Solar Energy – New Development and Future Trend

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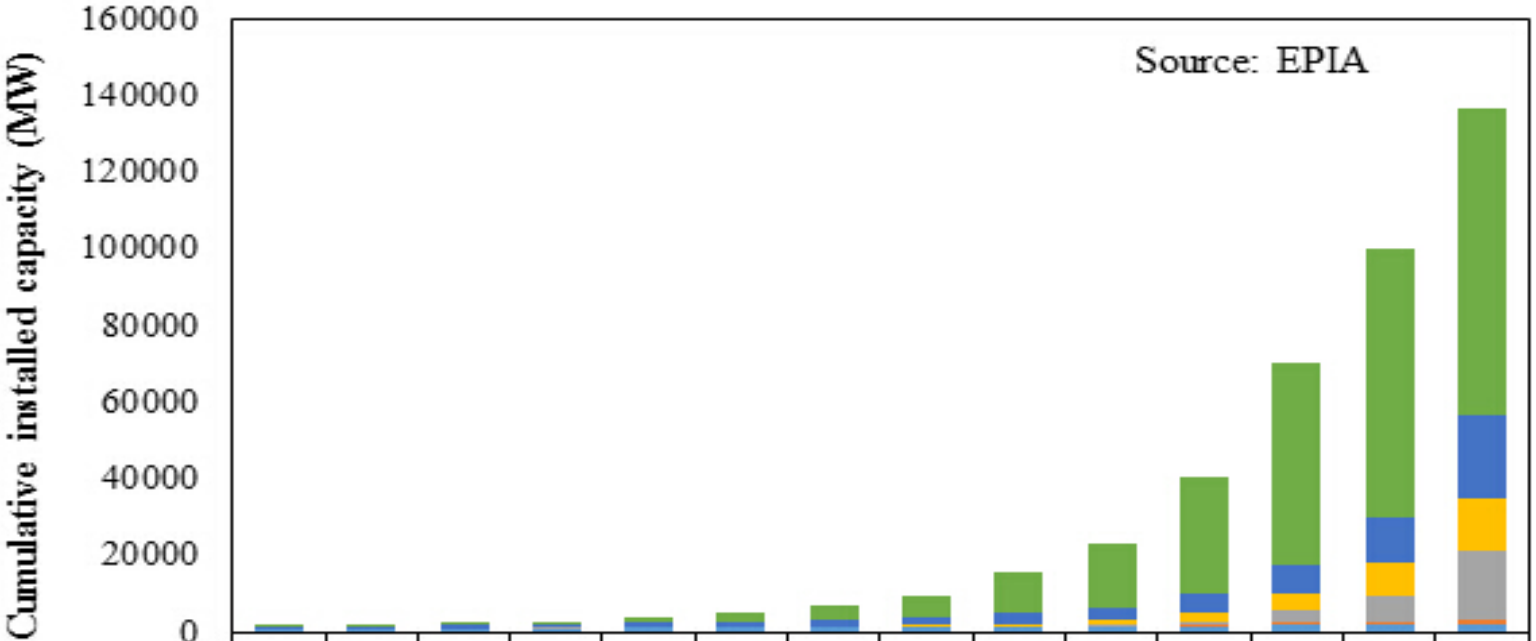
Topics:

- Rapid development of solar photovoltaic applications in China and in the world;
- Future trend of solar photovoltaic applications
- Potential BIPV applications in Hong Kong;
- Our other research projects in BIPV applications
- Conclusions

PV installation in the world

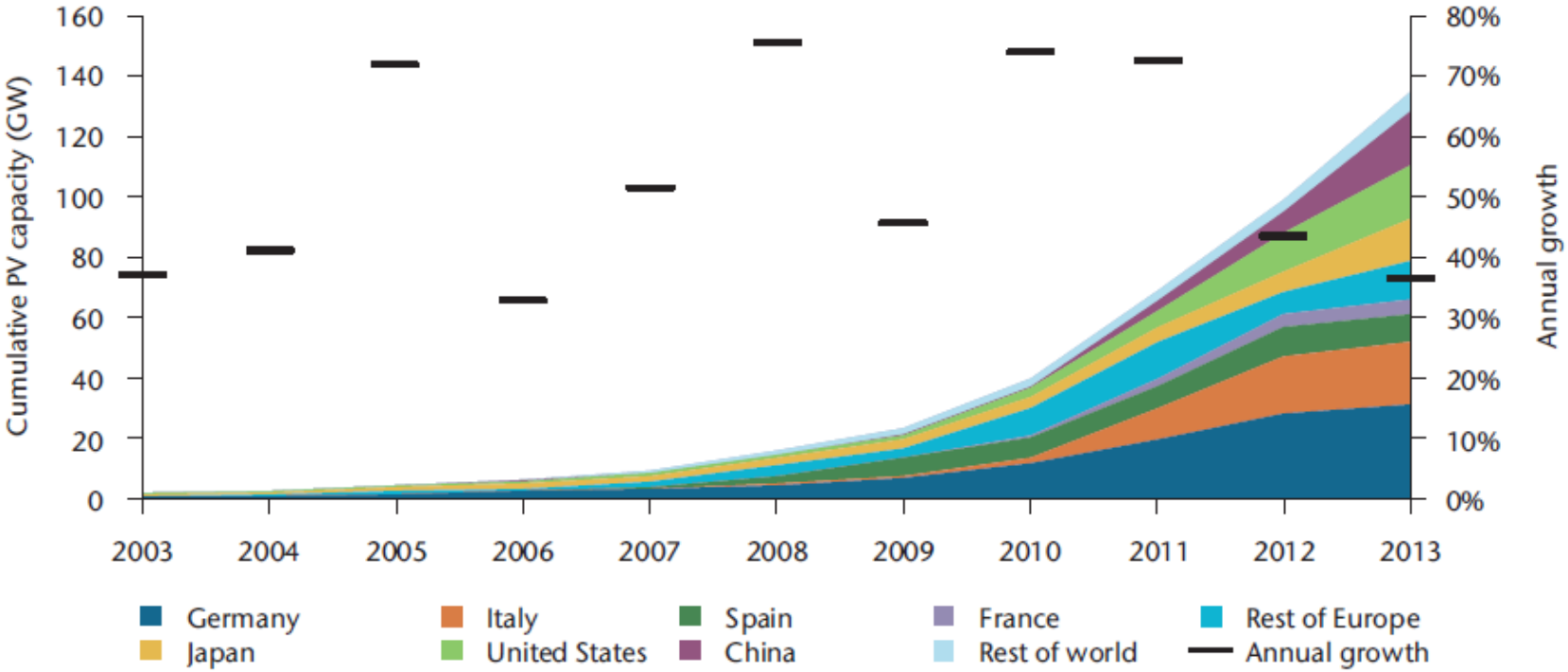


	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Europe	116	249	381	580	1283	2264	3258	5274	10970	16777	30352	52462	69699	79952
APAC	368	496	686	916	1198	1502	1827	2098	2628	3373	4951	7513	12159	21992
AMERICA	21	24	54	102	163	246	355	522	828	1328	2410	4590	8365	13518
China	19	24	42	52	62	70	80	100	140	300	800	3300	6800	18100
MEA	0	0	0	0	1	1	1	2	3	25	80	205	570	953
ROW	751	807	887	964	993	1003	1108	1150	1226	1306	1590	2098	2098	2183

Evolution of global cumulative installed capacity 2000-2013 (MWp)

PV installation in the world

Figure 1: Global cumulative growth of PV capacity

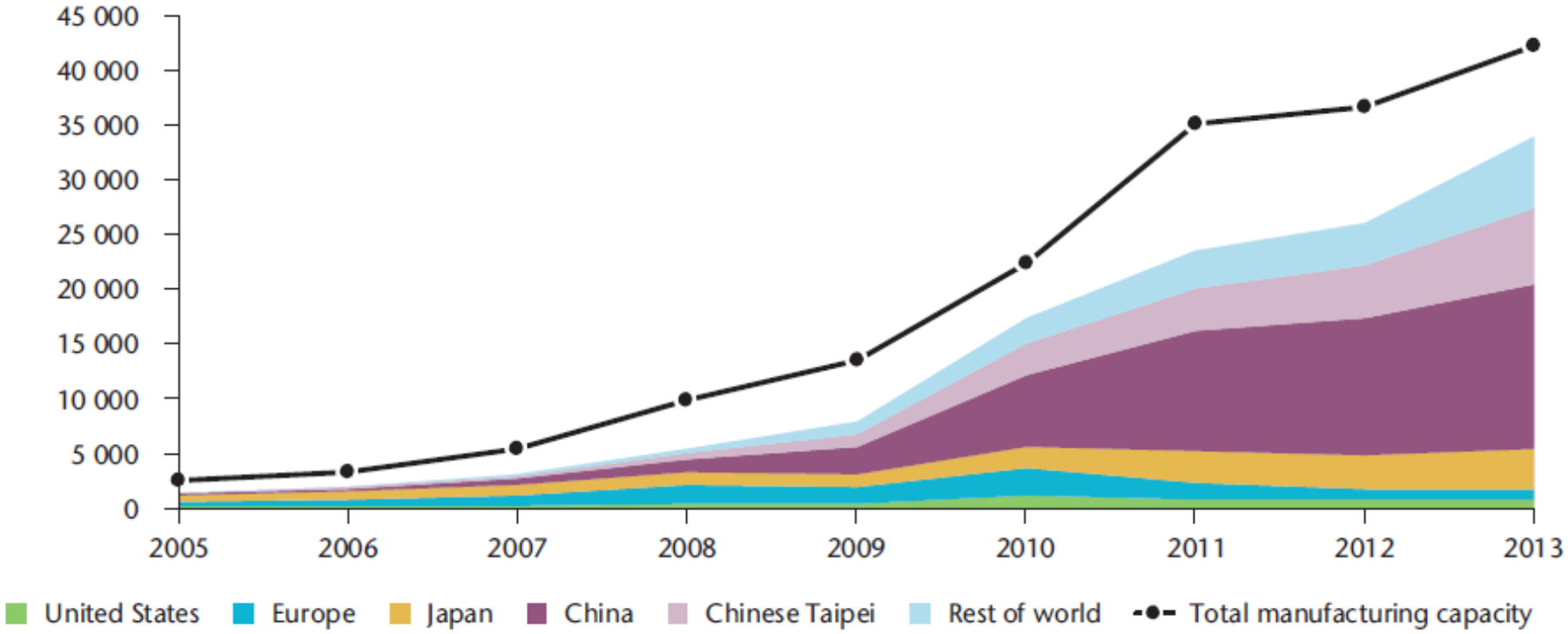


Source: Unless otherwise indicated, all tables and figures derive from IEA data and analysis.

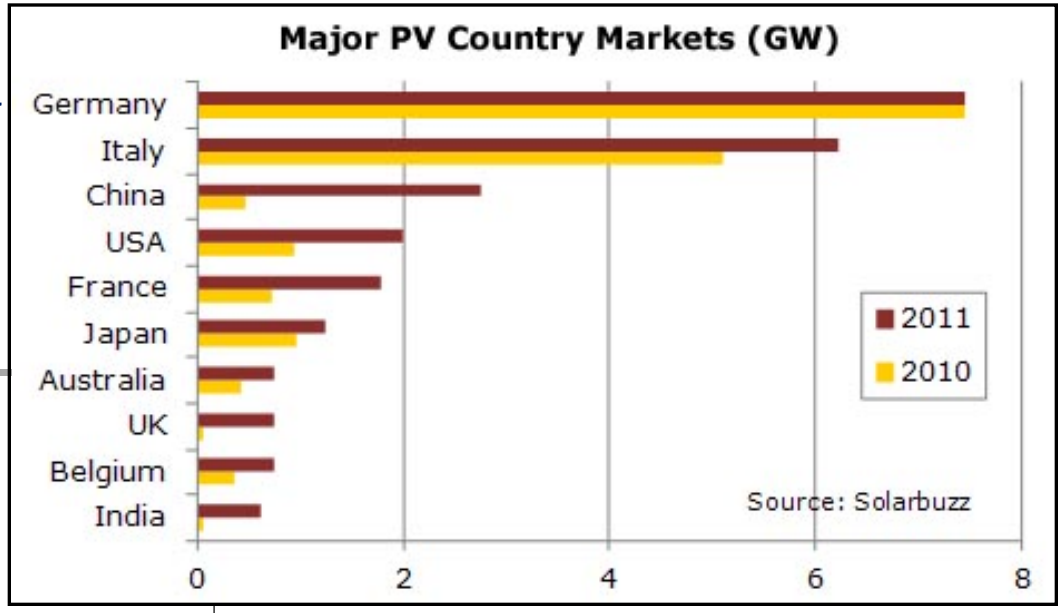
KEY POINT: Cumulative PV capacity grew at 49%/yr on average since 2003.

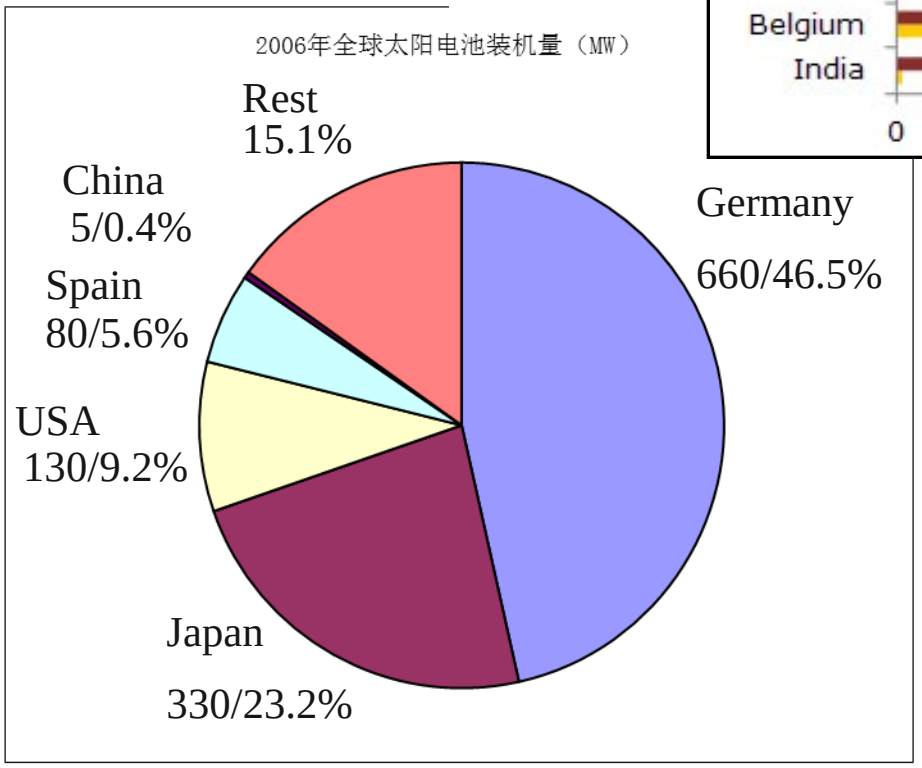
PV Manufacturing in the world

Figure 2: PV manufacturing by countries

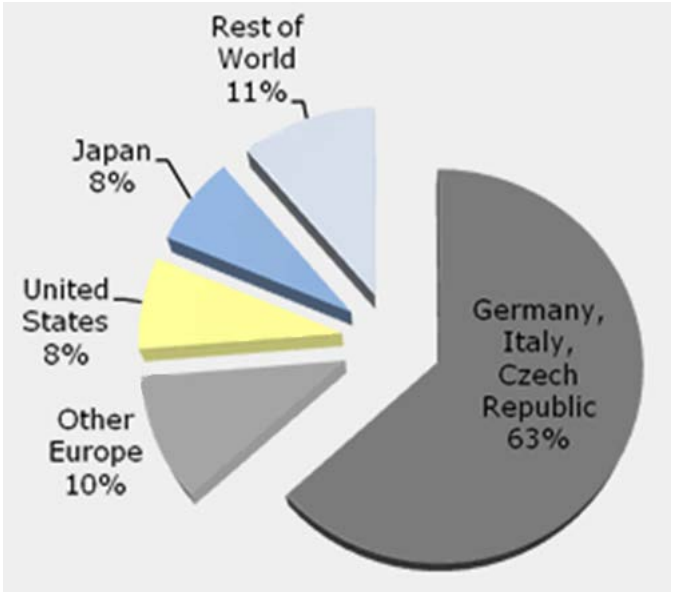


PV Installed Capacity (MWp)





2006年



2009年

PV Market in China

- 2010年安装约500MWp，累计安装800MWp，市场发展十分缓慢!
- 但是现在发展非常迅速，2.8GWp (2011), 3.5GWp (2012), 4.5GWp (2013);
- Europe has more than 80 percent of solar demand in 2010, declining to 53% in 2012 and only 39% in this year;
- 33% of global solar PV shipments ended up in China now;
- 7 out of the top 10 leading solar PV suppliers are based in China

Market PV module price 光伏板零售市场 价格

(RMB¥4.5 per Wp now in China！)

- 83% of PV module price has been reduced during last 6 years; the historic PV module price in China was shown in Figure 4. It was RMB 36 Yuan/Wp in 2007, and by 2011, it was RMB 9 Yuan/Wp. The lowest retail price once dropped down to ~RMB 5 Yuan/W (~0.63EUR) in 2011.

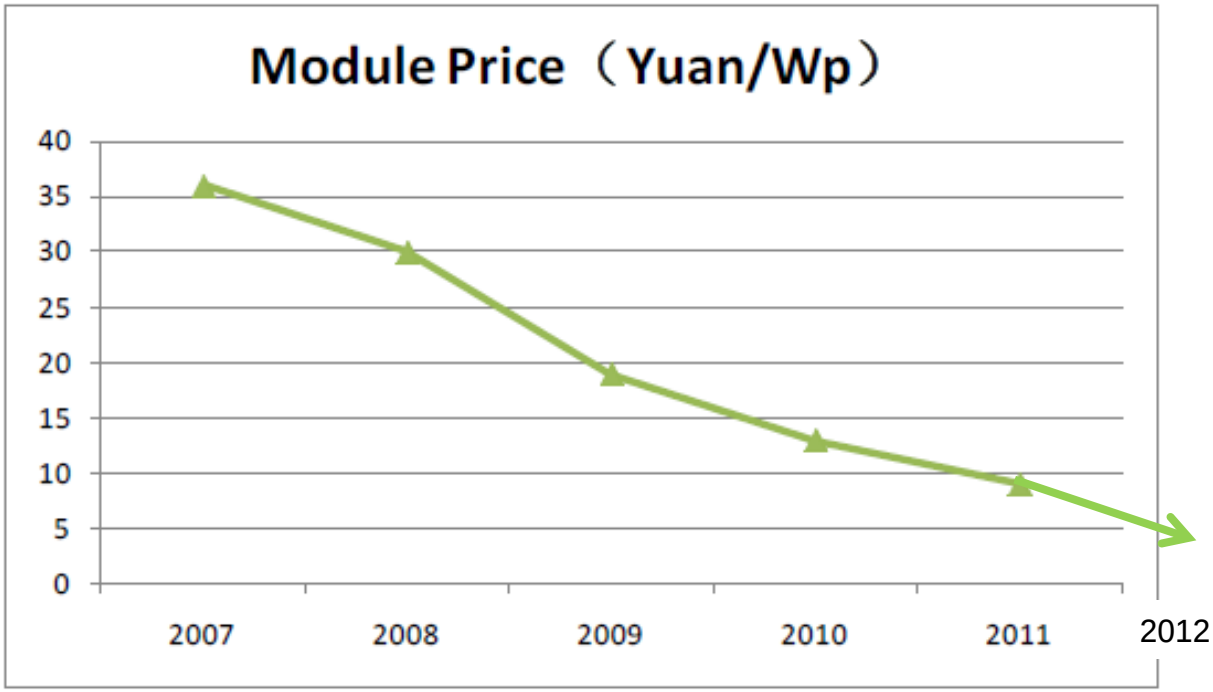
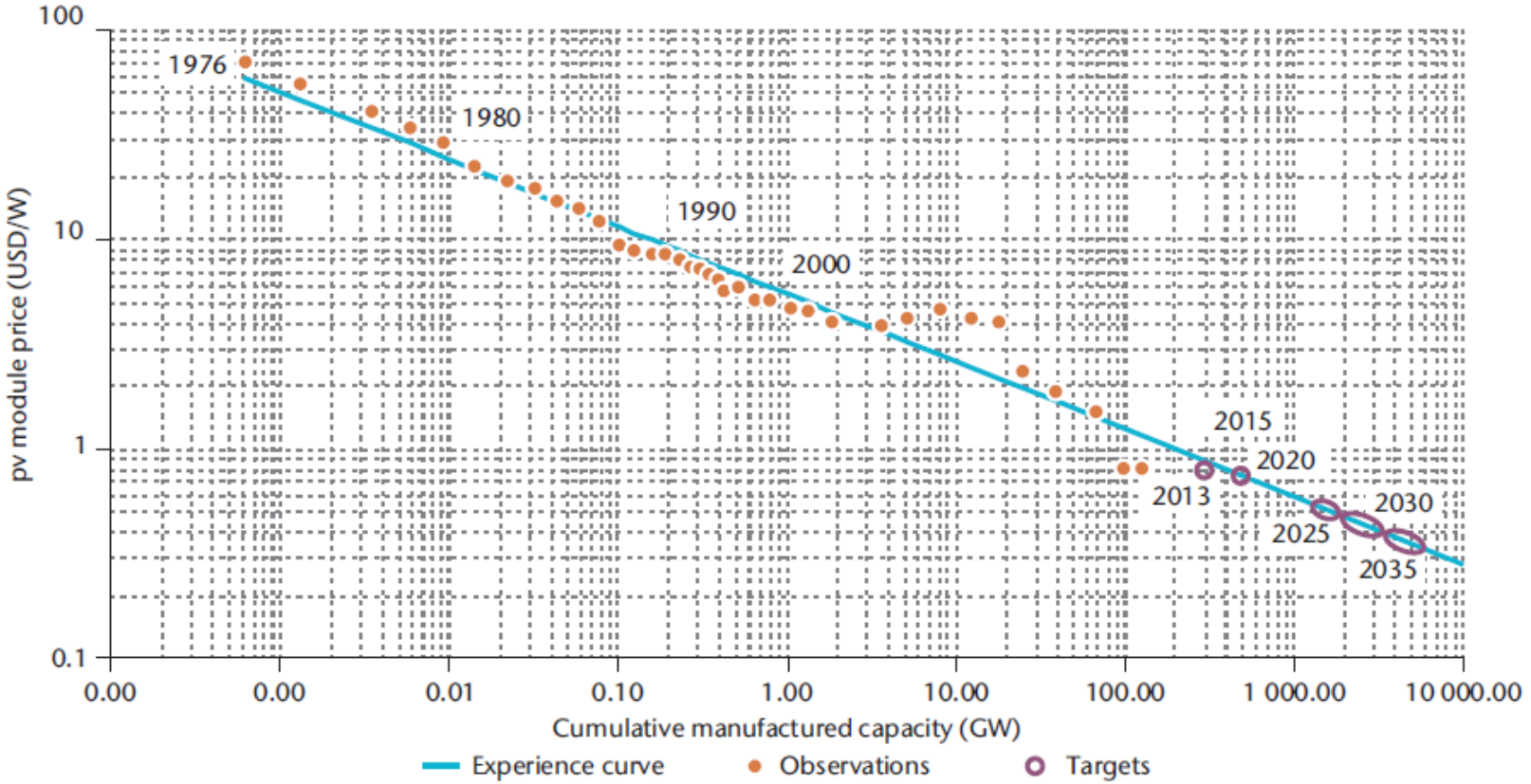


Figure 4: PV module price in China, 2007-2012

Market PV module price in the world

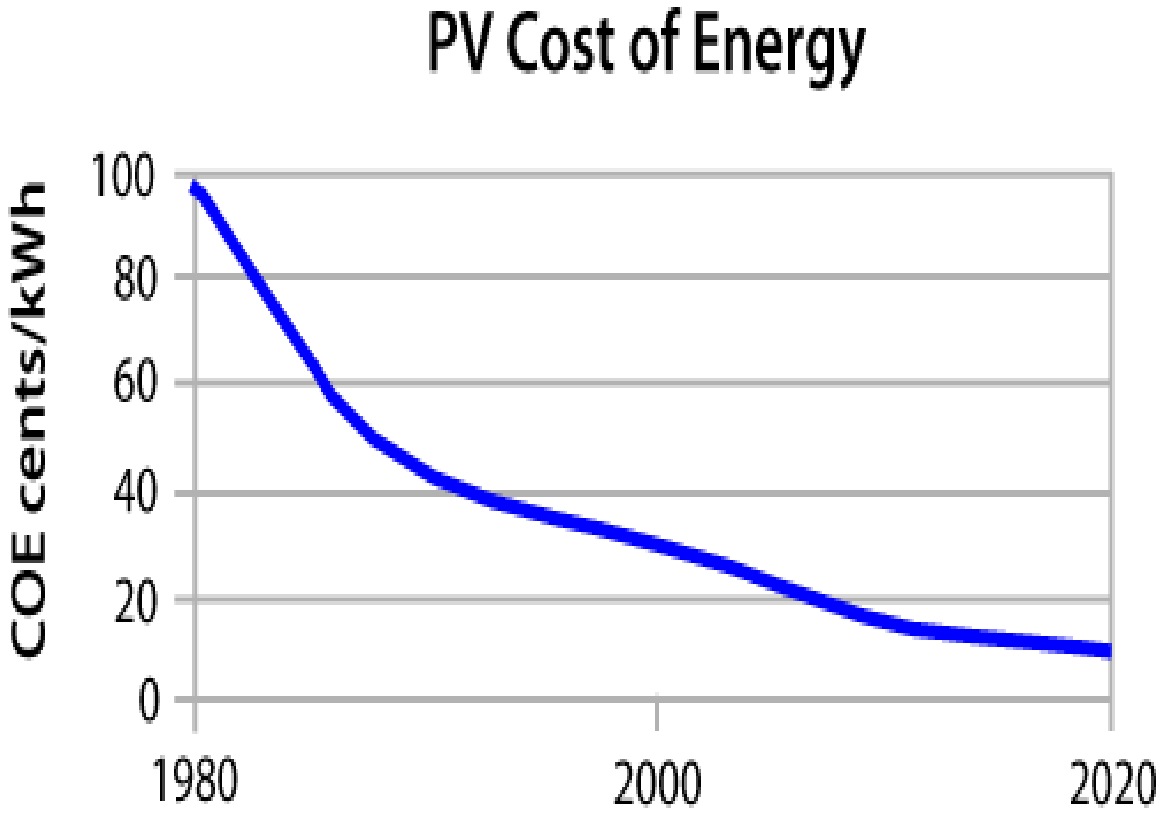
Figure 10: Past modules prices and projection to 2035 based on learning curve



Notes: Orange dots indicate past module prices; purple dots are expectations. The oval dots correspond to the deployment starting in 2025, comparing the 2DS (left end of oval) and 2DS hi-Ren (right end).

KEY POINT: This roadmap expects the cost of modules to halve in the next 20 years.

Electricity cost of solar power



Estimation of payback of a BV-roof

Location: Shenzhen User：Manufacturer

PV capacity：1000kWp (1M/Wp)

Initial investment：RMB¥10,000,000 (about ¥4-5/Wp for PV module, ¥2-3/Wp for inverter/controller /cables, and ¥2-3 for supporting frame and installation)

Annual power: 1,000,000×1.1kWh=1,100,000kWh

RMB¥1.00/kWh is charged to the user for 10 years:

Benefit：RMB¥1.00×1.0M×10= RMB¥10,000,000

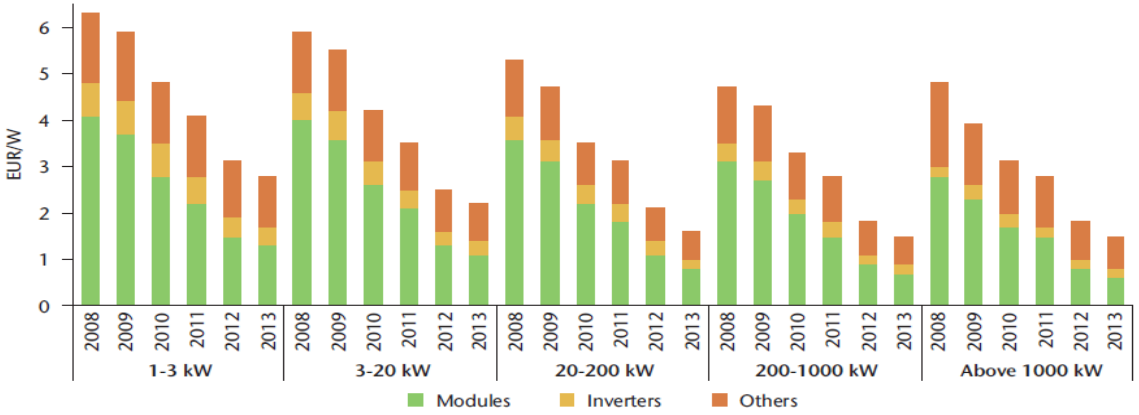
PV system cost in the world

Table 2: Typical PV system prices in 2013 in selected countries (USD)

USD/W	Australia	China	France	Germany	Italy	Japan	United Kingdom	United States
Residential	1.8	1.5	4.1	2.4	2.8	4.2	2.8	4.9
Commercial	1.7	1.4	2.7	1.8	1.9	3.6	2.4	4.5
Utility-scale	2.0	1.4	2.2	1.4	1.5	2.9	1.9	3.3

Sources: Friedman et al. (2014), *Comparing PV Costs and Deployment Drivers in the Japanese and U.S. Residential and Commercial Markets*, February, NREL/TP-6A20-60360; PV-PS IA (2014a), *PV Cost Data for the IEA*, personal communication, January.

Figure 3: System prices in Italy, 2008-2013

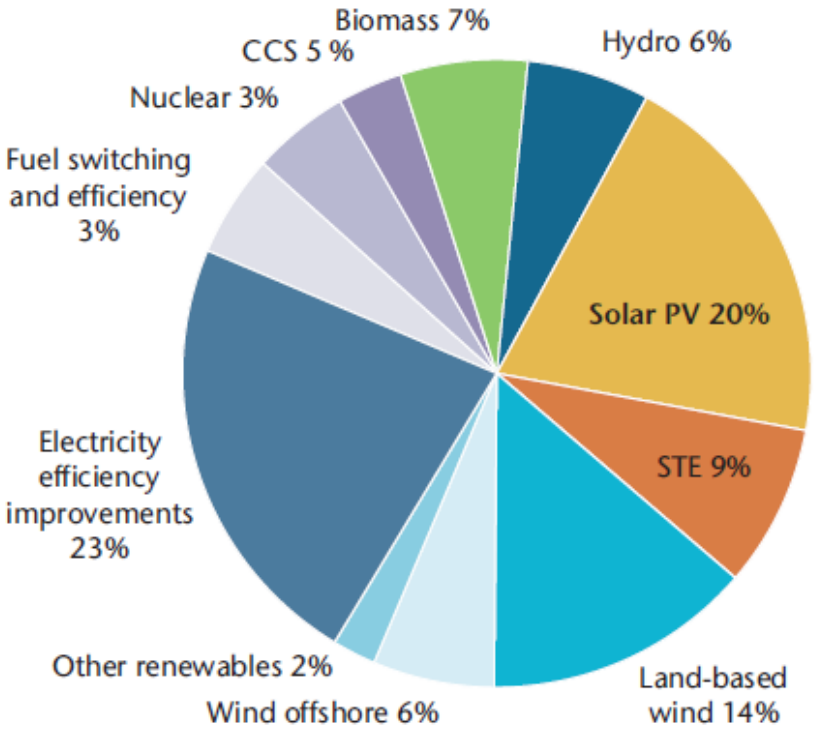


Source: Gestore dei Servizi energetici (GSE) (2014), *PV in Italy: Generation Costs and Value Chain*, May, Rome.

KEY POINT: In 2013, PV systems in Italy cost 30% to 44% of what they cost in 2008.

Forecast of PV power in the future

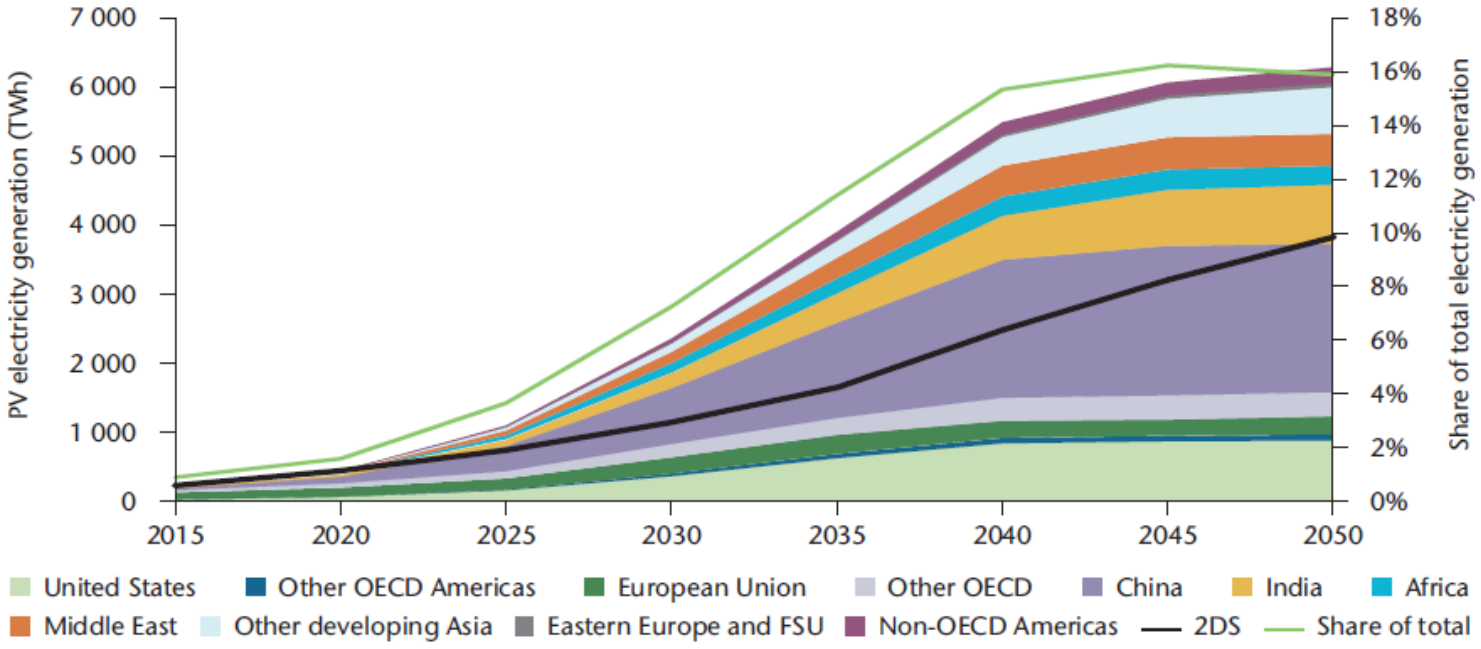
Figure 6: Cumulative technology contributions to power sector emission reductions in *ETP 2014* hi-Ren Scenario, relative to 6DS, up to 2050



KEY POINT: Solar PV would equal wind power in cutting CO_2 emissions over the next 35 years.

Forecast of PV power in the future

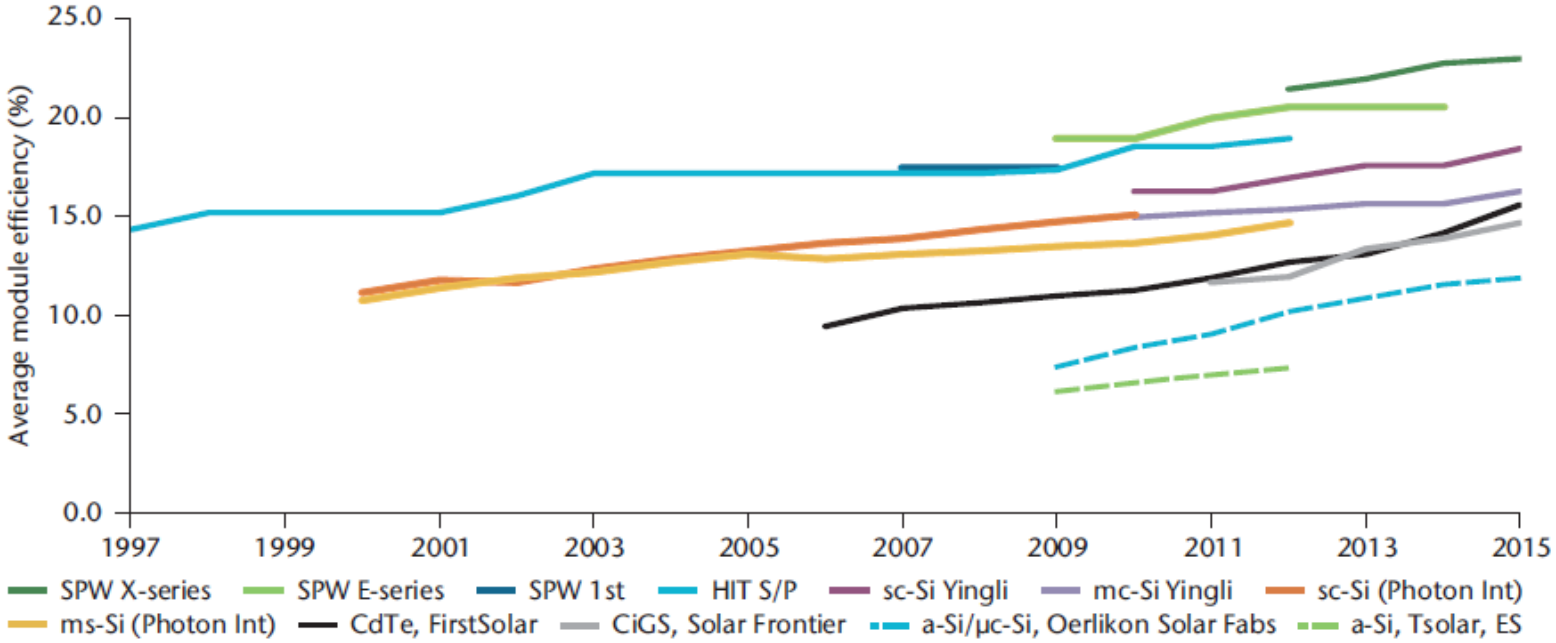
Figure 8: Regional production of PV electricity envisioned in this roadmap



KEY POINT: in the hi-Ren scenario, PV provides 16% of global electricity by 2050, and China has a 35% share of the total PV electricity production.

PV module efficiencies

Figure 13: Commercial 1-sun module efficiencies (actual and expected)

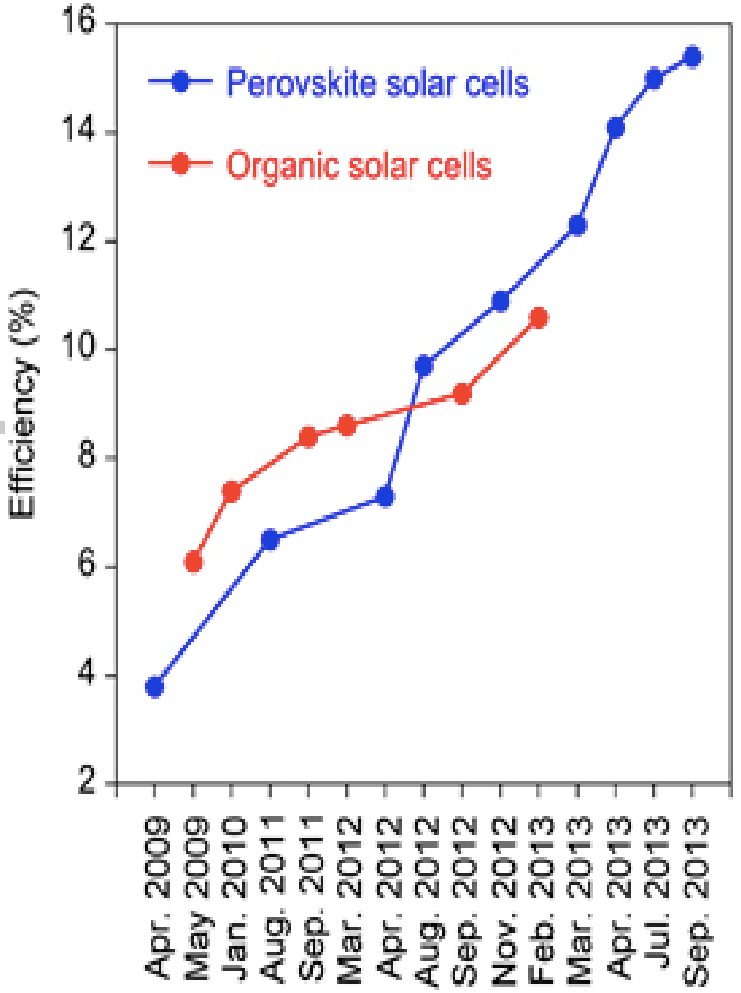


Note: SPW stands for *SunPower*, HIT S/P stands for *Heterojunction Intrisic Thin layer Sanyo/Panasonic*.

Source: De Wild-Scholten, M. (2013), "Energy payback time and carbon footprint of commercial PV systems", *Solar Energy Materials & Solar Cells*, No. 119, pp. 296-305.

Solar cell efficiencies

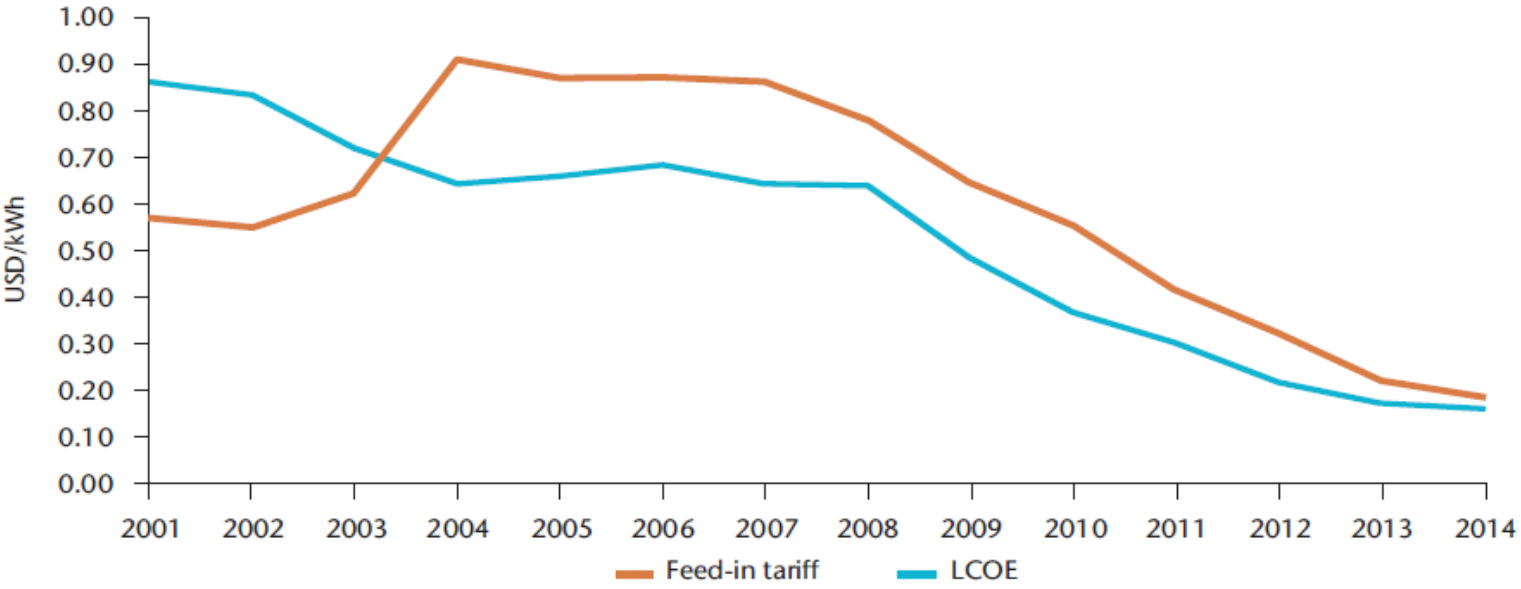
PV cell type	Efficiency （%）
Single Crystalline solar cell	25.6±0.5
Polytechnic Crystalline solar cell	20.4±0.5
Amorphous Crystalline solar cell	10.1±0.3
CIGS solar cell	20.5±0.6
CdTe solar cell	19.6±0.4
Dye-sensitized solar cell	11.9±0.4
Organic solar cell	10.7±0.3
Perovskite Solar cell	**17.9±0.8**



Perovskite Solar Cells Beat New Records to 17.9%

Energy policy in Germany

Figure 22: Feed-in tariff levels and LCOE of small rooftop in Germany (USD/W)



Note: The German feed-in tariff applies to systems <30 kW to April 2012 and to systems <10 kW after that. LCOE assumptions: real discount rate 2.4%, annual O&M 1% of initial investment, 1040 full load hours. All prices are in 2013 USD.

KEY POINT: Feed-in tariffs, if well-managed, can deliver PV deployment providing fair remuneration to investors.

Project: 10MWp in Inner Mongolia

工程项目: 中国内蒙古阿左旗二期地面光伏电站

装机容量: 10MWp

竣工日期: 2011年12月

工程项目: 中国青海格尔木(龙源)
类型: 地面电站
装机容量: 30MWp
竣工日期: 2011年12月
格尔木位于青海省西部，西接新疆自治区，南与西藏自治区毗邻，年日照超过3000小时，日最高发电量接近20万度电。

Project: Ge'ermu(Longyuan), Qinghai, China
Type: Utility
Capacity: 30MWp
Completion Data: Dec. 2011
Ge'ermu is in western Qinghai Province, adjacent to Xinjiang and Tibet, and the annual irradiation is over 3000 hours. The maximum generating capacity up to date is close to 200,000 kWh.

工程项目: 中国内蒙古四子王旗
类型: 地面电站
装机容量: 40MWp
竣工日期: 2011年12月
四子王旗位于内蒙古境内，年日照量在2,000小时左右，此项目可每年减少二氧化碳排放约6万吨。

Project: Siziwangqi, Inner Mongolia, China
Type: Utility
Capacity: 40MWp
Completion Data: Dec. 2011
Siziwangqi is located in Inner Mongolia, north of China. With sun irradiation of 2,000 hours per year, the project would save approximate 60,000 ton of CO2 emission every year

20MWp in Xuzhou

徐州协鑫光伏电力有限公司20兆瓦大型光伏地面电站正式实现并网发电

1MWp solar roof project in Shenzhen

- 深圳国际园林花卉博览园的1兆瓦光伏屋顶。

Functions of BIPV

- Power generator
- Part of construction materials
- Water proof
- Shading
- Noise barrier
- Insulation
- Natural lighting

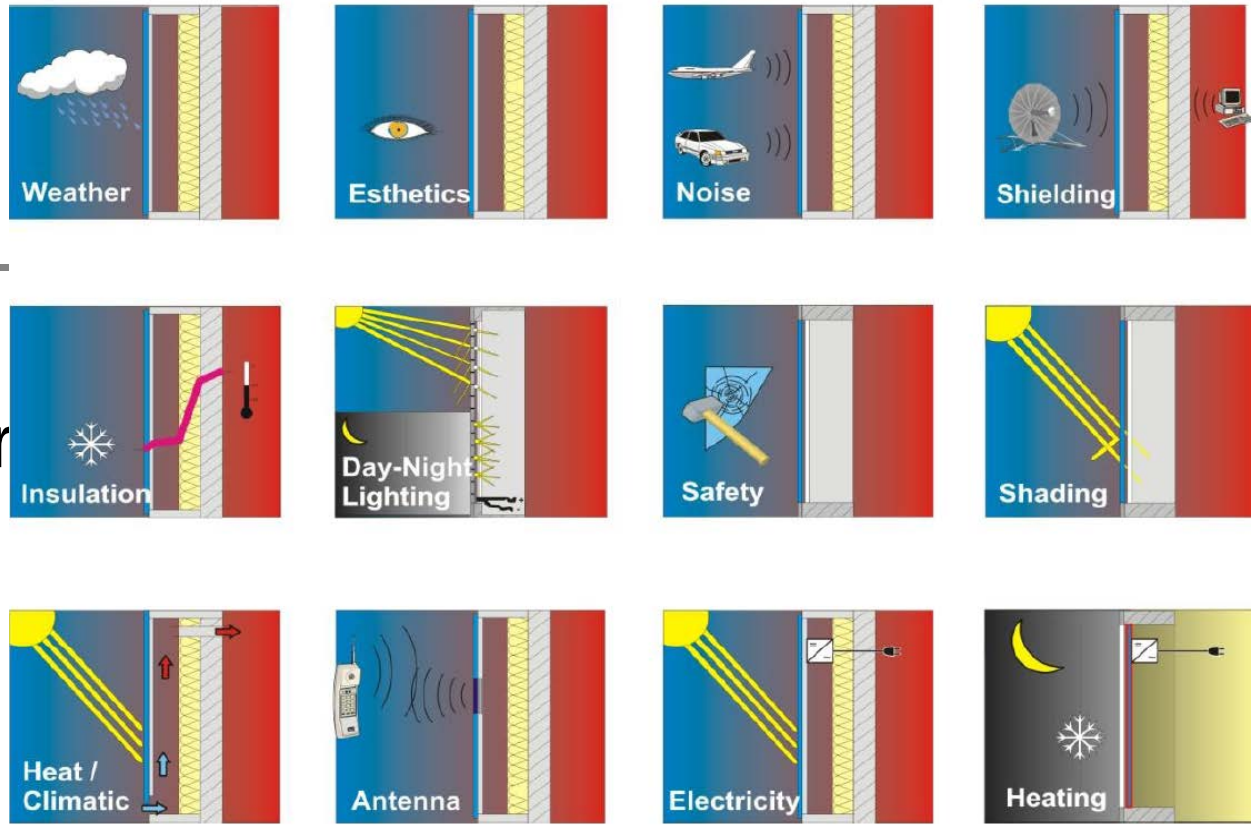


Figure 1. Multiple functions of PV modules. Source: Multielement project

Advantages of BIPV

- Power generation from renewable energy: clean and CO2 emission reduction;
- No need of expensive land is used in urban areas;
- Reduction of construction cost due to replacement of cladding;
- No power transmission is needed and power is used in the building;
- Peak power demand is reduced as solar power is generated when needed;
- Cooling load and lighting load may be reduced.

BIPV potential

Available Roof Surface					
	Net Available Solar Surface (Km^2)	Installable PV "Potential" (GW)	Estimated Electricity production (Twh/year)	Residential Electricity consumption 2006 (TWh/year)	% of PV
Europe (75%: Germany, France, UK, Italy, Spain)	3.723	465,4 ($8m^2$/Kwp)	511,9	859	59%
		161,9 ($23m^2$/KWp)	178,1		20%
USA	4.563	570,4 ($8m^2$/Kwp)	570,4	1351	42%
		198,4($23m^2$/KWp)	198,4		14%
Japan	1.050	131,3 ($8m^2$/Kwp)	118,1	229	51%
		45,7 ($23m^2$/KWp)	41,1		18%

** Facades not included*

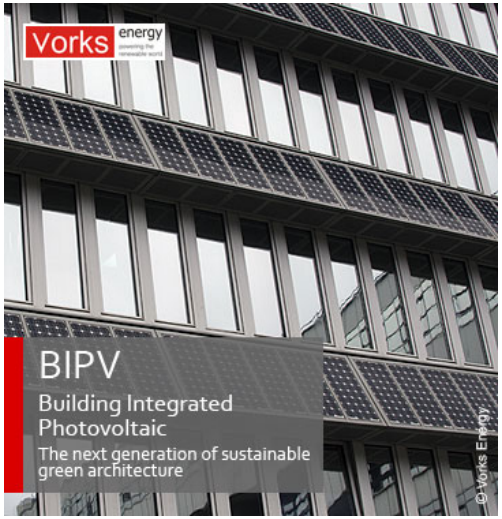
- 据NanoMarkets预测，2016年BIPV市场将超过110亿美元规模，并且BIPV装机容量也将增加十倍左右，从2011年343MW增长到2016年3.6GW容量,同时BIPV的成本可能达到$2.50/Wp。
- Pike research 预测，到2017年全球BIPV装机容量将达到4.6GW。

BIPV projects

BIPV projects: semi-transparent

BIPV Projectws

天窗、中庭

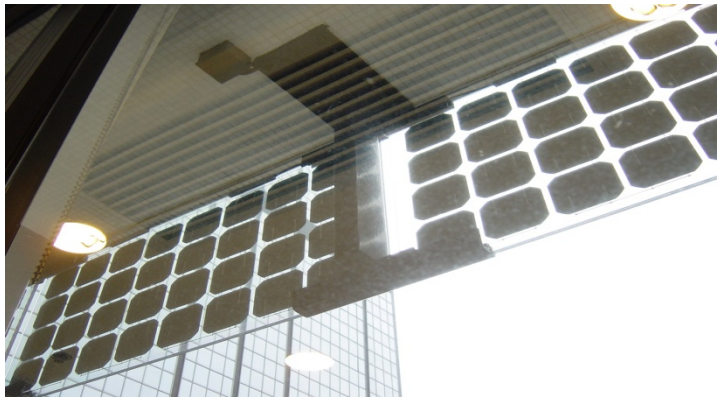


BIPV Projects

The CIS Tower in Manchester was clad in PV panels at a cost of £5.5 million. It started feeding electricity to the National Grid in November 2005.

The Wai Chai Tower BIPV project

Year of installation	2002
Power capacity	55 kWp
Type of integration	Vertical façade; semi-transparent modules; roof integrated modules



The BIPV projects in the Science Park

The BIPV systems in the Science Park:

•roof integration,

•sun-shaded type and façade integration

政府机电工程署大楼：350千瓦

EMSD Headquarters at Kowloon Bay (350 kW)

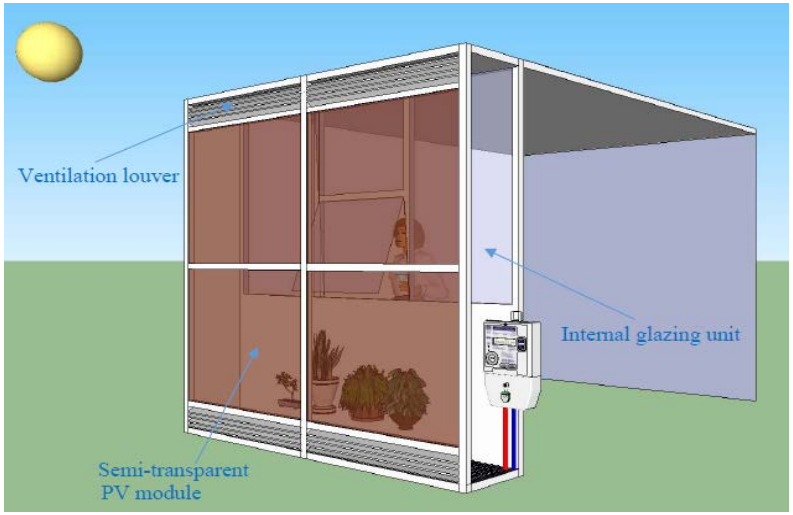
The Largest PV installation in Lammar Island:

550kWp

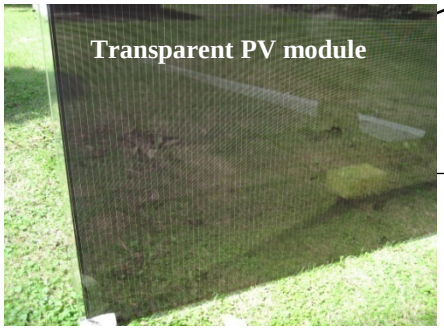
PV modules: DuPont
(Amorphous thin film)
Developer: HK Electric

- Amorphous silicon photovoltaic module – 5,500 pieces
- Total Area of PV modules – 8470 m²
- Maximum output of each PV module – 100 W
- Total installed Capacity – 550 kW
- Capacity Factor – 12.9%
- Anticipated power output – 620,000 kWh
- Design life – 20 years
- Project Cost – HK$23 million

Our recent research in BIPV



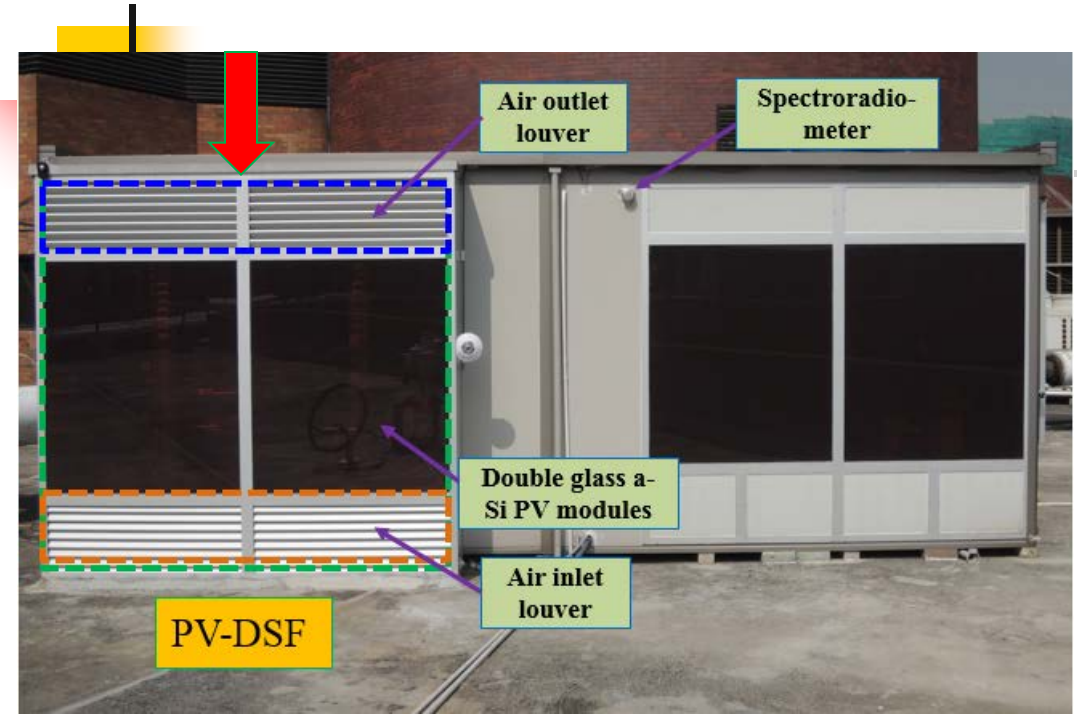
Airflow and heat transfer in open/close cavity



Close cavity

Open cavity

Development of a ventilated PV-DSF



Principle:

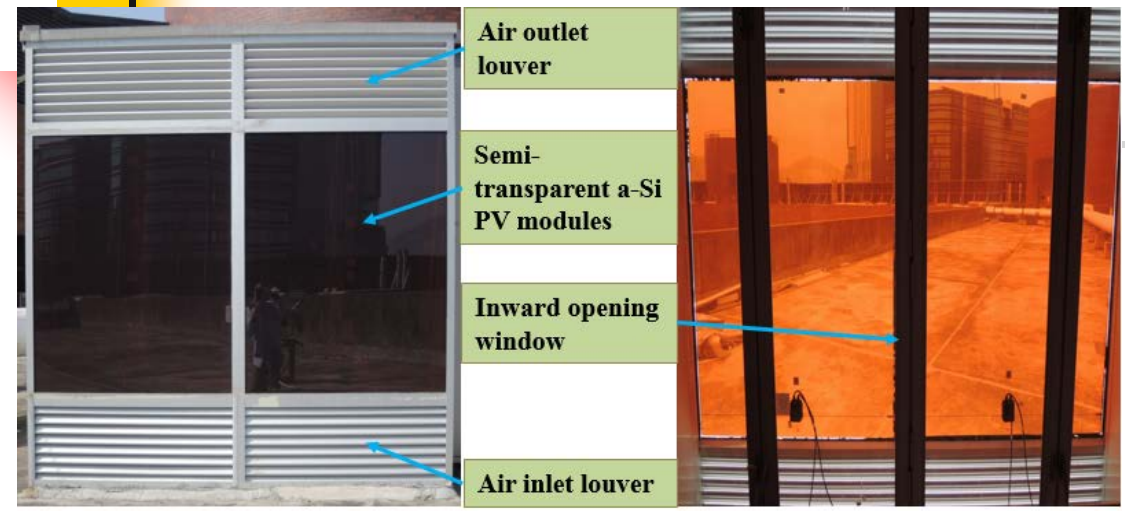
- Combining BIPV and DSF technologies to improve its thermal, power and daylighting performances

Research contents:

- Real-time power generation
- Thermal performance
- Daylighting performance

PolyU campus

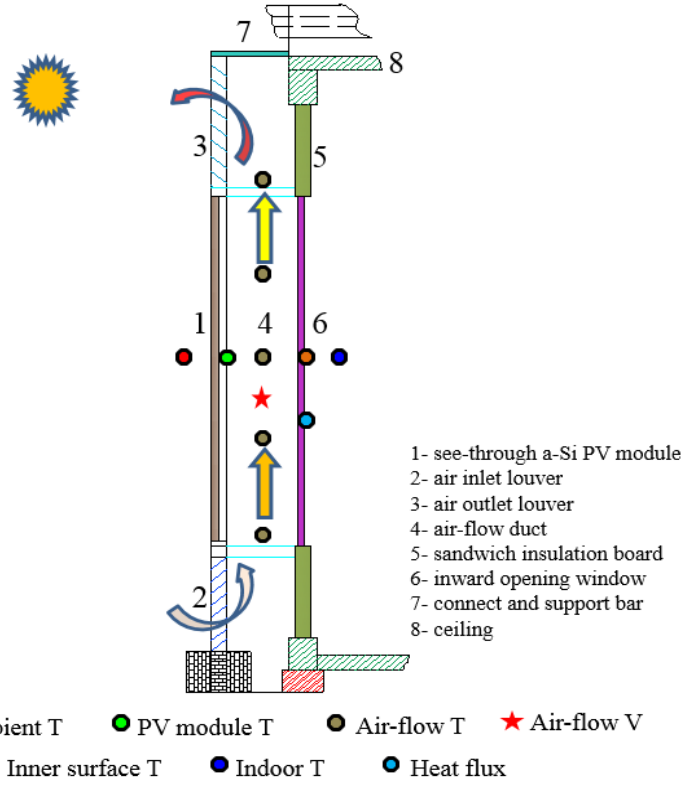
Structure of the PV-DSF



(a) Outside view (b) Inside view

Constituted by:

- a-Si PV laminates
- inward openable window
- airflow cavity
- air louvers

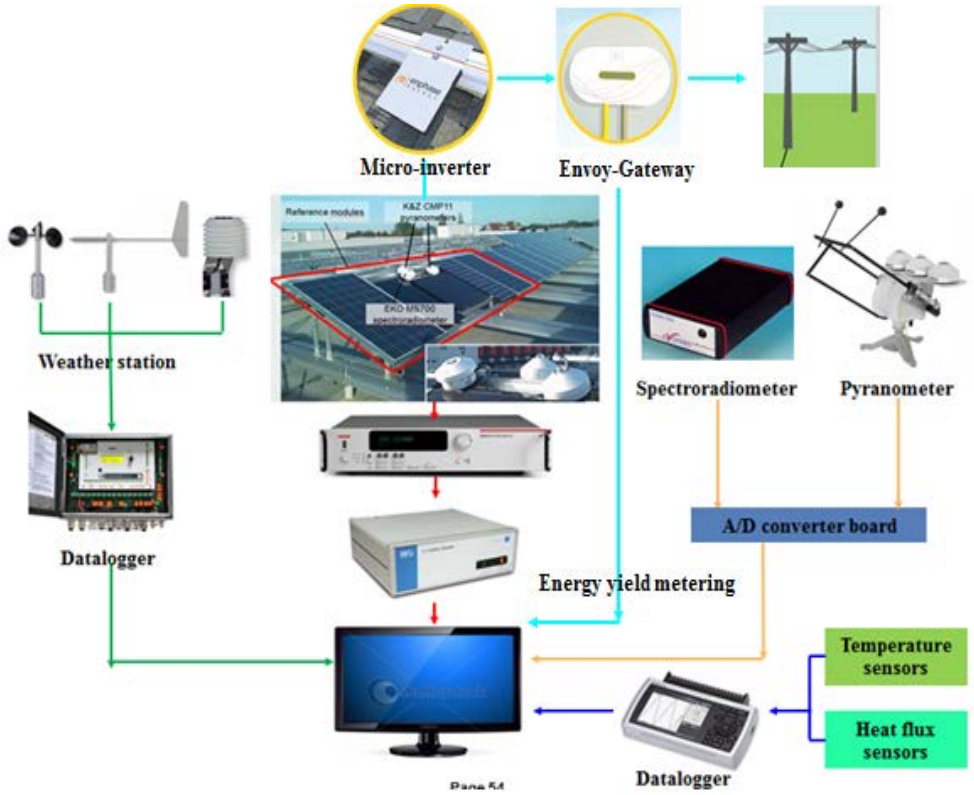


Advantages of the design:

- air exchange & solar passive heating
- improved daylighting performance
- ventilation design
  - reducing cooling load
  - enhancing PV energy efficiency

Testing and data acquisition system

- A testing and data acquisition system has been built for the BIPV testing facility.



- testing the I-V characteristic of different PV modules simultaneously
- quickly switching the status of PV module between I-V testing state and on-grid power generation state.
- weather data would be collected simultaneously.

Figure 1 the testing and data acquisition system for BIPV testing facility

Study on semi-transparent solar PV windows

- A trial facade for HA

Study on semi-transparent solar PV windows

PV systems	Solar cell types	Rated power	Efficiency/ Transmittance
PV window 1	Semi-transparent a-Si	a-Si: 56W*3	6.3%/20%
PV window 2	Semi-transparent hollow a-Si	97W	6.8%/20%
PV shading 1	Poly-Si	260W	16%/opaque
PV shading 2	CIGS	150W	12%/opaque
No ventilated PV	Poly-Si	260W	16%/opaque
Ventilated PV	Poly-Si	260W	16%/opaque

Study on semi-transparent solar PV windows

Inside views of PV windows

Ventilated PV window

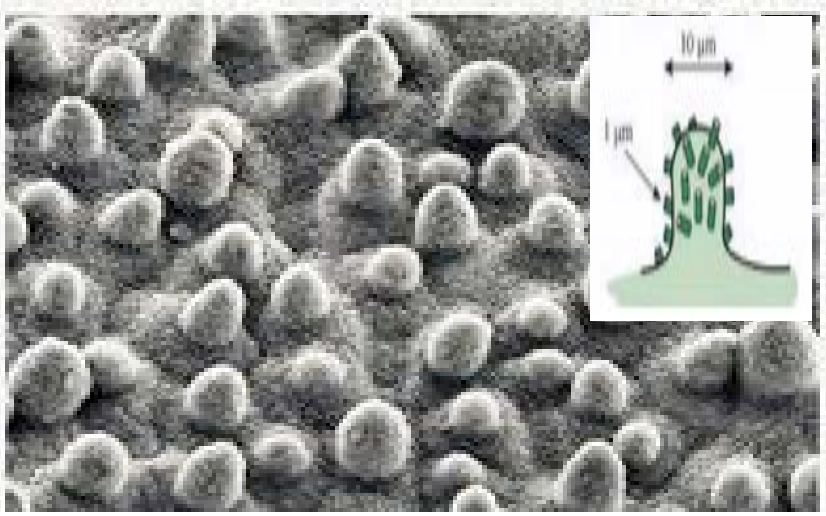
Efficiency: 6.8%
Transmittance:20%
Rated power: 68W/m^2

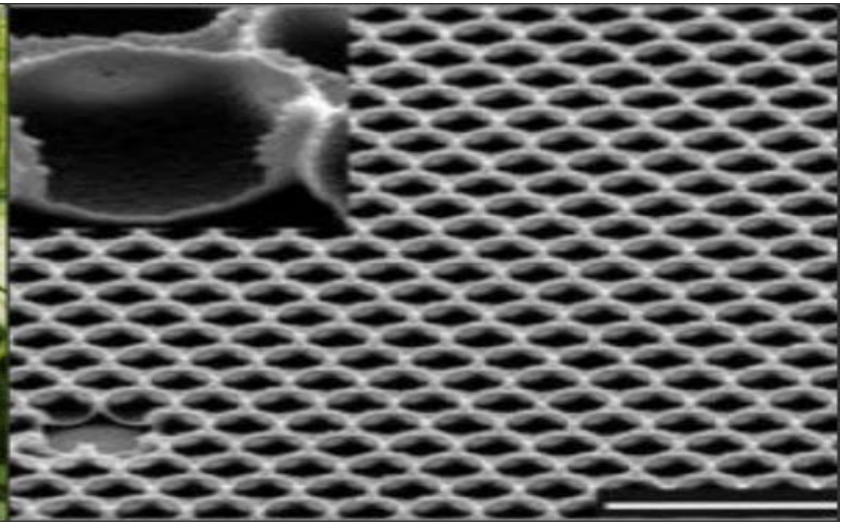
Efficiency: 6.3%
Transmittance:20%
Rated power: 63W/m^2

Hollow PV window

Study on self-cleaning technology for cleaning PV modules:

- A Concept From Bionic Structure

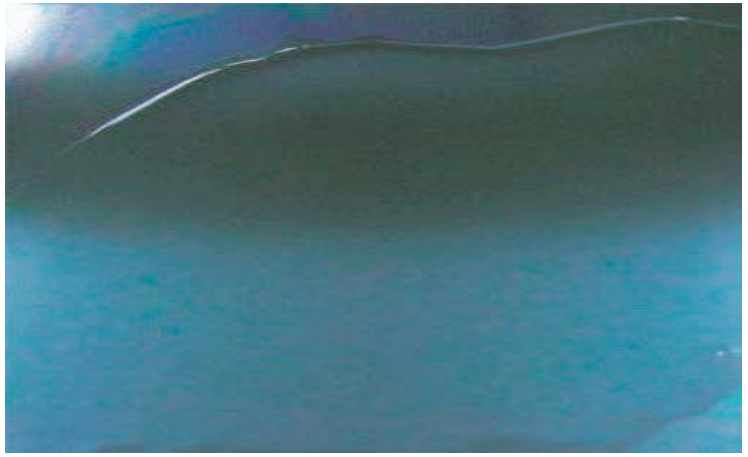




Super-Hydrophobic surface and Super-Hydrophilic surface

Super-hydrophobic , θ(Lotus leaf):>150°

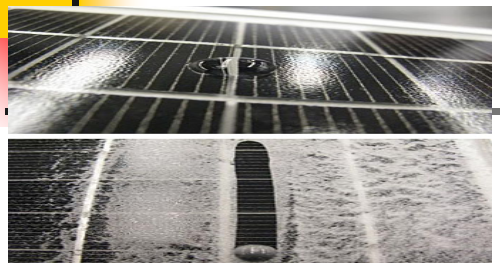
Super-hydrophobic self-cleaning glass



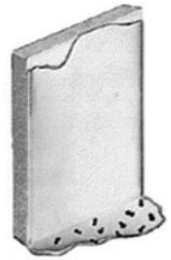
Super-hydrophilic, θ（clean glass surface）:<10°

Super-hydrophilic self-cleaning glass

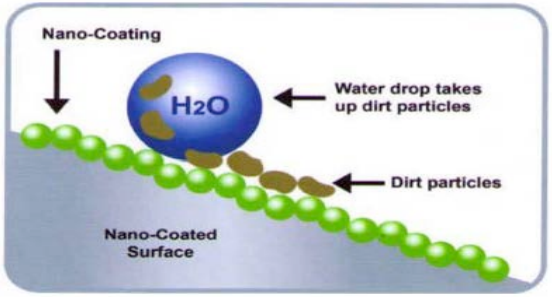
Super-Hydrophobic surface VS. Super-hydrophilic Surface



ordinary curtain wall



hydrophilic curtain walls coated with TiO_2



Super-Hydrophobic glass: A thin layer of nanostrcutured polymer or wax coating

Advantages:
(1) Super hydrophobic property to form the water droplet to wash away the inorganic dirt

Disadvantages:
(1)Can not remove organic grime
(2)A costly and time consuming process
(3)Short life time

Super-Hydrophilic glass: A thin layer of TiO_2 coating:

Advantages:
☎🗁） Photo induced super-hydrophilic properties to form the water sheet to wash away the inorganic dirt
（🗎） Photocatalysis to break down the organic grime into CO_2 and water

Disadvantages:
(1) Should be activated by sunlight after some time

Advantages of our product: Superior self-cleaning property

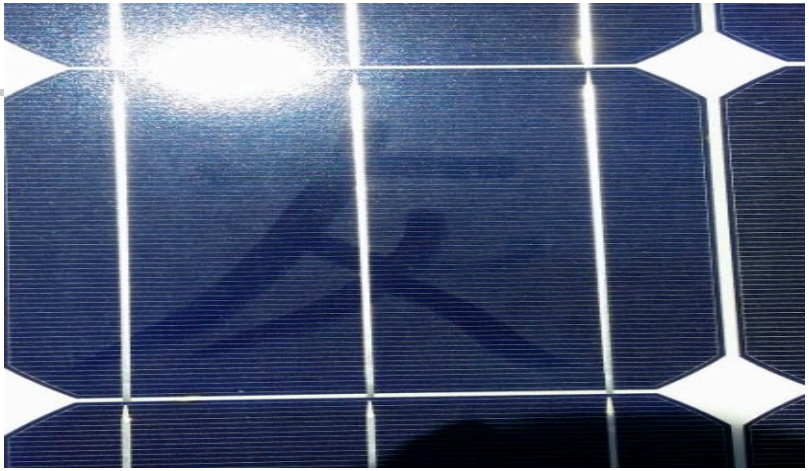
The comparison between two PV modules after two month. The self-cleaning coating has superior super-hydrophilicity.

Practical Applications: Shen Zhen

5% total power output increment

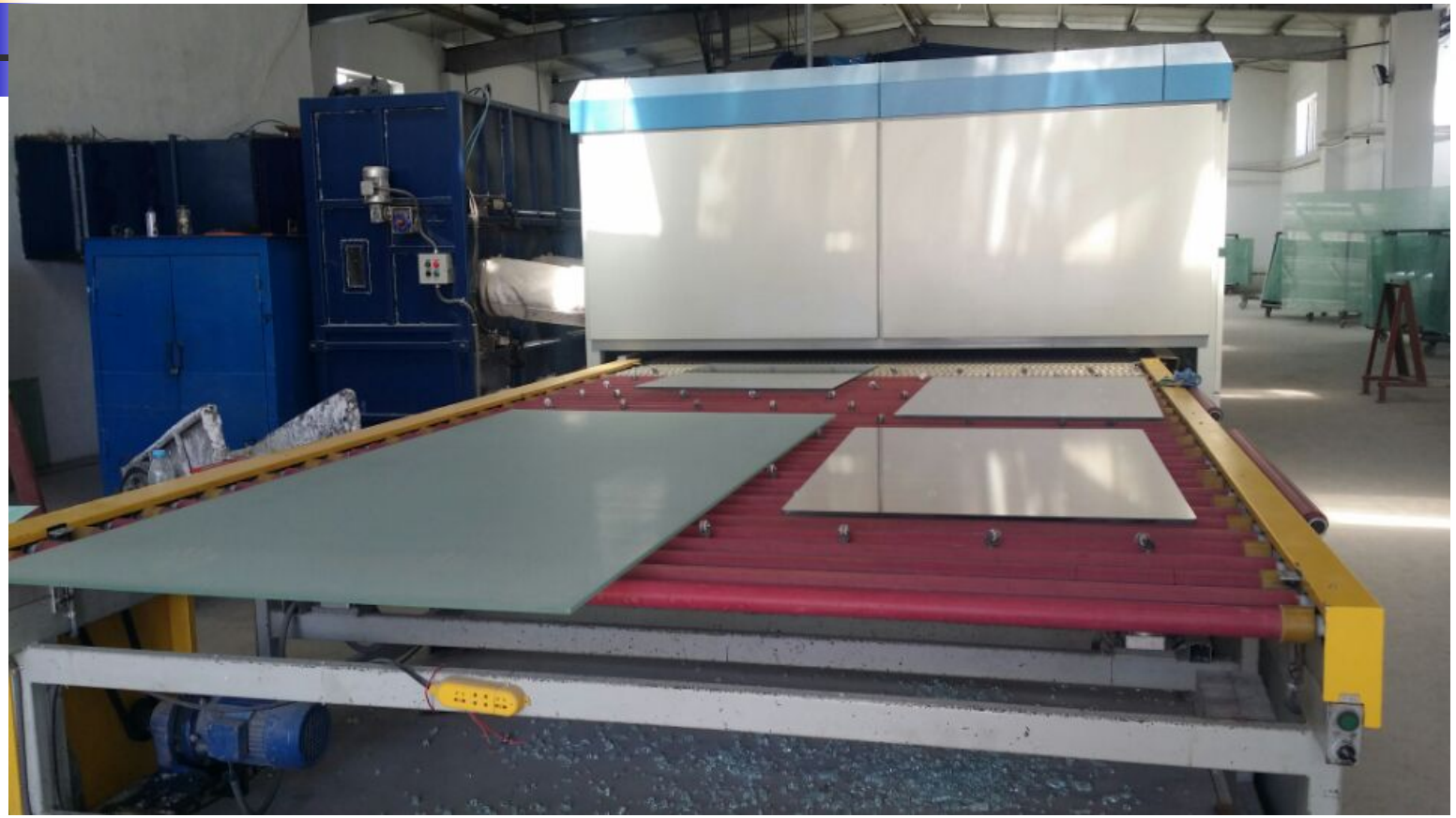
The photovoltaic power stations, Han’s Laser Co. Ltd, ShenZhen

Practical Applications: Gan Su



The 100 MW photovoltaic power stations in Jia-Yu-Guan, Gansu Province

Practical Applications: Glass Factory in ShenZhen



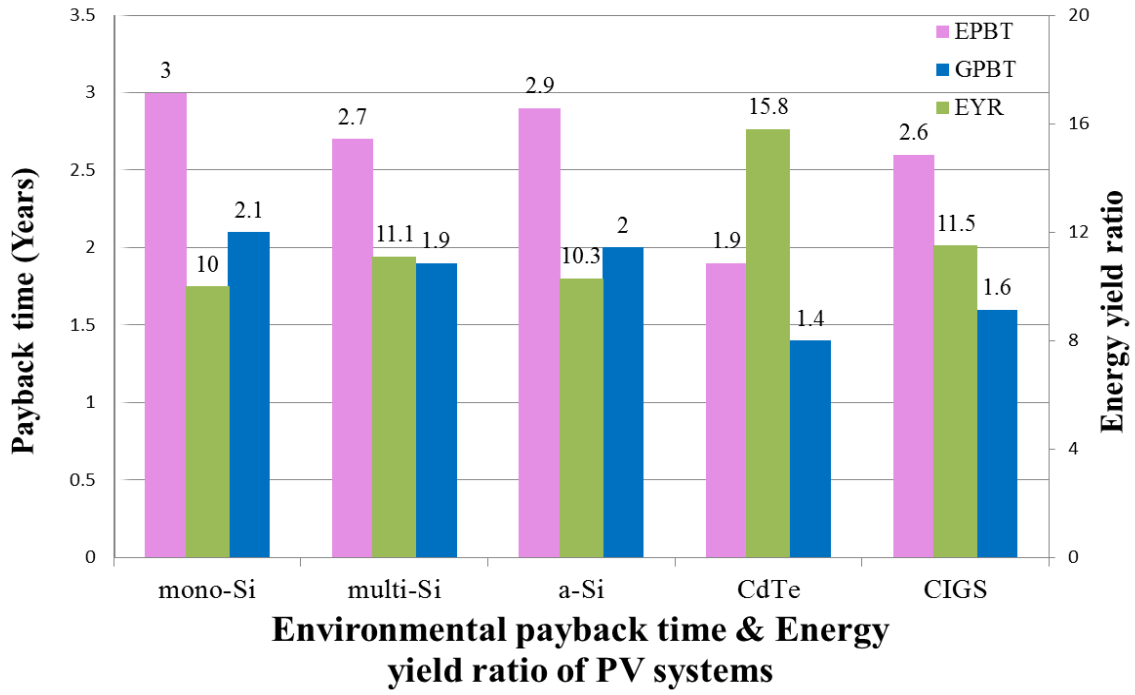
The tempered glass manufactory line: the self-cleaning coating is fixed onto the glass surface after the high temperature tempered process

Practical Applications: Washing machine

海爾洗衣機滾筒

We are now collaborating with Hai'er Group (海爾集團) for the development of auto cleaning function.

Study on energy payback and energy yield ratio



Environmental payback time & Energy yield ratio of PV systems

$$EPBT = \frac{E_{input} + E_{BOS,E}}{E_{output}}$$

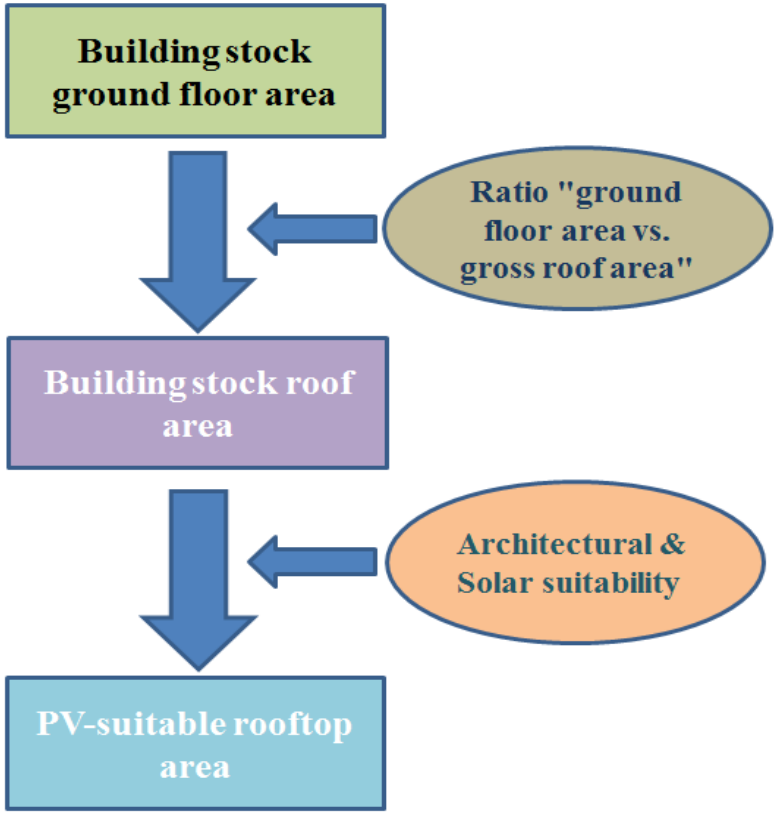
$$\mathrm{GPBT} = \frac{GHG_S + GHG_{BOS}}{GHG_{output}}$$

$$\mathrm{EYR} = \frac{\mathrm{E}_{gen} \times \mathrm{L}_{\mathrm{PV}}}{\mathrm{E}_{\mathrm{input}} + E_{BOS,E}}$$

- Energy payback time (EPBTs) and GHG payback time (GPBTs) range from 1.9 - 3.0 and 1.4-2.1 years, both are much less than their lifespans of 30 years.
- Energy yield ratio (EYRs) range from 10-15.8, i.e. generating power of about 10 times of the energy requirement during lifetime.

Study on potential BIPV power generation in Hong Kong

- Solar-architectural area estimation (rules of thumb) to estimate the PV-suitable rooftop area using buildings' ground floor area



The procedure to estimate the potential PV-suitable rooftop area

PV-suitable rooftop area (2)

Ground floor area	**117 km^2**
Ratio "gross roof area / ground floor area "	1.2
Gross roof area	140 km^2
Architectural suitability factor	0.7
Architecturally suitable roof area	98 km^2
Solar suitability factor	0.55
The potential PV-suitable rooftop area	54 km^2

Estimated potential PV-suitable rooftop area in Hong Kong.

Potentials of installation capacity and PV energy output

- The potential total active area of PV modules was calculated as 37.4km^2. The total potential installation capacity is estimated as 5.97 GWp.

$$A_{act.} = \frac{A_{pot.}}{A_{occu.}} \times A_{pv}$$

$$E_{potential} = A_{act.} \times G_{optimal} \times \eta_{stc} \times \lambda$$

- The potential PV electricity output is about 5981GWh, accounts for 14.2% of the total electricity use in 2011.
- Reducing imports of coal and natural gas by 25% and 54%, respectively, and mitigating about 3 million tons of GHG emissions yearly.

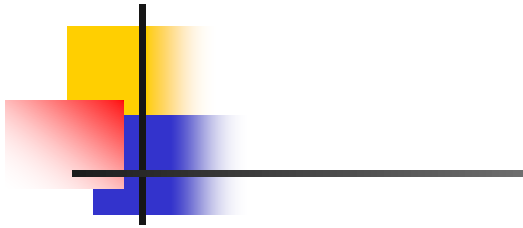
Potential power generation of BIPV in Hong Kong

Type of buildings	Roof area (km^2)	Facade area (km^2)
Residential	15	5.625
Commercial	0.8	0.3
Industrial	3.6	1.35
Public housing	5	1.875
Government, schools	7	2.625
Empty land	9	3.375
Total	40.4	15.15

Type of buildings	Roof (GWh/y)	Facade (GWh/y)	PV Generation (GWh/y)	Demand (GWh/y)	(%)
Residential	3116.9	1168.8	4285.7	—	—
Commercial	116.2	62.3	178.5	—	—
Industrial	748	280.5	1028.5	—	—
Public housing	1038.9	389.6	1428.5	—	—
Government, schools	1454.5	545.5	2000	—	—
Empty land	1870.1	701.3	2571.4	—	—
Total	8494.8	3148	11642.8	42640	27.3

Conclusions

- The cost between solar PV and traditional power is closing. It is the right time to invest more in this area, especially BIPV in urban arears like Hong Kong;
- Launch an incentive scheme to encourage building owners and investors for installation/adaptation of solar energy, just like the incentive scheme to diesel vehicles' owners to replace their cars with Euro IV ones;
- Other issues: labour policy; policy about Gross Floor Area (GFA) …



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