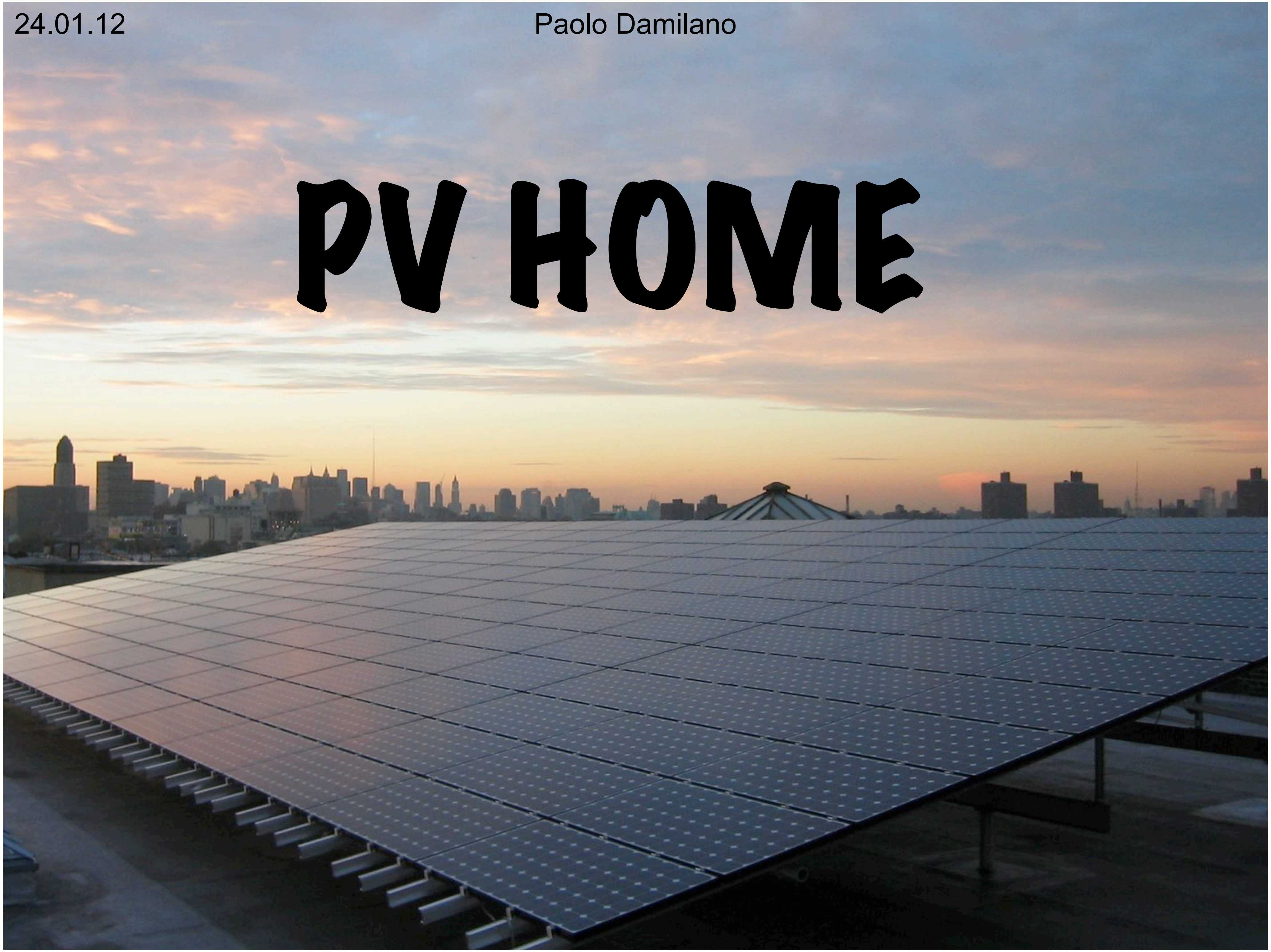
24.01.12

Paolo Damilano

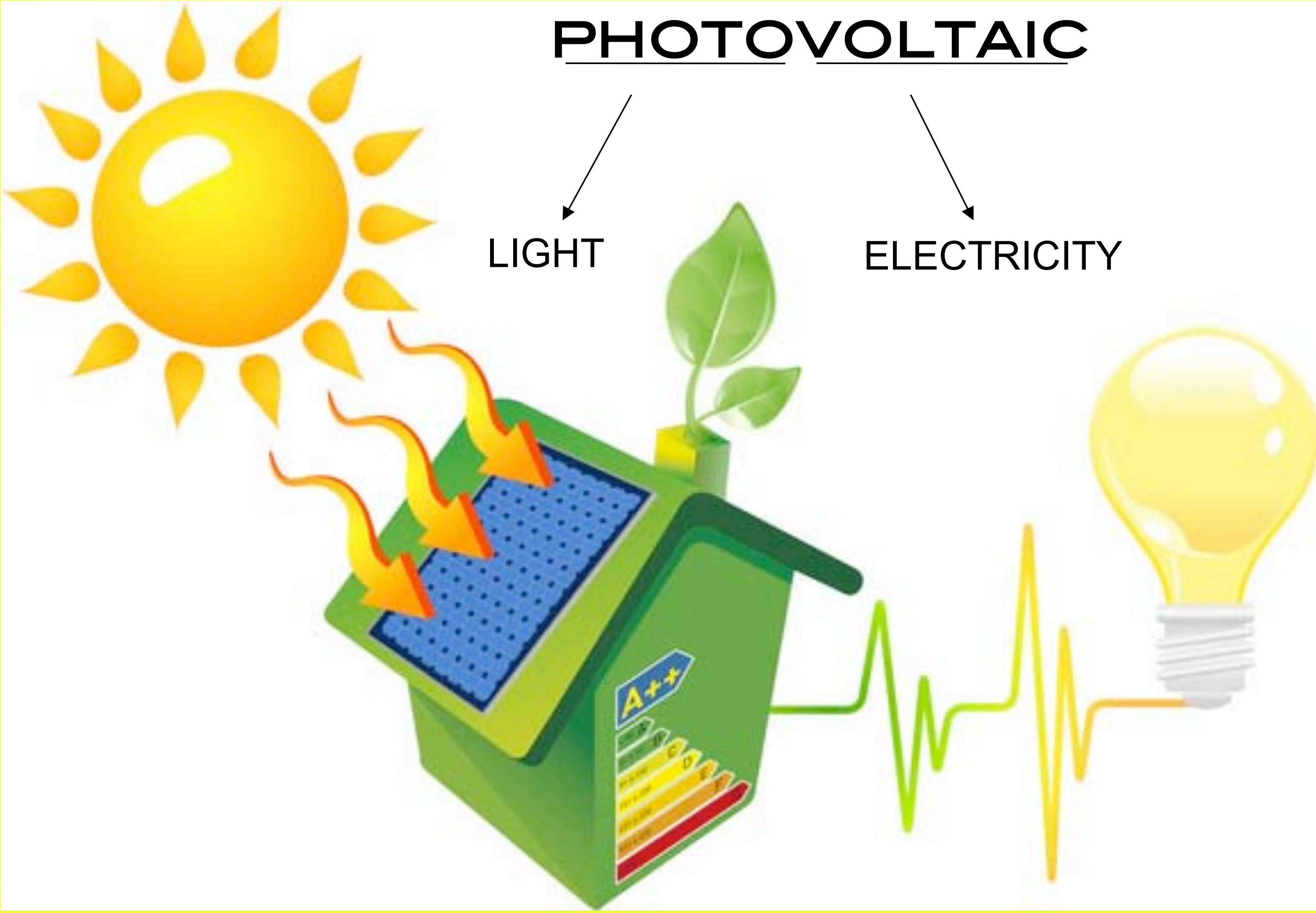
PV HOME



Outline

- HISTORY
- PHYSICS
- MARKET
- TECHNICAL CHARACTERISTICS
- STEPS FOR INSTALLATION (where and how)
- ECONOMY (cost & income)
- POLLUTION

INTRODUCTION



Photovoltaic cells, or solar panels, convert solar radiation into electricity

HISTORY

• 1839: The **photovoltaic effect was first observed** by Alexandre-Edmond Becquerel (24 March 1820 – 11 May 1891)

PHOTOVOLTAIC EFFECT: is the creation of voltage or electric current in a material upon exposure to light. Electrons are transferred between different bands (i.e., from the valence to conduction bands) within the material, resulting in the buildup of voltage between two electrodes.

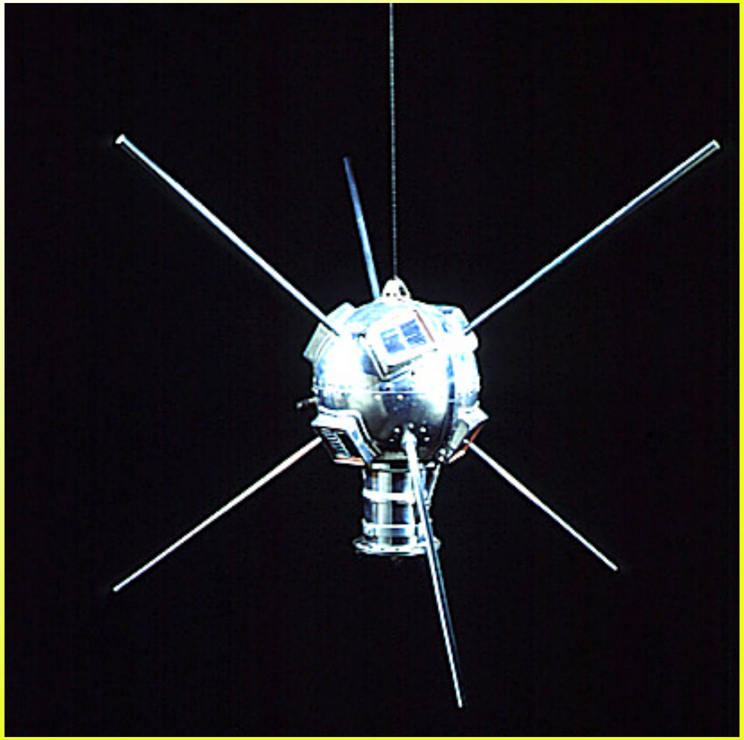
• 1889: the **first photovoltaic cell** was built, by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form junctions. → $\eta = 1\%$

• 1946: the modern solar cell, **silicon p/n junction cell**, patented by Russel Ohl (January 1898 - March 1987)

HISTORY

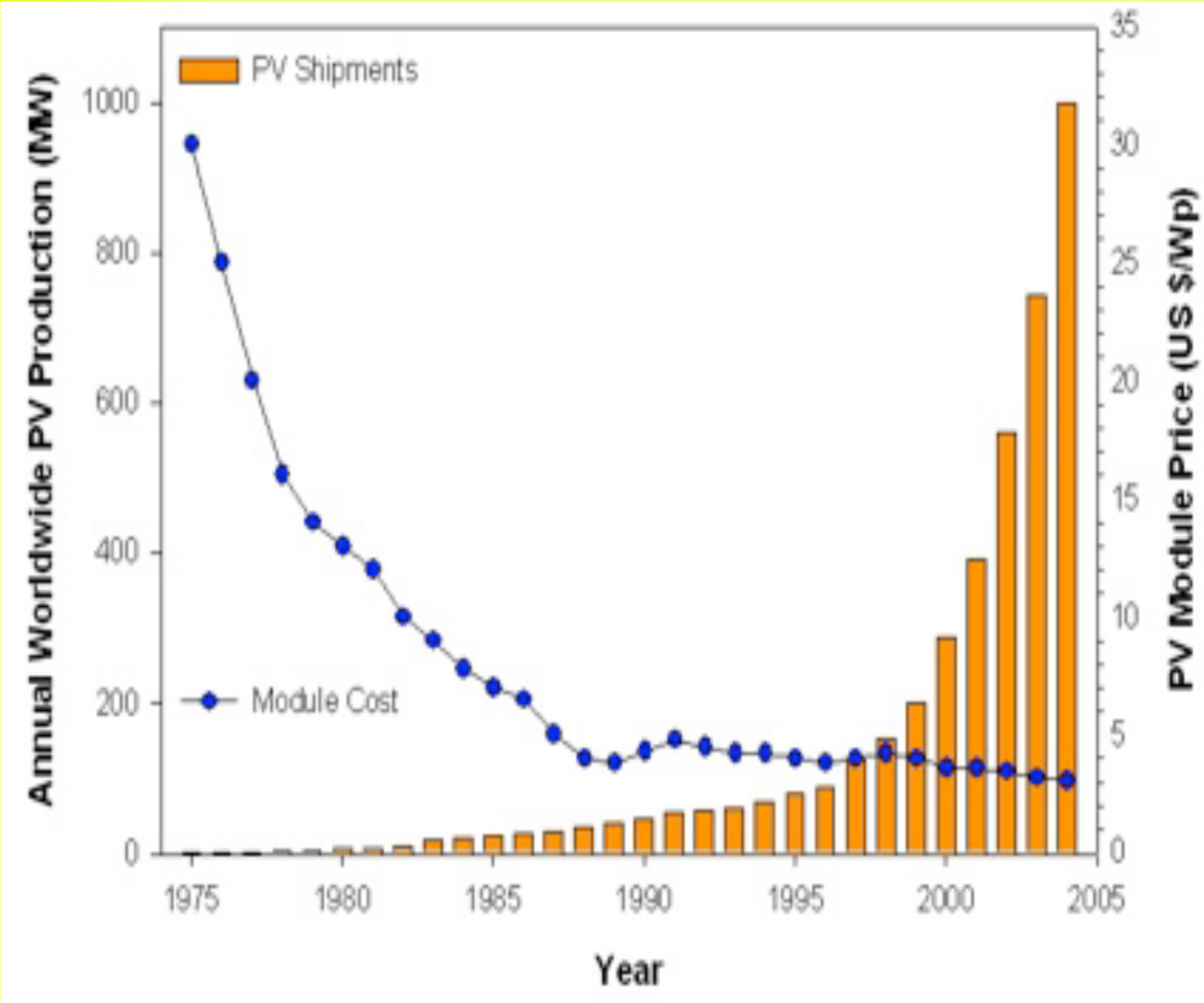
• 1954: the modern solar cell, **silicon p/n junction cell**, was developed in 1954 at Bell Laboratories by Daryl Chapin, Calvin Souther Fuller and Gerald Pearson. → $\eta = 5\%$
Very expensive: 1W → $250

• 1958: the first 108 solar cells for the supply of the Vanguard I satellite were put into orbit.



• 1960s: improvements were slow and the only widespread use was in space applications.
Price fell: 1W → $100

HISTORY



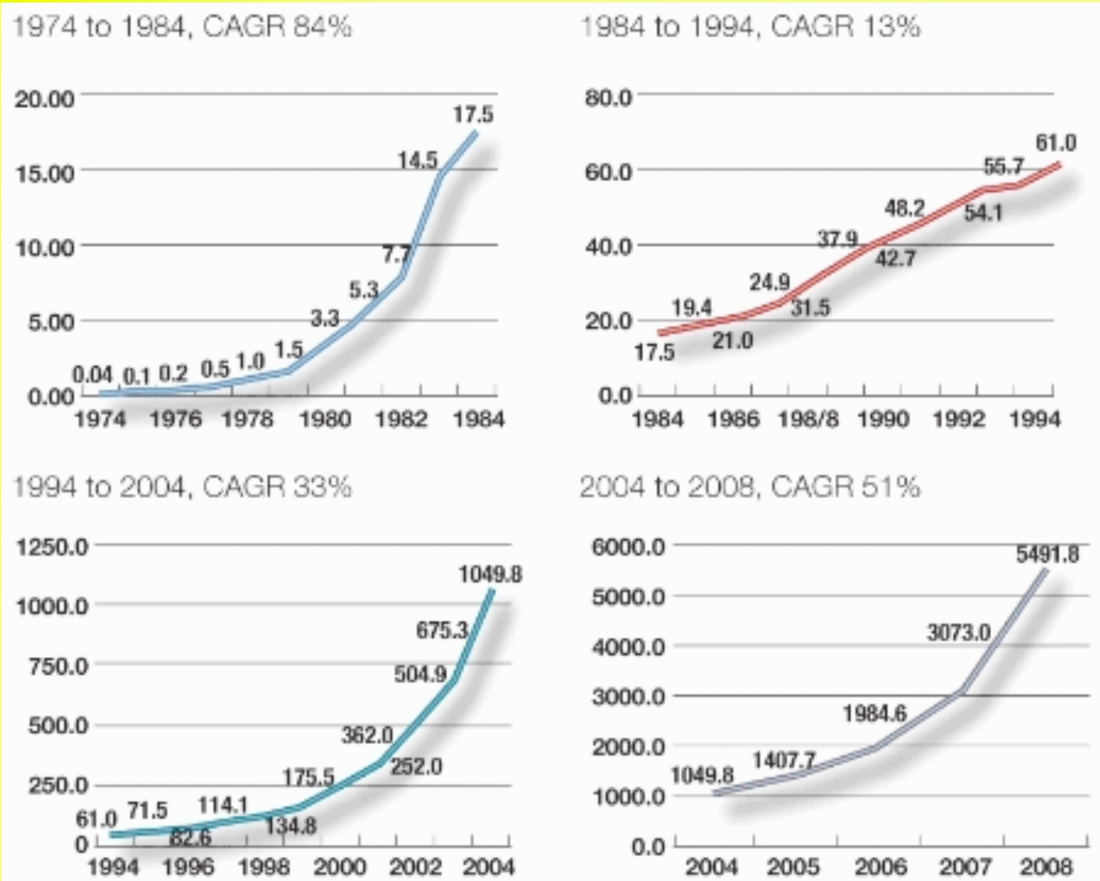
- 1970s:
Energy crisis

↓

development PV power systems for residential and commercial uses

1W → $20

HISTORY



- 1974-1984 : +84%

  utility and government-backed grid-connected demonstration projects

- 1984-1994 : +13%

  was due to an almost complete cessation of these projects

- 1994-2004 : +33%

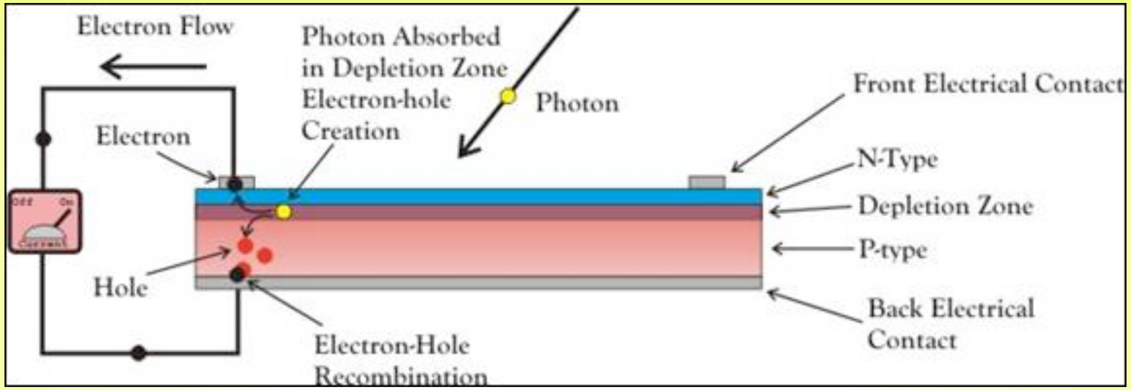
  reflects the beginning and continuation of the strong incentive programmes that continue to drive PV industry growth

- 2004-2008 : +51%

CAGR
compound annual growth rate

1W → $2.30 (December 2011)

How do solar panels work?

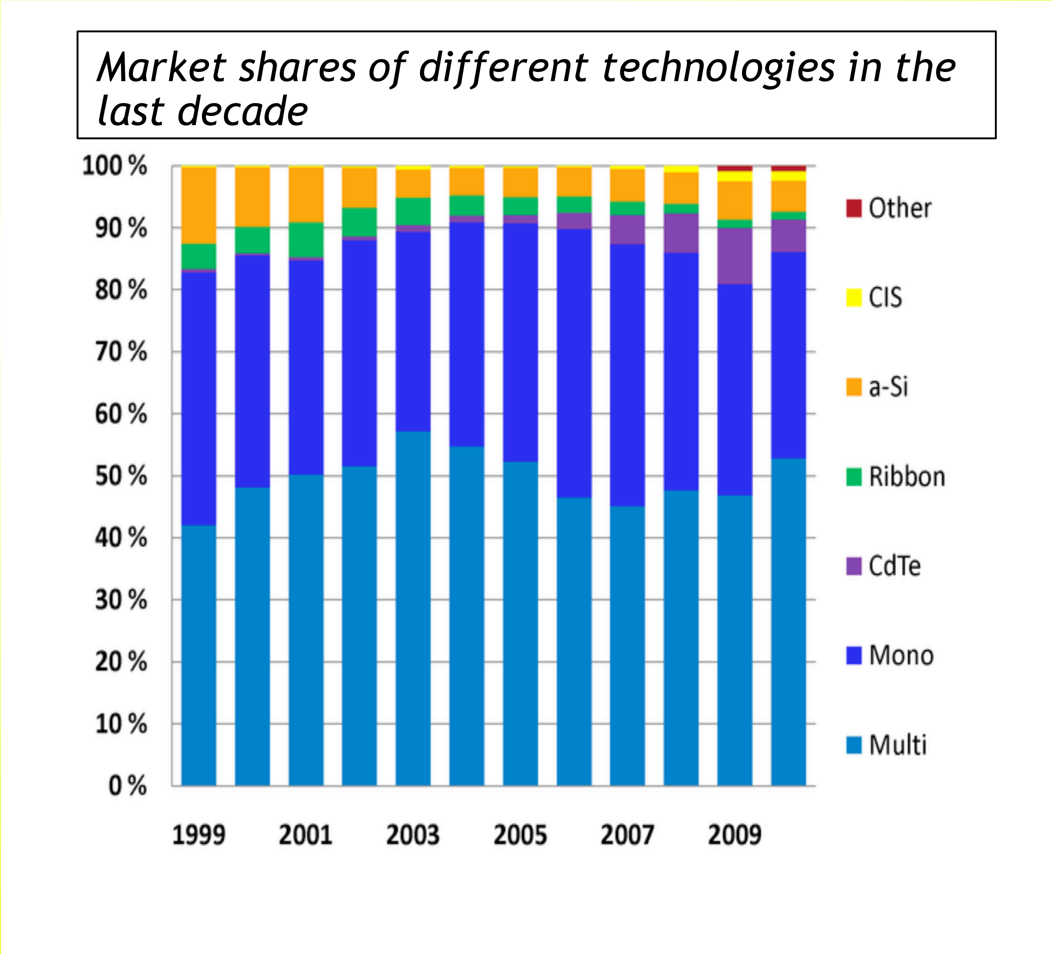


Nearly all solar cells work the same way – a semiconductor material utilizing a p-n junction to convert sunlight into electricity.The generation of electric current happens inside the depletion zone of the PN junction. The depletion region is the area around the PN junction where the electrons from the N-type silicon, have diffused into the holes of the P-type material. When a photon of light is absorbed by one of these atoms in the N-Type silicon it will dislodge an electron, creating a free electron and a hole. The free electron and hole has sufficient energy to jump out of the depletion zone. If a wire is connected from the cathode (N-type silicon) to the anode (P-type silicon) electrons will flow through the wire. The electron is attracted to the positive charge of the P-type material and travels through the external load(meter) creating a flow of electric current. The hole created by the dislodged electron is attracted to the negative charge of N-type material and migrates to the back electrical contact. As the electron enters the P-type silicon from the back electrical contact it combines with the hole restoring the electrical neutrality.

Which type of solar panels can I buy?

We have different materials that display different efficiencies and have different cost.
The most prevalent cells present on the PV market are(~80%):

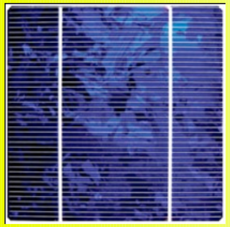
- Monocrystalline cells (c-Si)
- Polycrystalline cells (mc-Si)

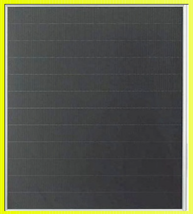


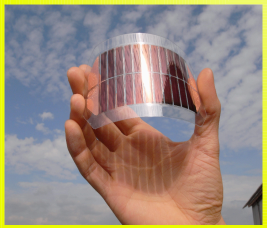
Other cells:

- Cadmium Telluride (CdTe)
- Ribbon silicon
- Amorphous silicon (a-Si)
- Copper Indium Gallium Selenide (CIGS)
- Gallium Arsenide Multijunction (GaAs)
- Light-assorbing dyes (DSSC)
- Organic/polymer solar cells
- Protocrystalline silicon
- Nanocrystalline silicon

Which are the efficiencies of solar panels?







First Generation

• MONOCRYSTALLINE
Laboratory ~ 24%
Modules ~ 14 - 18%

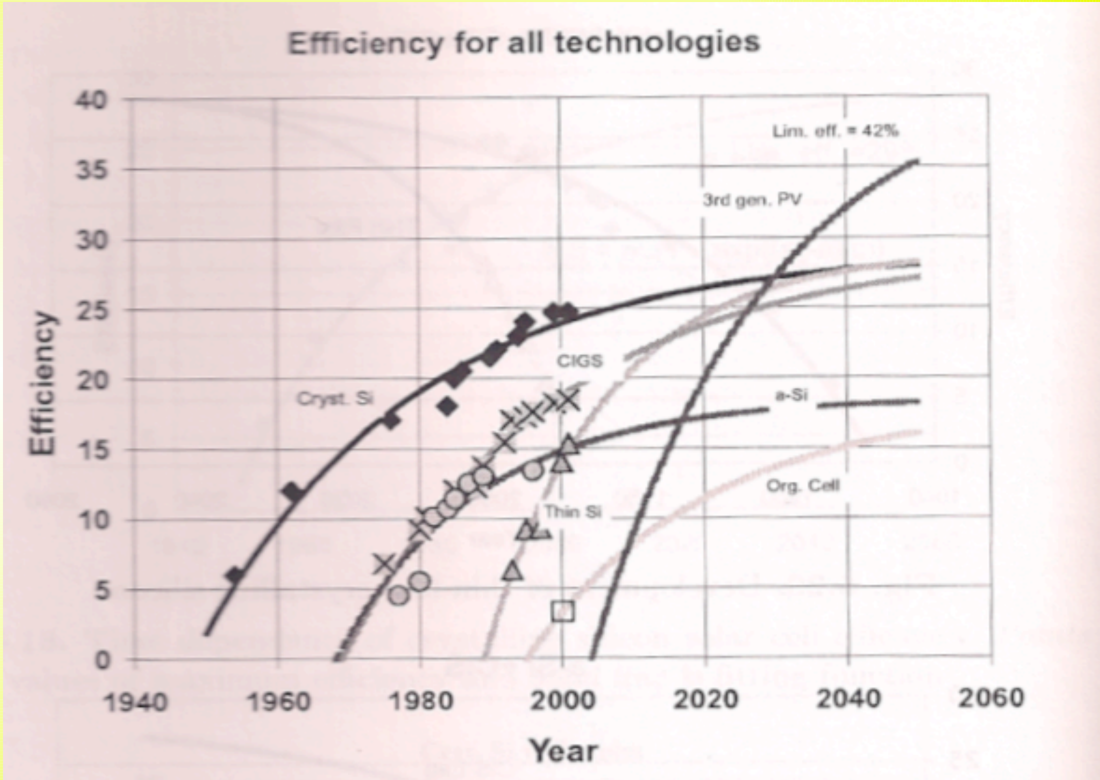
• POLYCRYSTALLINE
Laboratory ~ 18%
Modules ~ 13 - 15%

Second Generation

• CdTe Thin-Film
Laboratory ~ 15%
Modules ~ 5 - 7%

Third Generation

• Organic Tandem solar cell
Laboratory ~ 10%



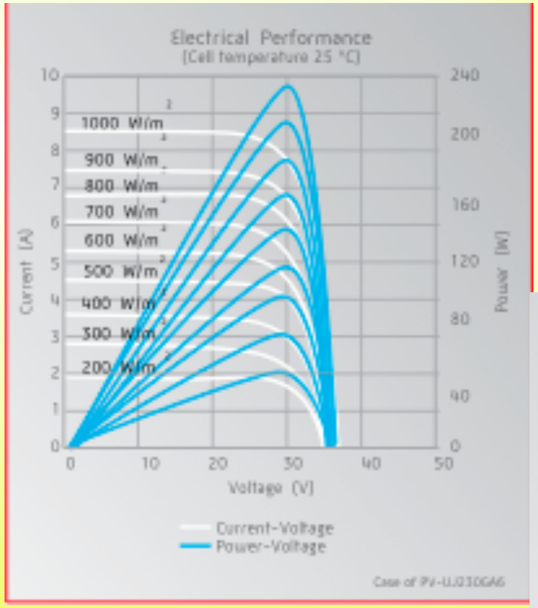
A century of photovoltaics. Past achievement and future prediction of highest solar cell efficiencies.

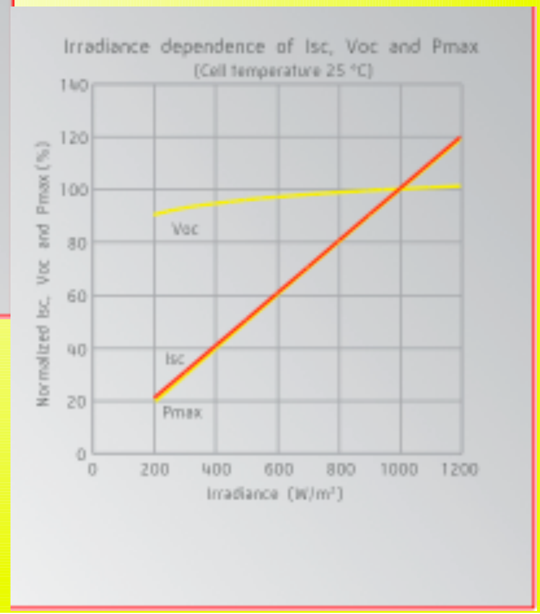
HOW CAN WE CHOOSE A PV?

Knowledge of the characteristics of the solar cells is a prerequisite for designing and dimensioning a photovoltaic power supply for our PV-home system.

We have to consider this foundamental characteristic of the PV cells:

- Short Circuit Corrent (I_{sc})
- Open Circuit Voltage (V_{oc})
- Maximum Power Point (MPP)
- Maximum Power Voltage (V_M)
- Maximum Power Current (I_M)
- Efficiency Value (η)
- Spectral Sensitivity





Specification Sheet

Electrical Specifications

Model	HIT Power 200 or HIP-200BA19
Rated Power (Pmax)[1]	200 W
Maximum Power Voltage (Vpm)	55.8 V
Maximum Power Current (Ipm)	3.59 A
Open Circuit Voltage (Voc)	68.7 V
Short Circuit Current (Isc)	3.83 A
Temperature Coefficient (Pmax)	-0.29% / °C
Temperature Coefficient (Voc)	-0.172 V / °C
Temperature Coefficient (Isc)	0.88 mA / °C
Cell Efficiency	19.7%
Module Efficiency	17.2%
Watts per Ft.^{2}	16.0 W
Maximum System Voltage	600 V
Series Fuse Rating	15 A
Warranted Tolerance (-/+)	-0% / +10%

Mechanical Specifications

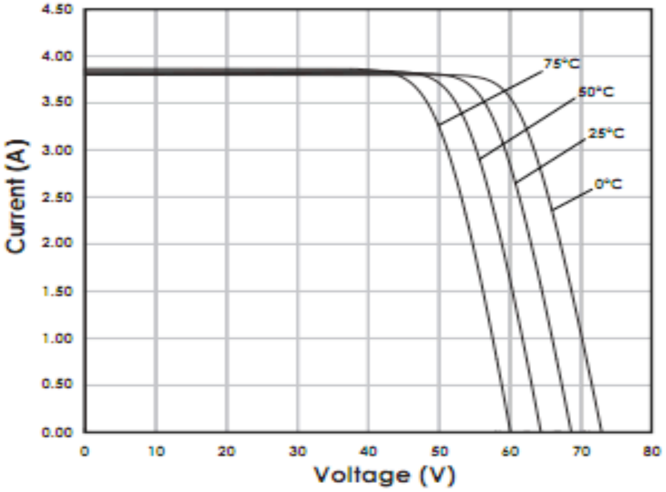
Internal Bypass Diodes	4 Bypass Diodes
Module Area	12.49 Ft.^{2} (1.16m^2)
Weight	33.07 Lbs. (15kg)
Dimensions LxWxH	51.9x34.6x1.8 in. (1319x880x46mm)
Cable Length -Male/+Female	30.7/24.8 in. (780/630mm)
Cable Size / Connector Type	No.12 AWG / MC4™ Locking Connectors
Static Wind / Snow Load	60PSF (2880Pa) / 39PSF (1867Pa)
Pallet Dimensions LxWxH	53x35x77 in. (1346x897x1952mm)
Quantity per Pallet / Pallet Weight	34 pcs. / 1102 Lbs. (500kg)
Quantity per 20', 40', and 53' Container	340 pcs., 714 pcs., 918 pcs.

Operating Conditions & Safety Ratings

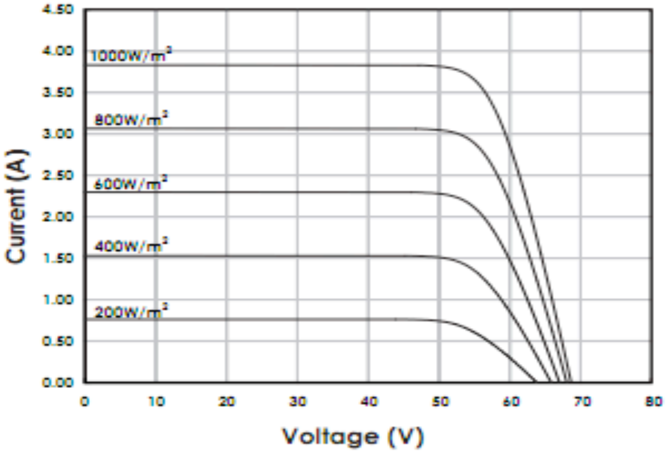
Ambient Operating Temperature	-4°F to 115°F (-20°C to 46°C)[2]
NOCT	116.4°F (46.9°C)
Hail Safety Impact Velocity	1" hailstone (25mm) at 52 mph (23m/s)
Fire Safety Classification	Class C
Safety & Rating Certifications	UL 1703, cUL, CEC
Limited Warranty	5 Years Workmanship, 20 Years Power Output

[1]STC: Cell Temp. 25°C, AM1.5, 1000W/m^2 [2]Monthly average low and high of the installation site.
Note: Specifications and information above may change without notice.

Dependence on Temperature[1]



Dependence on Irradiance[1]



Where can we install PV In our house?

The installation of PV systems in connection with buildings has important benefits. Infact,no additional areas are necessary because the solar generator can be mounted in or on existing parts of a building.
We can install our solar panel on:

- FACADES
- ROOFS → SLOPED
  → FLAT

The solar panel can be:

- Mounted on racks (e.g on flat roofs)
- Integrated into the roof or facade
- Mounted at a distance of several cm above the builing surface (for better tilt and cooling of the modules)

Potential of PV On roof and facade

Country		Building stock area (km^2)	Generation (TWh/y)
Australia	Roof	422.25	68.176
	Facade	158.34	15.881
Austria	Roof	139.62	15.197
	Facade	52.36	3.528
Canada	Roof	963.54	118.708
	Facade	361.33	33.054
Denmark	Roof	87.98	8.710
	Facade	32.99	2.155
Finland	Roof	127.31	11.763
	Facade	32.99	3.063
Germany	Roof	1,295.92	128.296
	Facade	485.97	31.745
Italy	Roof	763.53	103.077
	Facade	286.32	23.827
Japan	Roof	966.38	117.416
	Facade	362.39	29.456
The Netherlands	Roof	259.36	25.677
	Facade	97.26	6.210
Spain	Roof	448.82	70.689
	Facade	168.31	15.784
Sweden	Roof	218.77	21.177
	Facade	82.04	5.515
Switzerland	Roof	138.22	15.044
	Facade	51.83	3.367
United Kingdom	Roof	914.67	83.235
	Facade	343.00	22.160
United States	Roof	10,096.26	1,662.349
	Facade	3,786.10	418.312

Country	Electricity consumption in 2000 (TWh)	Percentage of PV power generation on roofs and facades
Australia	192.58	43.7
Canada	521.5	29.1
Germany	549.21	29.1
Italy	301.79	42.1
Japan	1,057.33	13.9
Spain	209.55	41.3
United Kingdom	358.28	29.4
United States	3,812.00	54.6

*Fig1. Potential of PV roofs and facades: Available are with good solar yield (**80%**) and the corresponding generation potential (Twh/y) for different countries.*

*Fig2. Amount of electrity consumption in **2000** and percentage of electricity consumption that could potentially be reached with PV on roofs and facades for selected countries*

HOW CAN WE INSTALL PV IN OUR HOUSE?

To get the most from solar panels,you need to point them in the direction that captures the most sun(e.g. panels that track the movement of the sun throughout the day) .

DIRECTION: **Solar panels should always face true South.**

TILT: **The advice is that the tilt should be equal to your latitude (plus 15° in winter and minus 15° in summer)**

For a better efficiency of your solar panels during the year you can chance the tilt 4 times

Optimum tilt for **WINTER**: (**latitude * 0.89) + 24°** (between 25°-50°lat.)

e.g. In BONN(50°N) the optimum tilt for winter is 68.5°

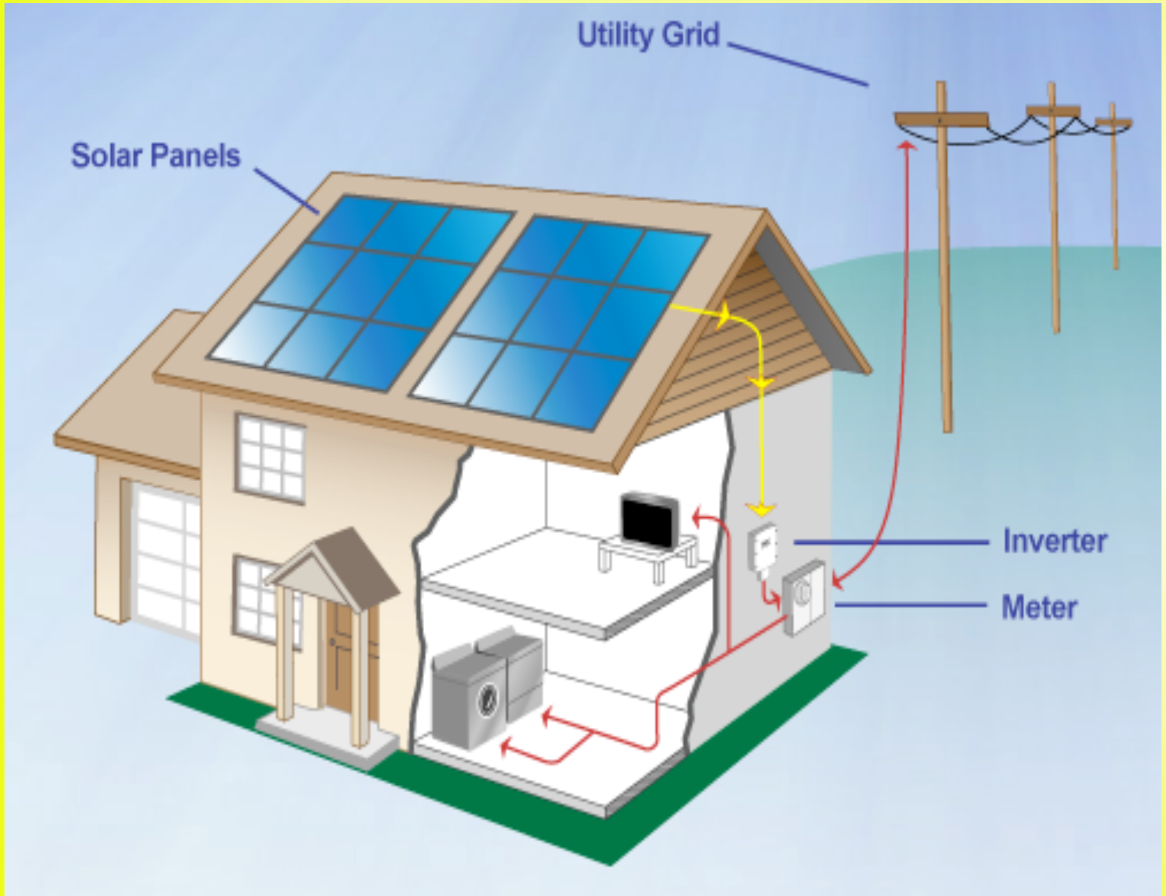
*Optimum tilt for **SPRING & AUTUMN**: (**latitude * 0.98) - 2.3°***

*Optimum tilt for **SUMMER**: (**latitude * 0.92) - 24.3°***

The best date to adjust the tilt of your panel 4 times a year are:

- WINTER → *October 7 to March 5*
- SPRING → *March 5 to April 18*
- SUMMER → *April 18 to August 24*
- AUTUMN → *August 24 to October 7*

FROM DC TO AC



Solar panels generate DC current so we need a

solar inverter or **PV inverter**

to convert the variable DC output of the PV modules into a utility frequency AC current

that can be fed

•into the commercial electrical grid
•used by a local, off grid,electrical network.

MPPT(maximum power point tracking):is a technique that solar inverters use to get the maximum possible power from the PV array

How much does a PV System cost?

Estimating the cost of photovoltaic system

STEP 1: Determine array size

a. Determine the energy load required in Wh per day.

b. Determine the hours per day of available sunlight in the worst month of the year.

c. Determine the PV array size needed. Divide **a.** by **b.**

STEP 2: Calculate the cost of PV system

a. Multiply the size of the array by 2.50 €(cost cells) per Watt

b. Multiply the size of the array by 0.55 €(cost inverter) per Watt

c. Multiply the subtotal above by 0.2 to cover balance of system costs(wire,fuses,switches,...)

d. Total estimated PV system cost

Module Pricing Trends per Watt peak			
United States	$2.42	↘	0%
Europe	€2.31	↘	-1%
Number of Prices <$2.00 or €1.54/Wp	313 (28% of survey)	⇧	11%
Lowest Mono-cSi Module Price	$1.28	⇨	0%
	€0.99	↗	9%
Lowest Multi-cSi Module Price	$1.14	⇨	0%
	€0.88	↗	2%
Lowest Thin Film Module Price	$1.15	↘	-3%
	€0.89	⇨	0%

Inverter Pricing Trends per Continuous Watt			
United States	$0.712	⇨	0%
Europe	€0.548	↗	3%

1a. 3500 KW/year → 9.5 KW/day
2b. Bonn(50°N) → 5 hrs/day in Winter
3c. 9.5 / 5 = 1.9 KWatts → **2 Kwp**

2a. 2000 * 2.5 = 5000 €
2b. 2000 * 0.55 = 1100 €
Subtotal = 22500+4500= 6100 €
2c. 6100 * 0.2 = 1220 €
TOTAL = 6100 + 1200 = 7300 €

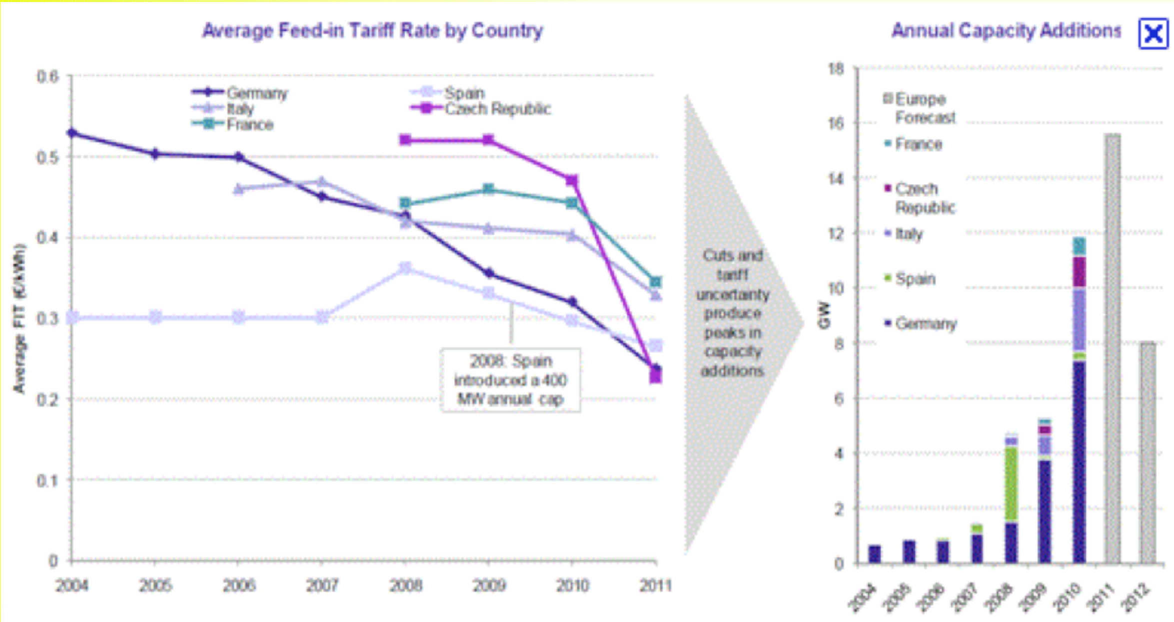
Solar panel income

The cost of electricity produced by photovoltaic systems is not very competitive with no political incentive. This is due to the high initial cost of the plant, while operating and maintenance costs are low.

Main incentive mechanisms are:

•**Investment subsidies**: the authorities refund part of the cost of installation of the system.

•**Feed-in Tariffs**: the electricity utility buys PV electricity from the producer under a multiyear contract at a guaranteed rate.



Example of solar panel income

City: DORTMUND(51°N)

Orientation modules: 160°S
Tilt modules: 35°

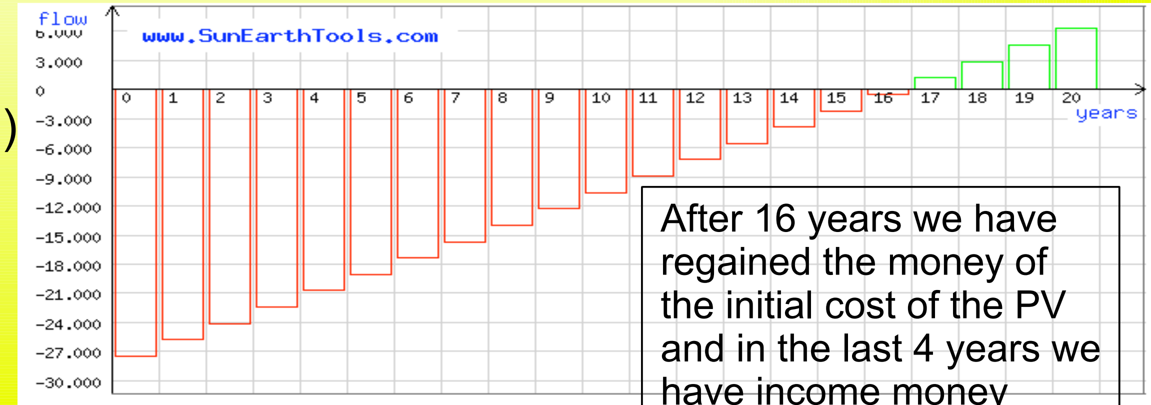
System: 8.74 KW(38 modules mono-Si 230W)
Cost: 27447 €

Energy production: 8303 KW/year
Lost for not correct orientation: 3%
Lost for not correct tilt: 0.25%
Energy production: 8033 KW/year

Energy used: 30% of the total production
Energy sold: 5623 KW/year

Price energy sold: 0.30 €/KW(Dec.2011)
Year income: 1711€
20 years income: 34220
20 years final income: 6261 €
Real year income: 313€ (+ no money for electricity)

System PV		Own consumption energy	
Peak power Wp	8740	Own consumption kWh/y	5623
Energy production KWh/y	8033	Cost €/kWh	0.3043
Decay module PV %	0.00	Own consumption €	1711
Costs		**Contribution**	
Initial cost €	27477	Contribution €/kWh	0.00
Cost €/KWp	3144	initial contribution €	0
Annual cost €	0	Annual contribution €	0
Final cost of disposal €	0		
Analysis period		**Bank financing**	
Years contributions	20	Mutual interests %	0.00
Years economic analysis	20	Annual loan installment €	0
Result			
Pay back [years | months]	[16 | 3]		
YTD Return (20 years)	1.14%	Cash balance (20 years) €	6261
Compound interest (20 years)	1.03%	Cash balance (20 years) €	6261



After 16 years we have regained the money of the initial cost of the PV and in the last 4 years we have income money

PV: IS IT REALLY GREEN ENERGY?

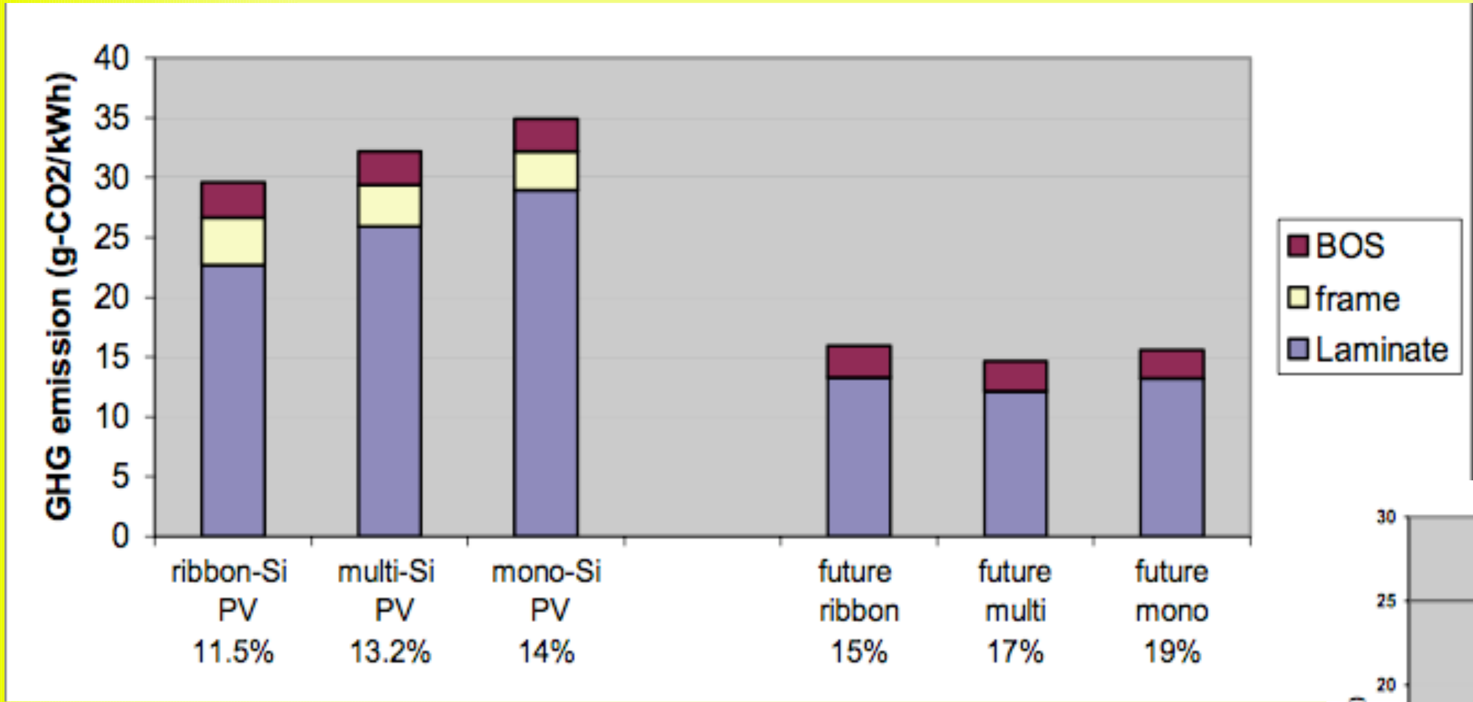
NO production of CO_2 and other Greenhouse gases during:

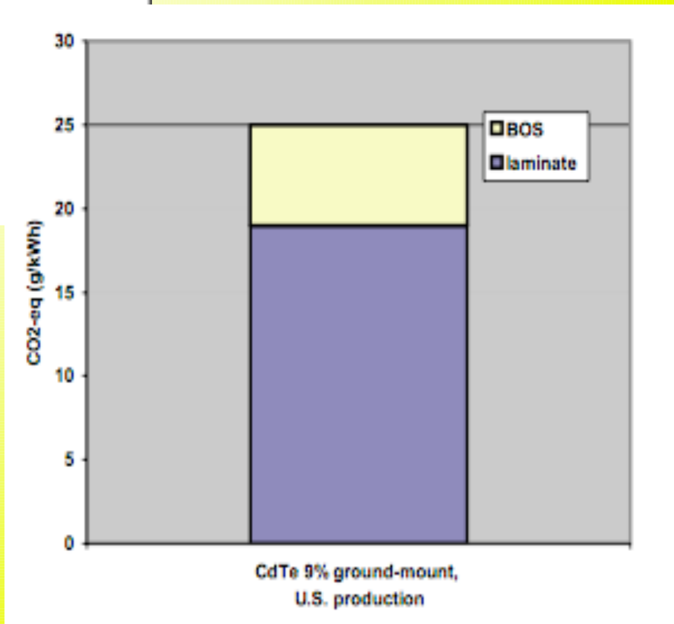
- Daily operation of the PV system(~20-30 years)

Production of CO_2 and other Greenhouse gases during:

- Manufacturing
  - Purification of Si
  - Crystallization of Si
  - Cutting the Si into wafers
  - Processing the wafers into cells
  - Assembling the cells into modules
  - Encapsuration of the modules into glasses
- Transport & Installation
- Recycling

GHG emissions

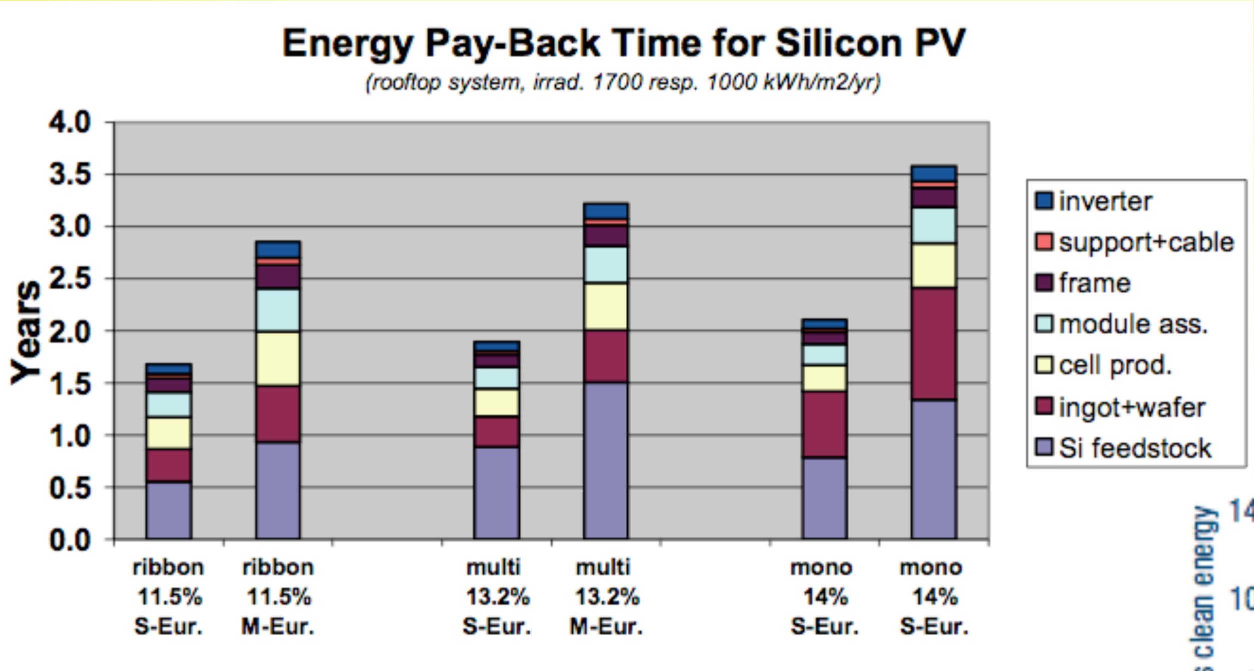




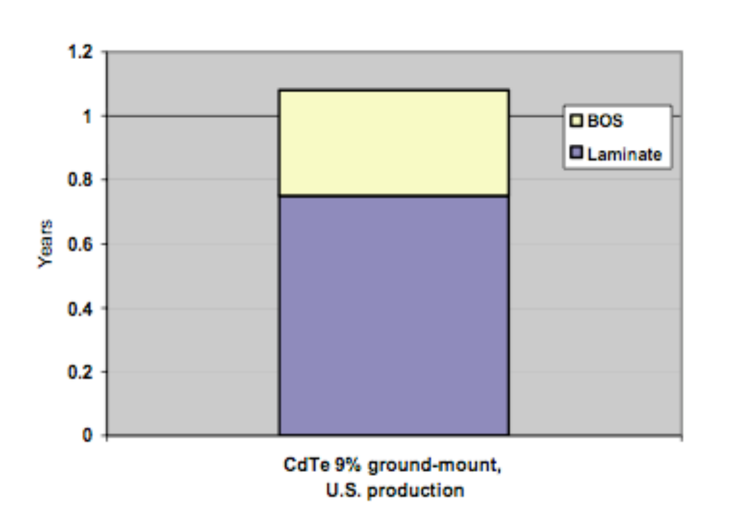
CO_2 emissions during solar panel life:

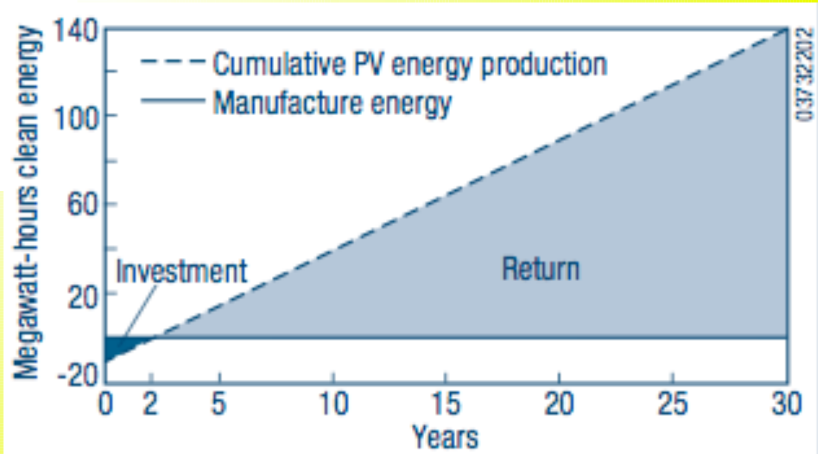
Ribbon-Si	30 g/Kwh
Multi-Si	32 g/Kwh
Mono-Si	35 g/Kwh
Cadmium-Telluride	25 g/KWh

Energy Pay-Back Time



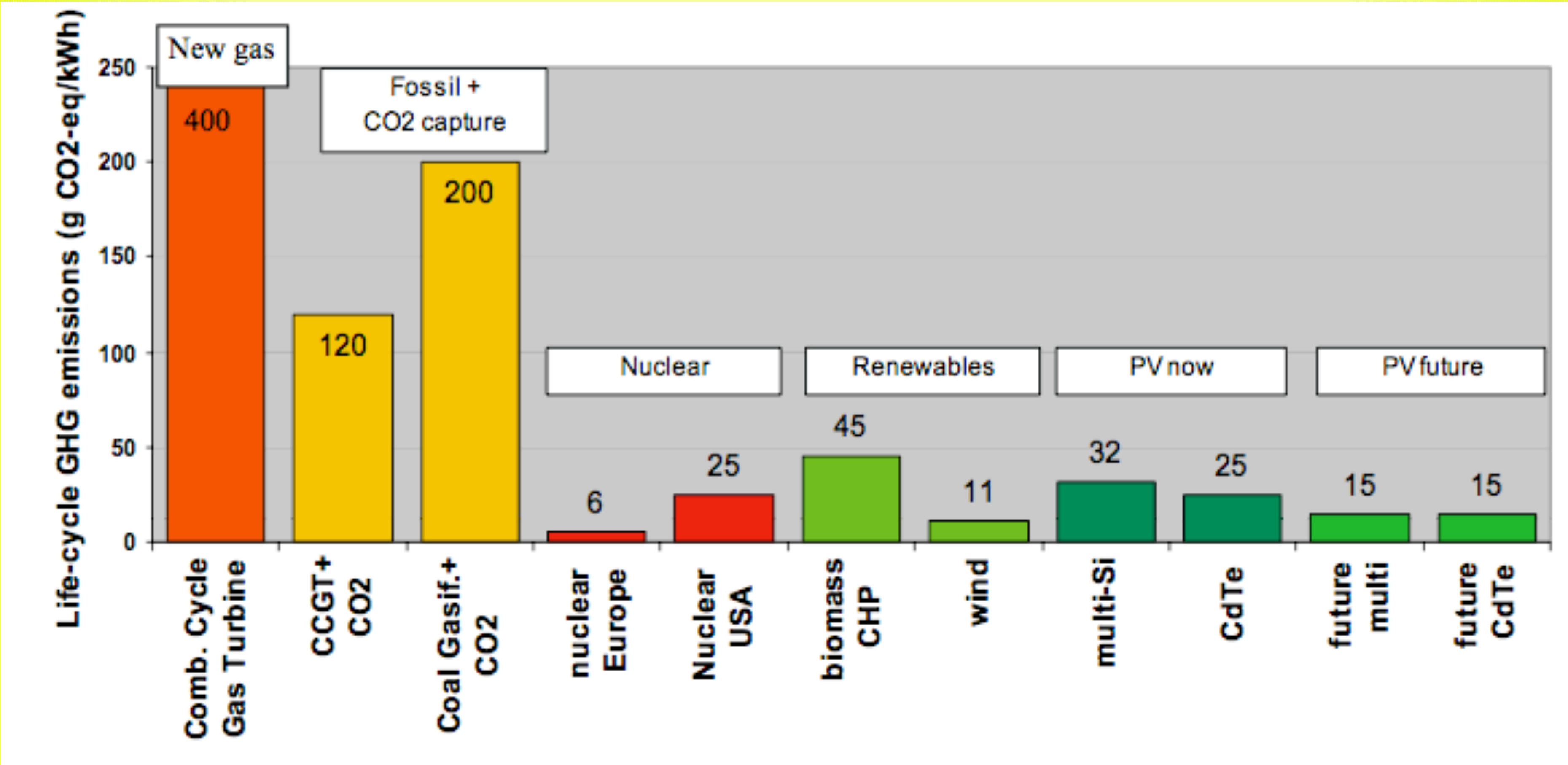
Energy Pay-Back Time(EPBT) is the time the PV module has to operate to recover the energy consumed for its production





PV systems can repay their energy investment in about 2 years. During its 28 remaining years of assumed operation, a PV system that meets half of an average household's electrical use would eliminate half a ton of sulfur dioxide and one-third of a ton of nitrogen-oxides pollution. The carbon-dioxide emissions avoided would offset the operation of two cars for those 28 years.

Comparison of GHG emissions



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SPECIAL THANKS

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The end