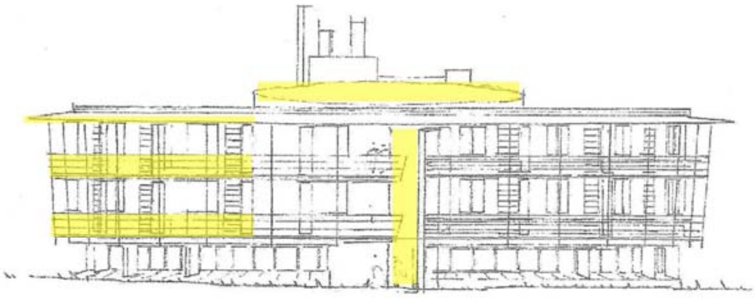
Plan ground floor

The ideal orientation of the elements is towards south, but about 20˚ off this direction to east and west is tolerable. This means that a 45˚ section of the south facade plus some south oriented elements are well enough exposed to the sun to be evaluated for PV fitting.
In addition, the roof has large surfaces suited for PV elements and the site has some suitable space to the north.

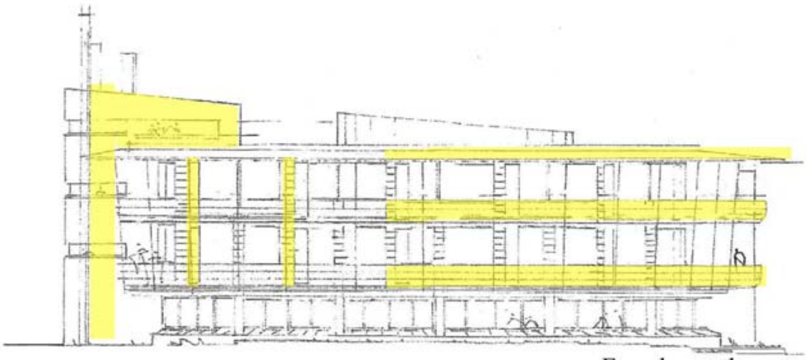




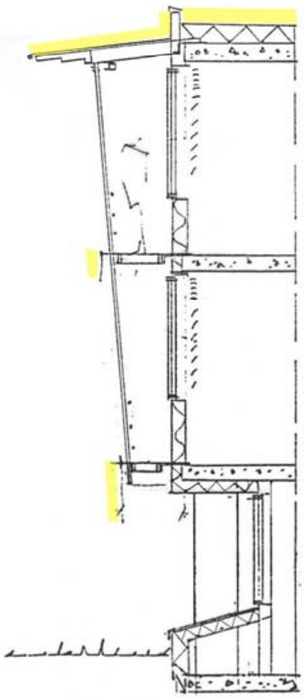
Section west - east



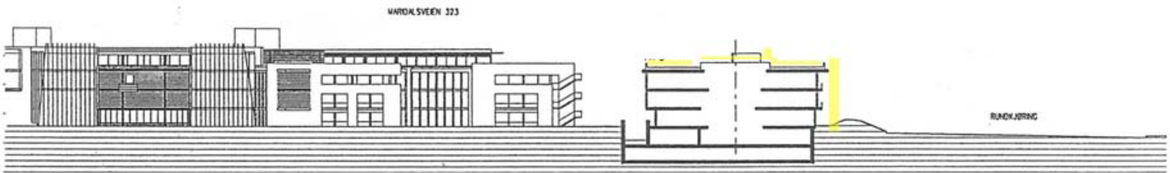
Facade southeast



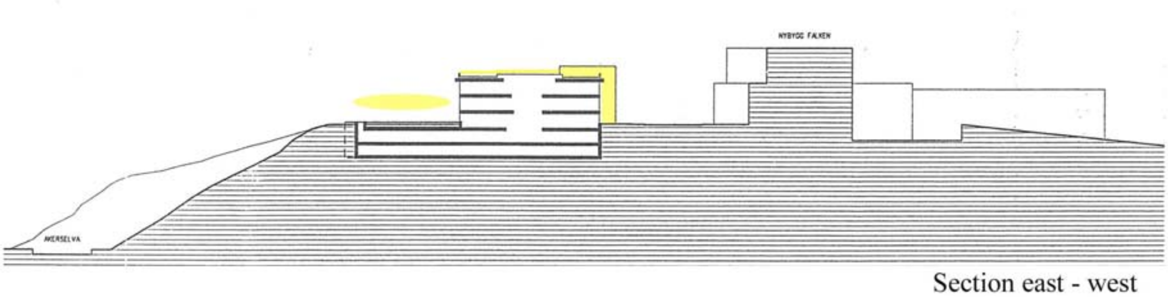
Facade southwest



Section east facade



Section north - south



Section east - west

For traditional PV concepts, this building offers some challenges. First, because it is curved, second, because it has large canopies to the south for sun protection, leaving much of the actual façade in shadow, and third, because of the wooden finish, leaving out typical façade systems in aluminium. The south direction is also the direction of the main view - towards the lower-laying city centre and the fjord. As a result of this, the concepts applying to this building more or less reduces itself to the roof surface.

The roof has two finishes: the normal, flat roof and the north-tilted central skylight over the atrium. For the roof, a relatively large area can be fitted with either flat, integrated modules, or with more optimally tilted ones, mounted on top of a regular roof. The first method eliminates the roof material where the modules are mounted, and is safer in terms of leakages than an externally mounted system. The flat mounting will have a smaller visual impact than tilted modules, as it does not affect the relief of the building. Careful choice of mounting areas may avoid that effect from the tilted modules, but will then reduce the usable area.

The skylight should be tilted to the south, as the installation of photovoltaics can shade the interior from excess sun. The use of transparent modules with integrated photovoltaics may give exiting light qualities to the interior and will be the most rewarding installation in terms of exposing a more expensive material and giving aesthetical- and image values to the tenants.

Further installations could be shading devices to the south integrated in the railings.

In chapter 6.2, the PV integration in the Pynten project is further elaborated.

6 Refocusing on PV

The success for BIPV-projects lies in most cases in the introduction of PV as architectural elements. This also goes for product development of the PV material.

The existing photovoltaic modules on the market have design considerations that raises questions concerning effort and gain vs. their high prices. Most of the photovoltaic research that is performed today happens in the technical field. With focus on energy, the main research areas are efficiency, price and longevity, in order to reduce the long payback times of photovoltaics on today's market.

The existing photovoltaics therefore obviously give no instant reward for the end users when applied on grid connected buildings. The only reward that photovoltaics give today is the farsighted ecological improvement for future generations of citizens. The lack of the instant reward for the end user provides very little attraction to the building market since there are only a few buildings that use photovoltaics as part of their energy consumption in spite of the fact that buildings have many potential areas where photovoltaics could be applied - not just as an add-on but even as an integrated layer of the building facade. The potential for applying photovoltaics in buildings is therefore far from reached.

At the same time, the energy focus gives the impression that photovoltaics are an alien technology without any architectural purpose or potentials. Its only obvious purpose is to serve the building with fresh energy and therefore it should be hidden, like any other technical object or space that serves the building. This focus reduces photovoltaics to an infeasible energy source due to an extremely long payback time, resulting in the fact that only a few architectural projects show interest in solar cells as an architectural element.

In order to achieve an architecturally successful integration of photovoltaics, we need to refocus: Instead of viewing photovoltaics as a source of energy that has to be put on a building in a discrete, nice way, one could view photovoltaics as a formable building material that is able to be configured in a certain set of ways, extending its functional and aesthetical contribution. Photovoltaics consist of a range of exiting materials from an aesthetical point of view, but the products developed up to today have far from taken out the potential as a building material.

It is necessary to focus on what photovoltaics can do for architecture and its users – making photovoltaics a means and not as a target in it self. In order to do this, the architect has to join the component design team very early in the sketch phase where the general design criteria are being generated. Here, the design process should not deal with developing the concept of a panel, but with configuring a material on the basis of the building criteria.

This focus on material configuration instead of energy output also removes the focus from payback time, as photovoltaics will not only be viewed as an energy source, but more as a cladding material with a certain visual expression and several functions - where one of them will be producing energy. Therefore it can not only be compared with energy prices of other sources, but also with prices of other building materials. As these have an eternal payback time due to no energy production, the energy/economy aspect somewhat changes to a broader discussion of added qualities.

It is essential for the continued rise of the PV industry that the architectural quality and flexibility is developed further. PV has a clear signal value which is a quality in itself. The coming years will require it to become a natural material that can be completely integrated in the building.

PV is harvesting light, but can also send light through to us in a number of ways. Light can create serenity, chaos, a feeling of temperature, a feeling of space. Are PV producers and designers able to give us tools for working with light, that inspire us to become light conscious?

The following chart is meant to serve as a sampling source for the design of BIPV components. It is an initial mapping of possible design variations targeting architectural issues and one can see them as design parameters that can be configured in relation to the design criteria of a certain component. The categories can be combined into many various expressions.

6.1 Examples of features/variation categories for PV

Variation Possibilities	*PV Possibilities*

1.1. FORMING

1.1.1	Pliability	Rigid	Feasibility: All PV modules today Concept: Shape-wise unchanging PV element.
		Pliability during operation	Feasibility: All thin film PV types with bendable substrates, such as amorphous silicon cells and future crystalline thin film cells. Concept: May be changing curves/shape due to natural influences, such as wind, temperature change and precipitation, or to other influences, such as running an electrical current through the material, inflating it or through motorised transformation.
1.1.2	Mobility	Stationary	Feasibility: All PV modules today. Concept: Fixed/integrated façade- or service element. Without possibilities to transfer to further use, the lifetime vs cost issue should be evaluated.
		Transferable to other location	Feasibility: Some small modules are presently feasible for this, but not practiced in buildings. Concept: The modules are of a character in their design, fixture and system that enables them to be dismounted and re-used. Low weight, solidity and access to fixation system are some key parameters for easy transfer of modules to new use.
		Mobile during operation	Feasibility: All PV types could be mobile, both as shading lamellas and as sun tracking devices. Today there are only a few examples of mobile BIPV. Concept: A motor (or other force) moves modules during operation to provide service to the building, like dynamic shading, expressive façade or optimised solar harvesting. Integrating the electrical system and the carrying structure is a key parameter. Scale and weight of the components are of importance for the scaling of the motors and the energy use.
1.1.3	Form possibilities	Flat	Feasibility: All PV modules today. Concept. Most facades today are flat or segmented (composed of flat units). Flat modules have an obvious market as a building material, as its shape easily integrates with other flat façade elements.
		Single curved	Feasibility: All thin film cells with curved or bendable substrates, such as amorphous silicon cells and future crystalline thin film cells. Concept: An increasing number of buildings have curved elements. Often, these elements are of the key design elements. Using photovoltaics here may express both modernity and a green image. The light-filtering abilities of PV may come to new expressions with physical curves in the patterns. A curved module may give a more even production of electricity over time, compared to a flat module, as it follows the sun path shape-wise.
		Double curved	Feasibility: No modules in production yet. New production methods with deposition on double curved substrates, or post-curving are necessary. Concept: Integration in advanced facades, possibly with customisation of each element.

1.2. PATTERN

1.2.1	Contacts	Hidden	Feasibility: All PV modules today. Concept: The contact pattern may be put on the backside of the cells or, if staying on the front, be made from a transparent material, as done on LCD-screens.
		Homogeneous	Feasibility: All PV modules today. Concept: Even, strict pattern of contacts, giving a calm expression and the best distribution on a homogeneously arranged PV material structure.
		Heterogeneous	Feasibility: All PV modules today.

			Concept: Playful contact pattern, suiting for a heterogeneous cell distribution or as a contrast to a rigid material pattern.
1.2.2	Cell pattern	None	Feasibility: Amorphous silicon and CIS cells. Concept: Even surface of PV material.
		Homogeneous	Feasibility: All PV modules today. Concept: Even distribution of PV cells, where the cell size and the interstices are main design parameters.
		Heterogeneous	Feasibility: All PV modules today. Concept: Uneven distribution of PV material. Can give the module different shading abilities over the surface, or screening special heights in the rooms behind from view. Can underline images suiting to special programs like kindergartens ,churches etc.
1.2.3	Pattern within cells	Rough	Feasibility: Polycrystalline cells (natural) and other PV materials. Concept: For polycrystalline cells, the play of light over the material surface, reflecting in the different crystals, creates an expressive surface. Fast grown cells will have the roughest crystal patterns. For other types, a rough pattern can be physically made by burning or cutting a pattern.
		Medium detail	Feasibility: Crystalline, amorphous and organic cells. Concept: Slowly grown polycrystalline cells or a physically made pattern can be burned or cut. This will give light qualities on the backside of the module, but not as a direct surface quality.
		Fine	Feasibility: Amorphous and organic cells. Concept: The material offers little or no structure, giving an evenly reflective surface.

1.3. LIGHT & COLOUR

1.3.1	Cell lucidity	Opaque	Feasibility: All PV modules today. Concept: A surface through which no light passes. The surface quality of the material is the only aesthetical feature of the material.
		Translucent	Feasibility: Thin layers of crystalline cells, amorphous cells and organic cells. Concept: Light passes through the material, and the material thickness determines the light levels. Materials may also be penetrated by laser cutting in patterns small enough to enable light but not view through the surface.
		Transparent	Feasibility: Organic cells or lamella arrangements. Concept: The PV material is either by its character see-through, or its arrangement, through laser burned openings, interstice between cells or lamella structure, enabling view through the surface. Awareness of glare is necessary, especially with small interstices between cells.
1.3.2	Light-transmission	Direct light	Feasibility: Organic cells. All module types if the cells are arranged with space between each other on a transparent substrate. Concept: The daylight preserves its character and direction passing through the module.
		Diffuse light	Feasibility: PV types that can be perforated with microscopic holes such as organic cells or cells deposited through a mask such as amorphous cells. All module types if the cells are arranged with space between each other on a translucent substrate or as lamellas. Concept: The light is filtered through the material in a way that significantly reduces the intensity. This may also happen when light is being sent via a surface that alters the light in the reflection process. Such a surface has a matte/ light spreading finish.
		Light guiding reflections	Feasibility: All PV types if arranged as profiled lamellas. Concept: The light is reflected on a shiny surface. The main character of the light is preserved, but the direction will be changed in the reflection process.
1.3.3	Colouring light	PV as colour filter	Feasibility: Thin layers of crystalline cells, amorphous cells and organic cells Concept: The light is filtered through the cells, letting only some parts of the light spectre through – thus colouring the light.

		Colour reflections of the cell	Feasibility: All PV types that are either coloured themselves or coated with a certain thickness of anti-reflection coating (light colours limit the efficiency of PV). Concept: light reflected off the PV material has changed colour through the absorption of a section of the light spectre. The reflected coloured light is used in the interior as secondary light, as it is not entering directly (as with filtered light)
		Colour of the substrate	Feasibility: All PV types. Transparent/translucent PV material (direct or interstices) can have a coloured back substrate. Concept: The front surface of the substrate can cause colour reflections, both with translucent and solid substrates. With a transparent, coloured substrate material, the light is coloured on the path through it.

1.4. UNIT

1.4.1	Module structure	Homogeneous	Feasibility: Amorphous silicon and CIS cells. Concept: The whole surface of the module is covered with an even PV material layer.
		Patterned	Feasibility: All PV materials today – usually square pattern units. Concept: The PV material is deposited in a pattern – usually in stripes, hexagons or squares. The potential for making different patterns is very high, both for crystalline and other materials, but may require new production methods to make it cost efficient.
		Lamellas	Feasibility: Various types - dependent on the scale of the lamellas. Concept: Lamellas in a system offer view and can better angled to the sun than vertical modules. Often used in/as shading systems.
1.4.2	Shape	Rectangular	Feasibility: All PV types Concept: Most common concept today, comprising a flat, rectangular module.
		Non-rectangular	Feasibility: All PV types, but in the present production system especially the amorphous types. Concept: A flat module cut in a non-rectangular shape – either organic or angled. Can make the modules more expressive elements in the façade, especially if they are individually mounted. A field of non-rectangular modules give extraordinary patterns.
		3D	Feasibility: All thin film PV types with bendable substrates, such as amorphous silicon cells and future crystalline thin film cells. Concept: The module is curved, either in one or two dimensions. Such a module may be integrated in the modern, organically shaped facades, or be used as special elements.
1.4.3	Size	Micro	Feasibility: All PV types Concept: Smaller units like tiles that can be used integrated with real tiles. Small units stop being individual elements when they are put together and will easier appear as a surface. Small units can be attached to machinery it is serving (such as a lamp or ventilation hatch), thus distributing power to the place of use and possibly serving as a sensor that can activate the item.
		Medium	Feasibility: All PV types Concept: Units fitting in for instance façade systems, scaled for fast mounting and less electrical work on site.
		Macro	Feasibility: All PV types Concept: The PV module
1.4.4	Weight	Light	Feasibility: PV types that have a higher tolerance for curving in the material during operation. This applies to thin film PV types with bendable substrates, such as amorphous silicon cells and future crystalline thin film cells. Also small modules, thereby including all PV materials. Concept: A light module will simplify the mounting significantly, excluding the need for heavy lifting machinery. This also is an advantage in terms of mobility during operation and for re-use in a different location. The energy used for transporting the element is also reduced, along with the embodied energy of the substrate material. Poly-carbonate is a feasible substrate material, but this requires new methods for depositing the PV material onto the substrate, as this is

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1.4.5	Lifecycle		now done under high temperature/pressure. Using lightweight material may also enable larger modules, eliminating much of the carrying structure, making the system sleeker.
		Medium	Feasibility: All PV types Concept: Current materials/systems. Requires lifting machinery for mounting. Solid, suiting for all PV materials in terms of stability.
		Heavy	Feasibility: All PV types Concept: Heavyweight materials can give the module extra stability or thermal storage capacity.
		Short	Feasibility: Newer, cheaper PV materials, like organic PV or solar grade silicone. Concept: PV systems aimed at a shorter lifespan, either as part of a component or in terms of reducing the investment for a building (for instance assuming repeated façade or system changes).
		Durable	Feasibility: All PV types Concept: The component is meant to be functioning a long time, making the use of durable materials and finishing details important.
		Replaceable	Feasibility: All PV types Concept: The modules have a mounting system that enables one or more components to be removed without larger effort.
		Re-useable	Feasibility: All PV types Concept: The modules are designed so that they easily may be removed from one location and mounted in another. This enables the investor in the PV array to adjust the size of the array or the layout of the façade according to shifting needs and paves the way for a second hand PV market.

6.2 Re-thinking Pynten

Using the above features as guidelines, one can again evaluate the office building Pynten in terms of PV, even though it will be a futuristic perspective over the task.

FORMING
The main challenge of the building is its curved shape and the conflict between view and the need for screening to the south. The most applicable features from the forming category are using single curved elements to fit with the building shape and using elements that are mobile during operation. An extra feature that may be valuable is to have modules that are transferable to another location, as the building is probably having changing tenants, possibly requiring image changes to the façade on regular basis.

PATTERN
The building's material qualities are made up of a matte, natural finished wood along with glass panes. Focusing on the PV elements as a material will simplify the task of integrating the elements with the architecture of the buildings. Distributing the material in a way that gives some view through the modules may lessen the conflict to the south. It could be an interesting composition of materials to have a rough crystal pattern put together with the wood surfaces. There are many interesting combinations of materials that can create interesting patterns and contrasts when put together.

LIGHT & COLOUR
In terms of enabling some view to the south, also under sunny conditions, the modules should be transparent. This means either the choice of a transparent material or a deposition on the substrate that has sufficient interstices to enable view. It also means the interior will receive some direct light that has to be under control in terms of glare and overheating. A coloured, transparent substrate may reduce the sun-induced problems, though it affects the character of the view. Done with consideration, this may become a quality in the interior.

UNIT
The structure of the modules should be either homogeneous, to fit with the "clean" look of wood and glass or be of a lamella character, enabling view. The lamellas may break up the PV surface, not making it so dominant versus the other materials.
The shape could be a curved rectangle to not take attention away from the material to the module. Size-wise, a micro- or macro module would be preferable, as the first refer to the lamellas and the second to a large module that enables the material to dominate the appearance.
In terms of weight, a light or medium heavy module would be most appropriate, as it will need some strength to be suitable for being mobile, though design-wise, a more slender construction is desirable and the possible re-use in a different location would benefit from light, manoeuvrable units.

Collecting the design preferences and looking at conflicts with the PV materials forms two concepts. The first is based on polycrystalline materials, where the material quality is an exiting contrast to the wooden facade. Large, curved exterior lamellas offer protection from undesirable sun angles while offering view. The lamellas are in a fixed position, but may possibly change angles during operation. The lamellas are curved to fit the building, reducing the importance of being reusable, as they then will have problems finding a suitable building. The colour of the substrate and the cells may have influence on the interior. As office buildings may have problems with excess heat, a blue may reduce the mental impact, while emphasizing the warm colour of the wood.

The second concept is one or more large, mobile fields of transparent PV material. This concept enables view, though filtering the light to a less intense character/colour. This would mean using amorphous silicone or, preferably, organic PV. Such big modules will have a strong impact on the light quality in the space behind it, thus making the mobility aspect vital to be able to alter the character in the rooms behind. A larger surface would also screen the gallery better from wind, giving it more functionality in the Nordic climate. Using segments offer a bigger chance of re-use, though a curved element would give a better aesthetical link to the building. Organic PV is expected to have a low price, though with a simultaneous low electricity outcome. To have any energy impact beyond reducing interior cooling needs, the concept of a large surface is appropriate.

A combination of the two would give good control and variety of the space behind, offering different degrees of sun protection and view, while simultaneously giving the building a dynamic expression and complimenting the original choice of materials.

Compared to the short present-day evaluation of Pynten in chapter 5, this section shows that new thinking can give photovoltaics a bigger role, both aesthetically and in square meters, in the architecture.

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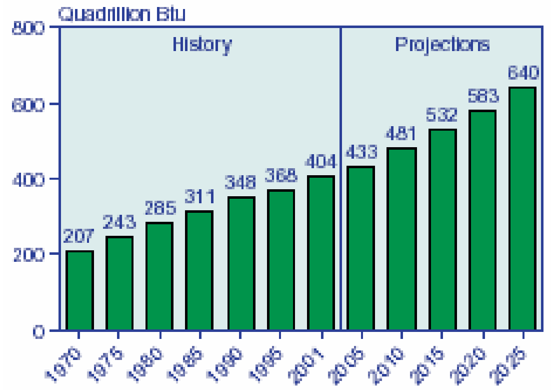
Appendix A - Energy consumption and projections for the future

This analysis of present and future energy consumption is based mainly on the 2003 EIA report “International Energy Outlook”. Additional sources are included to broaden and add depth to the analysis and to enable different scenarios within the range of results. The main focus is on the use of electric energy. The chapter is divided in three parts, covering the world, Europe and Norway as different levels of detail.

Predictions on world energy supply and PV

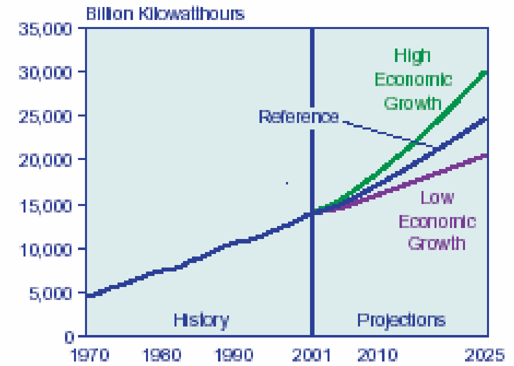
In the *International Energy Outlook 2003* (*IEO2003*) reference case, world energy consumption is projected to increase by 58 percent from 2001 to 2025. Worldwide net electricity consumption is projected to increase at an average annual rate of 2.4% in the same period - from 13.9 trillion kWh to 24.7 trillion kWh. Strong growth in electricity use is expected in the countries of the developing world, particularly developing Asia.

Figure 2. World Energy Consumption, 1970-2025



Sources: History: Energy Information Administration (EIA), *International Energy Annual 2001*, DOE/EIA-0219(2001) (Washington, DC, February 2003), web site www.eia.doe.gov/iea/. Projections: EIA, System for the Analysis of Global Energy Markets (2003).

Figure 77. World Net Electricity Consumption in Three Cases, 1970-2025



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The *IEO2003* projections for hydroelectricity and other renewable energy resources include only on-grid renewables because there are few comprehensive sources of international data on off-grid energy use.

Renewable energy, predominantly hydropower, accounted for one-fifth of the world’s energy use for electricity generation in 2001, where it is expected to remain through 2025. Generation technologies using non-hydroelectric renewables are expected to improve over the forecast period, but they still are expected to be relatively expensive. Of the world’s consumption of renewable energy for electricity production in 2001, the United States/Canada accounted for 29 %, Western Europe for 20 % and Central/South America 19 %.

Solar power and the IEA–PVPS program

With great diversity between countries participating in the IEA–PVPS program and though this survey does not capture the whole PV market worldwide, it does indicate global trends. Since 1999, between 70 % and 86 % of PV production in the reporting countries can be accounted for by the capacity installed in the IEA–PVPS member countries, and the IEA–PVPS countries have accounted for more than 90 % of global PV production. The annual rate of growth of PV installed has varied between 20 % in 1994 and 40 % in 2000. However, the rate of growth between 2001 and 2002 (34 %) was similar to the rate of growth between 2000 and 2001 (36 %). Doubling of market size in the IEA–PVPS countries has occurred a little more than every two years in recent years. This is mainly due to large scale, government or utility supported programs, especially in Japan, Germany and the USA, which focus on PV in the urban or suburban environment. However, off-grid applications still account for more total installed capacity and new capacity installed in 2002 in the majority of the reporting countries. Countries experiencing rapid growth in the rate of installation of PV capacity continue to be supported by significant public budgets for market stimulation, research and development, and demonstration and field trials. However, the amount of money made available in the reporting countries varies widely. In general, the budget for the demonstration and field trials of PV systems continues to represent a small proportion of the public budgets.

Security-of-supply issues have raised political interest in all domestic and distributed energy supplies, including PV. Climate change negotiations have raised the profile of renewable energy in general, but the implications for PV remain uncertain. The industry development aspects of PV (including the opportunities to provide jobs) are receiving attention with the publication of a number of ‘technology roadmaps’. Whilst total national budgets for R & D, demonstration / field trials and market stimulation measures remain strong, there are increasing proportions of the budgets spent on market initiatives rather than demonstration / field trials in many countries.

The PV business continues to expand rapidly. Total photovoltaic cell production volume for 2002 was reported to be 520 MW, an increase of 51 % from 2001. The cell production capacity grew from 494 MW to 801 MW, an increase of 62 %. Module production and production capacity enjoyed similar strong growth throughout 2002. Japan produced 47 % of the cells (244 MW) and 54 % of the modules (260 MW) reported. Germany showed an expansion of over 40 % for module production, to account for 8,5 % of the total reported market. Interestingly the German production is reported to account for less than half of the local demand in 2002. The United States is still a large producer of PV cells (121 MW) but their expansion is not as rapid as in the other countries.

Installed PV power and module production in the reporting countries

Year	Cumulative installed power and percentage increase						Power installed during year	Module production in year
	Off-grid		Grid-connected		Total			
	MW	%	MW	%	MW	%	MW	MW
1992	78	-	32	-	110	-	-	-
1993	95	21	42	32	136	24	26	52

1994	112	19	51	24	164	20	28	-
1995	132	18	66	29	199	21	35	56
1996	157	19	87	32	245	23	46	-
1997	187	19	127	45	314	28	69	100
1998	216	15	180	42	396	26	82	126
1999	244	13	276	54	520	31	124	169
2000	277	14	449	63	726	40	206	238
2001	319	15	671	49	990	36	264	319
2002	343[1]	8	969[1]	44	1 328[2]	34	338	482

System prices have continued their general downward trend, but include fluctuations and variations between countries, which should be expected given the stage of market deployment and the impact of non-technical factors. More significantly the trend in (current) price reduction for modules (which are internationally traded and can typically cost around 60 % of the system price) shows decreases of between 10 % and 17 % per doubling of market size.

Another feature was the significant number of companies in different countries that put PV products for building integration on the market. These products rely on both crystalline silicon and thin film technologies. While the markets for such products are still relatively limited, the number of products available clearly indicates that producers believe this will become an important market segment. In general, public opinion appears to be supportive of PV and electricity utilities are starting to

Figure 4: PV module production and module production capacity between 1993 and 2002

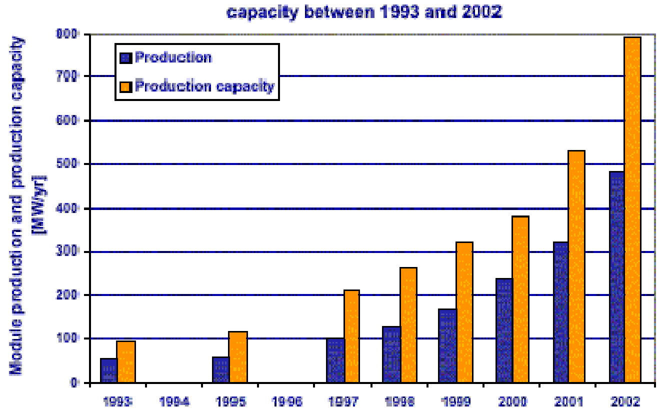


Figure 1: Cumulative installed PV power by application area in the reporting countries

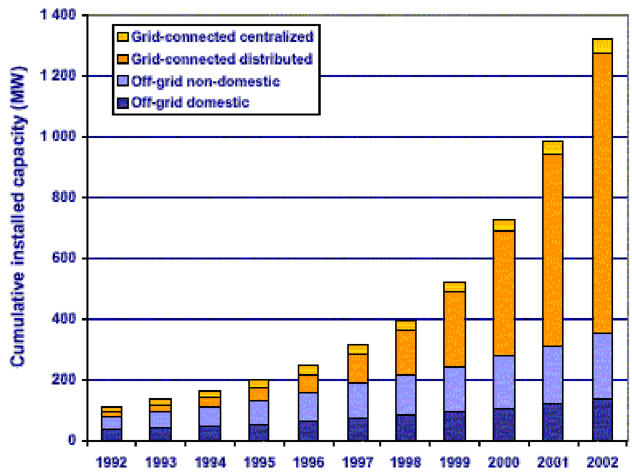
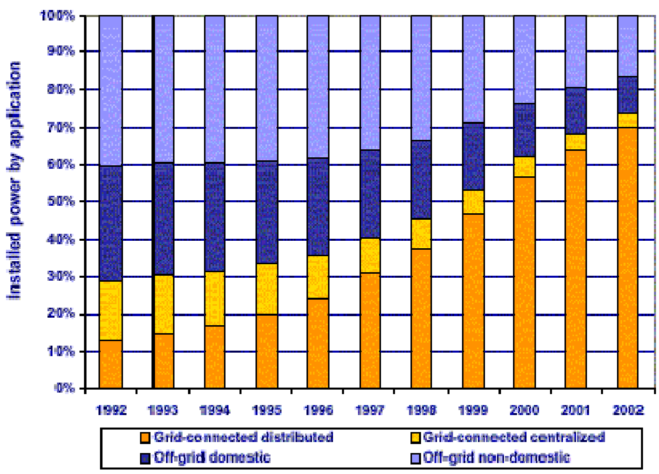


Figure 2: Percentage of grid-connected PV power in the reporting countries (centralized and distributed)



identify many of the opportunities provided by PV. However, the added values of grid-connected PV – electricity network, architectural, environmental and socio / economic benefits – are yet to be systematically incorporated by policy makers and regulators. New stakeholders such as the building and finance sectors now provide additional challenges. Figure 2 illustrates that since 1999 the majority of PV capacity has been installed in grid-connected applications. However, in over half of the reporting countries this is not the case. Over 80 % of PV capacity in Australia, Canada, Finland, France, Israel, Korea, Mexico, Norway and Sweden is for off-grid applications. In the Nordic countries, the majority of applications are leisure homes, whilst PV in Australia, France and Mexico is used as one of the means to achieve rural electrification. In Canada, Israel and Korea, most systems are for industrial and commercial applications including telecommunications and remote monitoring. High rates of growth continue to be driven by government or utility supported programs that tend to concentrate on grid-connected PV in the urban environment.

Norwegian energy use and production

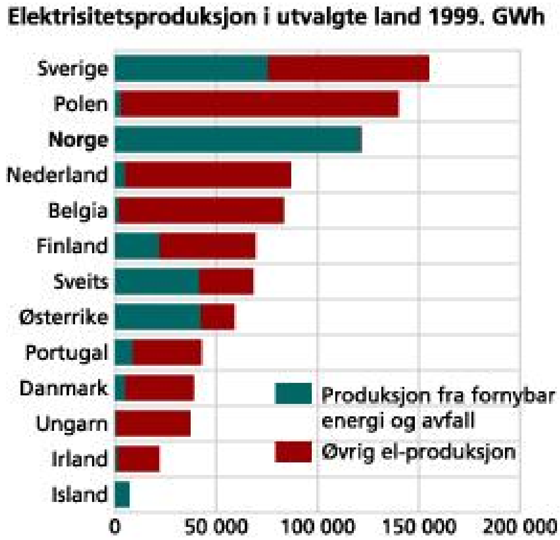
Norway is in a unique energy situation, being the world's second largest oil exporter and holding large natural gas volumes. Norway also has a great potential for wind power, wave power and other renewable sources. These resources are not widely exploited today. Hydropower, on the other hand, is widely used. In Norway, almost all electricity comes from hydropower facilities, producing relatively cheap electricity, benefiting both the industry and the population. The electricity prices in Norway are low compared to other OECD countries, with only Slovakia, The Czech Republic and Mexico having lower prices. As a result of this situation, a system distributing electric energy to all mainland sectors was developed. Although Norway and Iceland have the largest contribution of renewable sources and waste in their energy production, electricity is extensively used for tasks where other sources would be more sensible to utilize. A report published by IEA shows that Norway has a total energy use per inhabitant just over average OECD levels, if you correct for differences in climate and industrial structure. In 1998, Norway spent more than 10 times more electricity than the average of the world and 35% more than number two on the list.

By the turn of the last century, Norwegian authorities turned down further development of hydropower for environmental reasons. The present dependency of electricity makes the country very vulnerable, with security of supply issues. As environmental obligations increase, the importance of reducing growth in electricity demand grows heavier. Developing alternative distribution systems and utilizing alternative renewable energy sources implies huge costs and many challenges. The large and increasing demand for electricity in Norway has put pressure on increasing production capacity for electricity. At the same time, focus is increasing on developing new renewable energy sources and measures for reducing energy consumption in all sectors.

In 2001, Norway had a stationary energy production of 160 TWh, consisting of 122 TWh of electricity and 38 TWh heat. This implies 76 % electricity and 24 % heat. Other countries have a much larger proportion of heat in their energy production. In addition, Norway produced 162,5 million tons of oil and 51,7 million oil equivalent tons of natural gas. This is 4,5 % of world oil production and 2,3 % of world gas production. Most of this is exported, but some is used in the transport sector and for heating.

Production of electricity

Both geography and climate makes it natural to utilize hydropower in Norway, and Norway is one of few countries in the world that produces almost all electricity from renewable sources. Norway is Europe's largest and the world's 6.th largest producer of hydropower. In a year of normal access to water, Norway produces 118 TWh of electricity. To get a more stable national market, storage dams and transfer connections across the border have been built to use the larger market as a buffer between supply and demand. Electricity supply is a significant business in Norway. Sales figures in 2000 reached 24,7 billion NOK or 2,3 % of Norwegian BNP. Simultaneous investments in the sector amounted to 4 billion NOK.



Production of heat

Norwegian authorities are moving towards replacing electricity as a heat source in dwellings with heat. Present heat production used in dwellings is mainly on-site installations. In addition, some district heating is supplied in some areas by pipes. Sustainable production of heat mounts to 40 % of total production with general aspirations to increase this share.

Production from new renewable energy sources

New renewable energy sources produced 0,5 % of Norway's total electricity in 2001. Wind power mounted to 0,02 %. During the last 10-15 years, this sector had priority with Norwegian authorities and their goal is to raise production to 7 TWh by 2010 (7 TWh heat and 3 TWh wind generated electricity). Effort is also made in developing and promoting technologies that today have small market shares, like solar and bio-energy. The low electricity price in Norway is making competition hard for the new technologies and they are still depending on some public funding for their implementation.

Nordic energy supply and PV

There are quite a few photovoltaic systems in the Nordic countries. Norway's population of 5 million has more than 100.000 of them, alone, though most are small arrays on leisure cabins. The challenge now is to achieve a broad use of photovoltaics also in urban areas, with larger arrays integrated in buildings. To reach this market, it is important to address problems connected to different building typologies, developing models, design trends and their implications for possible PV use. New buildings can without extraordinary effort achieve energy savings of up to 70 % with a focus on energy performance in the design process.

Liberalization of the energy market

Norway was the second country within Europe that facilitated more market oriented principles for energy trade through the Energy law of 1991. An important supposition in a free energy market is that the electricity net is made available to all users in an equivalent way. The energy is free floating in the continuous transfer net in Norway, thus a system for measuring delivered and consumed energy in all ends is necessary. The new market oriented system also enables customers to freely choose their suppliers of energy. This situation is positive for small scale producers of energy and may support a broader development of small scale and decentralized producers.

Appendix B - Energy use in Norwegian office buildings

The design of new buildings is largely depending on the evolving business- and work structures and flexibility is becoming one of the main issues, as the building may be redefined and restructured several times during its lifetime. The built structure and underlying service facilities must be designed in such a way that it is the building and system that adapts after its content and not vice versa. Building codes and legislation is also becoming stricter and more detailed concerning structure and service. These are some major factors that contribute to a demand for new solutions from both the technical and architectural point of view.

Norwegian energy use in office buildings
In January 2003, there were 37 377 office buildings in Norway. The gross surface area of this building category in 2002 was 53 million m², making up 16,1 % of the built mass. Temperature adjusted figures for 2001 show an average of 243 kW/ m² for the heated area. Annually Norway uses 130 billion Nkr on running and maintaining buildings. In addition, 90 million Nkr is invested in new buildings and refurbishment. In total, the building industry do business for 220 billion Nkr every year, mounting to 20 % of Norwegian BNP.

One of the main challenges for the building and property sector is its high energy consumption. In a normal year, building operation counts for 82 TWh/38 % of national stationary energy consumption. Energy use in commercial buildings mounted to 35 TWh in 2001, where half went to heating purposes. These buildings typically have high demands for ventilation and cooling compared to dwellings. Circumstances that affect energy use in commercial buildings are: Occupants and business type, new versus old building, energy prices, technological development, ownership or rental, market trends and changes in economical growth and finally the climate.

The estimated environmental potential for the Norwegian building and property sector can be separated in the scenarios of new and old buildings. In new buildings, savings of up to 70 % is feasible with a focus on energy performance in the design process. Reduced energy consumption and a conversion from oil/electricity to local renewable energy sources could save 22 % in a 20 year perspective in the whole sector.
Rational planning can reduce the amount of built area and thus lower the need for resources and service. In addition, waste reduction and recycling in the building sector has great potential.

Heating
Heating comprises heating of space, water and ventilation air and is the task most feasible for use of other sources of energy than electricity. The source flexible part of energy use in a building can vary between 20 % and 75 %. The most common system for space heating is central heating based on warm water, electrical panel ovens or a combination. The energy can come from an on-site energy source or from district heating. About 65 % of commercial floor area is heated by radiators. In Norwegian commercial buildings, hot water is usually heated in an electric boiler (65 %). In buildings with central heating, ventilation air is usually pre-heated by warm water. The rest use electricity for this assignment. In a typical office building,

space heating comprises 25-30 % of the total energy use, pre-heating of ventilation air uses 15-20 % and warm water merely 5 %.

Choice of heating system is usually based on an evaluation of a buildings size and use, available energy sources and profit. A direct electrical heating system has low investment cost and maintenance, but the energy price is rising. An energy flexible system usually has higher investment costs and maintenance needs, but has a lower energy price than electrical heating in the long run.

Cooling
New modern buildings are usually well insulated, have large glass surfaces and large internal heat contributions from light, equipment etc. This can give a heat surplus in the summer, implying cooling of the buildings under the new comfort standards. Cooling of space or ventilation air now starts at outdoor temperatures that previously implied a need for heating. This is due to the increasing use of electrical equipment.

Heat contributions to a building come from a range of sources. Correct dimensioning of climate conditioner means including all these sources:
Solar radiation through windows etc
Heat conduction through walls, windows and roof
Contributions via ventilation air and infiltration
Internal loads from light and equipment
Heat radiation from persons

Technical equipment
Energy used for equipment can reach 50 % of total energy use in an office building.
The recent technological development has led to more energy effective products. Some devices use only 20 % of the energy they typically used in the eighties. In total we use more technology and devices today, leading to an increase in energy use for this category. Much energy is consumed by devices in stand-by modus.
Area efficiency is receiving increasing attention in design of new buildings and renovation. Focus on efficiency and organization is also resulting in a different choice of equipment. Portable laptop computers and flat LCD screens use less energy and space and offer new possibilities concerning work situations. Multi-function machines use less space and energy than the sum of machines they replace.

Sensible resource consumption
Many commercial buildings are equipped with large ventilation units that consequently serve all areas within the building with the same effect. By separating the building in zones and adapting the ventilation to local needs, large savings can be made on energy- and service expenses, although the initial investment is high.

Integration of daylight in the lighting of a building gives more comfortable light conditions and can save much energy, both for running lamps and in reducing the heating and ventilation load.

Appendix C - 3 scenarios for world PV development

The appendix presents scenarios for 2010, 2030 and 2050 in terms of PV development and it's role in the energy supply.

Three scenarios for World PV development

2010
By 2010, thin-film technologies could be strong competitors to crystalline silicon technology, thus sharply reducing PV module costs and making PV much closer to competitiveness with other energy technologies over the full range of applications. This outcome strongly depends on the success of demonstration projects and on the implementation of accelerated R&D policies during the first decade of the new century. Uncertainty about this explains the gap by a factor of over 60 between the most conservative and the most optimistic fore cast values for 2010 (from 4 GWp to 265 GWp installed worldwide.

As electricity demand strongly increases in the developing world, solar energy demand will also dramatically rise in those regions. According to the World Energy Council scenario (WEC 1994), in 2010 Asian countries alone will account for one-third of world solar demand. At that time local mass production of entire PV systems (including modules) is likely to begin in China, India, and other South-East Asian countries. In these countries and in some regions of Latin America, PV applications will likely include building-integrated systems in highly polluted megalopolises and large power plants for big remote applications and for local grid support. In Africa the main demand will still come from rural electrification systems.
In Europe, the full implementation of R&D and environmental accounting programmes will possibly lead to the installation of a 25 GW_p capacity (practically all decentralized, grid-connected systems), providing 3.4 per cent of annual electricity demand at that time (TERES 1994). In 2010, PV is not likely to have expanded strongly in the former centrally planned East European economies (including the CIS) because their priority is likely to be given to energy-saving and other infrastructural measures.
Finally, according to the NREL study, PV capacity of 9-40 GWp could be installed in the United States, depending on whether R&D programmes are implemented (NREL 1990). According to World Energy Council projections, this would correspond to about 25 per cent of the total world PV demand.

2030
In 2030, all the various PV technologies will eventually have reached a high level of maturity and be economically competitive with other energy sources.
Given their extremely high electricity demand (more than all OECD countries together), Asian countries will not only be the largest PV "consumers" (accounting for around 40 per cent) but could eventually be among the world's biggest PV producers. In those countries, PV could meet 5 per cent of total electricity demand (Johansson et al. 1993). Larger proportions could be supplied only with some large-scale storage systems (hydropower stations or hydrogen production).
Overall, developing countries are expected to account for 50-60 per cent of worldwide PV demand in 2030. The major uncertainty for 2030 regards former centrally planned East European economies. On the one hand, high electricity intensity, the need to substitute for obsolete coal and nuclear power plants, and the high technical skill of local engineers and scientists would suggest rapid and extensive PV diffusion in those countries. On the other hand, because of non optimal insulation, other competing (renewable and non-renewable) technologies might be preferred. According to these two different scenarios, former centrally planned East European economies could account for 8-21 per cent of worldwide PV demand.

2050

In 2050, the regional distribution of PV demand is likely to be similar to that in 2030: 60 per cent of demand will come from the developing countries. Asian countries alone will be responsible for up to or even more than 40 per cent of total world demand, while PV penetration in Africa and Latin America is expected to be lower because of abundant biomass resources. Europe will account for only 5 per cent of demand because of non-optimal insulation and land constraints. Japan will account for 3 per cent. The rest, with some degree of uncertainty owing to factors mentioned earlier, will mainly be shared between the United States and former centrally planned East European economies.

Interestingly, all scenarios we compared for 2050 forecast a world total installed PV capacity of between 1,000 GWp and 2,000 GWp. The electricity produced would then be of the same order of magnitude of 10 per cent of world electricity demand (3,075 TWh/year according to the IPCC "accelerated policies" scenario.

Although this is a significant figure for PV diffusion in 2050, it should be not taken as an upper limit to PV expansion in the future, mainly because by that time the direct input of electricity from an intermittent source into the grid will no longer be a major technological issue. As pointed out by Johansson et al. (1993), the contribution of total intermittent renewables (all solar and wind) to total electricity demand will be locally very high (up to 37 per cent) in 2050. This will be possible owing to two factors. First, wind and solar are independent, not correlated, intermittent sources. By 2050 advanced electricity network optimization methods will be available that will allow the maximum contribution to be achieved from these intermittent sources together. Second, additional great flexibility will be guaranteed by advanced natural gas and coal combined-cycle turbine power plants for peak generation, which are able to adjust output quickly and which will be the best complement to intermittent renewable energy technologies.

Thus, although a 28 per cent share for PV in total intermittent renewables is significant, larger percentages are in principle possible. In fact, whereas wind and solar thermal stations (for electricity production) are most suitable for mid power generation in isolated areas (>100 kW_p), PV systems are the only renewable technology likely to be used for electricity generation in urban areas. Given the potential for roof-integrated systems in OECD countries (van Brummelen and Alsema 1994), a relevant fraction of the total PV systems could come from roof-integrated systems. Moreover, the coupling of PV building integrated systems with other solar-active or solar-passive and/or energy-saving measures, and the fact that power is supplied where and when needed, substantially increases the attractiveness of PV systems compared with solar thermal and wind systems. This holds for both industrialized and developing countries. These two factors (not taken into account in the previous scenario) could lead to even higher shares of PV in total intermittent renewables, thus leading to higher PV penetration.

Finally, by the middle of the twenty-first century, electrolytic hydrogen production from intermittent sources is very likely to be a well-established and mature technology. This would definitely solve the storage problem of solar produced electricity. This is not likely to happen before 2030 because of the lack of the huge hydrogen storage and transportation infrastructures needed, and because hydrogen would eventually be mainly produced by much cheaper steam reforming of natural gas and biomass.

In 2050 however, large-scale hydrogen diffusion infrastructures will begin to appear, and advanced and efficient hydrogen storage methods will be available. Of course, other advanced electricity storage means, from advanced electrical batteries to superconductivity, could also be available at that time. With such storage systems, there would be no more technological limits to PV expansion.

Concluding remarks on PV and eco-restructuring
Today, major economic constraints limit the diffusion of PV in the world energy system. However, it is argued that this renewable energy technology will play a major role in the eco-restructuring transition leading towards a sustainable energy system for the twenty first century.
First, PV is fully compatible with the long-term targets of such a sustainable system. It is environmentally benign, because it uses the sun as a fully clean source. It is fully compatible with a decarbonised system using electricity and hydrogen as energy vectors. A major part of PV systems will be installed on surfaces already occupied by buildings (the theoretical potential of PV on rooftops alone could satisfy up to one-third of world electricity demand), thus significantly limiting the main environmental impact of PV, namely the occupation of land. Other indirect environmental burdens (i.e. generated during module manufacturing) are already low and will decrease with future PV technologies. PV will be economically compatible in the long term, because module and installation costs will decrease, as a result of technological innovation and economies of scale. It is a socially compatible energy technology, because it has a wide range of applications and involves a wide set of actors and users. Owing to some unique features, such as modularity, flexibility of use, silent and clean use, it has hardly any problems of public acceptance (even fewer than for other renewables, e.g. wind). Moreover, PV is geopolitically compatible. The sun is a "shared" primary energy resource throughout the world. Most developing countries have excellent potential for the direct use of solar energy. The majority of them have higher insulation than world average values and large areas (e.g. deserts) suitable for solar panels. Today, PV modules are produced almost entirely in industrialized countries, but in the future developing countries (particularly Asian countries) will be both major users and producers of PV.
Second, PV is very open to innovation and technical change. The key feature of PV is its extraordinary flexibility in terms of technological options for different PV devices, and in terms of the wide range of applications. In contrast with other energy technologies, PV involves not only utilities but also many other interested actors, from energy distribution companies, to architects, up to final users. PV is strongly oriented towards the delivery of energy services, particularly as far as applications in buildings are concerned. In fact, building integrated PV systems can also act as energy-saving systems (e.g. as sun-shading devices) and as small co-generation systems. Furthermore, PV in buildings has great synergy with other solar-active and solar-passive energy technologies, with energy-saving measures, and also with demand-side management.
Finally, PV is fully compatible with hydrogen energy technologies. The solar-hydrogen energy technology cycle is the most likely target for a sustainable energy system for the mid-twenty-first century. The cycle includes the direct use of solar energy, the electrolytic al production of hydrogen, the use of hydrogen as a chemical energy storage means and as an energy vector, and the eventual re-electrification of hydrogen by means of fuel cells. It is a fully clean cycle that uses electricity and hydrogen as energy vectors and that is capable of providing all energy services needed. The use of hydrogen as a means of energy storage is the final solution to the intermittent nature of the solar primary energy source, and virtually eliminates the ultimate technological limit of PV.
By 2050, PV is likely to supply about 10 per cent of world electricity demand. Most importantly, however, PV is open to a lot of other benign energy technology options. PV is consistent with all sustainable energy patterns and has no real long-term limits on its exploitation potential. It will therefore play a major role in the eco-restructuring transition and in the world energy system of the second half of the twenty-first century.