PV technology, trends & tropical common sense

BCA GMM

Christophe Inglin

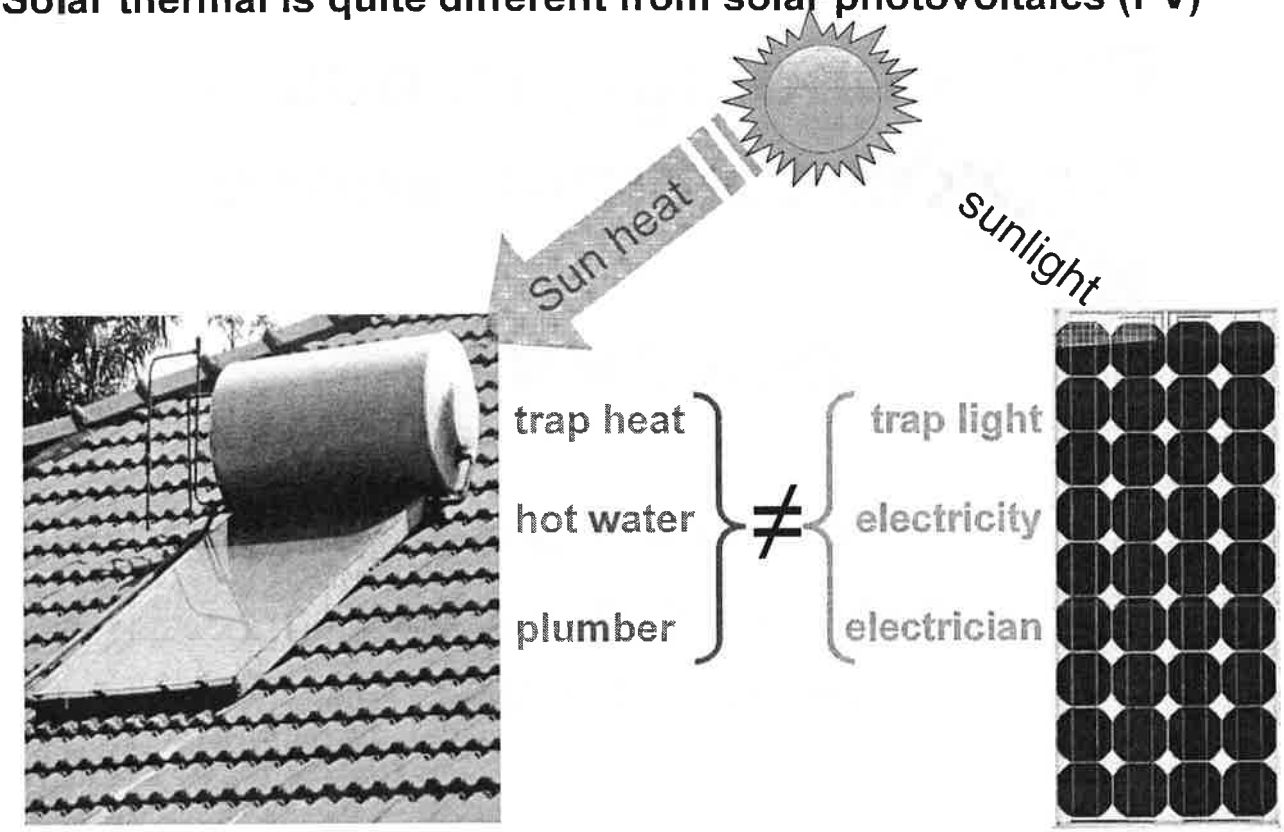
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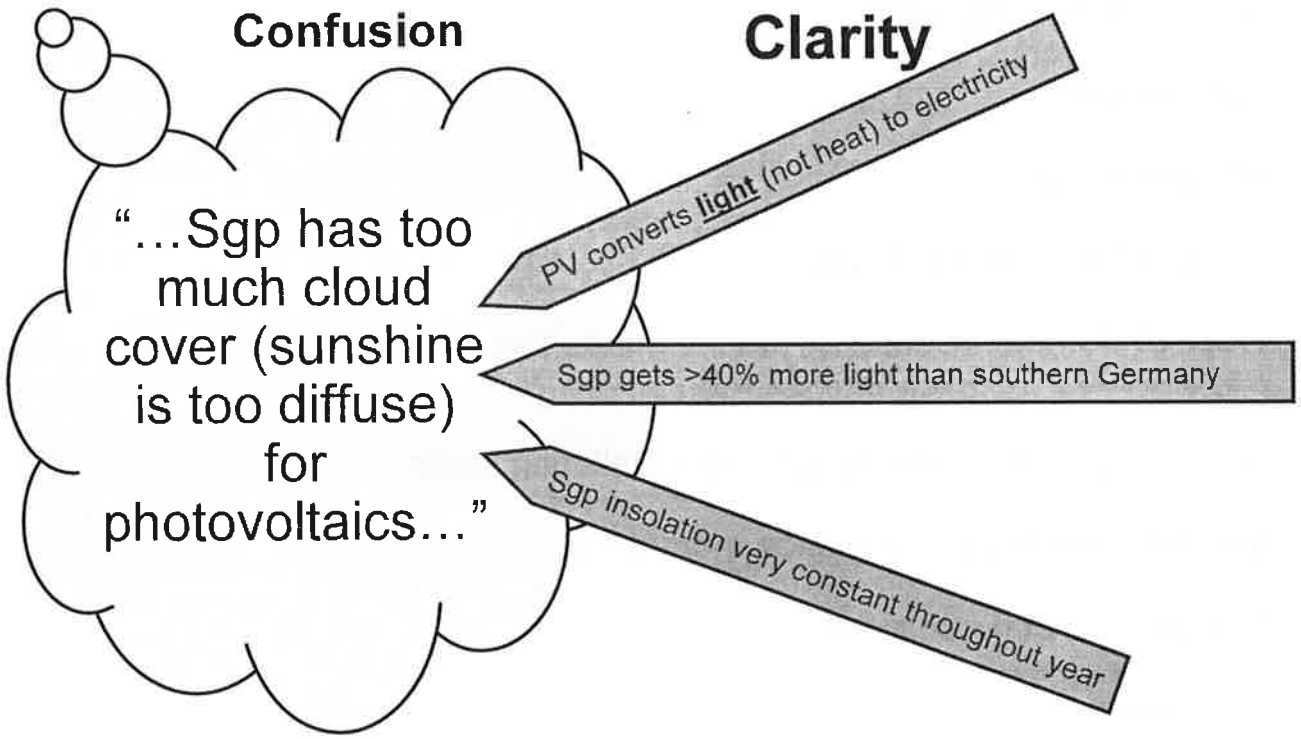
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- Energy yield and economics
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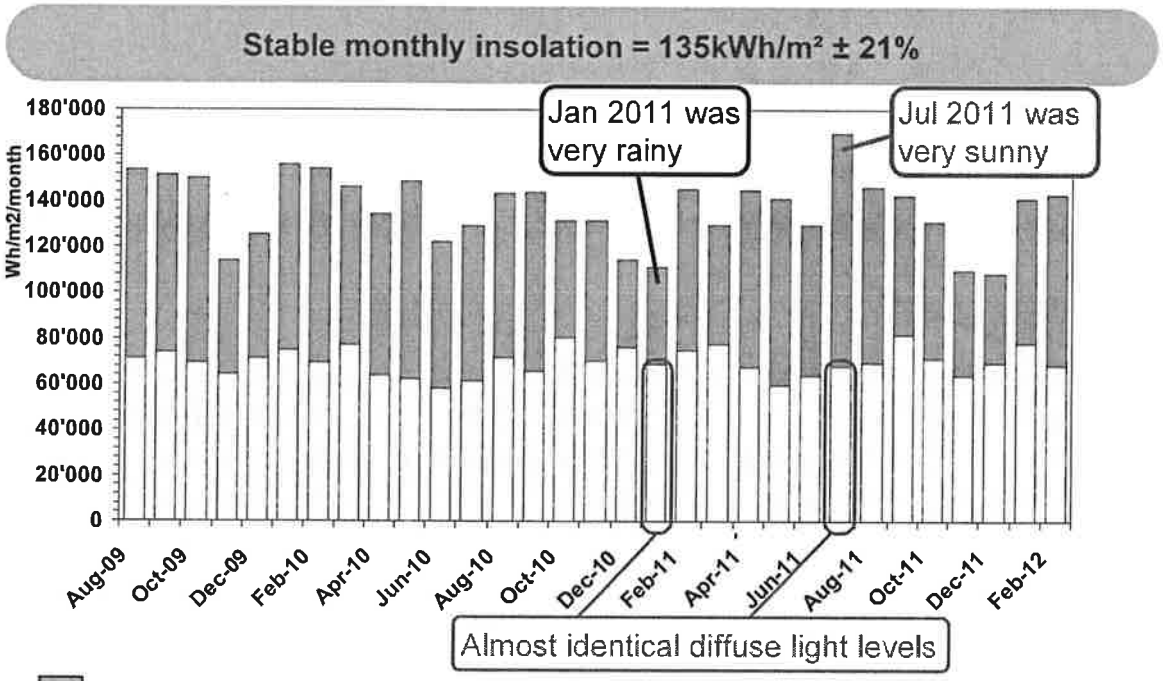
Solar thermal is quite different from solar photovoltaics (PV)



Do not allow misconceptions to cloud our judgement



Singapore gets more sunlight than most major cities

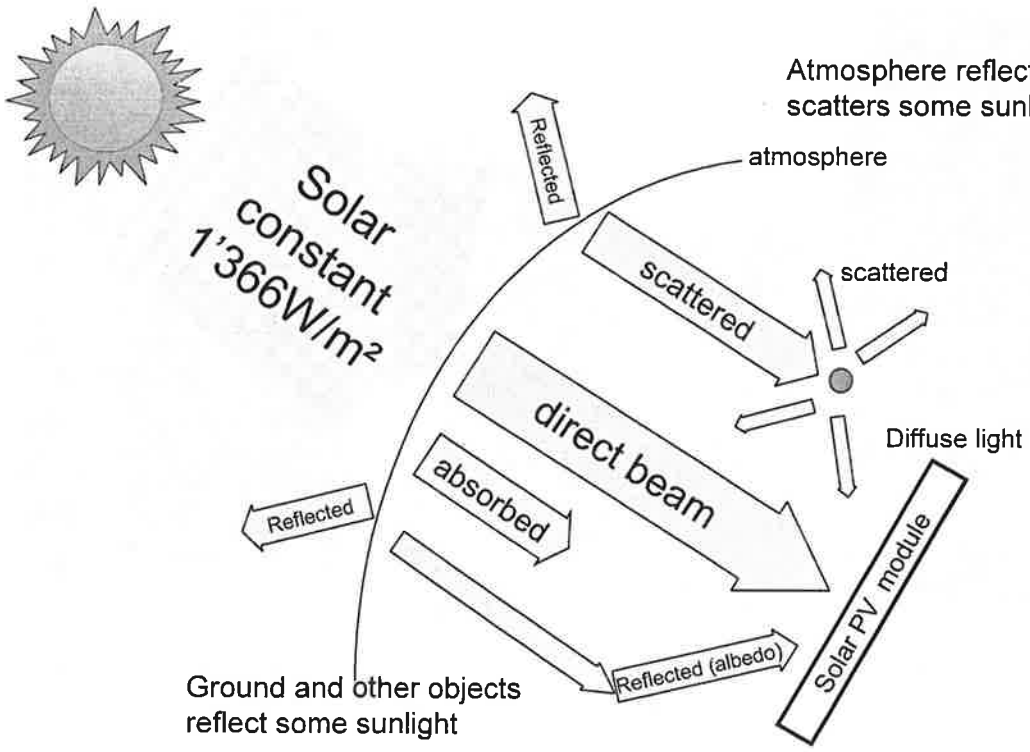


Direct insolation varies quite widely between dry and wet months

Diffuse light varies very little from month to month

Chart data: Phoenix Solar (from ZEH) = monthly isolation, measured in Siglap

PV modules convert direct, diffuse and reflected light



Many applications for Photovoltaics (PV)

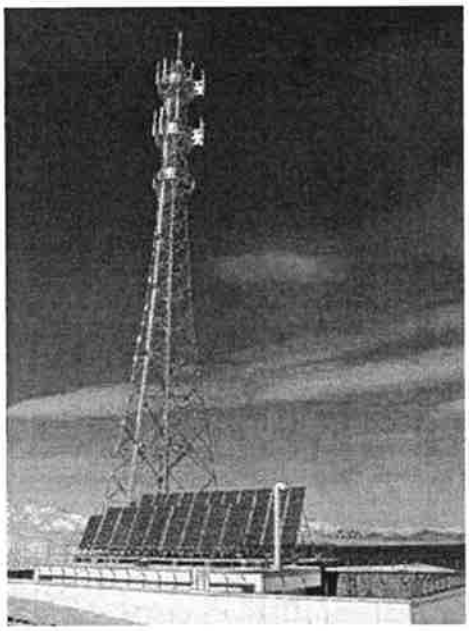
Off-grid

- **Industrial**
  - Telecoms
  - Traffic control
  - Oil & gas
- **Rural**
  - Habitation
  - Pumping
  - Street lights
- **Consumer**
  - Toys/gadgets
  - RVs

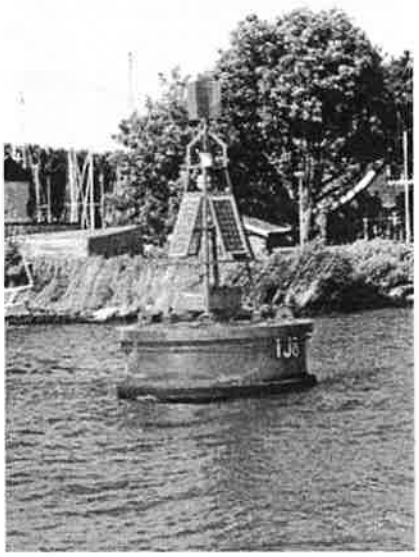
Grid-connected

- **On buildings**
  - Residential
  - Commercial
  - Industrial
  - BIPV
- **Power plant**

PV already a key enabler of commercial infrastructure



Telecoms repeater station, China

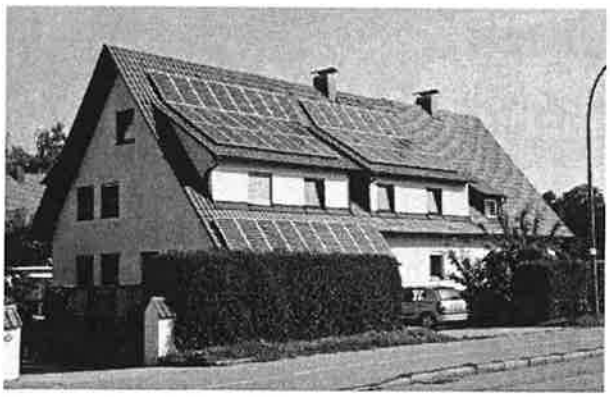


Navigation warning light, Netherlands



Parking sign, S'pore

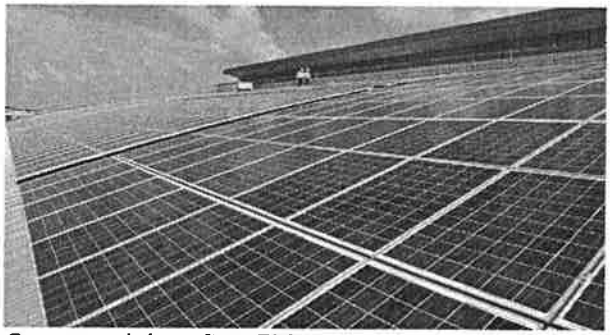
Grid-connected PV markets are driving global growth



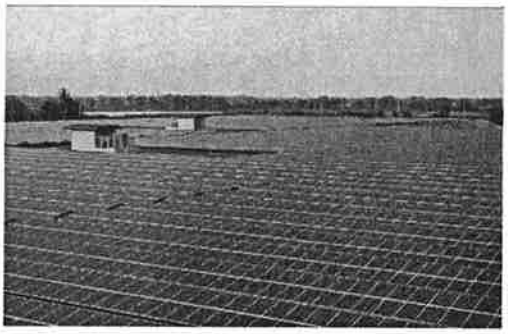
Residential rooftop PV system, Germany



Residential rooftop systems, Japan

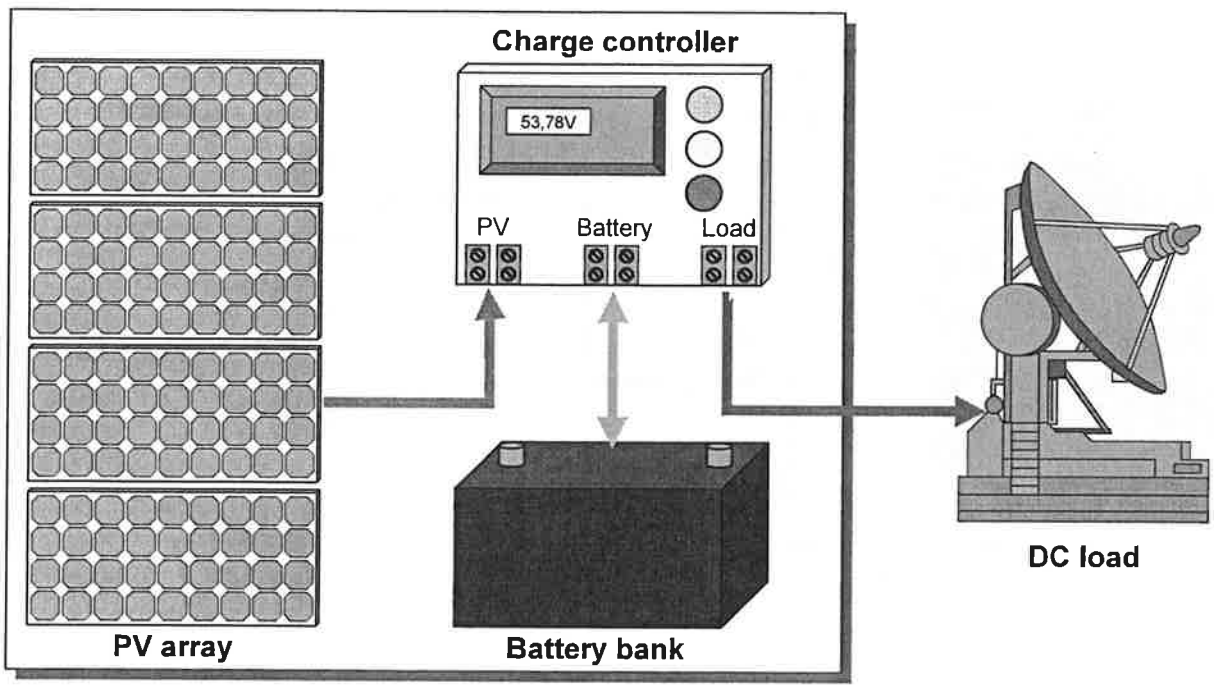


Commercial rooftop PV system, Singapore

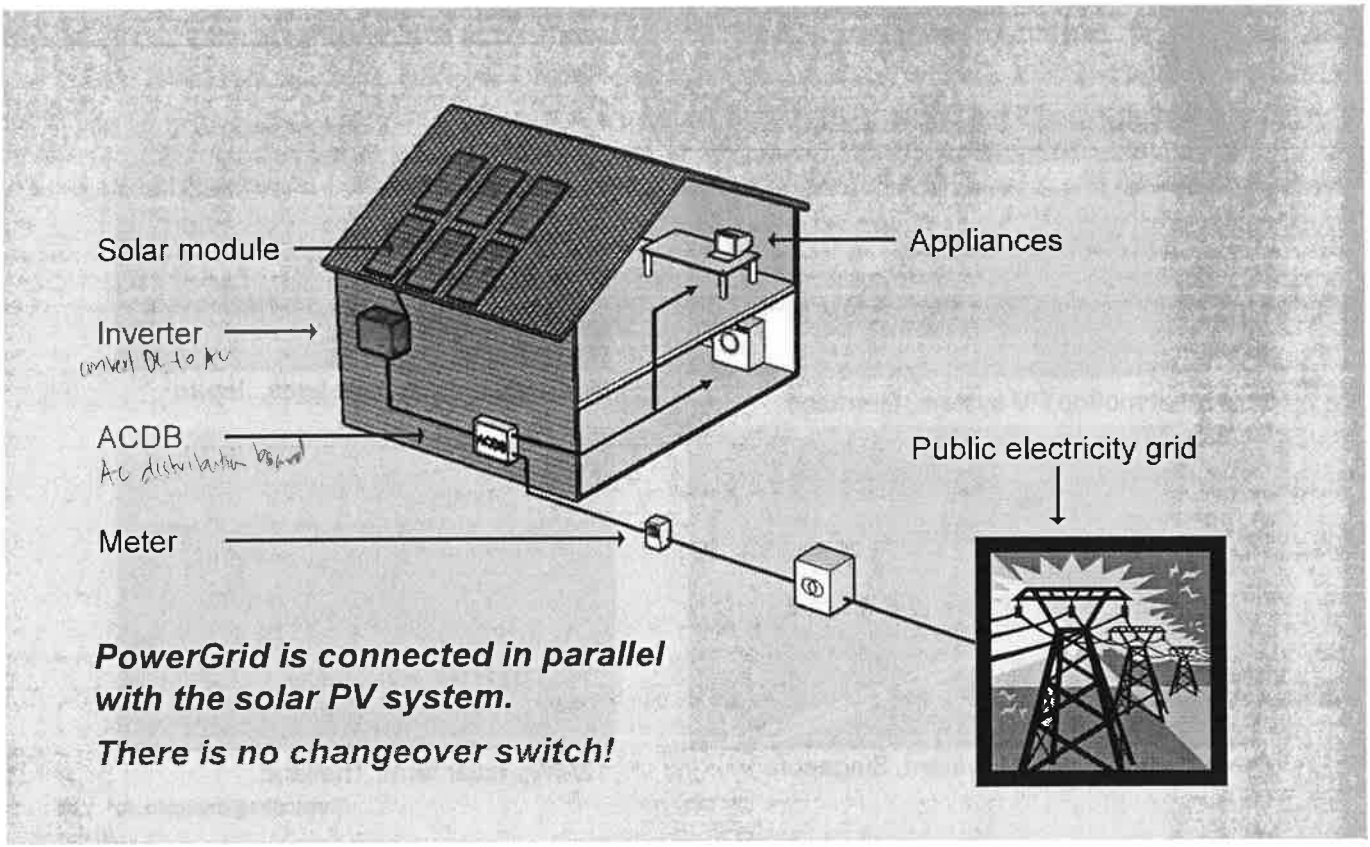


12MWp solar farm, Thailand

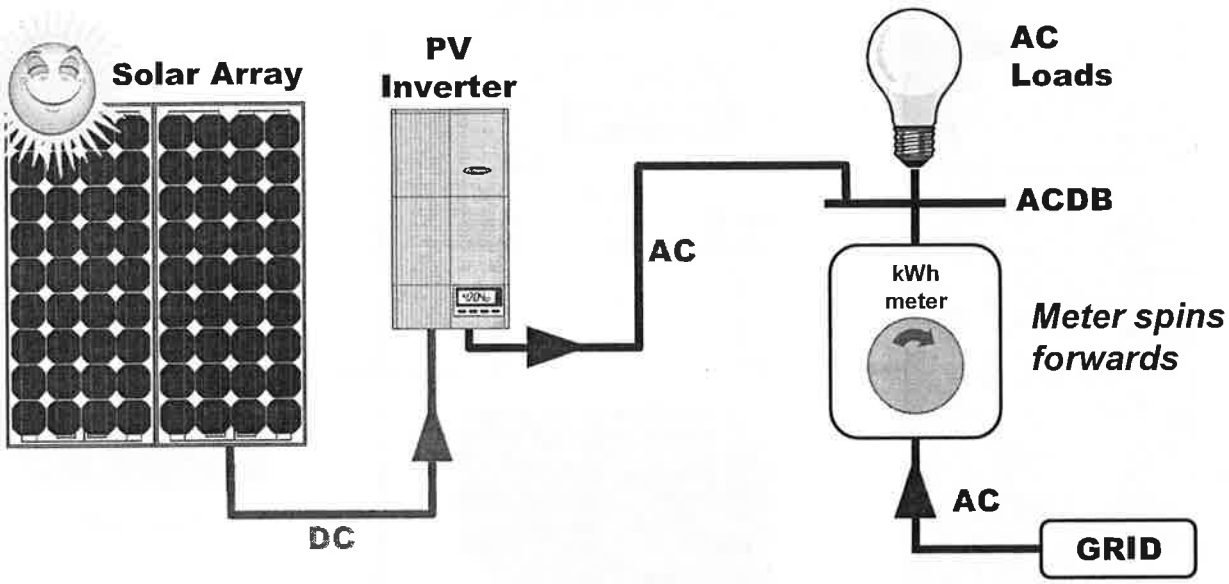
Off-grid system configuration - PV charges battery



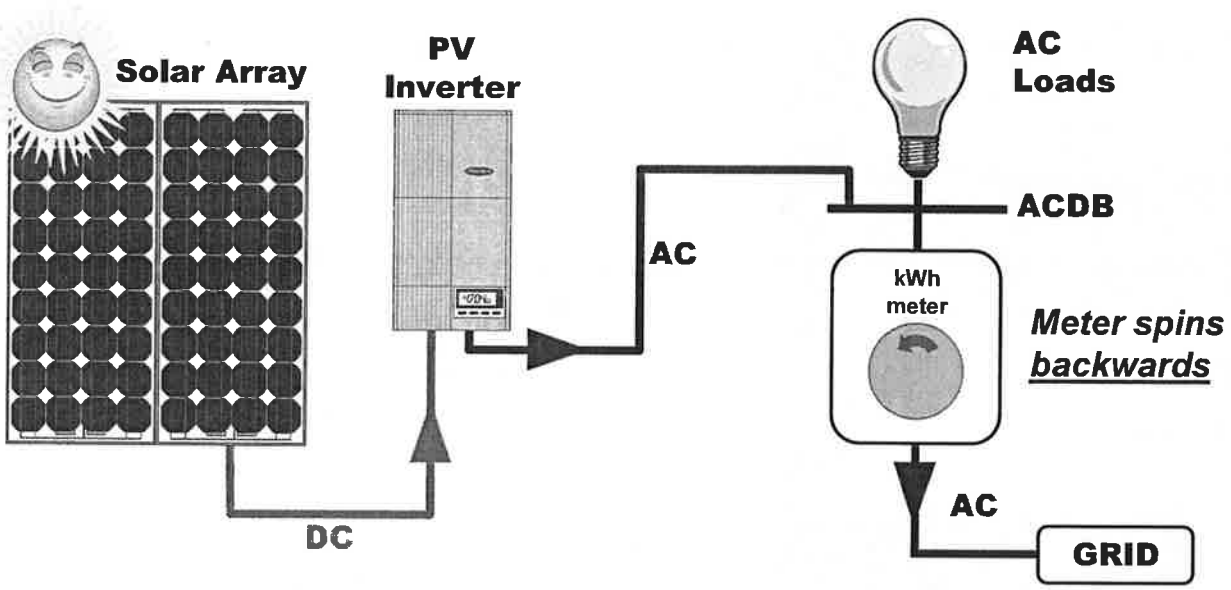
Grid-tied system configuration – no batteries!



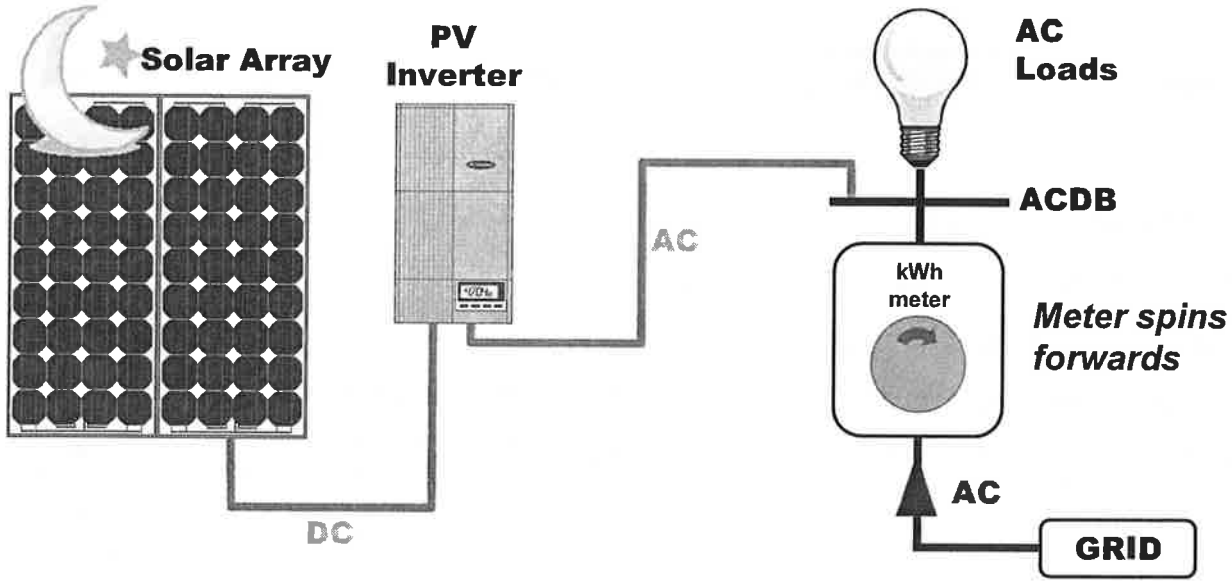
Daytime, PV + grid jointly supply the load



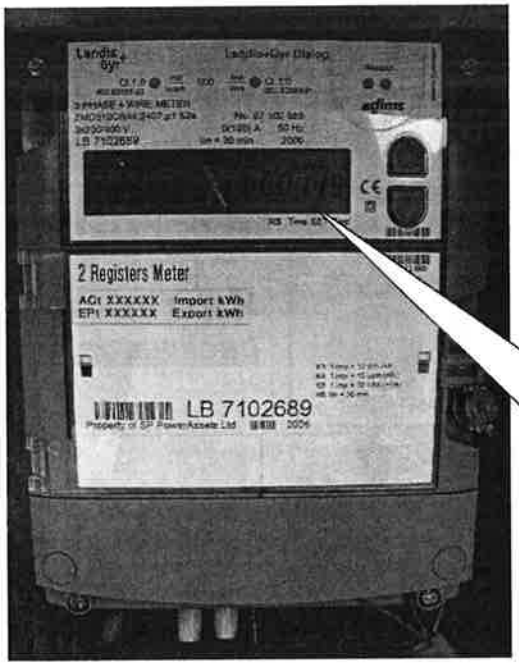
Daytime (load switched off) - PV feeds into PowerGrid



Night-time, load powered by grid only



Retail consumers get paid for energy they export



New meter has two registers:

1. Import kWh (from PowerGrid to bldg)
   - Pay normal retail tariff
2. Export kWh (excess PV electricity from bldg to PowerGrid)
   - Earn retail tariff minus grid charges (currently SGD0.0505/kWh)

Display alternates between import & export registers

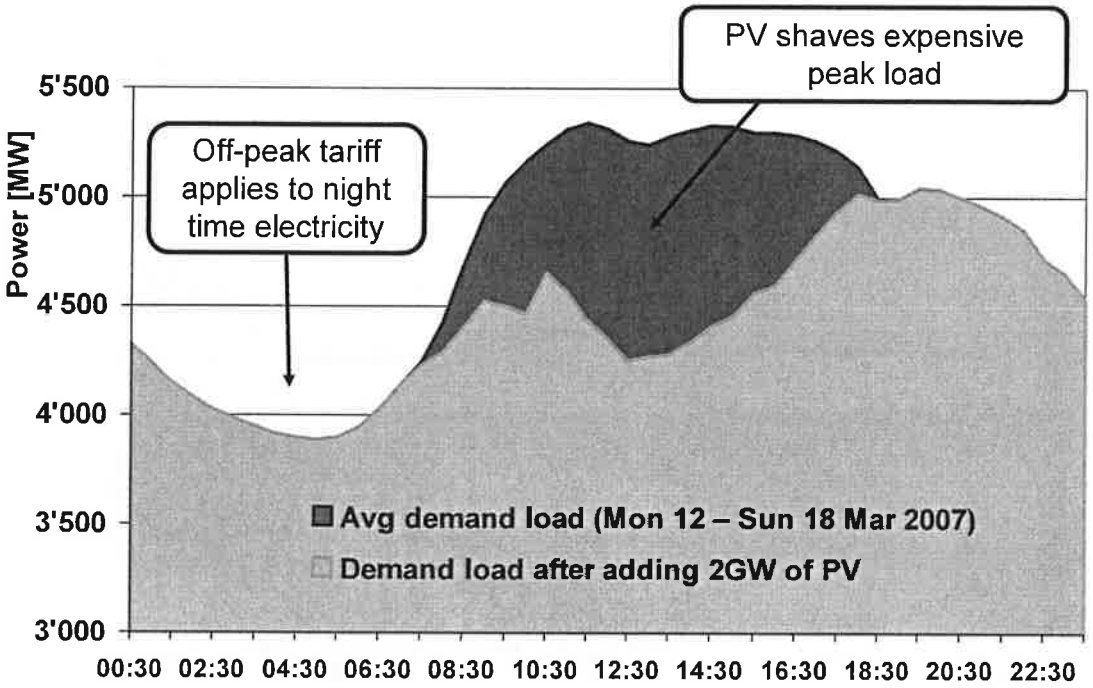
SP Services bill credits surplus electricity fed to grid

ZEH utility Bill 24 July – 20 August 2008

CURRENT MONTH CHARGES	Usage	Rate ($)	Amount ($)	Total ($)
Electricity Services				
Reading taken on 20-08-2008 : 1566				
Reading taken on 20-08-2008 : 908				
Import of elect for PV meters	358 kWh	0.2507	89.75	
Export of elect for PV meters	690 kWh	0.1972	-136.07	**-46.32**

Negative figure is offset against garbage and water fees

Better to shave peak load than charge up batteries



More valuable to offset daytime peak load than night time off-peak load

Demand load data from EMA (Singapore)

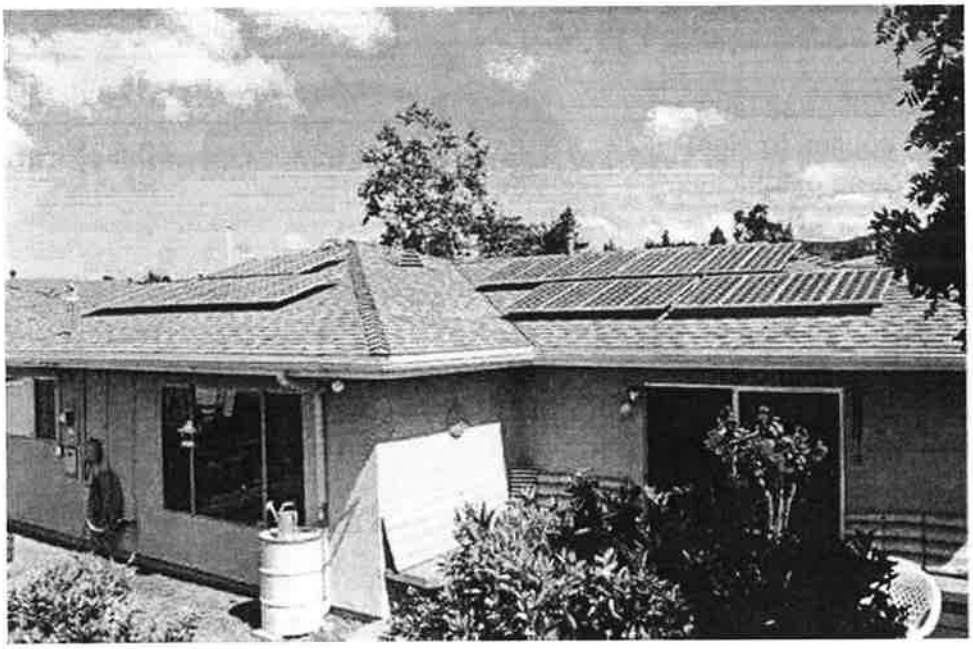
Better to sell surplus to SP Services than to store it*

Transaction	Value calculation	Value of electricity [SGDc/kWh]
Consume PV electricity in-house, to offset retail tariff + GST*	23.29 x 1.07 tariff x GST	24.92
Sell surplus PV electricity to SP Services, to earn retail tariff minus grid charges (no GST*)	23.29 – 5.05 no GST	18.24
Store daytime surplus in a battery, to use at night and offset night time retail tariff + GST*. … *But battery charge/discharge cycle loses 20-30% of energy*	23.29 x 1.07 x 70-80%	17.44 - 19.94 … … *minus depreciation expense on battery!*

… but for EV owners, better to charge car battery than export surplus to grid!

* Figures apply to non-contestable customers who are not GST-registered (eg residential & small commercial)
Retail electricity tariff for Q1/2015 = SGD0.2329/kWh

Retrofit rooftop modules do not really enhance the aesthetics…



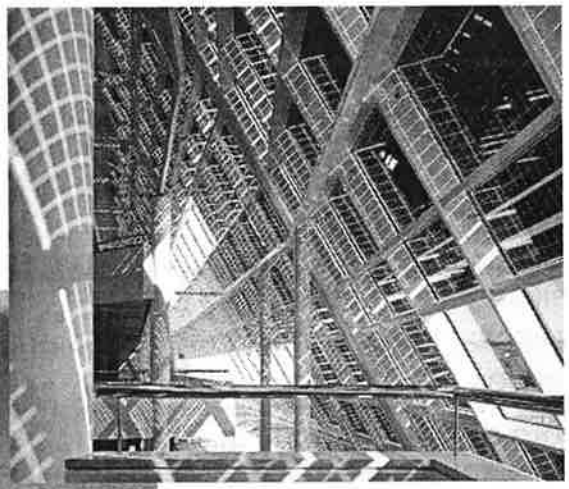
PV system on a California residential rooftop, ca 1998

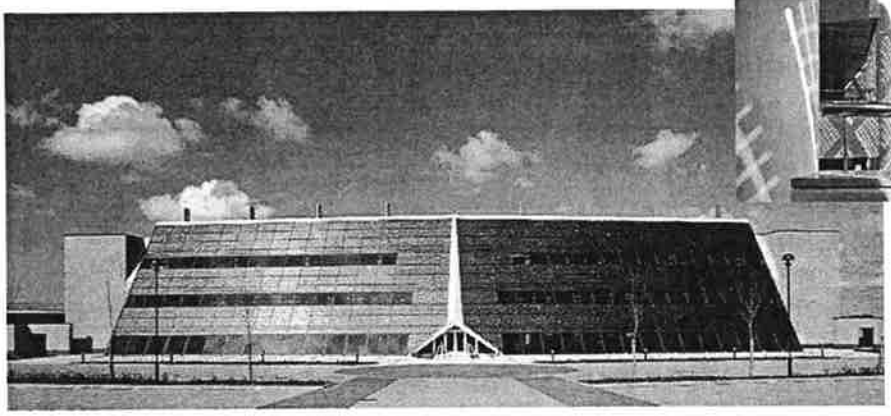
True BIPV makes a strong architectural statement

Dramatic façade and lively light play at the Solar Office Doxford International, UK.

Awards:

Eurosolar Award 1999
Design Council Millennium Product Award 1999
Energy Globe Award 2000





Client: Akeler
Architects: Studio E Architects
Main contractor: Bowmer & Kirkland

Images downloaded from IEA PVPS
website: www.iea-pvps.org/cases/gbr_02.htm
Photos © Dennis Gilbert

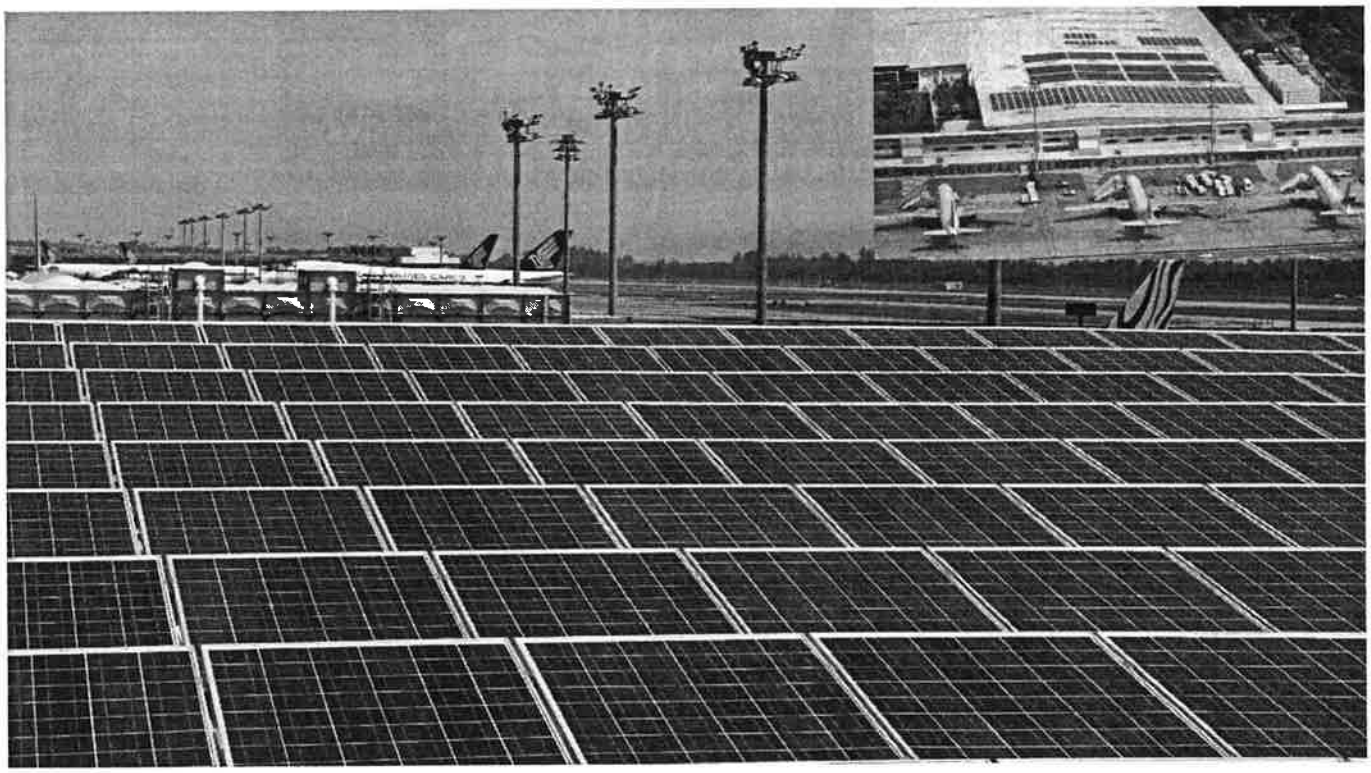
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Case studies in Singapore

1. Crystalline silicon technology
2. Rigid thin film technology
3. Flexible thin film technology
4. BIPV – customised crystalline silicon technology

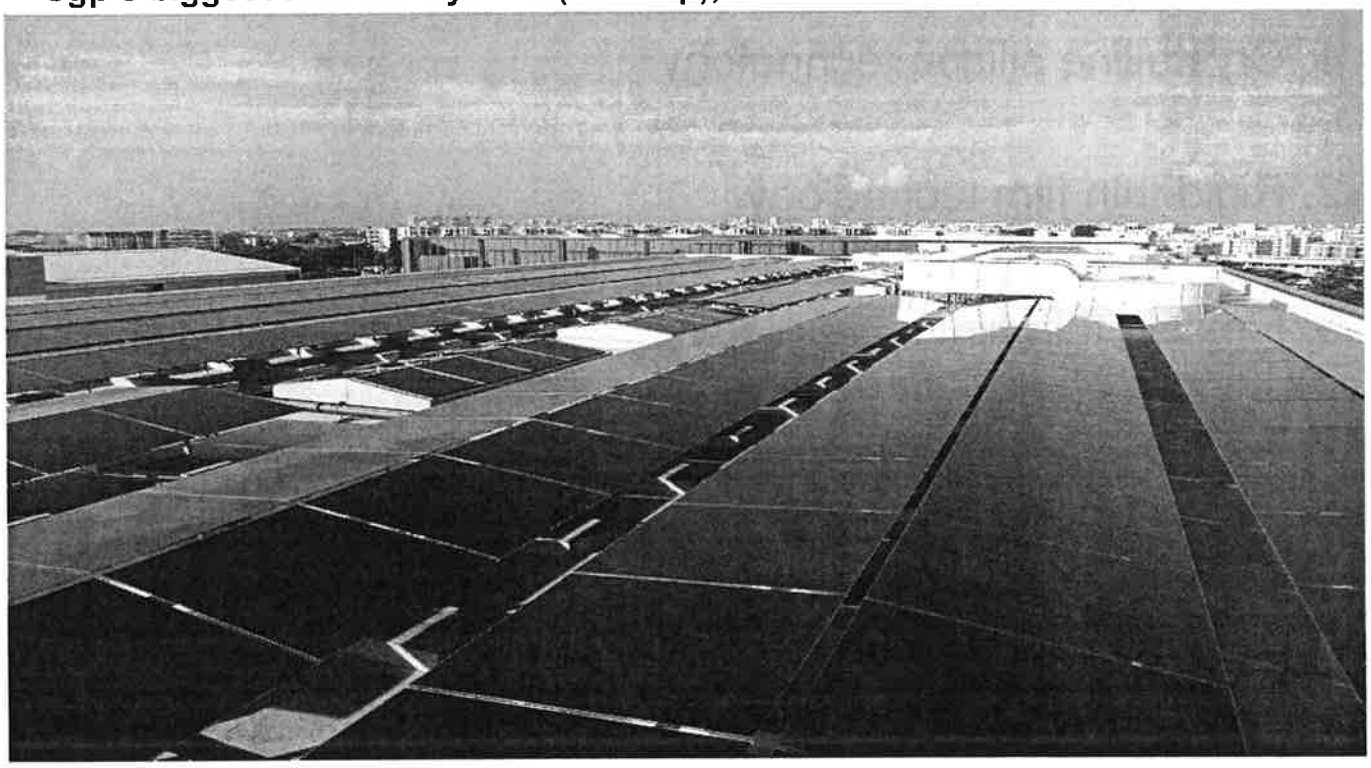
Changi is SE Asia's first commercial airport with PV power plant



ASEAN Energy Award 2011 winner (1st runner up, on-grid category)

Tandem a-Si/µ-Si thin film in 5.7m² format

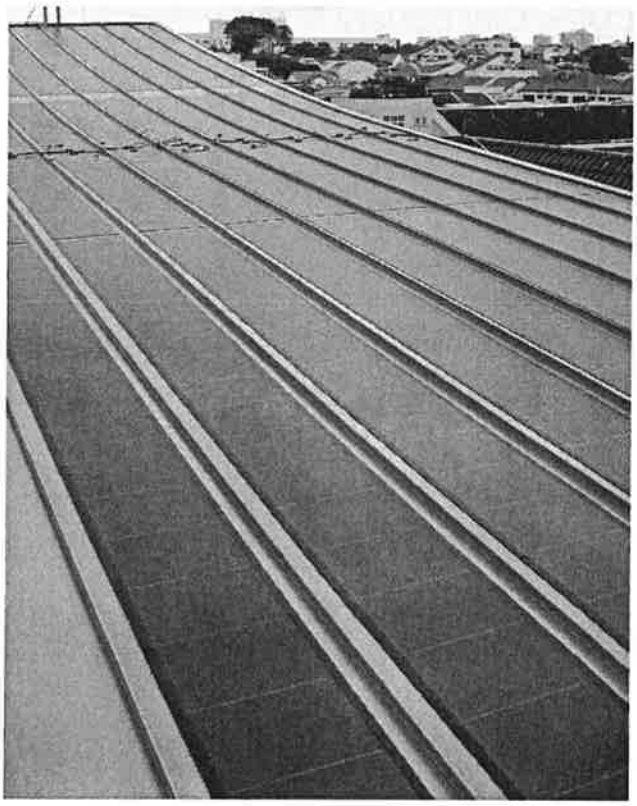
Sgp's biggest thin film system (385kWp), Solar Pioneer Award & GM Platinum



Lightweight, flexible thin film laminates on metal roofs







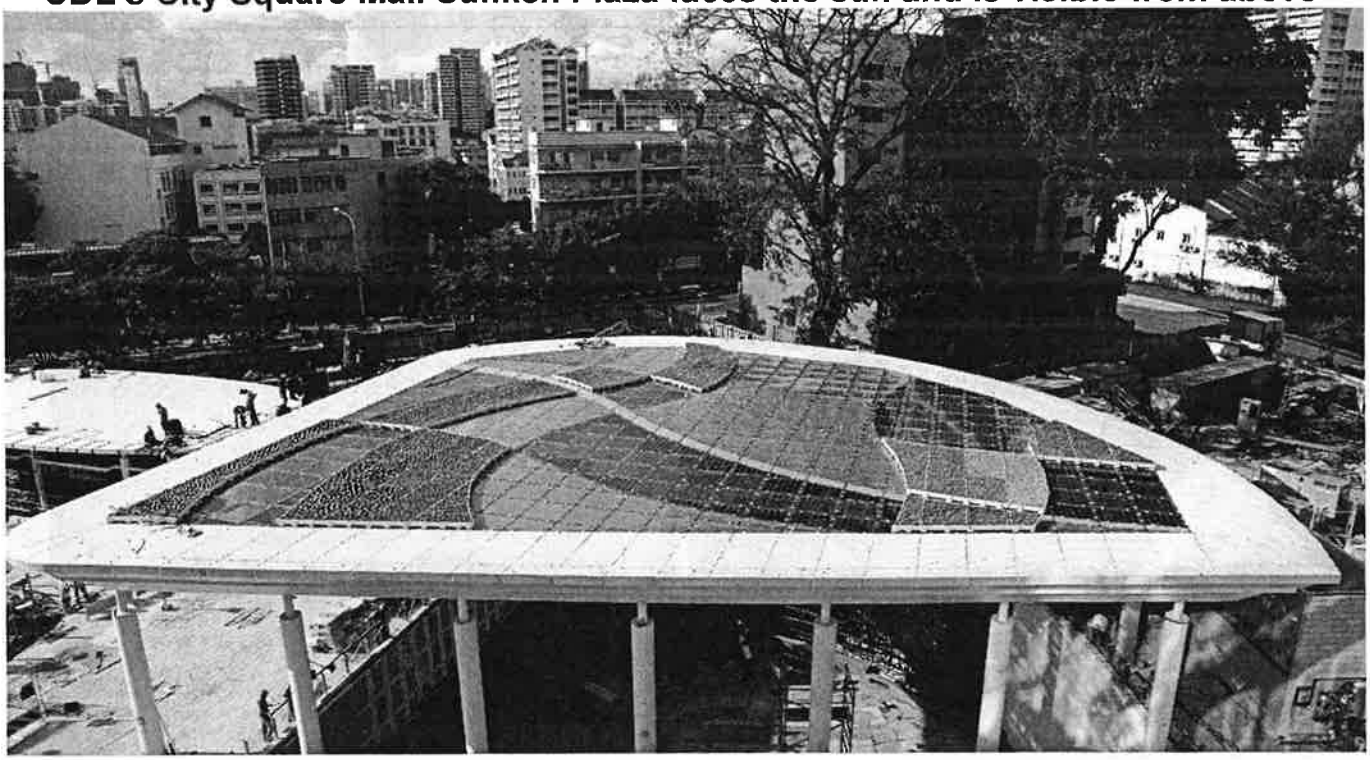
Key criteria for Uni-Solar systems – roof material



- Roof slope min 3°, max 60°
- Roofing pan with flat surface (without pencil beads or decorative stippling)
- Min pan width 406mm (16")
- PVDF Coated (Galvalume® or Zincalume®) steel metal
- New or qualified new roof installations
- Installation by certified installers only

Semi-transparent crystalline silicon canopy

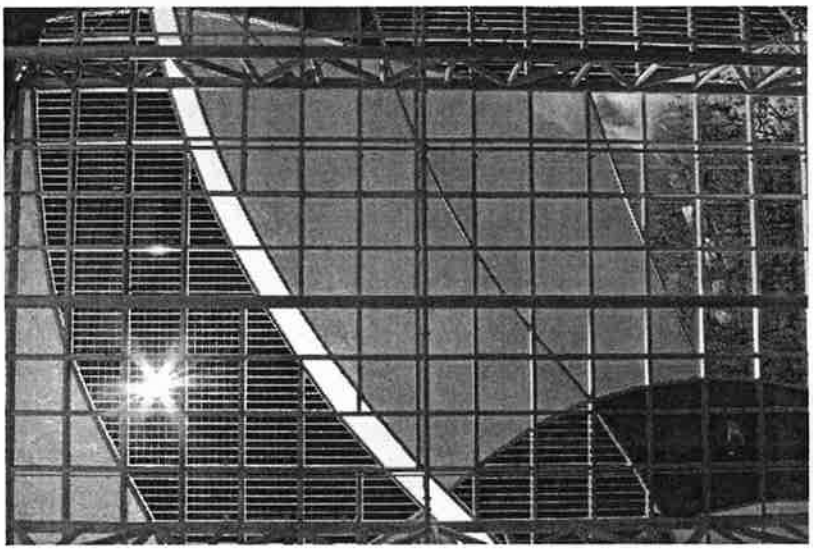
CDL's City Square Mall Sunken Plaza faces the sun and is visible from above



Semi-transparent crystalline silicon canopy

Also visible from below, ie Farrer Park MRT entrance (GM Platinum)





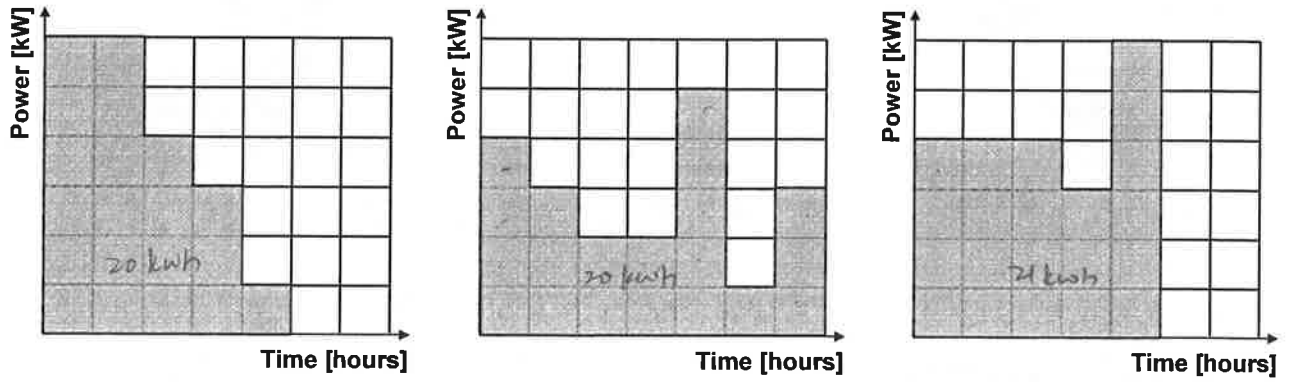
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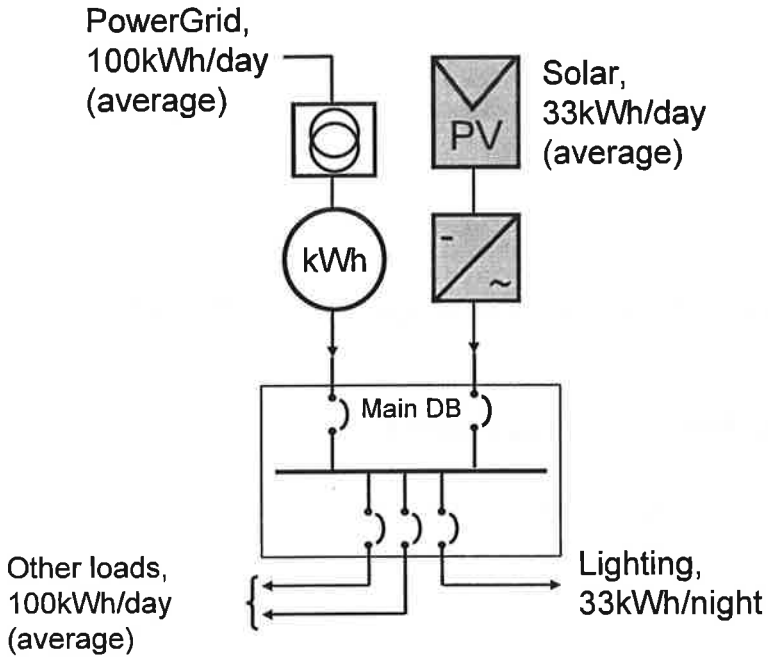
Energy = power x time (*never forget this!*)

- Energy is work, while power is the rate at which work is done
- Energy is measured in Joules (J), or calories (4.18J = 1 calorie)
- Power is measured in Watts (W)
- One Watt = "spending" 1 Joule per second
  - Conversely, to get 1 Joule, you must maintain 1 Watt for 1 second = 1Watt-second

1. One kWh = 1'000Wh = 3'600'000Ws = 3.6MJ
2. 3.6MJ = 860kilocalories = 150g chocolate, or 330g ice cream, or 660g rice…
3. Human muscles are only around 25% efficient



Matching input with output – keep it simple!



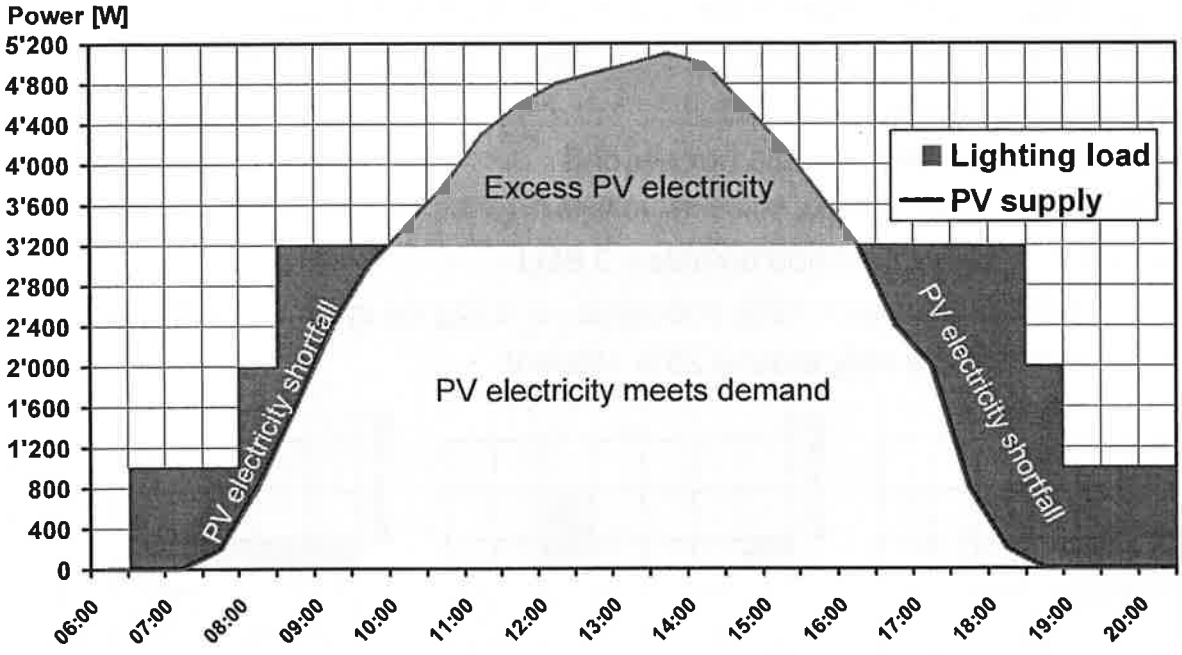
Consider a PV "bank account"

Pay kWh into the account during the day.

Withdraw kWh for night time lighting.

Just feed the PV energy directly into the ACDB, without batteries!

Sizing PV system to meet a specific load



Shop's lighting load = 39kWh per day, or 12'000kWh/yr (assume 6 days/wk)

Needs PV system size of 12'000kWh/yr ÷ 1'200kWh/kWp/yr = 10kWp

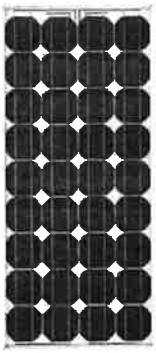
Summarising the key terminology

W	Watts - instantaneous **power** generated when PV module is exposed to light (W varies with light intensity).
Wp	Watts peak - rated **power capacity** of a module or array under Standard Test Conditions (ie in a lab). PV modules and systems are priced by the Wp.
kWp	Rated **power capacity** of an array or system under STC (1kWp = 1'000Wp).
kWh/yr	Annual Yield - **energy** generated by PV system in 1 year (remember, Energy = Power x Time).
kWh/kWp/yr	Specific Yield - in Singapore, a decent PV system generates at least 1'200kWh of **energy** per year for every kWp of capacity
STC	Standard Test Conditions for measuring module capacity in a laboratory (1'000W/m² irradiation, 25ºC cell temp and spectrum from air mass = 1.5)

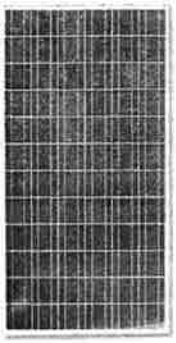
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PV building blocks – crystalline and thin film modules



Mono-Si



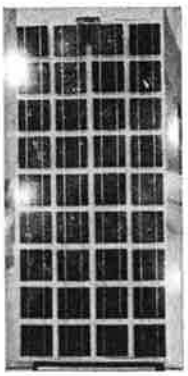
Multi-Si

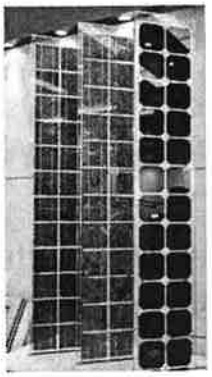


CIGS thin film



semi-transparent a-Si thin film for BIPV



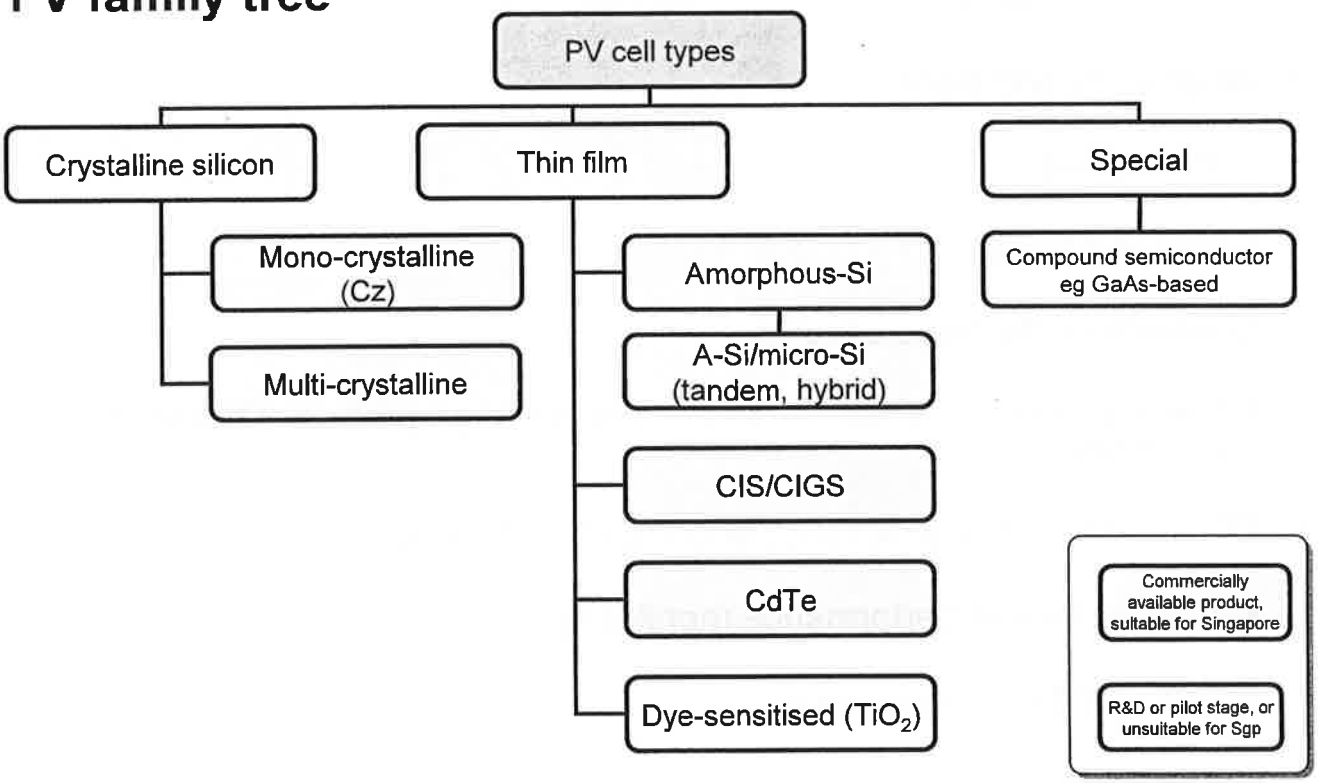


BIPV with crystalline cells



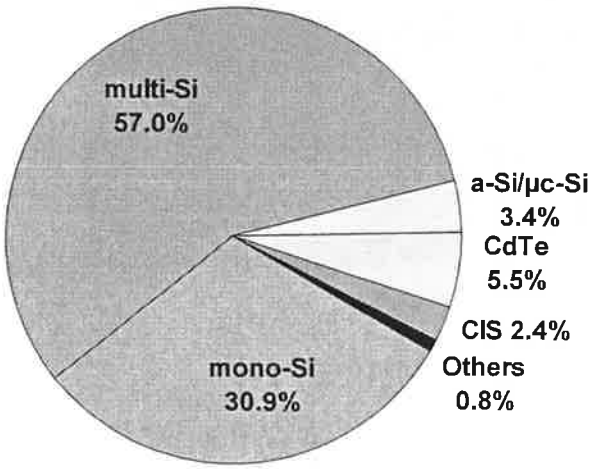
Flexible a-Si thin-film

PV family tree



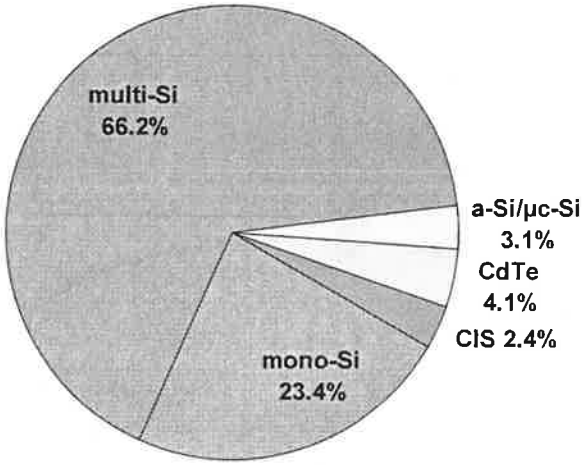
PV technology shares dominated by crystalline Si

2011: c-Si = 88%



Data: Photon International (2012/03)

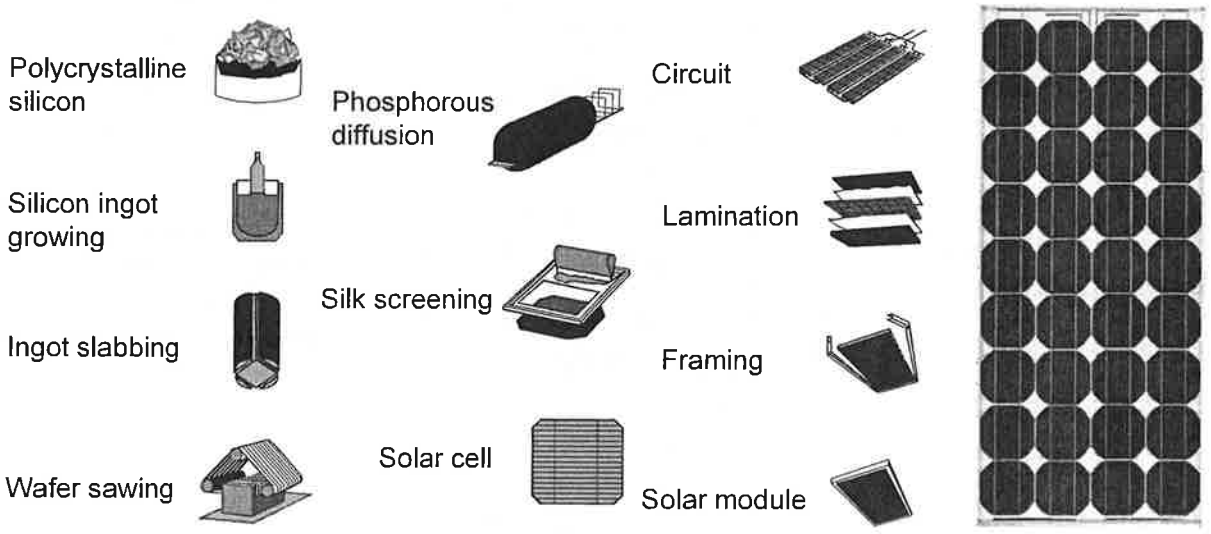
2013: c-Si = 90%



Data: GTM Research (2014/04)

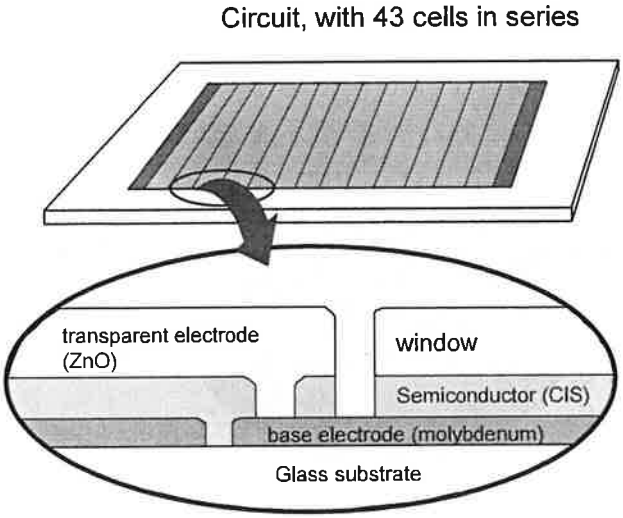
Crystalline PV uses same raw materials as semicon industry

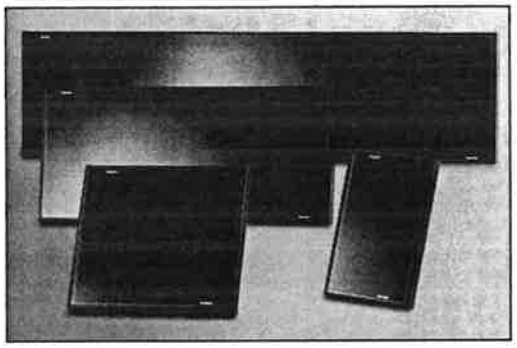
Each cell is a light-sensitive diode - ca 0.5V. Put cells is series to make a module.



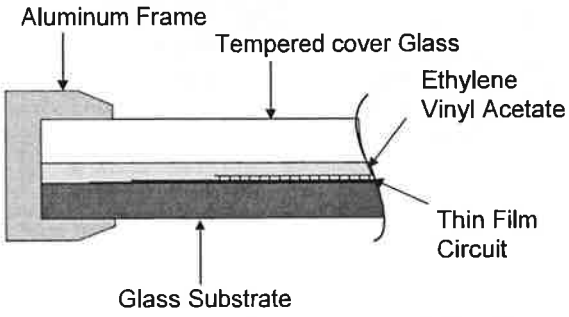
Thin film technology uses a fraction of the active material

Thin film CIS/CIGS structure





Module



Many factors affect performance (cost per kWh)

Scope to improve both numerator and denominator in each equation:

Module technology

Cost per unit area ($/m²)

Efficiency (kWp/m²)

Module technology
- **Temperature coefficient**
- **Low-light performance**
- **Shading tolerance**
- **Tolerance (mismatch loss)**

Cost per unit of capacity ($/kWp)

Output per unit of capacity (kWh/kWp)

System design
- **Structures**
- **Installation cost**
- **Reliability (O&M cost)**

System design
- **Array Orientation**
- **Cabling losses**
- **Inverter efficiency**

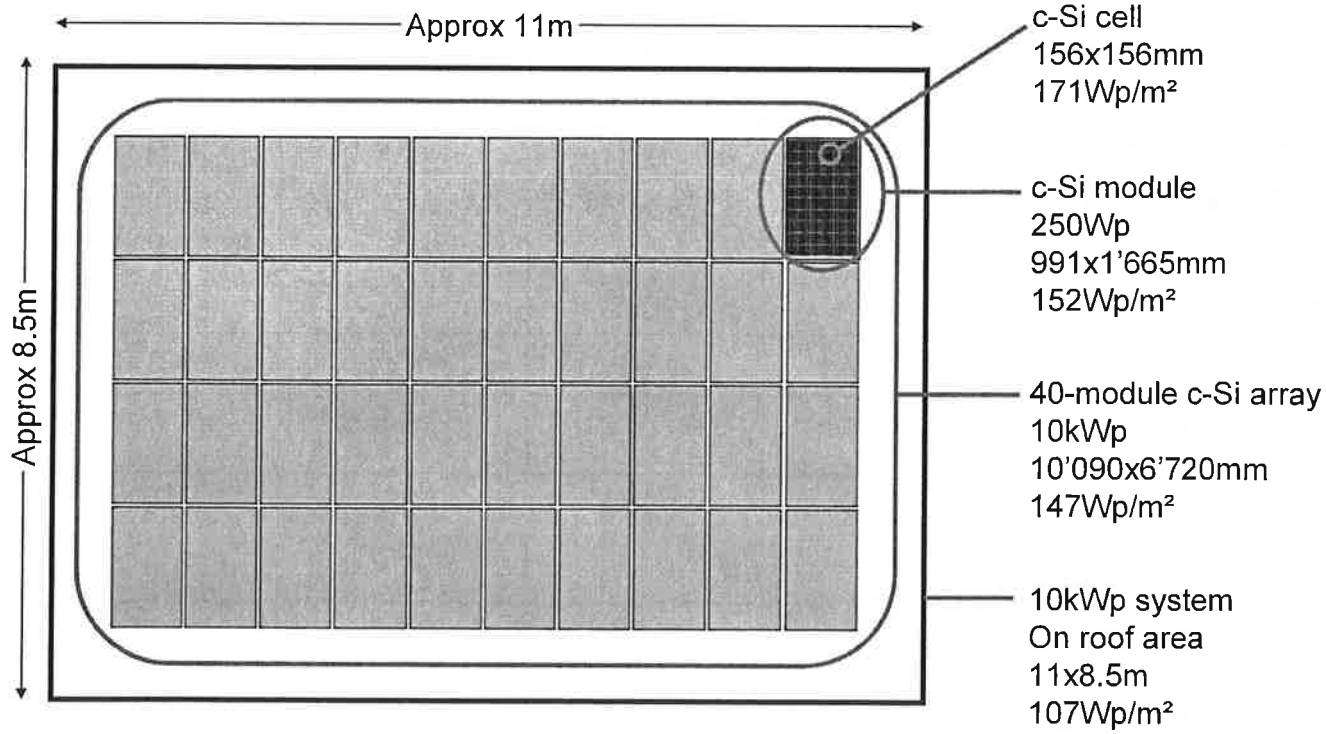
Cost per unit of energy ($/kWh)

Efficiencies vary by technology, and are increasing

- Module efficiency is:
  $$\frac{\text{rated output/module area}}{1'000 W/m^2}$$
- Eg: module rated 250Wp
  dimensions = 1'665x991mm
  area = 1.65m²
  Efficiency = 250/1.65/1'000
  = 0.1515
  = 15.2%
- Depends on cell efficiency, shape, spacing between cells and margin to module frame

Typical commercially-produced cell & module efficiencies		
Technology	**Cell η**	**Module η**
Mono-Si (most) SunPower	16-20% 20-24%	14-18% 16-21%
Multi-Si	15-18%	13-16%
CdTe	-	12-15%
CIGS/CIS	-	12-14%
a-Si on μ-Si	-	8-10%
a-Si	-	5-8%

Estimating roof coverage with crystalline modules

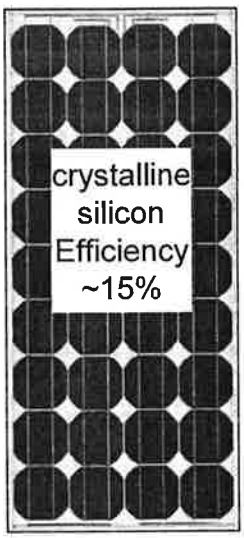


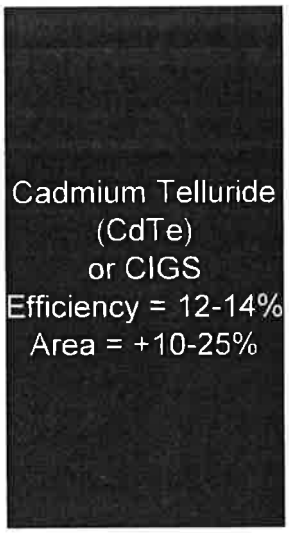
System energy yield in Sgp: 10kWp x 1'200-1'300kWh/kWp/yr
= 12'000-13'000kWh/yr (approx SGD2'900 @ SGD0.2329/kWh tariff)

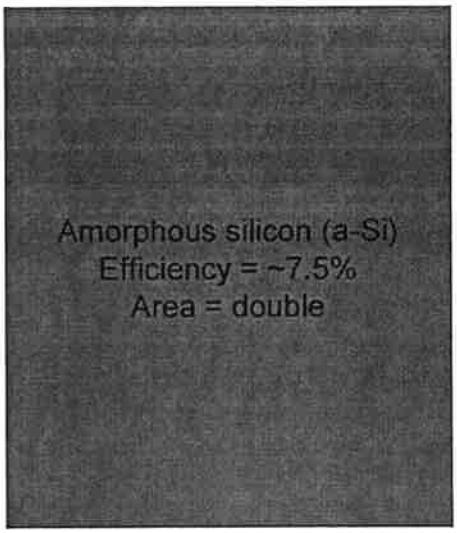
Thin film takes more area per kWp than crystalline technology

Unlike fossil fuel, sunshine is free, so efficiency is less relevant than capex!

Bigger area means slightly higher cost of structures and cabling …







… but thin film modules compensate with lower price per kWp

Module parameters for worked examples

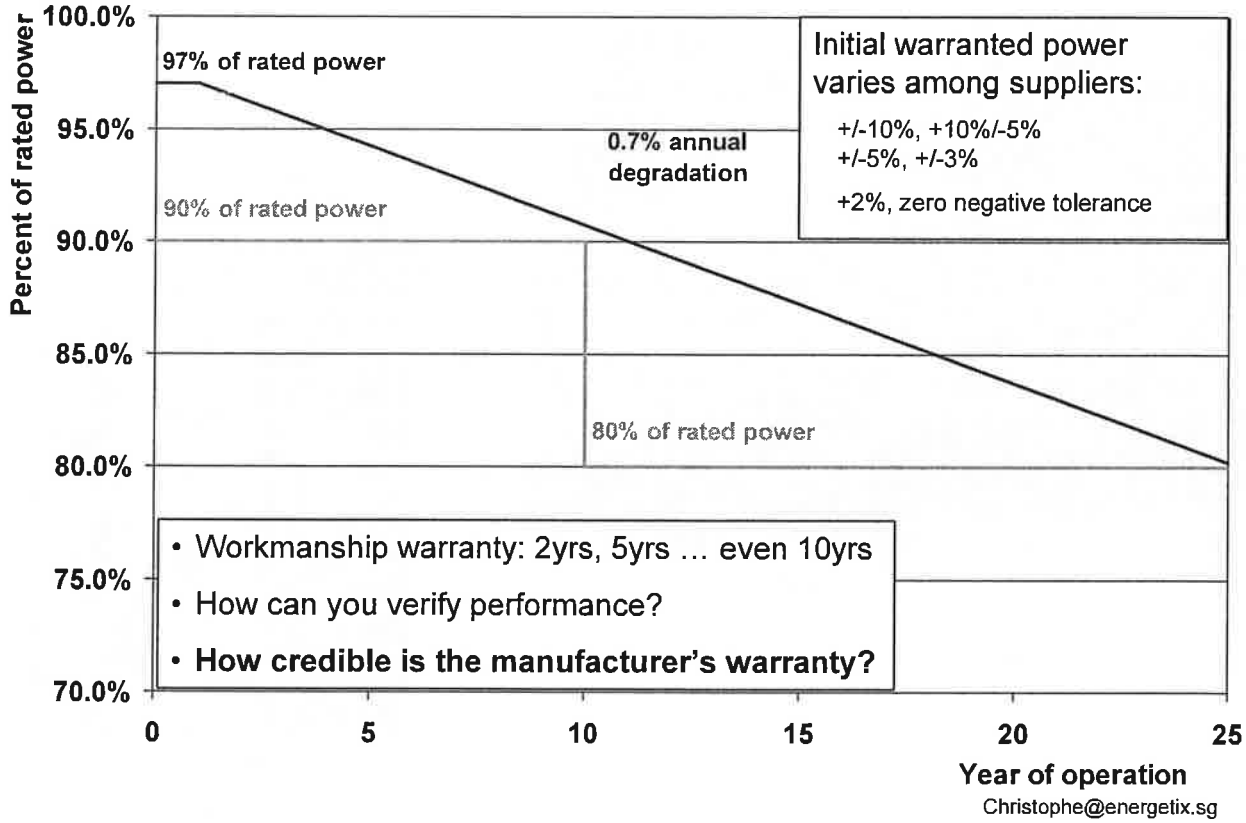
Technology	c-Si	a-Si	a-Si/μSi	CIGS
Rated power [Wp]	260	100	160	140
Dimensions [mm]	1'650 x 1'000	1'414 x 1'114	1'412 x 1'112	1'650 x 650 (frameless)
Weight [kg]	18	20.5	19.5	15
Module efficiency	15.8%	6.3%	10.2%	13.0%
Typical coverage	~100Wp/m²	~40Wp/m²	~65Wp/m²	~80Wp/m²
Energy yield [kWh/kWp/yr]	1'250	1'400	1'350	1'350
System cost [S$/Wp] (for ~100kWp)	3.00	3.50	3.30	3.20

Worked example for a 6-storey commercial bldg

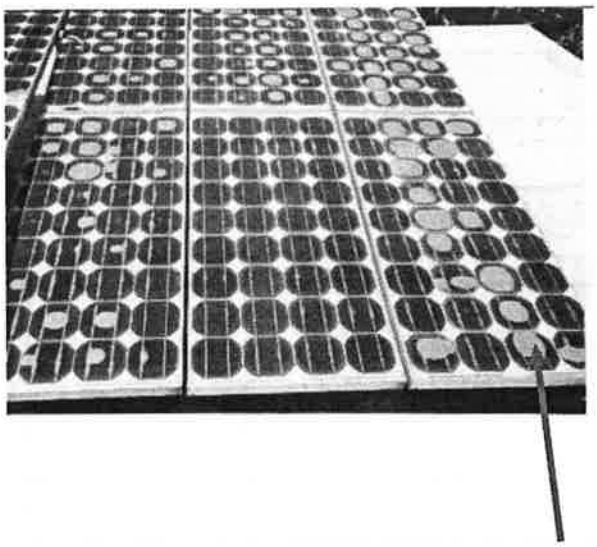
Available unobstructed roof space		1'000m²		
GFA		24'000m²		
Designed electricity consumption		150kWh/m²		
Aim to generate 3% of building's electricity with PV (3%x24'000x150 =108'000kWh/yr)				
Option with crystalline silicon	1250 kwh/kwp	87 kwp	100 w/m²	870 m²
Option with a-Si	1400 kwh/kwp	77 kwp	40 w/m²	1925 m²
Option with tandem a-Si/µ-Si	1350 kwh/kwp	80 kwp	65 w/m²	1230 m²
Option with CIGS	1350 kwh/kwp	80 kwp	80 w/m²	1000 m²

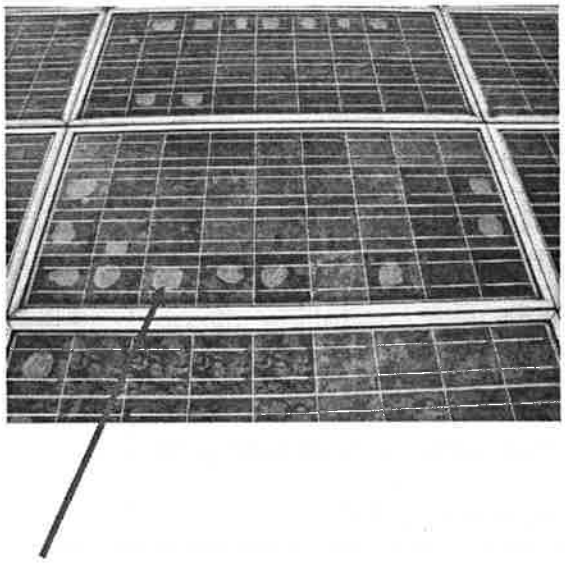
How many kWp required for each technology?
What is the ROI for each technology?

Comparing manufacturer's limited power warranty



Module delamination is very rare

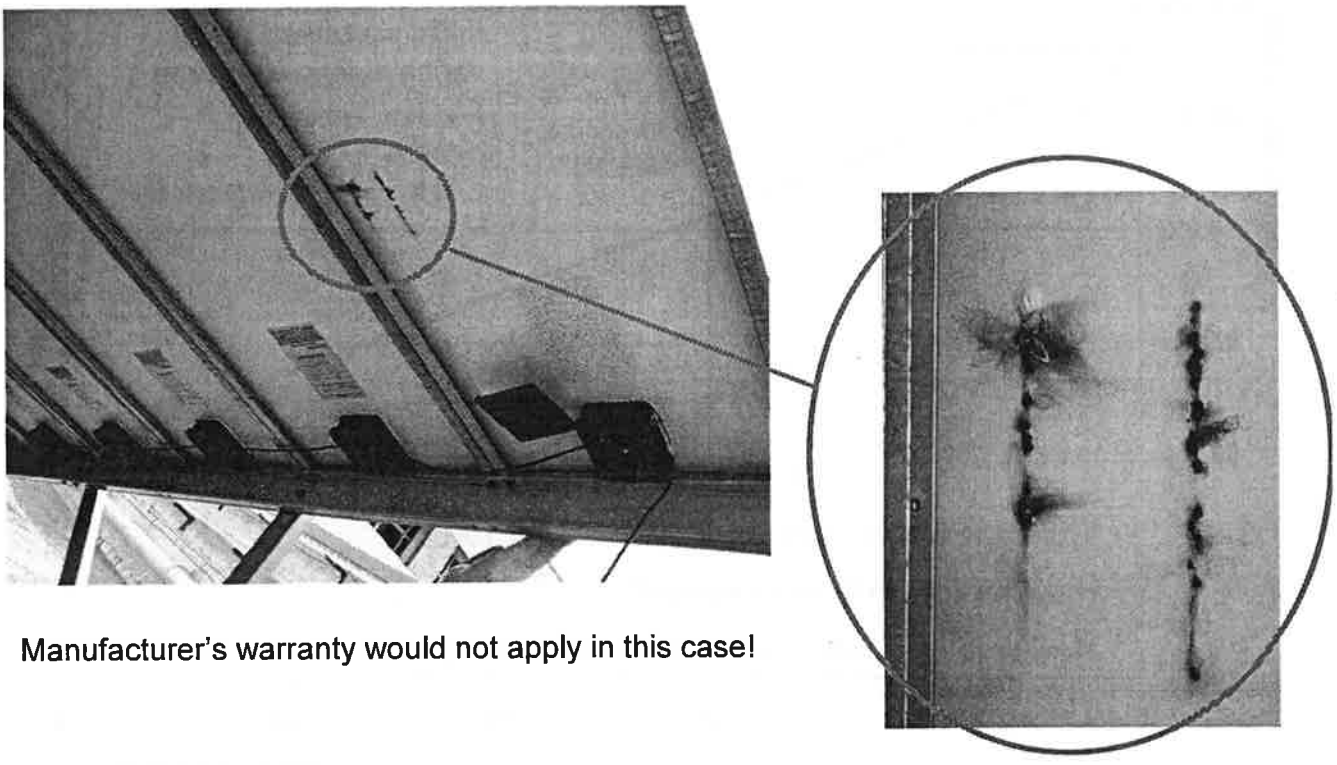




"Cancerous" patches on cells indicate delamination

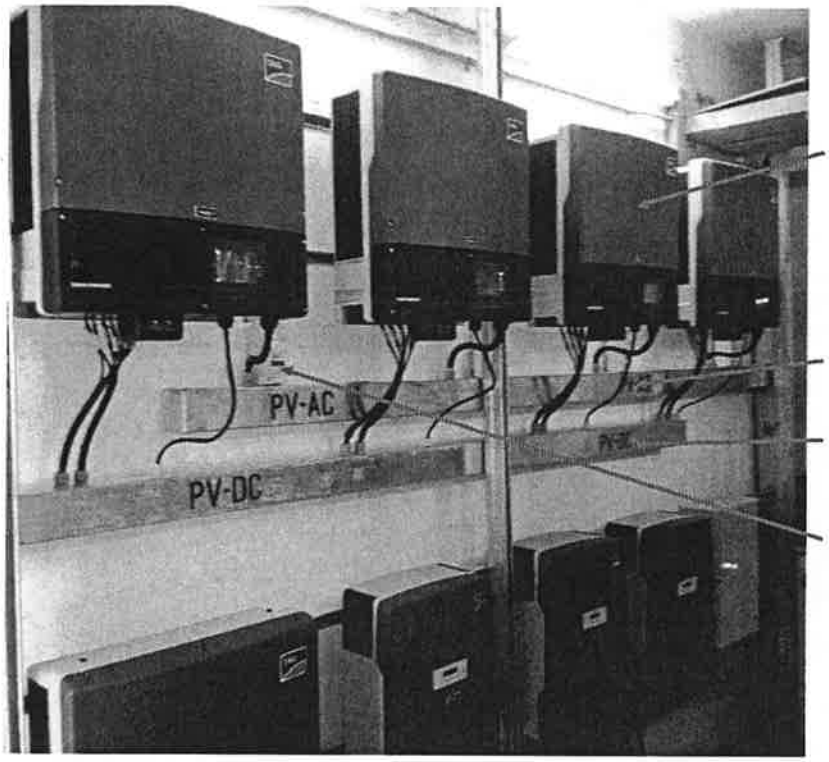
Manufacturers will replace modules like these, unless the delamination results from tampering or physical damage.

This module was damaged by improper installation



Manufacturer's warranty would not apply in this case!

Plan space for inverters in ACDB room



3-phase inverter, 17kW capacity
Size 665 x 690 x 265mm, 65kg
Min 300mm space between inverters

AC output from inverter to ACDB

DC input from PV arrays to inverter

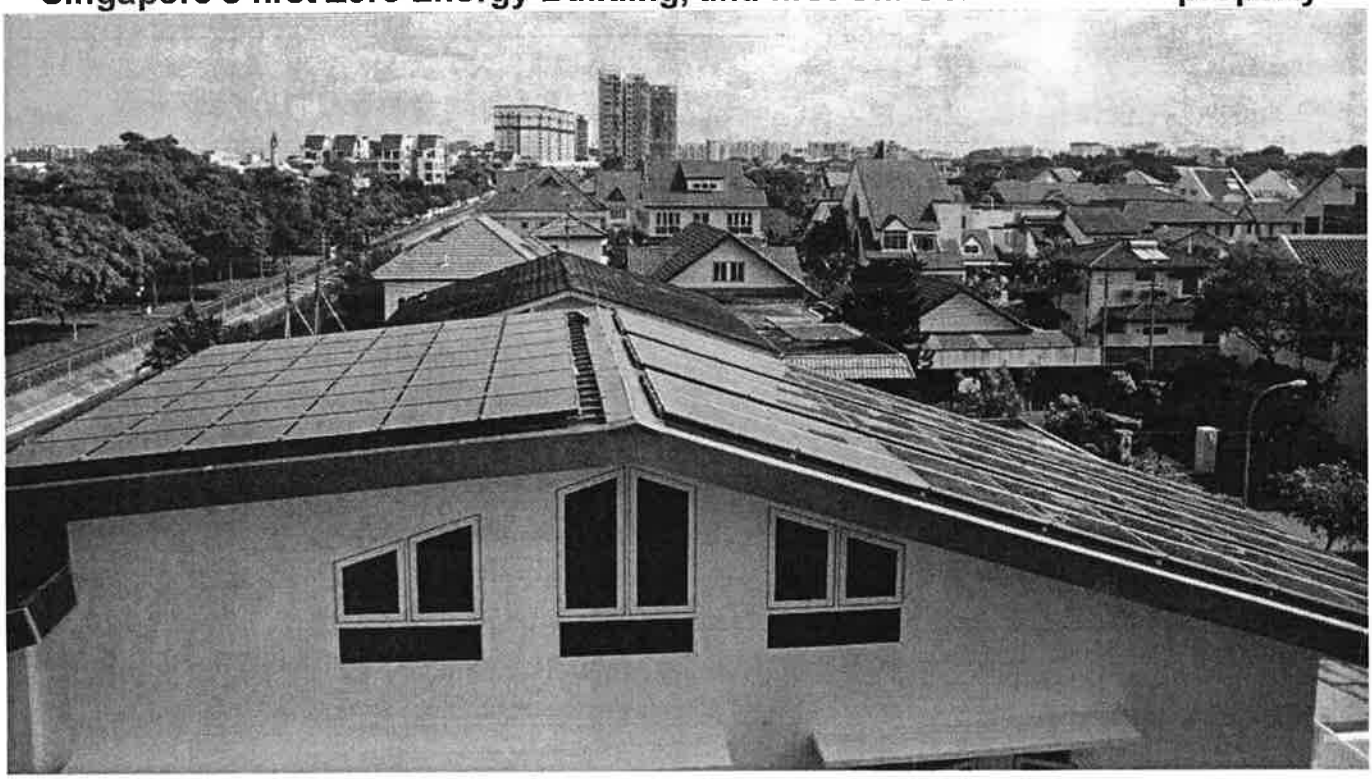
AC disconnect

PV technology, trends & tropical common sense

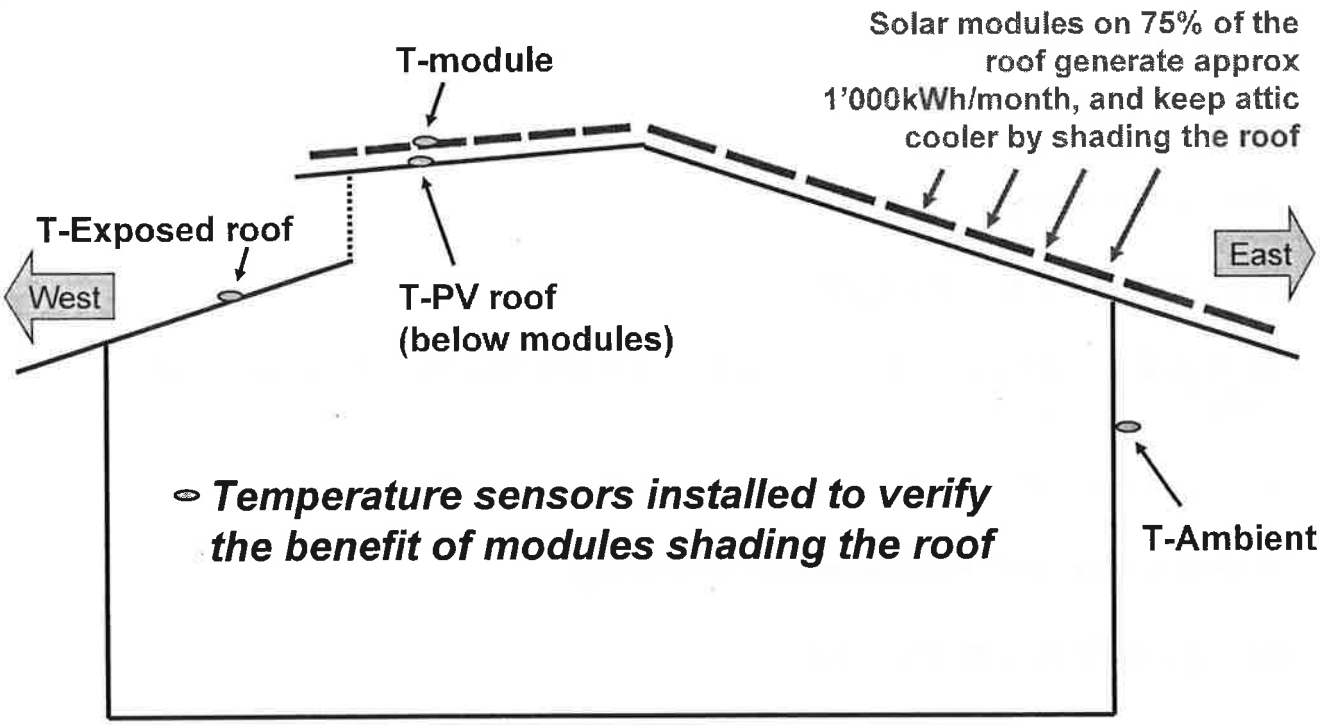
- What is PV and BIPV?
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Tandem a-Si/μ-Si and a-Si rigid thin film – 8.58kWp

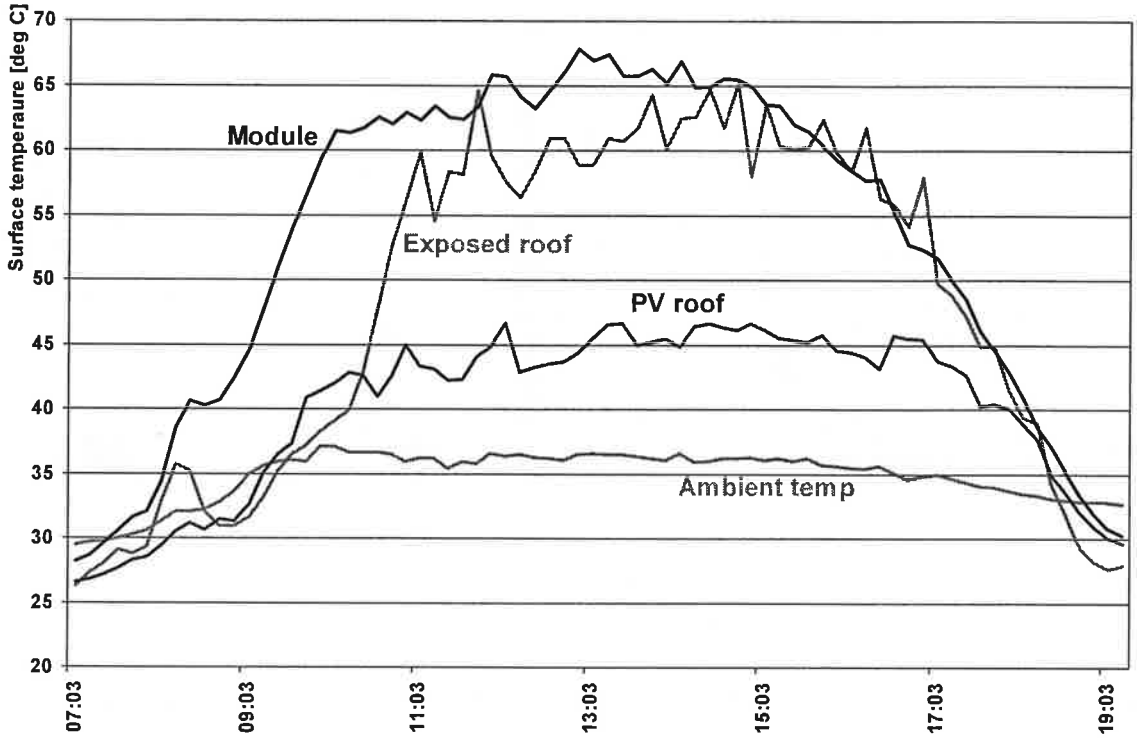
Singapore's first Zero Energy Building, and first GM Gold for landed property



Benefits of PV modules above metal roof



Much lower roof temperature beneath modules reduces aircon demand

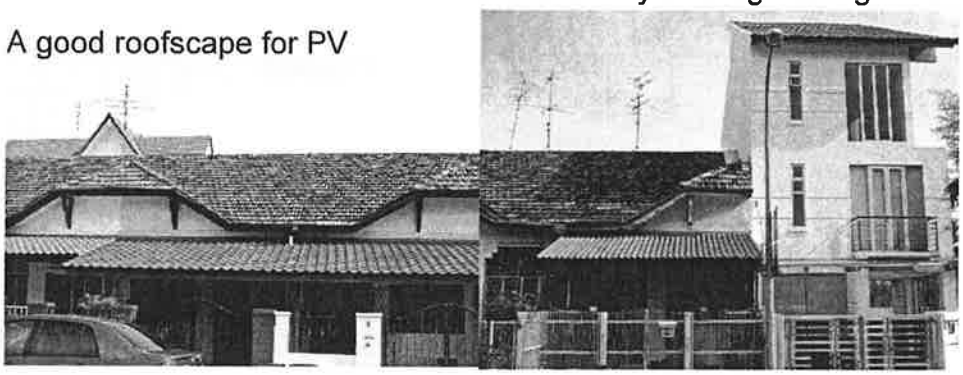


Data: ZEH 17 Oct 2009 (very sunny day)

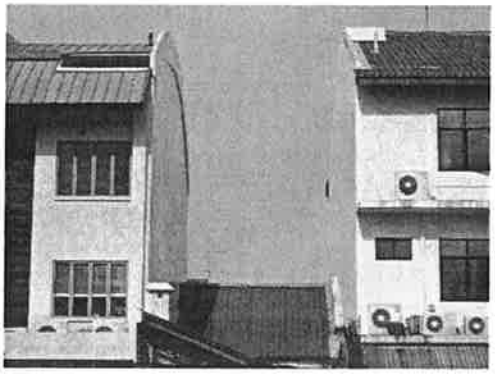
Neighbours might not cooperate with your PV plans …

A good roofscape for PV

But what if your neighbour grows?



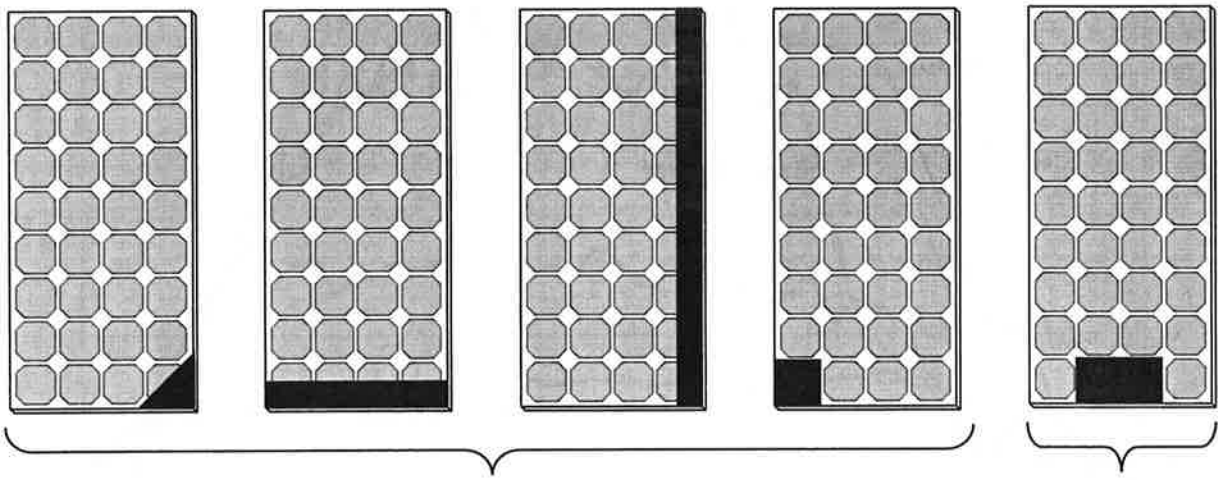
How about this sandwich?



- PV installations should last 20+ years
- But will the assumptions used to calculate energy yield hold for that long?

Even partial shading has a dramatic effect

Examples of partial shading on a 36-cell crystalline silicon module

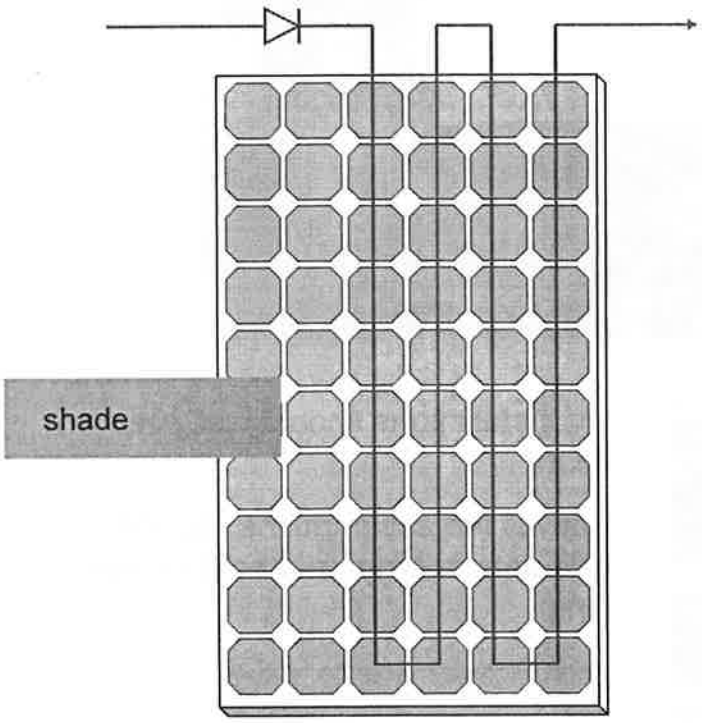


PV module output drops by half

PV module output drops to zero!

This happens because of the protective bypass diodes →

Bypass diodes divert current past shaded strings



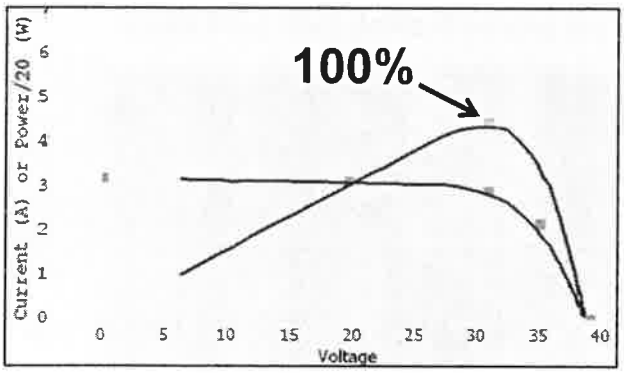


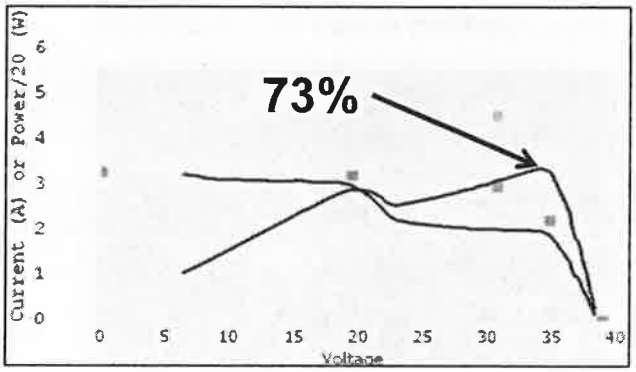
When a single cell is shaded, its entire string (2 columns) gets bypassed.

This reduces the module voltage (and hence power) by one third.

(without any bypass diodes, a shaded cell on a module exposed to strong sun would get very hot)

Crystalline modules badly affected by partial shade



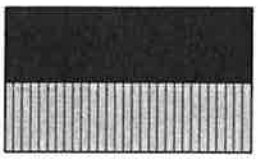




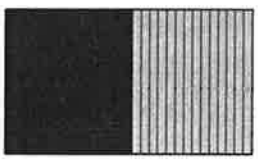
Business Card covering half of one cell



Thin film shade tolerance depends on orientation



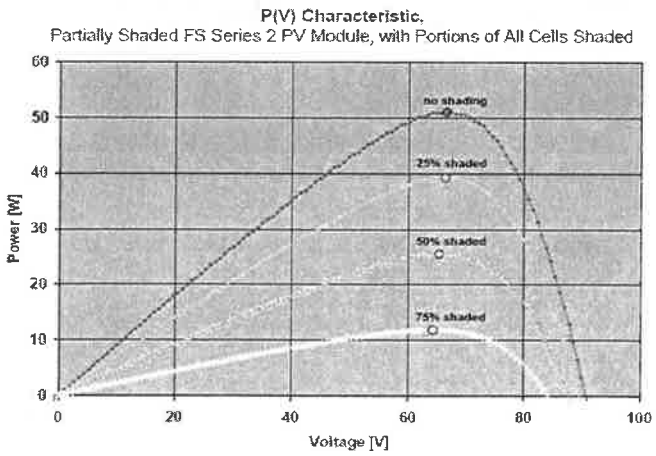
Shading perpendicular to cells (along 1'200mm edge)

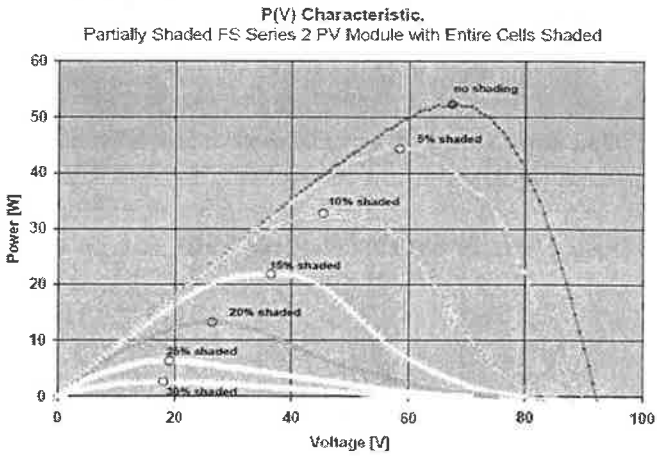


Shading parallel to cells (along 600mm edge)

Excellent shade tolerance

Poor shade tolerance

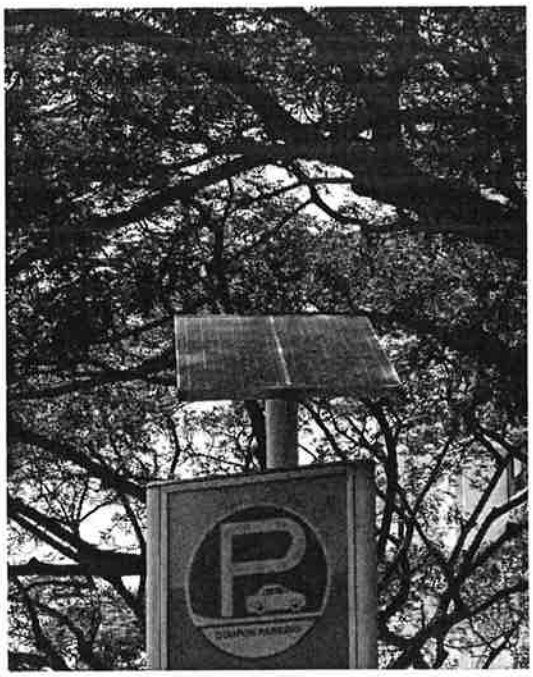




Source: First Solar

These unhappy modules are starving for sunlight …

What were they thinking, when they installed these PV modules?



The more the pigeons "perform", the worse the module performs!



Where to locate the PV modules?

Many options for installing PV & BIPV, but not all make sense in Sgp

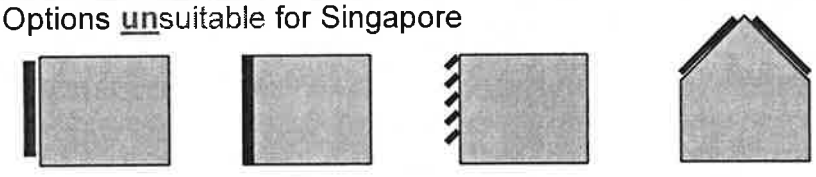
The roof is best location, but must avoid shading from:

- Neighbouring taller buildings (consider future zoning plans…)
- Tall trees (remember they will grow taller…)
- Fixtures like air-con condensers, lift engine rooms

Options suitable for Singapore

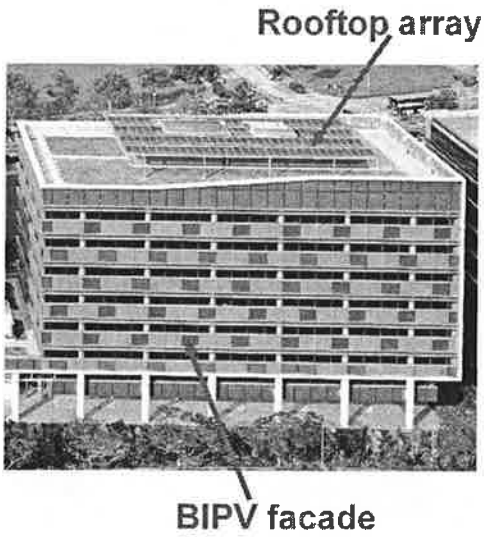


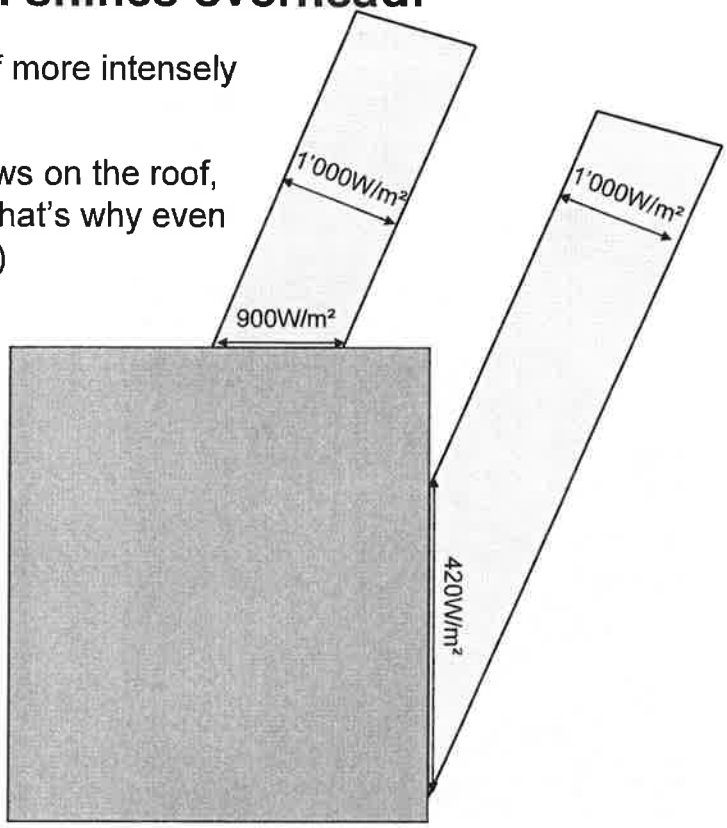
Options unsuitable for Singapore



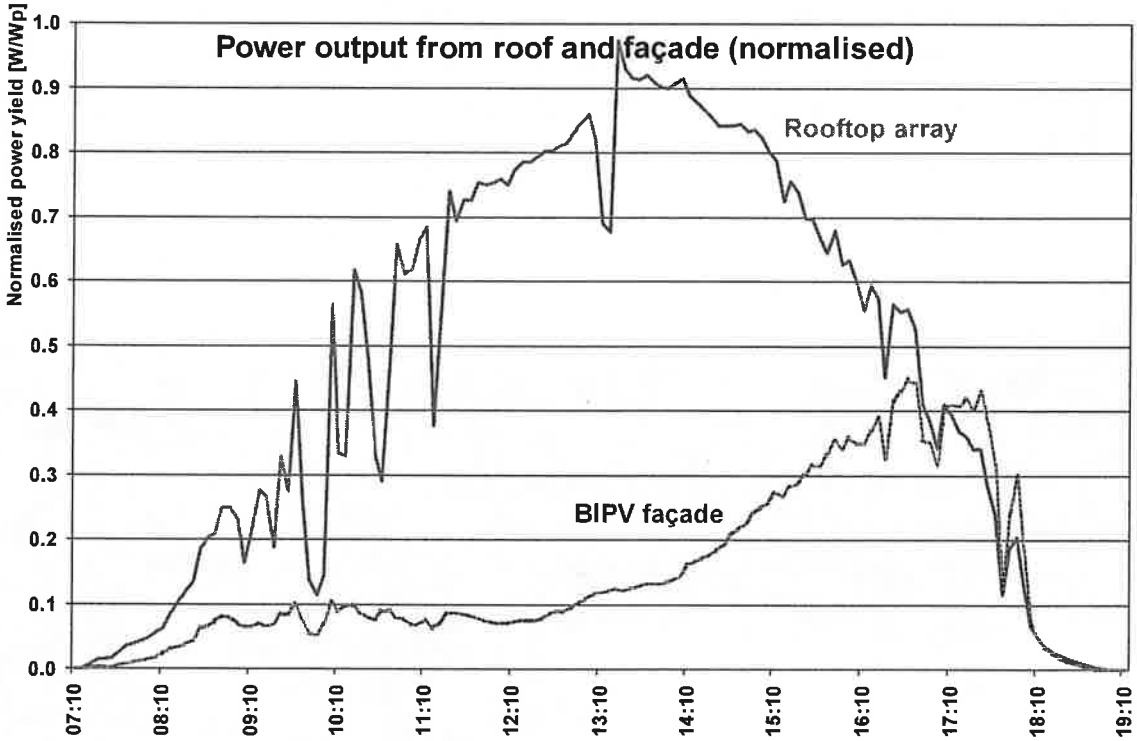
Near the Equator, the sun shines overhead!

- Equatorial sunshine strikes the roof more intensely than the walls
- Obstructions cast only short shadows on the roof, but long shadows down the walls (that's why even small window shades are effective!)





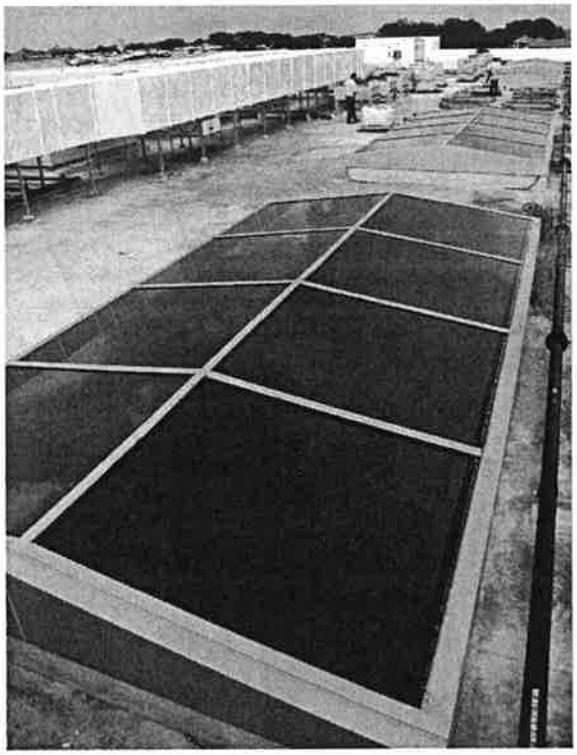
Rooftop array 3-6 times more effective than the façade

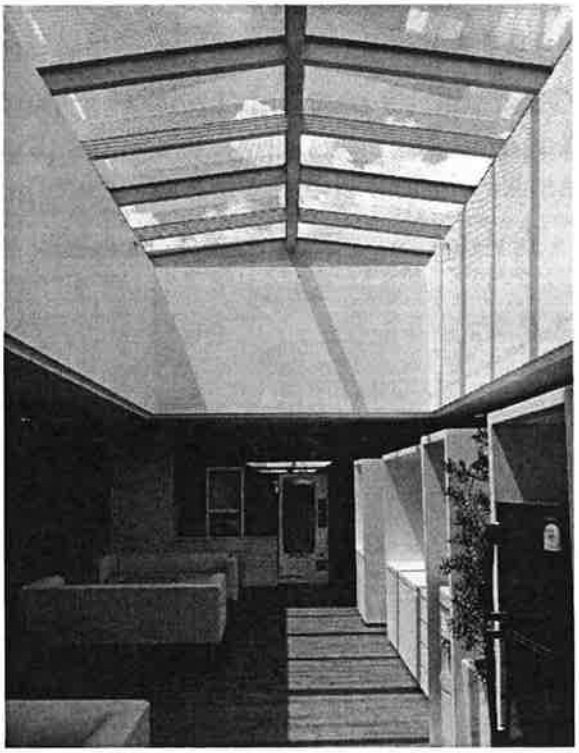


Data: Rooftop (TG T2-3) and façade array outputs on 29/08/09

Skylights are a better application for tropical BIPV

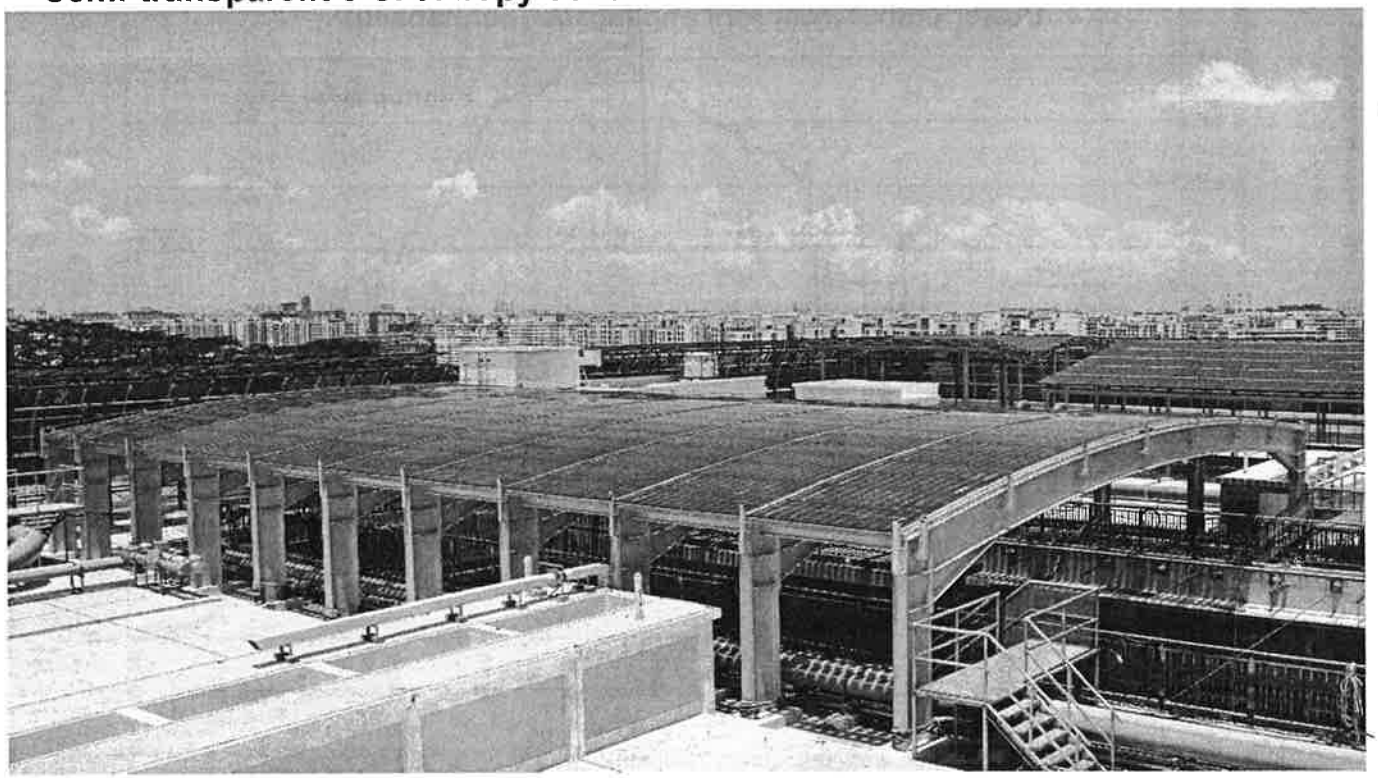
Generate electricity and cut glare without casting harsh shadows





Singapore's largest BIPV canopy

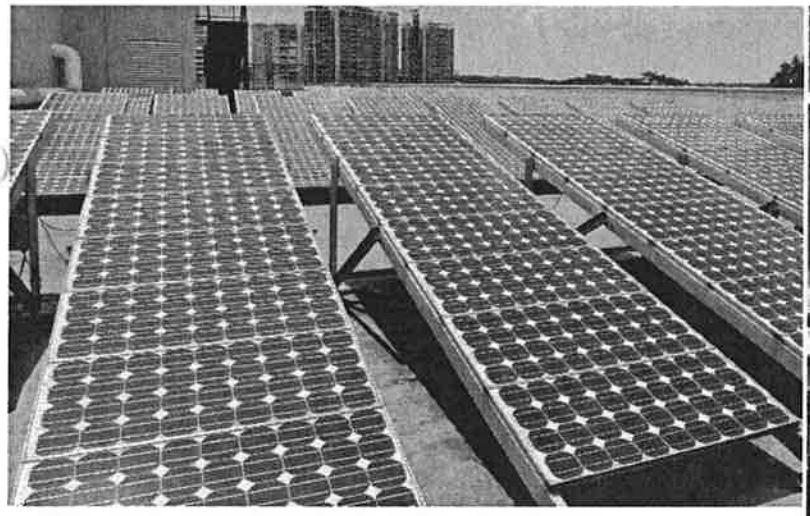
Semi-transparent c-Si canopy covers CleanTech One's atrium



PV technology, trends & tropical common sense

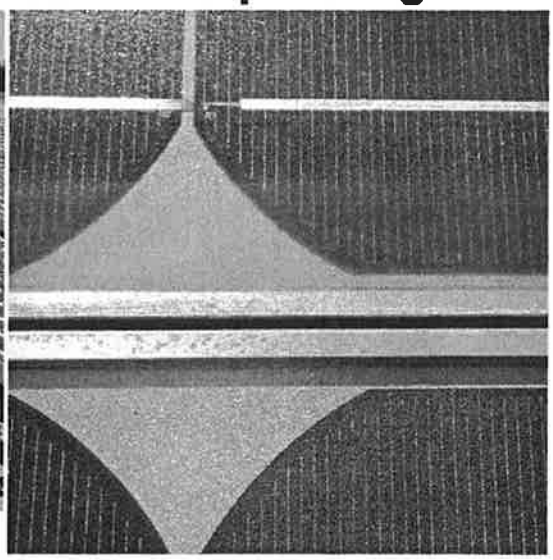
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Rainfall cleans module well if its tilt is steep enough



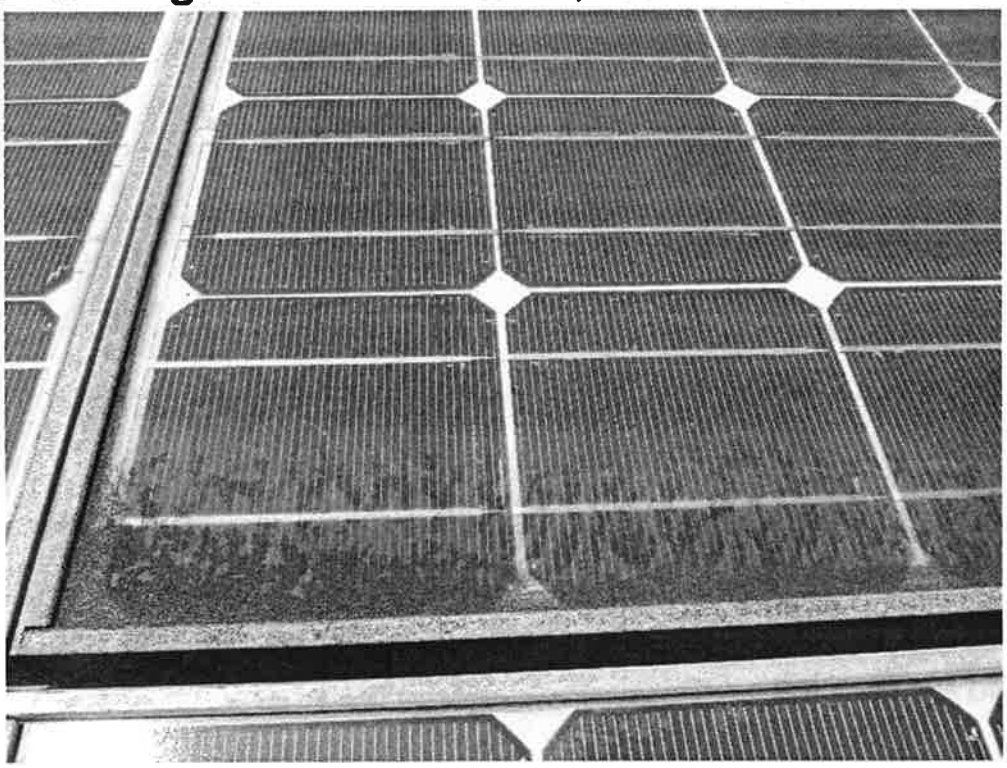
Arrays installed around 1998 at Singapore Polytechnic.

- Slope 15°
- Never washed except by rainfall



Only slight dirt build up at module edges

If tilt angle is too shallow, then dirt accumulates



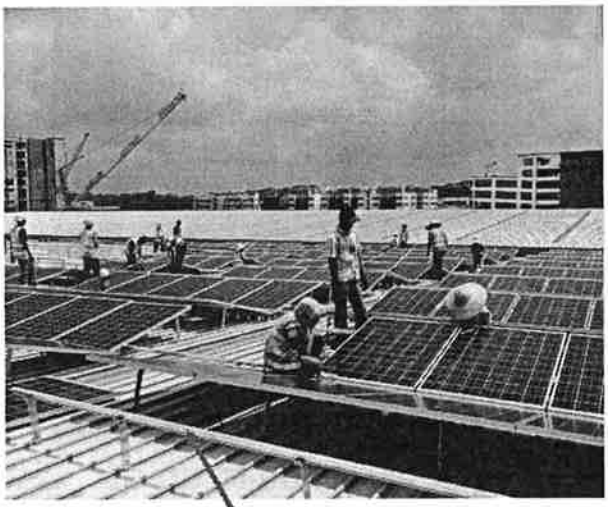
Arrays installed around 1996 at Singapore Polytechnic.

Slope 3°

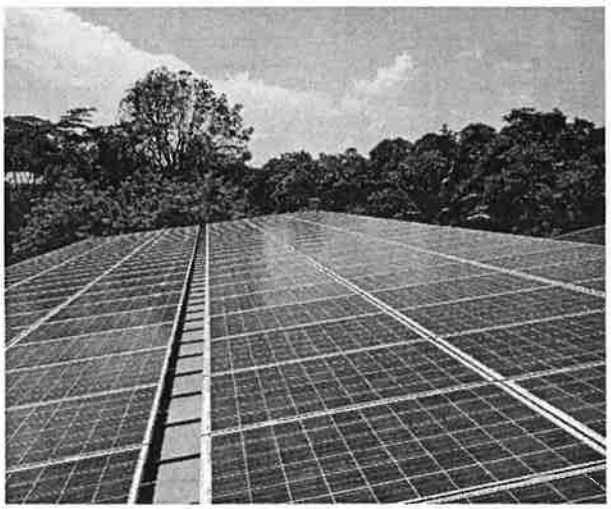
Never washed except by rainfall

Reduce costs with PV-compatible metal roof design

Include 10° slope for the roof, to save cost of additional structures



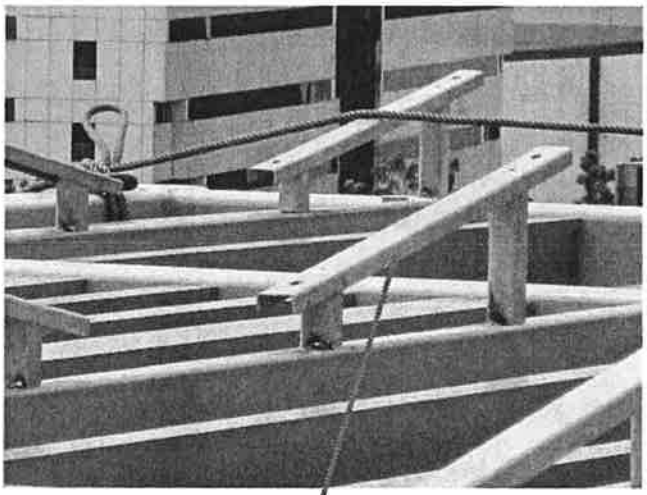
Raised module structures to enable 10° module slope



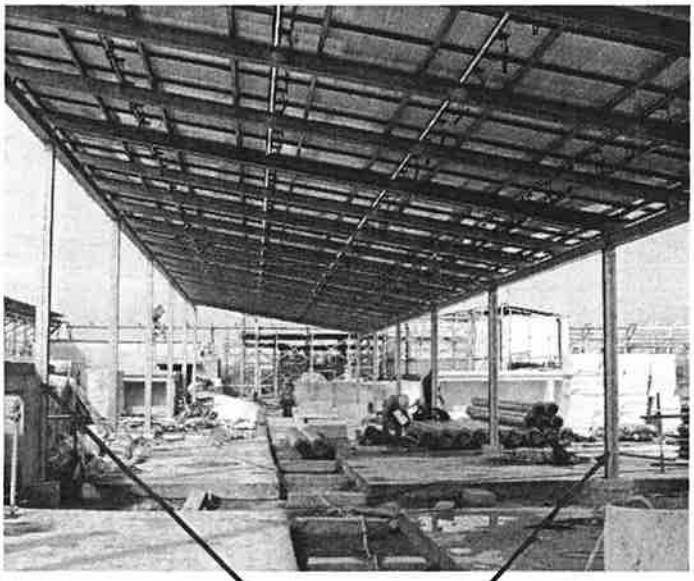
Modules at 10° slope, yet parallel to roof

Reduce costs with PV-compatible trellis design

Avoid cost of additional structures: use two column heights for 10° slope

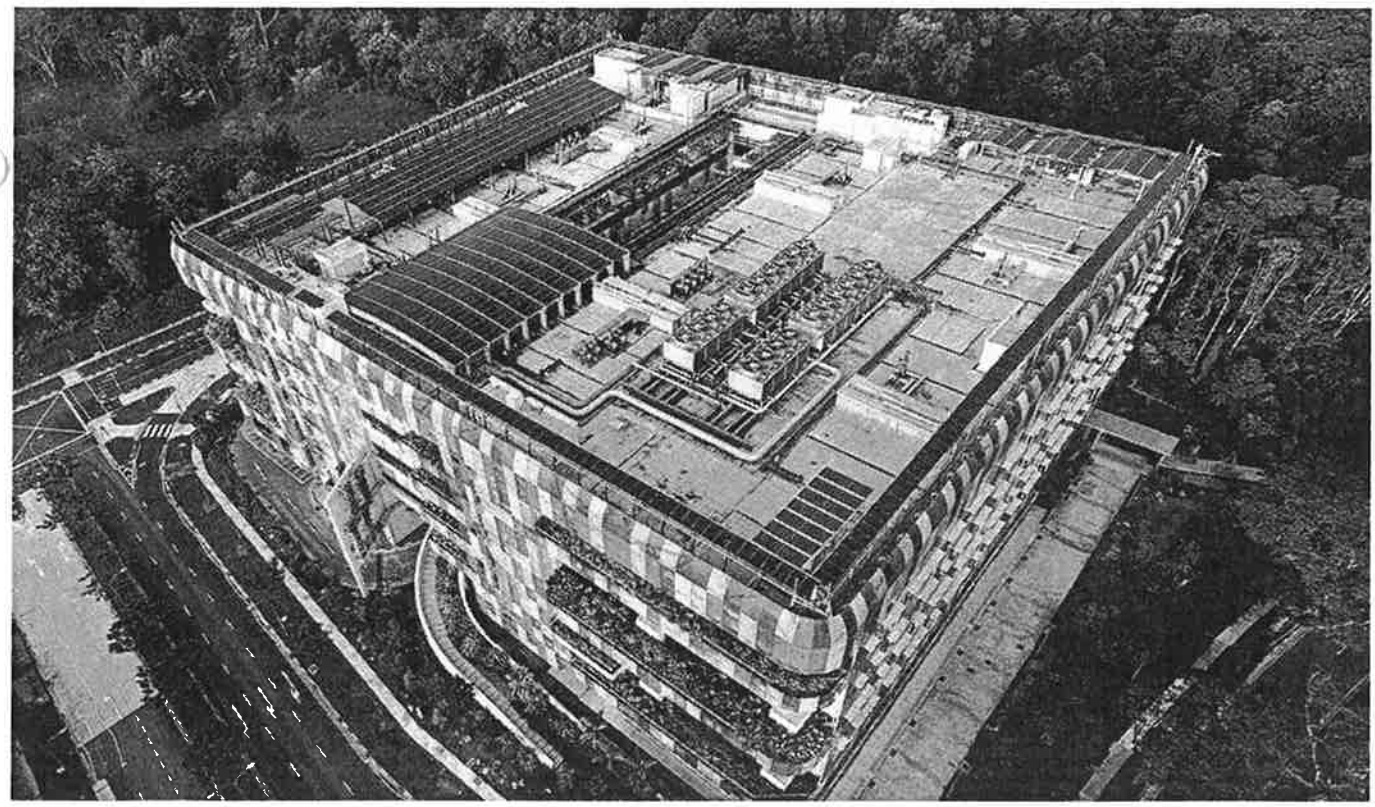


Need additional steelwork to achieve necessary slope



Taller and shorter columns create necessary slope

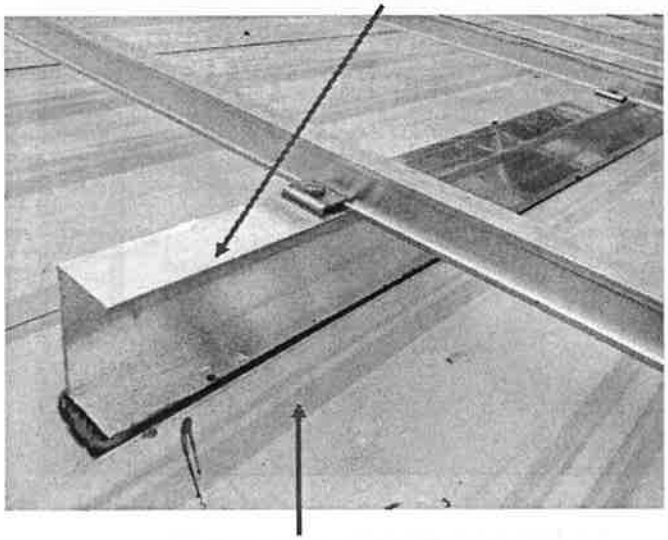
At CleanTech One, all trellis structures have 10° slopes



Reduce costs with PV-compatible metal roof design

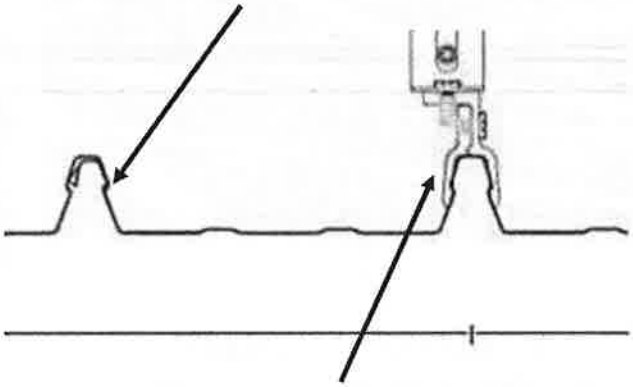
Specify clampable roof seams to reduce cost of anchoring PV rails

Need adhesive to attach support rail
More material, more labour, more time, more cost



Seam clamps cannot grip trapezoid roof profiles

Roof seam with clampable profile



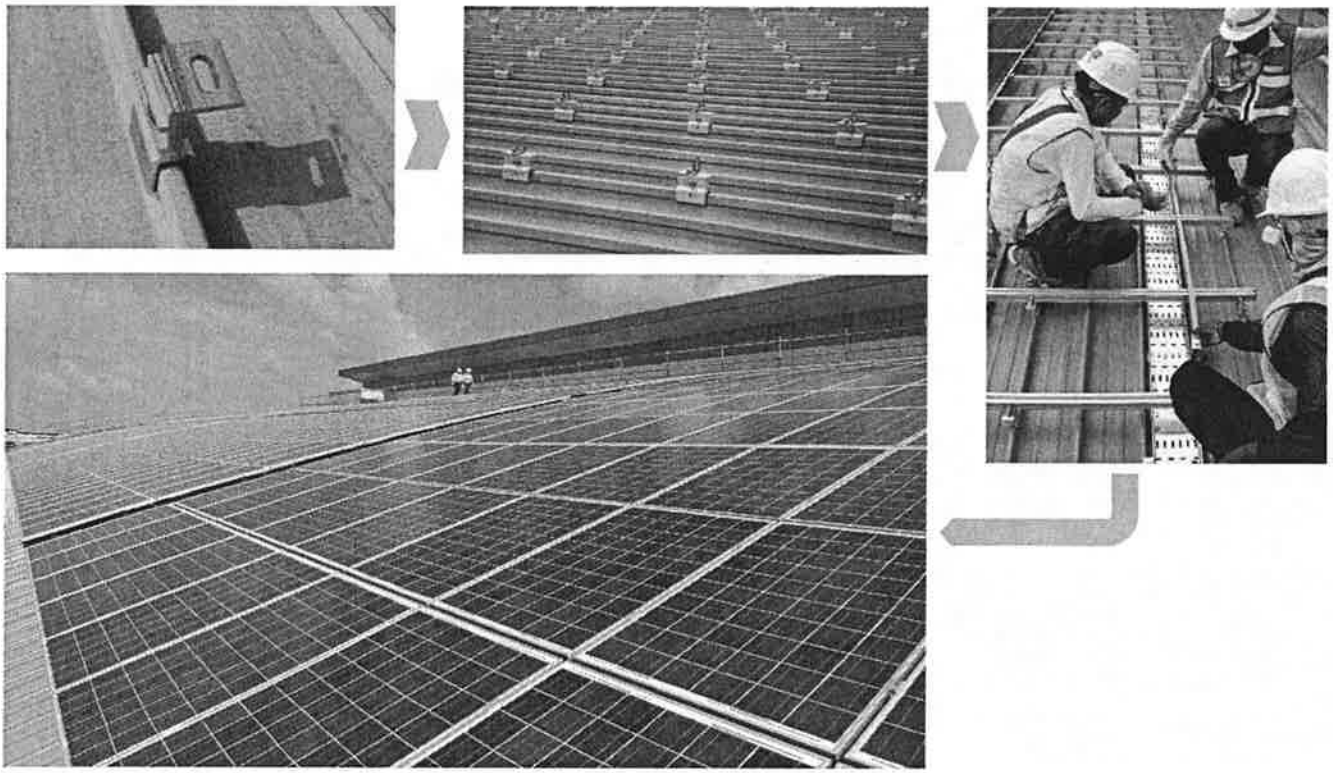
Cost-effective seam clamp does not penetrate roof

Lonza Biologics added 181kWp on its curved metal roof



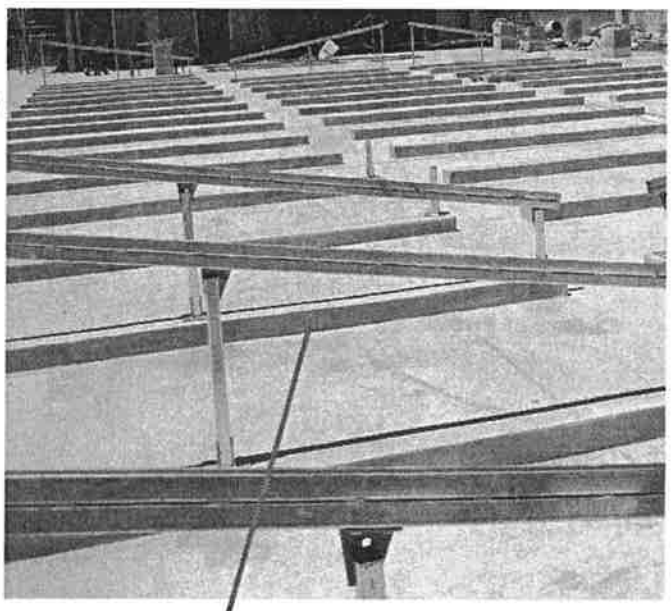
Solar Pioneer Award winner and Green Mark Gold
Photo by Lonza Biologics Pte Ltd

Module arrays follow roof curvature with no roof penetrations

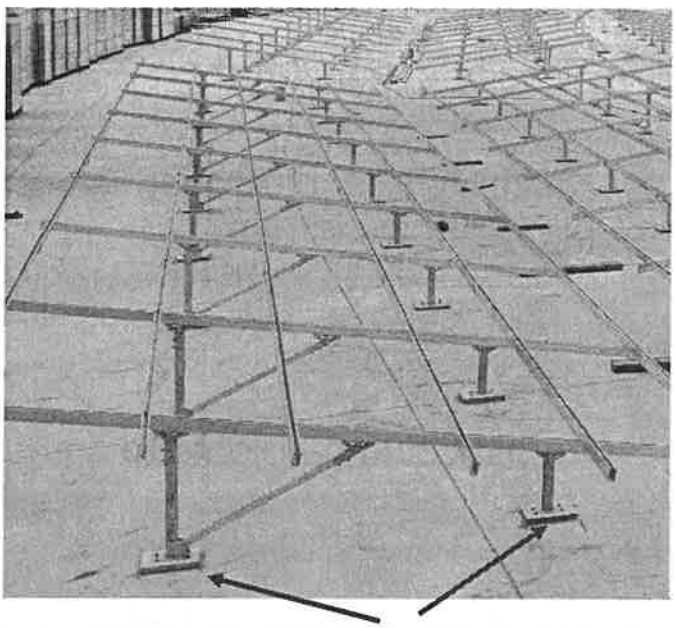


Reduce costs with PV-compatible RC roof design

Save ballast costs: plan for anchor points before waterproofing the roof



Expensive (and heavy) RC ballast
~60kg RC per m² of modules



Cost-effective anchor points

Singapore's National Stadium with 707kWp on RC roof

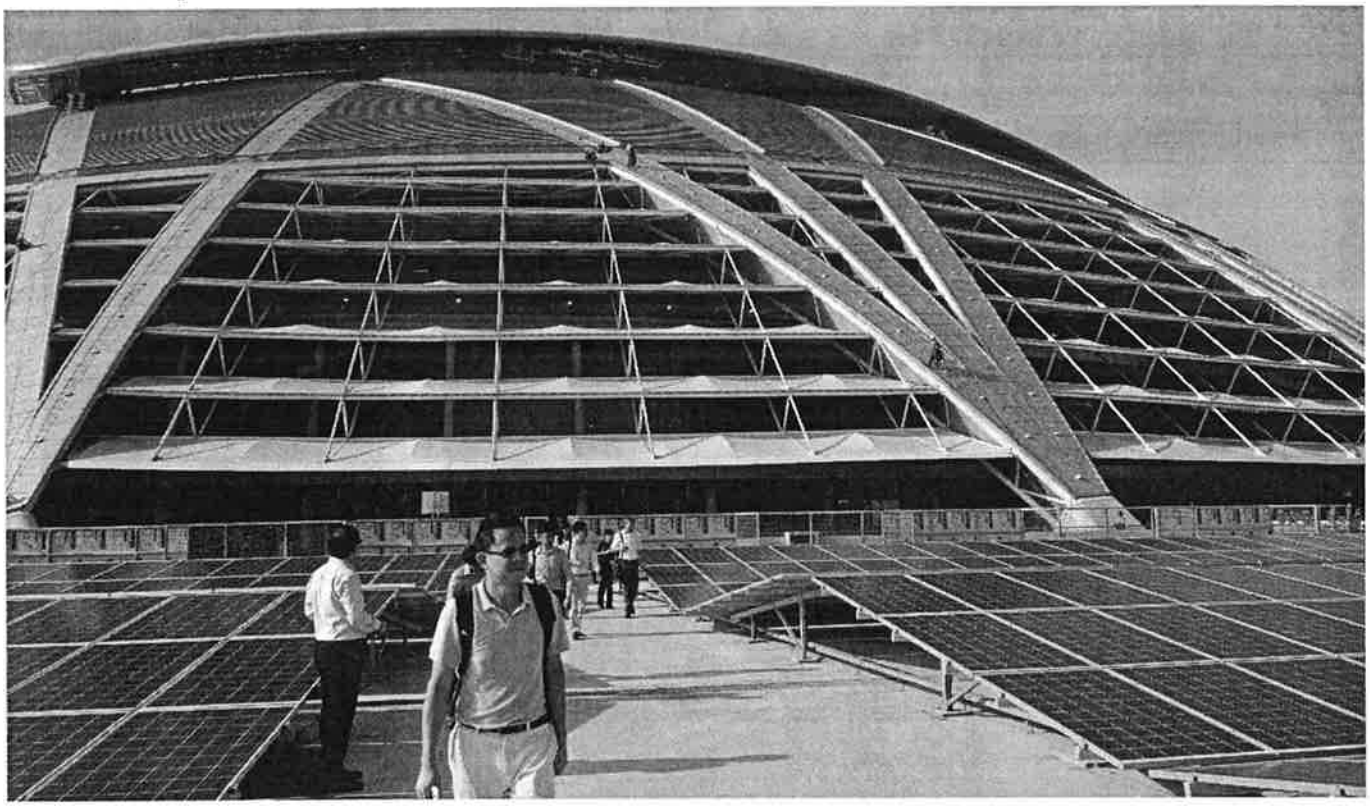


Photo by Phoenix Solar

Reduce costs with PV-compatible building design

Metal roof

- 10° slope is better than 2-3° slope
  - Cheaper to install modules flush with roof, but need 10° slope for self-cleaning in rain
- Kalzip or KlipLok/Speed Deck seams allow lowest cost non-penetrating clamps.
  - Folded seams are second-best solution.
  - Avoid trapezoidal or corrugated profile with no clampable seams

Trellis

- Adjust column heights to create 10° slopes
  - Saves additional structures on top of flat trellis

RC roof

- Install anchor points before applying waterproofing layer
  - Saves costly ballast later on

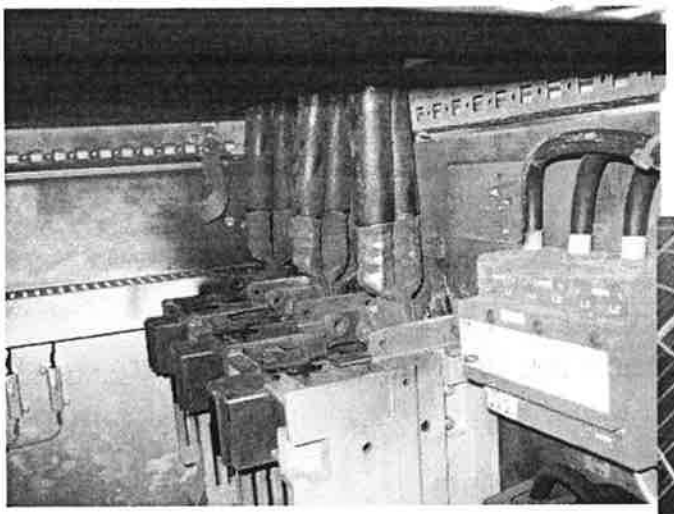
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Very low maintenance costs

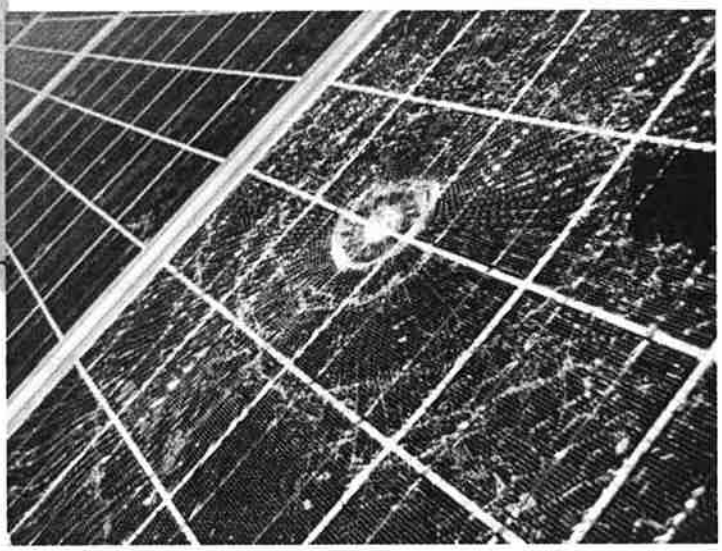
No moving parts to wear and tear **(except some inverter cooling fans)**	No need for "grease and rags"!
Inspection only <u>once</u> a year **(no monthly site meetings or quarterly inspections)**	Check for loose bolts, corroded structures, worn out surge arrestors, dirty modules. Measure key elec parameters.
Monthly, quarterly, annual reports	Remote data retrieval via internet.
Back-to-back supplier warranties	5 years for inverters. 20-25 years for modules.

Low maintenance does not mean no maintenance - 1



Over heating

Vandalism

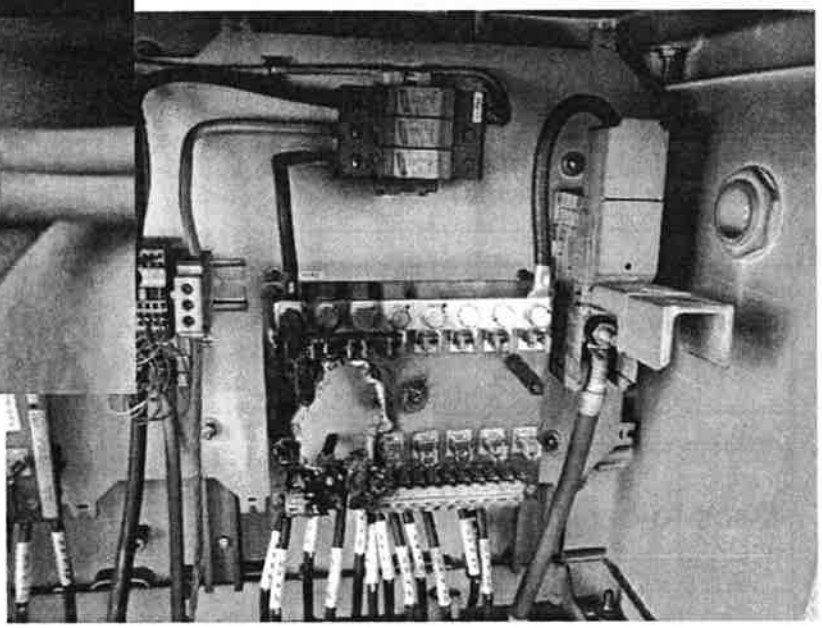


Low maintenance does not mean no maintenance - 2

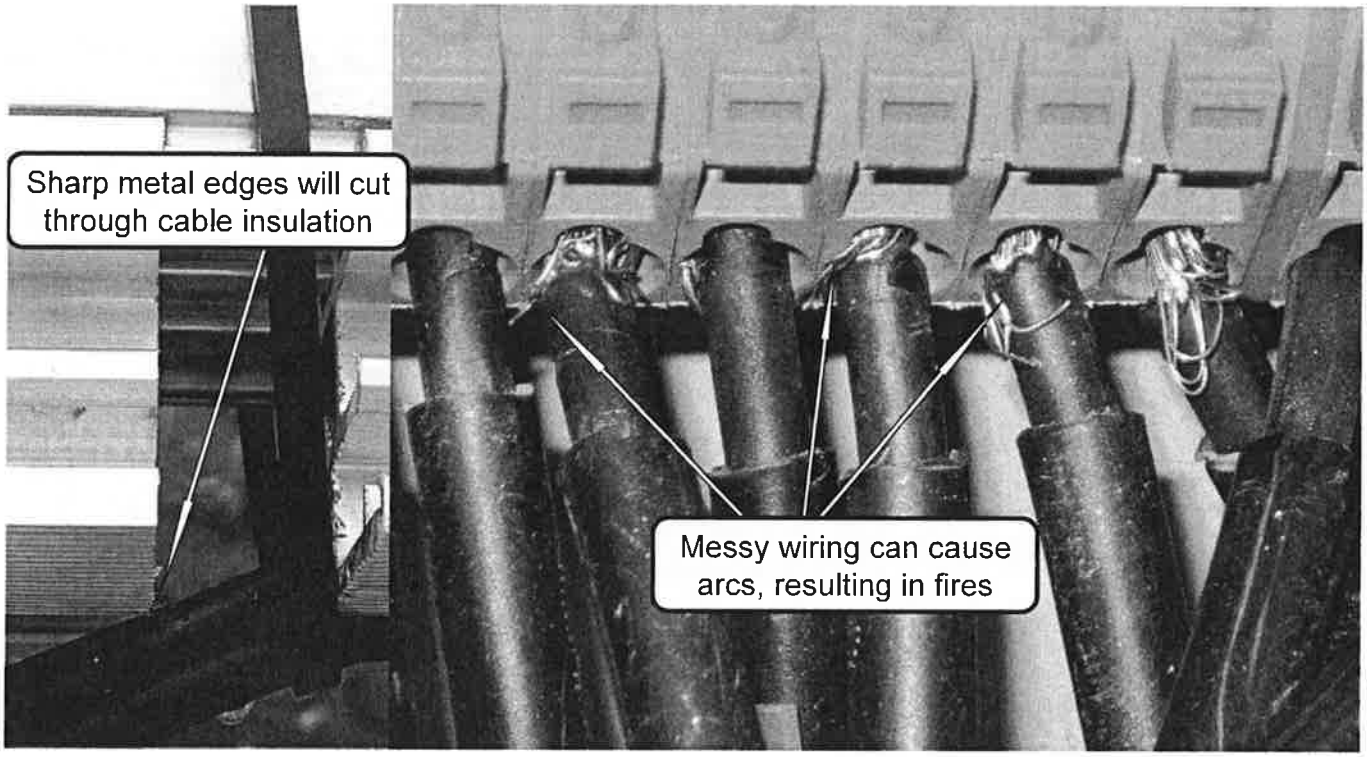


Damage caused by wild animals

DC short circuit

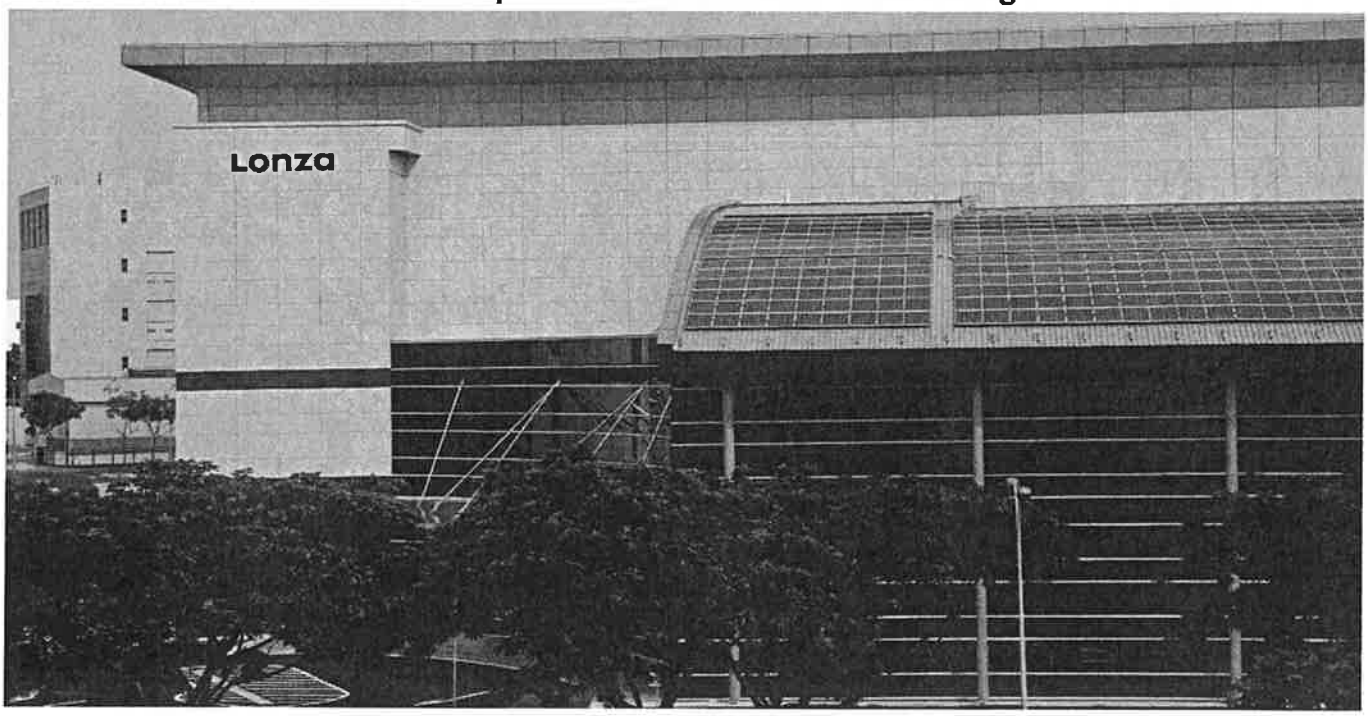


Sloppy installation can take time to affect performance



How to safely inspect modules on roof like this?

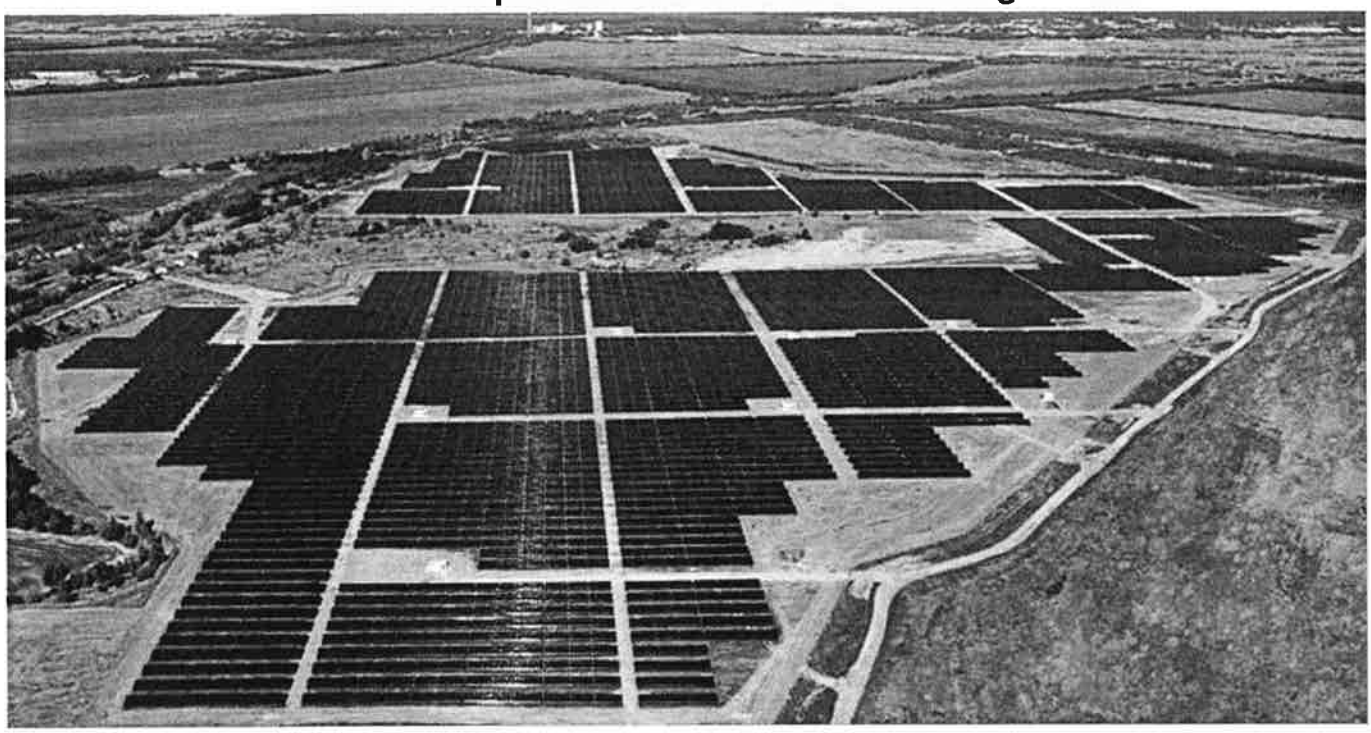
You need professional remote monitoring!



181kWp rooftop system at Lonza Biologics, Tuas, Singapore

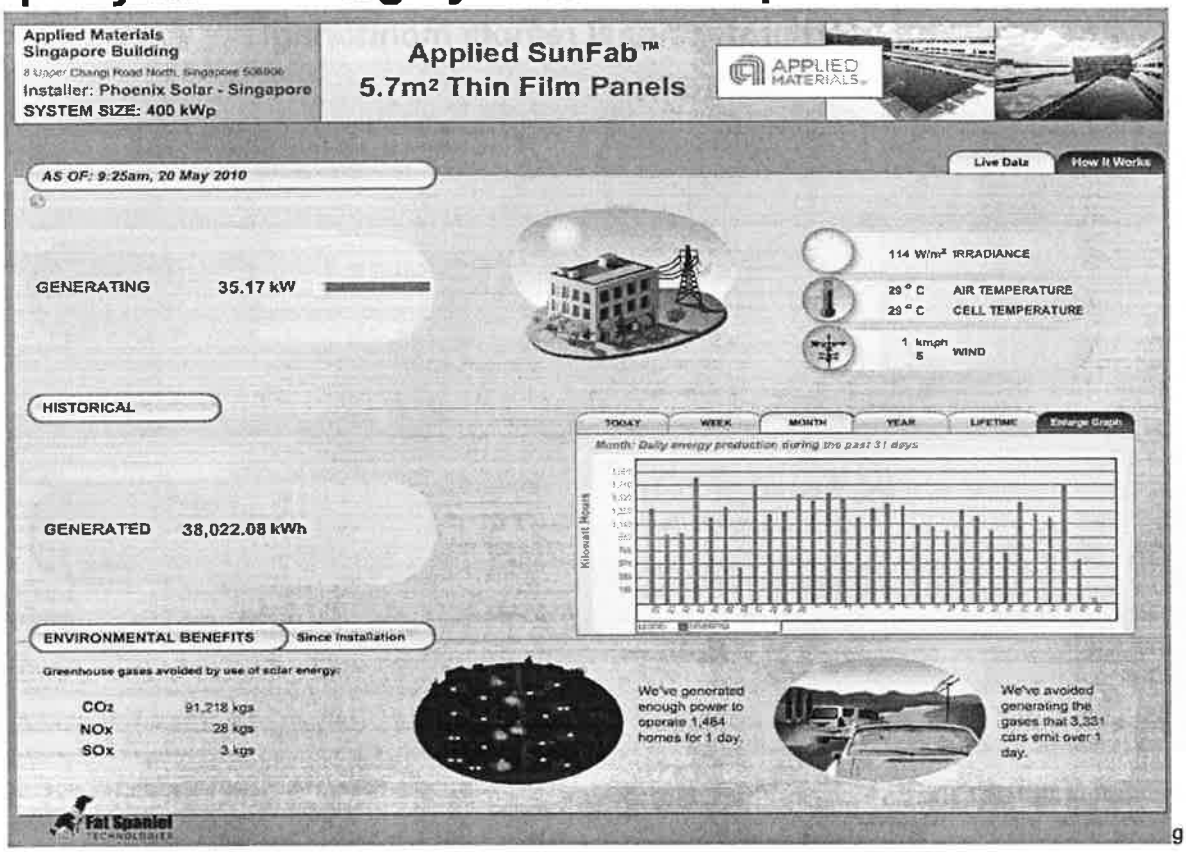
How do you maintain 80km of module arrays?

You need professional remote monitoring!



18.2MWp power plant in Senftenberg, Germany. >240'000 modules, >75km of arrays

3rd-party monitoring system tracks performance

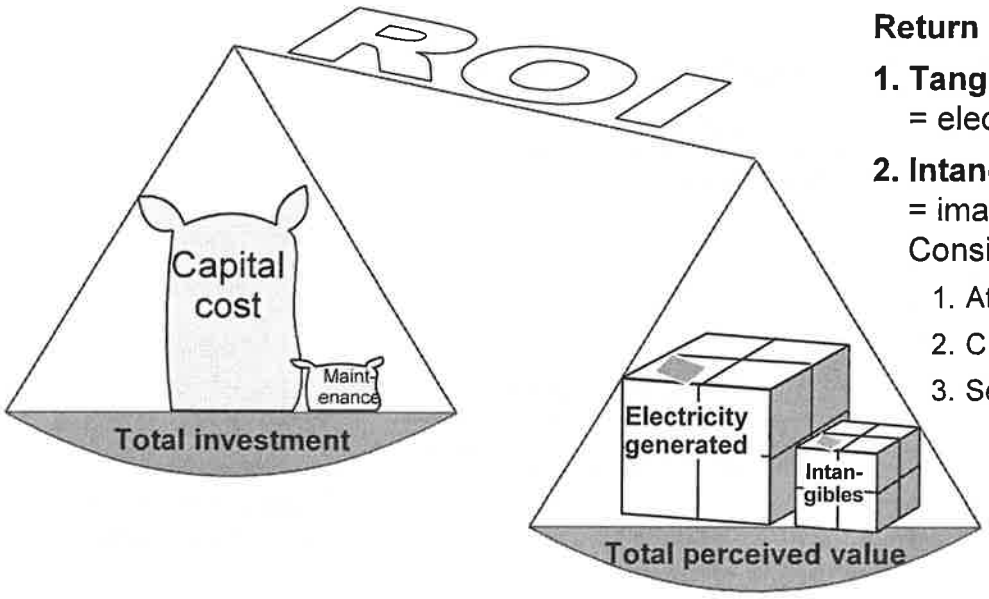


PV technology, trends & tropical common sense

- What is PV and BIPV?
- Case studies
- Key terminology
- Comparing PV technologies
- Tropical Common Sense 1 – let PV shade the property, not the other way around
- TCS 2 – reduce maintenance and installation costs
- Maintenance and performance monitoring
- **Energy yield and economics**
- Conclusions

Good news – positive returns even without subsidies!

Calculating return on investment (ROI) needs a close look at both sides of the equation:



Return has two components:

1. **Tangible return**
   = electricity generated
2. **Intangible return**
   = image and reputation.
   Consider value of:
   1. Attracting more customers
   2. Charging a premium
   3. Selling faster (cashflow)

BCA Green Mark PV example, 20'000m², S$70m project

(Assume Energy Efficiency Index EEI > 30kWh/m²/yr)
Up to 20 bonus points for PV. Two ways of scoring:

- 5 points for each 1% of total building load supplied by PV
- 3 points for each 1% of common load (total minus tenant)

Target office space annual energy consumption (top 10% for office bldgs surveyed by E*A*S*T)	150kWh/m²
Annual energy consumption for 20'000m²	3'000'000kWh
4% of building load per year (to earn 20 GMA points)	120'000kWh
Required rooftop PV system (generating 1'200kWh/kWp/yr)	100kWp
Estimated installed cost of PV system	S$220'000
Approx roof space needed for crystalline modules (Approx roof space needed for thin-film modules)	1'000m² (1'600-2'000m²)
PV system cost as percentage of total building cost	0.3%

Simple payback period a proxy for return on investment

- Annual energy per kWp from well-exposed rooftop system is 1'200-1'300kWh
- Installed cost of 500kWp system = approx SGD1m (SGD2'000/kWp)

$$\text{Simple payback period in years} = \frac{\text{Capex}}{\text{Annual yield x tariff}}$$

Cost per kWp for large rooftop system

$$\text{For 500kWp system:} = \frac{\text{SGD2'000/kWp}}{\text{1'200kWh x SGD0.20}} = \underline{\textbf{8.3yrs}}$$

Energy yield per kWp (conservative)

Relevant tariff per kWh of electricity

Simple payback period excludes operating costs (maintenance, insurance)

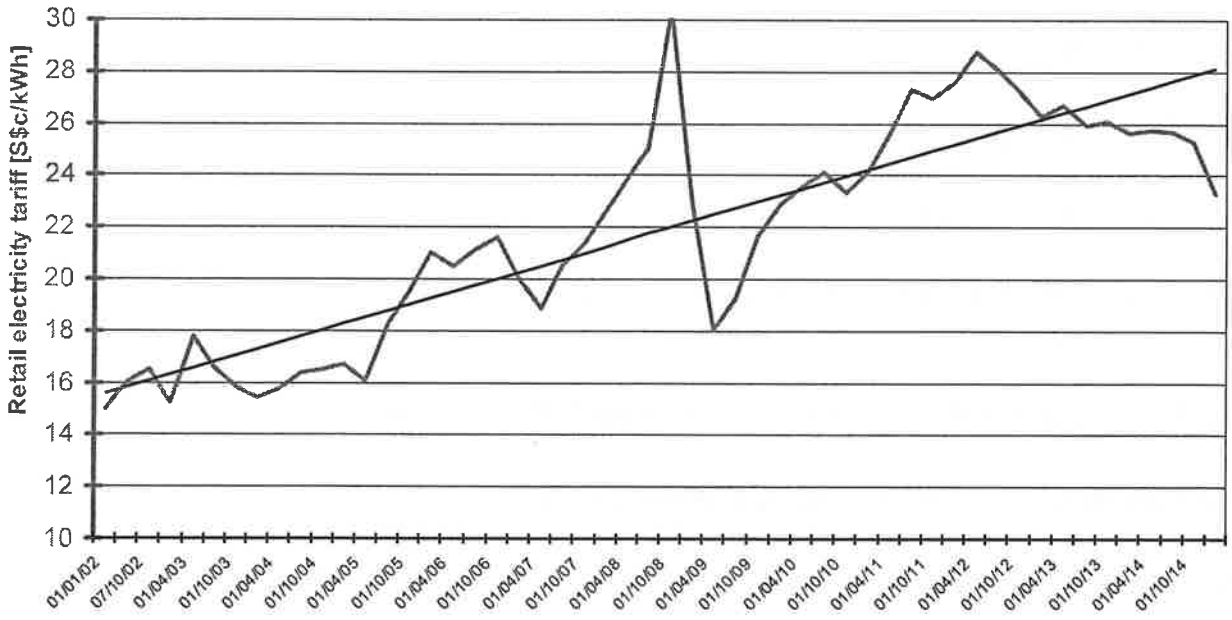
PV is commercially viable without any incentives

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- Installed cost of 500kWp system = approx SGD1m (SGD2'000/kWp)

$$\text{Simple payback period in years} = \frac{\text{Capex}}{\text{Annual yield x tariff}}$$

Retail tariff [SGD]	Annual energy yield [kWh/kWp]		
	1'200	1'250	1'300
0.20/kWh	8.3	8.0	7.7
0.25/kWh	6.7	6.4	6.2
0.30/kWh	5.6	5.3	5.1

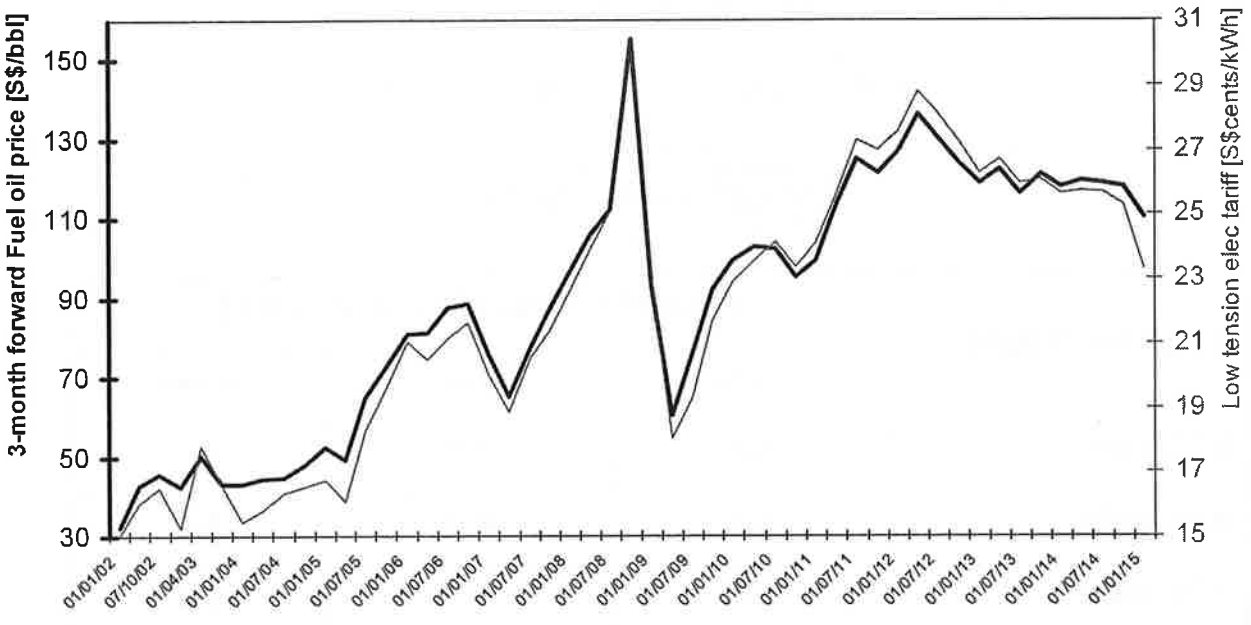
Long term tariff trend since Jan 2002 = +1 cent/year



Data: SP Services

Retail tariffs will rise with global demand for fuel

Electricity generation costs closely linked to fuel costs



Data: SP Services

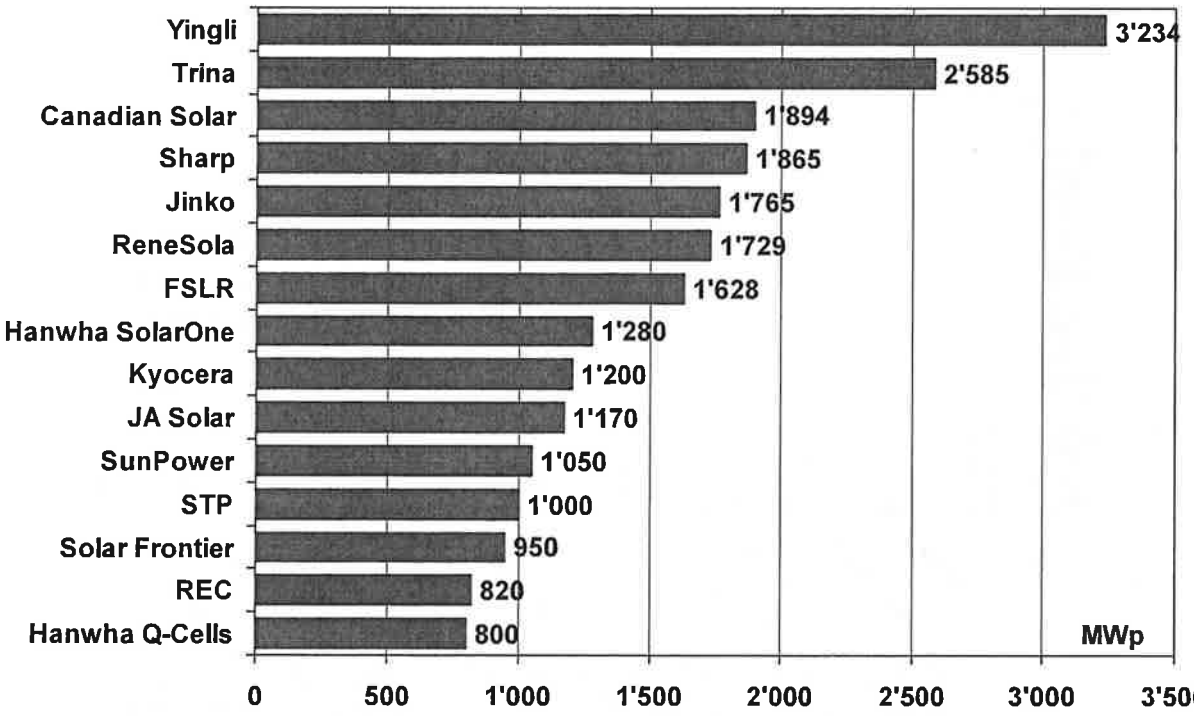
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Select the right manufacturer for the job

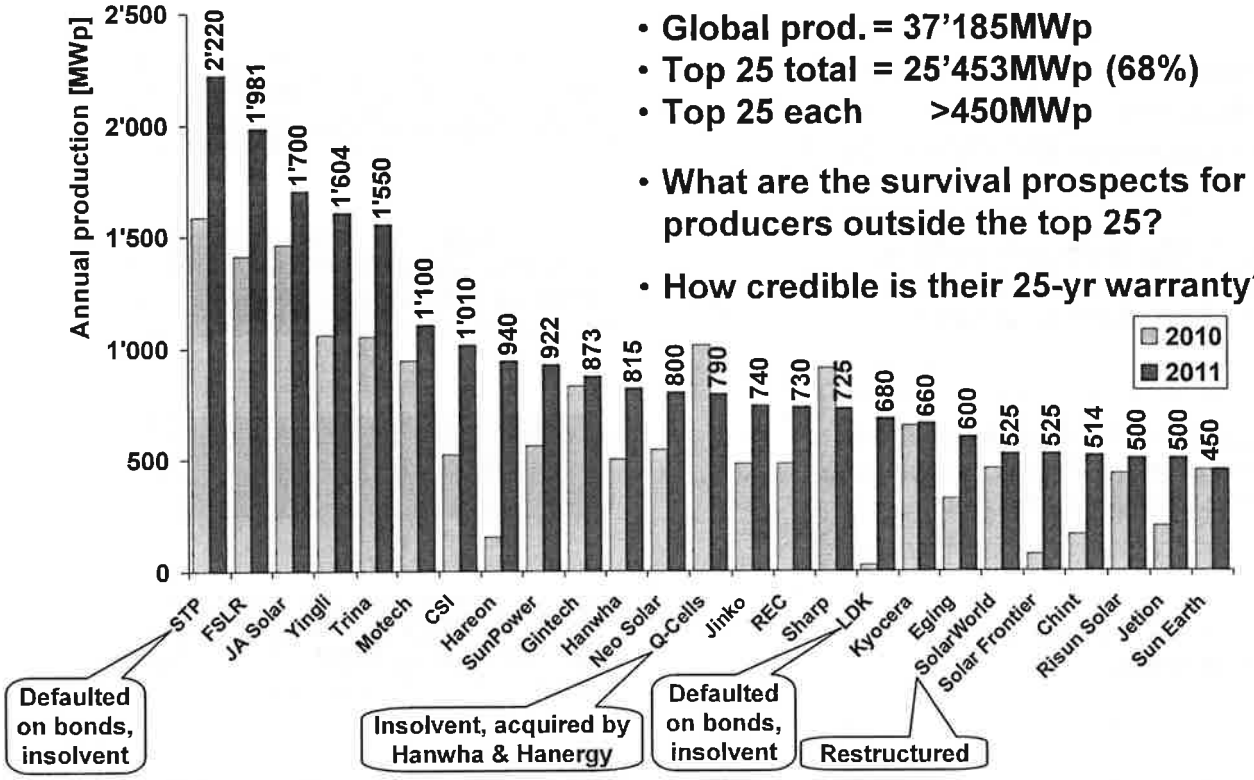
Reliability through volume production - top 10 producers each exceeded 900MWp in 2013	Of the hundreds of also-rans, many will not survive.
Reliability through volume production - don't just look at overall production volume	Consider volumes of individual module in question.
Quality control and extent of value chain – how credible are certificates and warranties?	What share of production is in-house, and who supplies components?
Product stability and consistency	Is the product in pilot phase or in mass production?

Top 15 module companies by 2013 shipments



SOURCE: Annual reports, IHS and GTM estimates

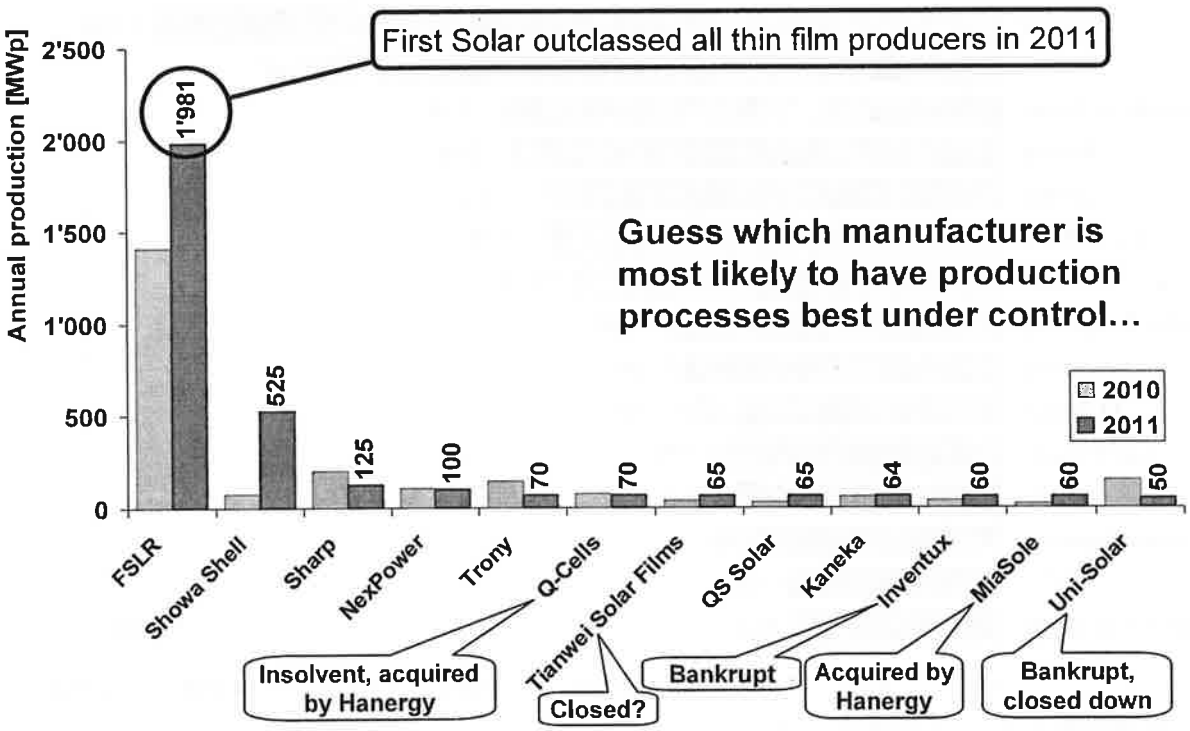
Top 25 thin film & crystalline cell producers (2010-11)



- Global prod. = 37'185MWp
- Top 25 total = 25'453MWp (68%)
- Top 25 each >450MWp
- What are the survival prospects for producers outside the top 25?
- How credible is their 25-yr warranty?

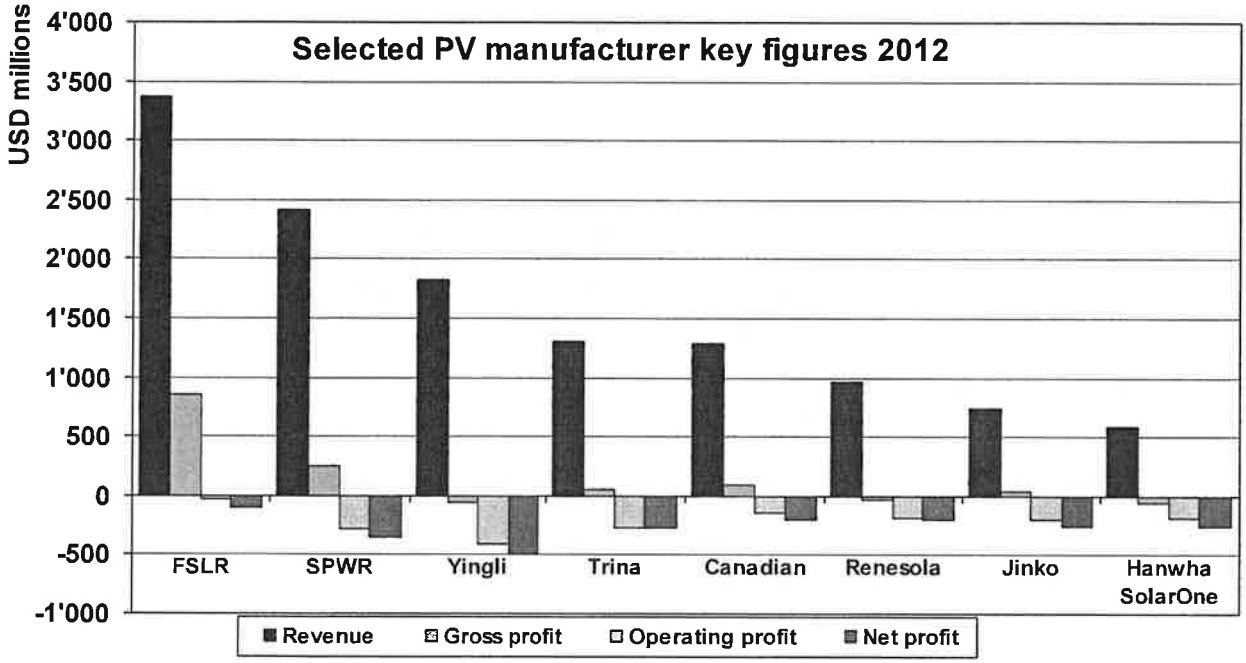
Production data: Photon International (2012/3)

Top thin film module producers (2010-11)



Data: Photon International (2012/3)

All major PV manufacturers lost money in 2012



Data: Annual reports (US GAAP)

Is the contractor truly competent?

Track record – what have they really done?	Check references and customer testimonials, plus kWp installed
Documented technical competence	Accredited by recognised body (*BCA work head for PV = ME03*)
Relationship with key suppliers	Letters of authority and training certificates
Training and after-sales capability	Inverters and spare parts in stock

Guidelines and rules of thumb

- 80-130Wp/m² roof space for crystalline modules (typically 100Wp/m²)
- 40-80Wp/m² roof space for thin film modules (typically 50Wp/m²)
- **1'200-1'300kWh/kWp energy yield per year (typically 1'200kWh/kWp/yr)**
- S$2-10/Wp installed capacity
- An **energy-efficient** semi-D needs ca 10kWp to cover electricity demand
  - Ca 100m² of roof space (crystalline modules) and <S$30'000 investment
  - Generates approx 1'000kWh/month
  - System will export excess daytime electricity to grid, and offset with imports at night
- No need to clean modules if mounted at a tilt angle (rain will clean)
- If tilt angle is shallow (<10°), better to use frameless laminates
- Do not add batteries to grid-connected system!
  - But during grid black-out, PV inverter also disconnects
- Useful website:
  - www.ema.gov.sg/images/files/handbook_for_solar_pv_systems.pdf

Photovoltaics – powering the future, today.

Thank you

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