Photovoltaic power plants

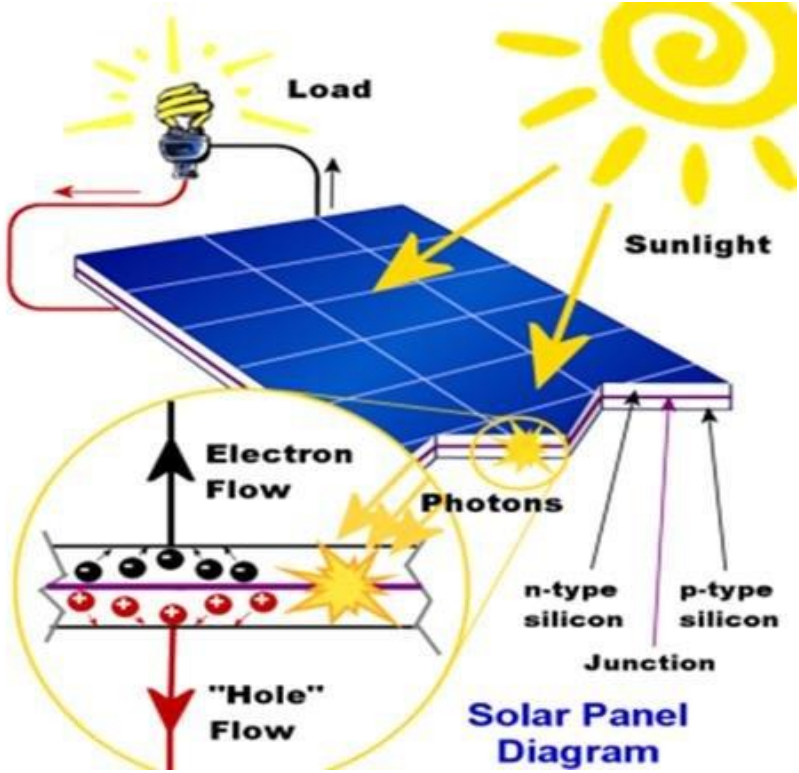
13 April 2021

Project HUSKROUA/1702/6.1/0075
"Cross-border network of energy sustainable universities (NET4SENERGY)"

Lead Beneficiary: Ivano-Frankivsk National Technical University of Oil and Gas, project coordinator Prof.Maksym Karpash mkarpash@nung.edu.ua, +380342547430

Principle of photovoltaic panel (PV) - Photovoltaic effect of solar panel

- The photovoltaic effect is the generation of **voltage** and **electric current** in a material upon exposure to light.
- It is a **physical** and **chemical** phenomenon.
- In either case, light is absorbed, causing **excitation of an electron** or other charge carrier to a higher-energy state.



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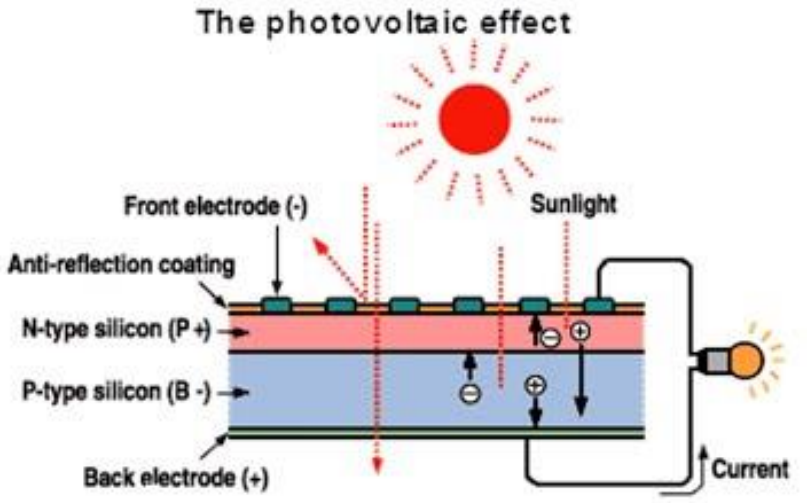
Process of Photovoltaic effect

- The photovoltaic effect occurs in solar cells.
- These are composed of **two different types of semiconductors** a **p-type** and an **n-type**, that are joined together to create a p-n junction.
- By joining these two types of semiconductors, an electric field is formed in the region of the junction as electrons move to the **positive p-side** and holes move to the **negative n-side**.
- This field causes negatively charged particles to move in one direction and positively charged particles in the other direction.



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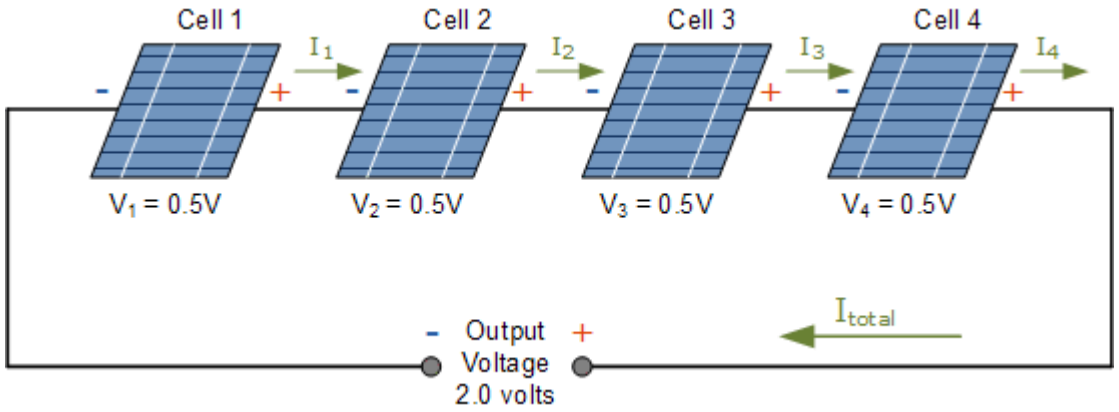
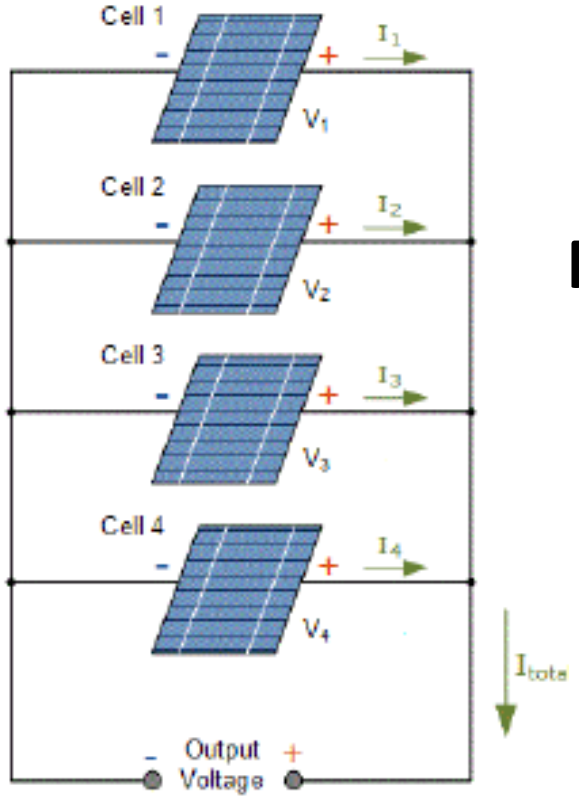
Connection of Photovoltaic panel (PV) - series and parallel

Series connection

Voltage increase





Parallel connection

Current increase

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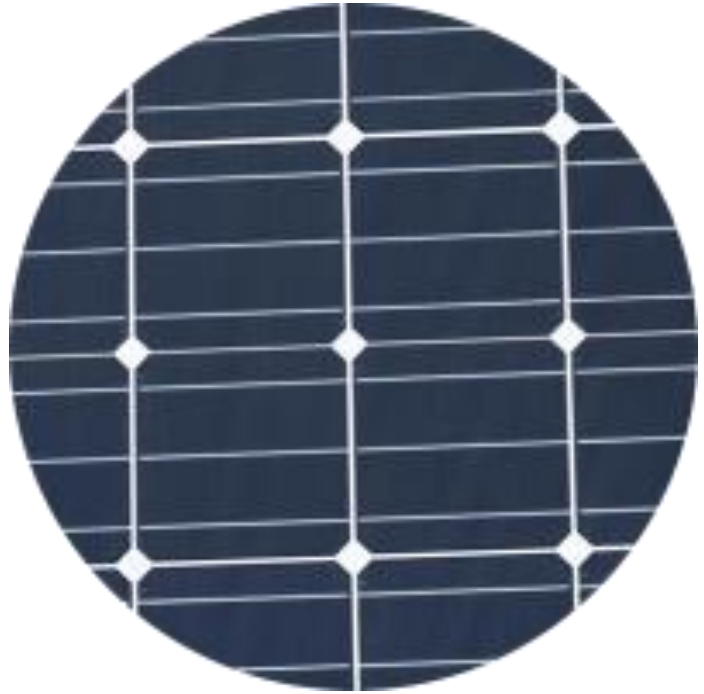
Basic Type of Solar Panels

1st Generation Solar Panels - Monocrystalline Solar Panels (Mono-SI)

- These are the traditional types of solar panels made of monocrystalline silicon or polysilicon and are most commonly used in conventional surroundings.
- This type of solar panels (made of monocrystalline silicon) is the purest one. You can easily recognise them from the uniform dark look and the rounded edges.
- The silicon's high purity causes this type of solar panel has one of the highest efficiency rates, with the newest ones reaching above 20%.



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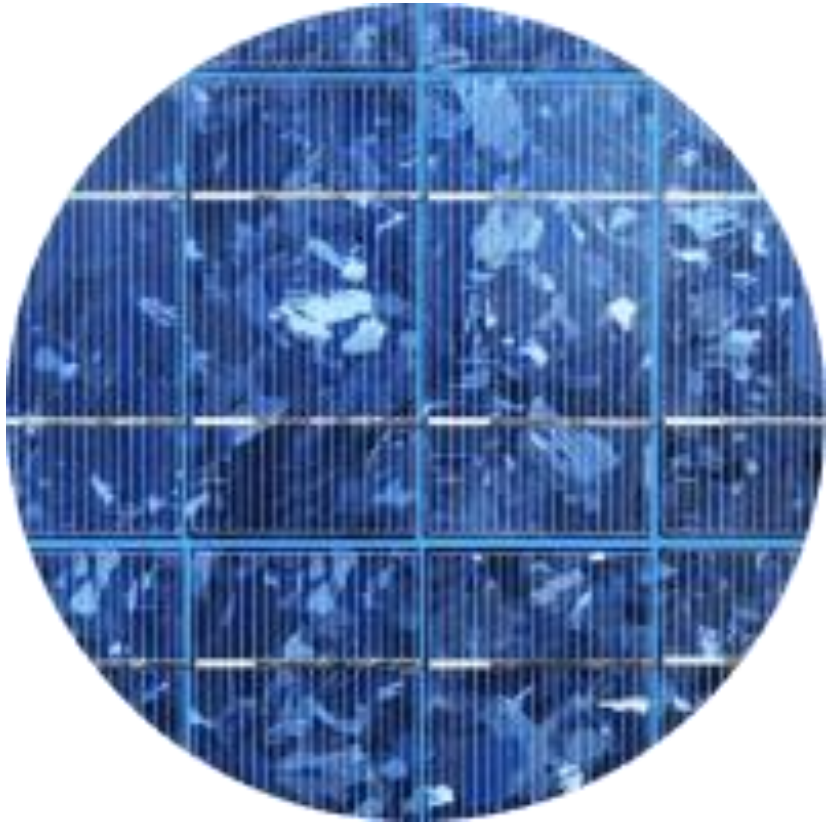
1st Generation Solar Panels - Polycrystalline Solar Panels (Poly-SI)

- You can quickly distinguish these panels because this type of solar panels has squares, its angles are not cut, and it has a blue, speckled look.
- They are made by melting raw silicon, which is a faster and cheaper process than that used for monocrystalline panels.
- This leads to a lower final price but also lower efficiency (around 15%), lower space efficiency, and a shorter lifespan since they are affected by hot temperatures to a greater degree.
- The first option offers a slightly higher space efficiency at a slightly higher price but power outputs are basically the same.



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2nd Generation Solar Panels - Thin-Film Solar Cells (TFSC)

- If you are looking for a less expensive option, you might want to look into thin-film.
- Thin-film solar panels are manufactured by placing one or more films of photovoltaic material (such as silicon, cadmium or copper) onto a substrate.
- These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production.
- They are also **flexible**—which opens a lot of **opportunities for alternative applications**—and is less affected by high temperatures.
- The main issue is that they take up a lot of space, generally making them **unsuitable for residential installations**.
- Moreover, they carry the **shortest warranties** because their lifespan is shorter than the mono- and polycrystalline types of solar panels.
- However, they can be a good option to choose among the different types of solar panels where a lot of space is available.

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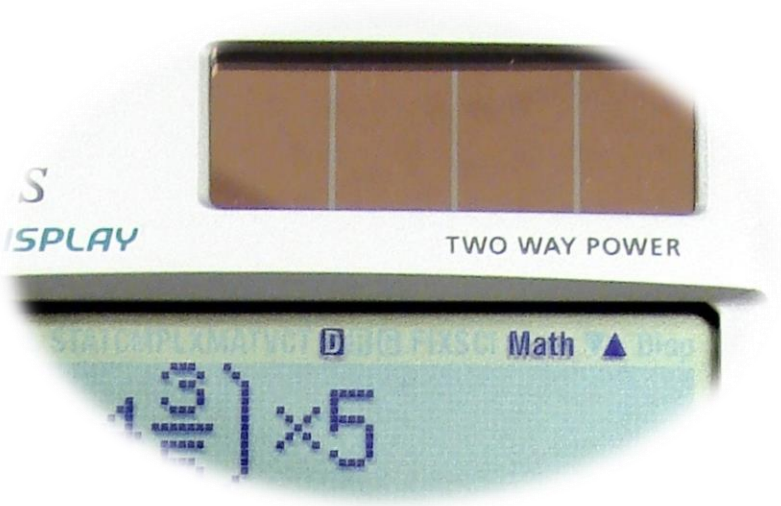
2nd Generation Solar Panels - Amorphous Silicon Solar Cell (A-Si)

- Have you ever used a solar powered pocket calculator? Yes? Then you have definitely seen these types of solar panels before. The amorphous silicon solar cell is among the different types of solar panels, the one that is used mainly in such pocket calculators. This type of solar panel uses a **triple layered technology**, which is the best of the thin film variety.

- Just to give a brief impression of what “thin” means, in this case, we’re talking about a thickness of **1 micrometre** (one millionth of a metre). With only 7% efficiency rate, these cells are **less effective** than crystalline silicon ones—that have an efficiency rate of circa 18%—but the advantage is the fact that the A-Si-Cells are relatively low in cost.



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3rd Generation Solar Panels

- 3rd generation solar panels include a variety of thin film technologies but most of them are still in the **research or development phase**. Some of them generate electricity by using organic materials, others use inorganic substances (CdTe for instance).

Biohybrid Solar Cell

- The Biohybrid solar cell is one of the types of solar panels, that is still in the research phase. It has been discovered by an expert team at Vanderbilt University. The idea behind the new technology is to take advantage of the photosystem 1 and thus emulate the natural process of photosynthesis. In case you want to learn more about how the biohybrid solar cell works in detail, read more about it in the American Journal of Optics and Photonics. It explains more detailed how these cells work. Many of the materials being used in this cell are similar to the traditional methods, but only by combining the multiple layers of photosystem 1, the conversion from chemical to electrical energy becomes much more effective (up to 1000 times more efficient than 1st generation types of solar panels).

Cadmium Telluride Solar Cell (CdTe)

- Among the collection of different types of solar panels, this photovoltaic technique uses Cadmium Telluride, which enables the production of solar cells at relatively low cost and thus a shorter payback time (less than a year).

- Of all solar energy technologies, this is the one requiring the least amount of water for production. Keeping the short energy payback time in mind, CdTe solar cells will keep your carbon footprint as low as possible.

- The only disadvantage of using Cadmium Telluride is its characteristic of being toxic, if ingested or inhaled. In Europe especially, this is one of the greatest barriers to overcome, as many people are very concerned about using the technology behind this type of solar panel.

Concentrated PV Cell (CVP and HCVP)

- Concentrated PV cells generate electrical energy just as conventional photovoltaic systems do. Those multi-junction types of solar panels have an efficiency rate up to 41%, which, among all photovoltaic systems, is the highest so far.

- By this means, CVP cells have become one of the most efficient solar panels, with a high performance and efficiency rate of up to 41%.
- What remains is the fact, that such CVP solar panels can only be as efficient if they face the sun in a perfect angle.
- In order to reach such high efficiency rates, a solar tracker inside the solar panel is responsible for following the sun

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Summarization

Solar Cell Type	Efficiency-Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High efficiency rate; optimised for commercial use; high life-time value	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price	Sensitive to high temperatures; lower lifespan & slightly less space efficiency
Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-10%	Relatively low costs; easy to produce & flexible	shorter warranties & lifespan
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate	Solar tracker & cooling system needed (to reach high efficiency rate)

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RENEWABLES (RES) STATUS

- Global renewable power capacity totalled 2,378 GW (in 2018)

- SOLAR PHOTOVOLTAICS (PV): The annual global market for solar PV was up slightly to exceed 100 GW (direct current) for the first time, with a year-end total of 505.5 GW. Higher demand in emerging markets and in Europe compensated for a substantial decline in China that resulted from policy changes mid-year, although Asia still eclipsed other regions for new installations.

RENEWABLE ENERGY INDICATORS 2018

		2017	2018
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	326	**289**
POWER			
Renewable power capacity (including hydropower)	GW	2,197	**2,378**
Renewable power capacity (not including hydropower)	GW	1,081	**1,246**
Hydropower capacity[2]	GW	1,112	**1,132**
Wind power capacity	GW	540	**591**
Solar PV capacity[3]	GW	405	**505**
Bio-power capacity	GW	121	**130**
Geothermal power capacity	GW	12.8	**13.3**
Concentrating solar thermal power (CSP) capacity	GW	4.9	**5.5**
Ocean power capacity	GW	0.5	**0.5**
Bioelectricity generation (annual)	TWh	532	**581**
HEAT			
Solar hot water capacity[4]	GW_{th}	472	**480**
TRANSPORT			
Ethanol production (annual)	billion litres	104	**112**
FAME biodiesel production (annual)	billion litres	33	**34**
HVO biodiesel production (annual)	billion litres	6.2	**7.0**

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SUMMARY RESULTS – Slovak republic

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electricity															
Hydro	376,6	376,7	377,1	377,9	383,3	369,3	376,9	376,7	377,5	382,1	381,8	378,5	375,3	369,3	370,7
Wind	0,5	0,6	0,6	0,7	0,6	0,5	0,4	0,4	0,4	0,6	0,6	0,4	0,5	0,5	0,5
Solar	0,0	0,0	0,0	0,0	0,0	0,0	1,5	34,1	36,5	50,6	51,3	43,5	45,8	43,5	50,3
Solid biofuels	0,3	0,3	31,6	37,9	41,3	42,4	52,1	58,6	62,3	58,2	78,8	94,5	97,1	92,9	92,0
All other renewables	1,5	2,4	2,7	2,8	3,2	3,8	4,8	11,8	18,7	20,1	43,1	48,4	51,8	53,0	47,7
Total (RES-E numerator)	**378,8**	**380,0**	**411,9**	**419,3**	**428,3**	**416,0**	**435,6**	**481,6**	**495,3**	**511,6**	**555,5**	**565,3**	**570,4**	**559,1**	**561,3**

Notes: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and solar thermal generation. All other renewables includes electricity generation from gaseous and liquid biofuels, renewable municipal waste, geothermal, and tide, wave & ocean.

- 1ktoe = 11630MWh = 41868GJ
- 2010: Solar = 1,5ktoe = 17445MWh = 62802GJ
- 2018: Solar = 92ktoe = 1069960MWh = 3851856GJ

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SUMMARY RESULTS – EU-27 (2020)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electricity															
Hydro	29 217,7	29 320,1	29 190,5	29 269,3	29 252,6	29 350,1	29 684,2	29 682,8	29 552,9	29 714,7	29 642,1	29 682,0	29 601,1	29 460,7	29 640,2
Wind	4 796,4	5 753,9	6 811,5	8 219,0	9 612,2	11 025,2	12 492,0	14 009,4	15 604,6	17 308,2	19 010,7	21 450,4	23 379,4	25 705,9	27 529,0
Solar	59,4	125,4	214,1	324,6	639,5	1 212,7	1 996,9	4 066,1	6 034,1	7 231,7	8 097,1	8 672,2	8 687,4	9 279,9	9 886,7
Solid biofuels	3 117,0	3 489,5	3 883,3	4 098,7	4 572,5	4 930,9	5 581,0	5 772,4	6 197,4	6 063,3	6 081,8	6 196,8	6 224,7	6 383,4	6 531,2
All other renewables	1 936,8	2 263,5	2 649,4	3 183,1	3 533,7	3 944,7	4 525,3	5 014,7	5 742,7	6 420,7	6 902,3	7 260,9	7 393,4	7 462,2	7 473,8
Total (RES-E numerator)	**39 127,4**	**40 952,3**	**42 748,8**	**45 094,6**	**47 610,5**	**50 463,6**	**54 279,4**	**58 545,5**	**63 131,8**	**66 738,5**	**69 734,0**	**73 262,3**	**75 286,0**	**78 292,2**	**81 060,9**

Notes: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and solar thermal generation. All other renewables includes electricity generation from gaseous and liquid biofuels, renewable municipal waste, geothermal, and tide, wave & ocean.

- UNIT: „thousand tonnes of oil equivalent“ - 1ktoe = 11630MWh = 41868GJ
- 2010: Solar = 1,5ktoe = 17445MWh = 502286209.2GJ
- 2018: Solar = 92ktoe = 139523947MWh = 3851856GJ

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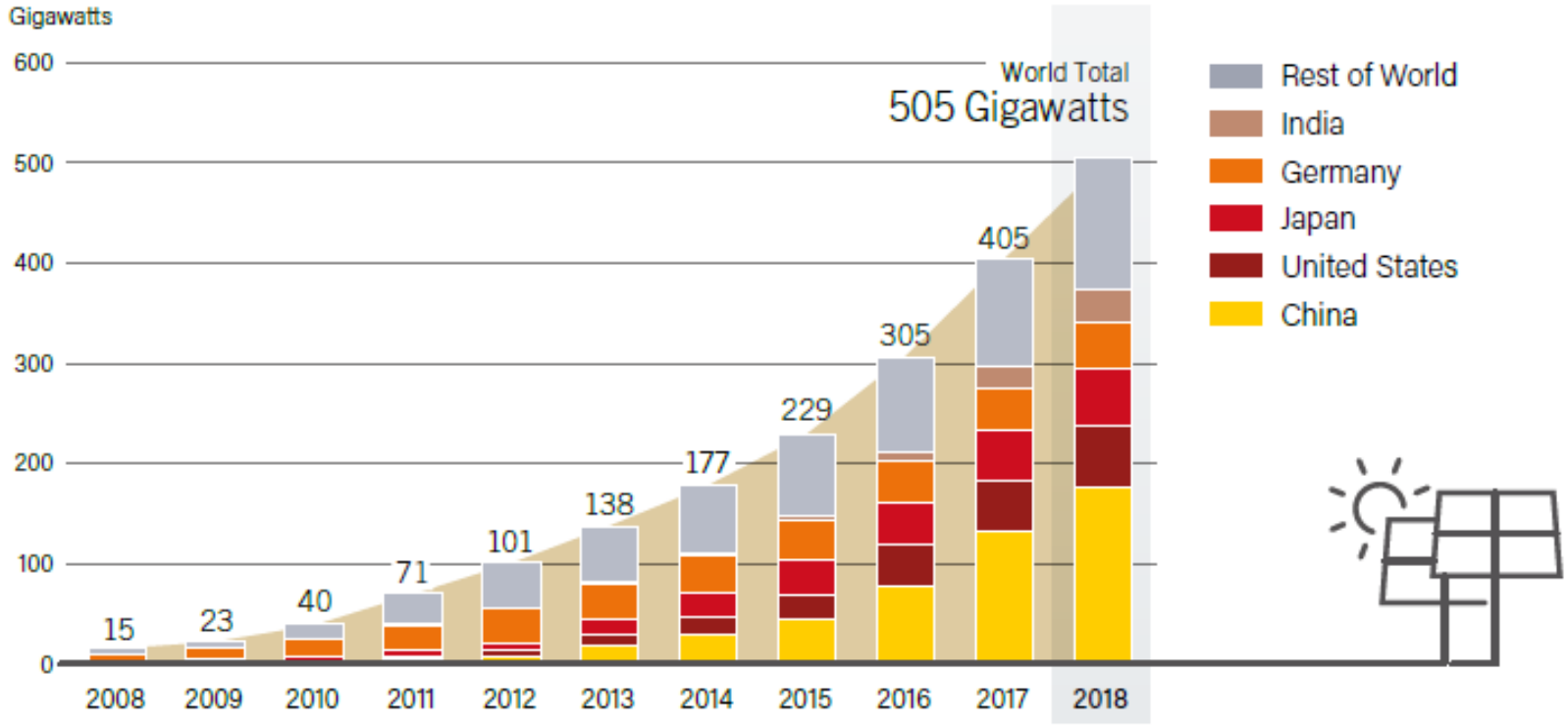
SUMMARY RESULTS – GLOBAL

Solar PV Global Capacity, by Country and Region, 2008-2018



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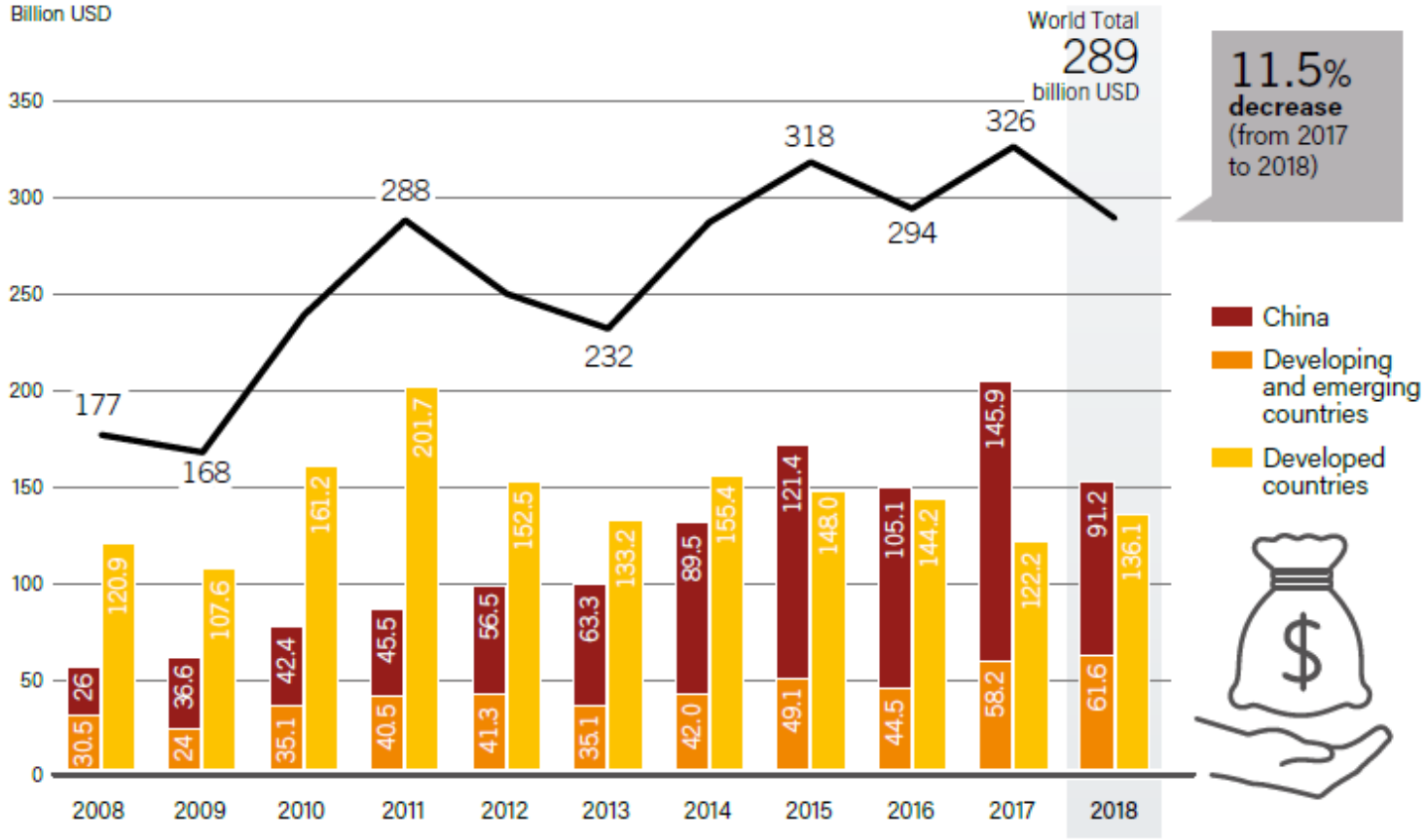
SUMMARY RESULTS – INVESTMENT FLOWS

Global New Investment in Renewable Power and Fuels in Developed, Emerging and Developing Countries, 2008-2018

- Global investment in renewable power and fuels reached 288.9 billion USD in 2018.



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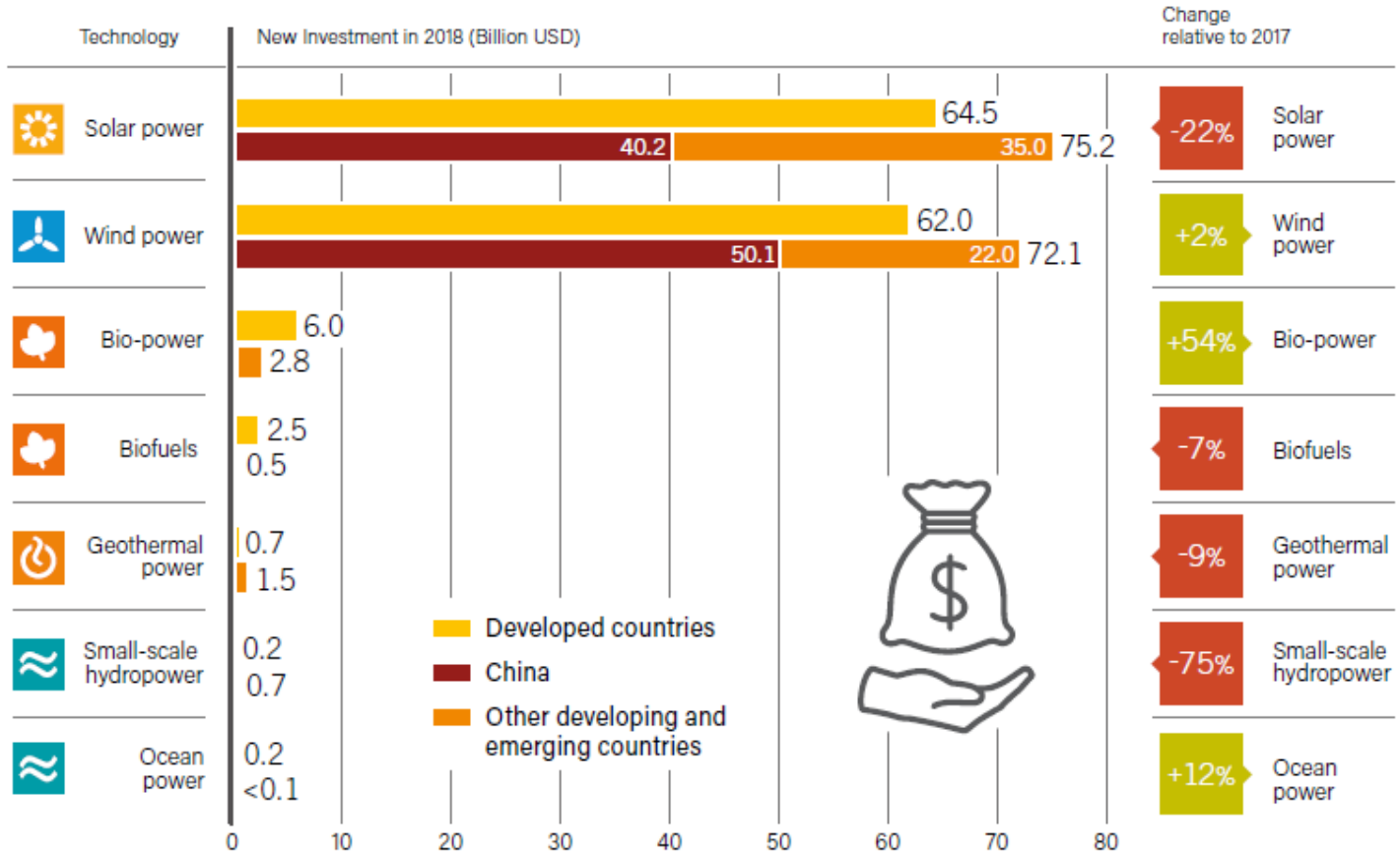
SUMMARY RESULTS – INVESTMENT FLOWS

Global New Investment in Renewable Energy by Technology in Developed, Emerging and Developing Countries, 2018



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EUROPEAN UNION

Any Questions?

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