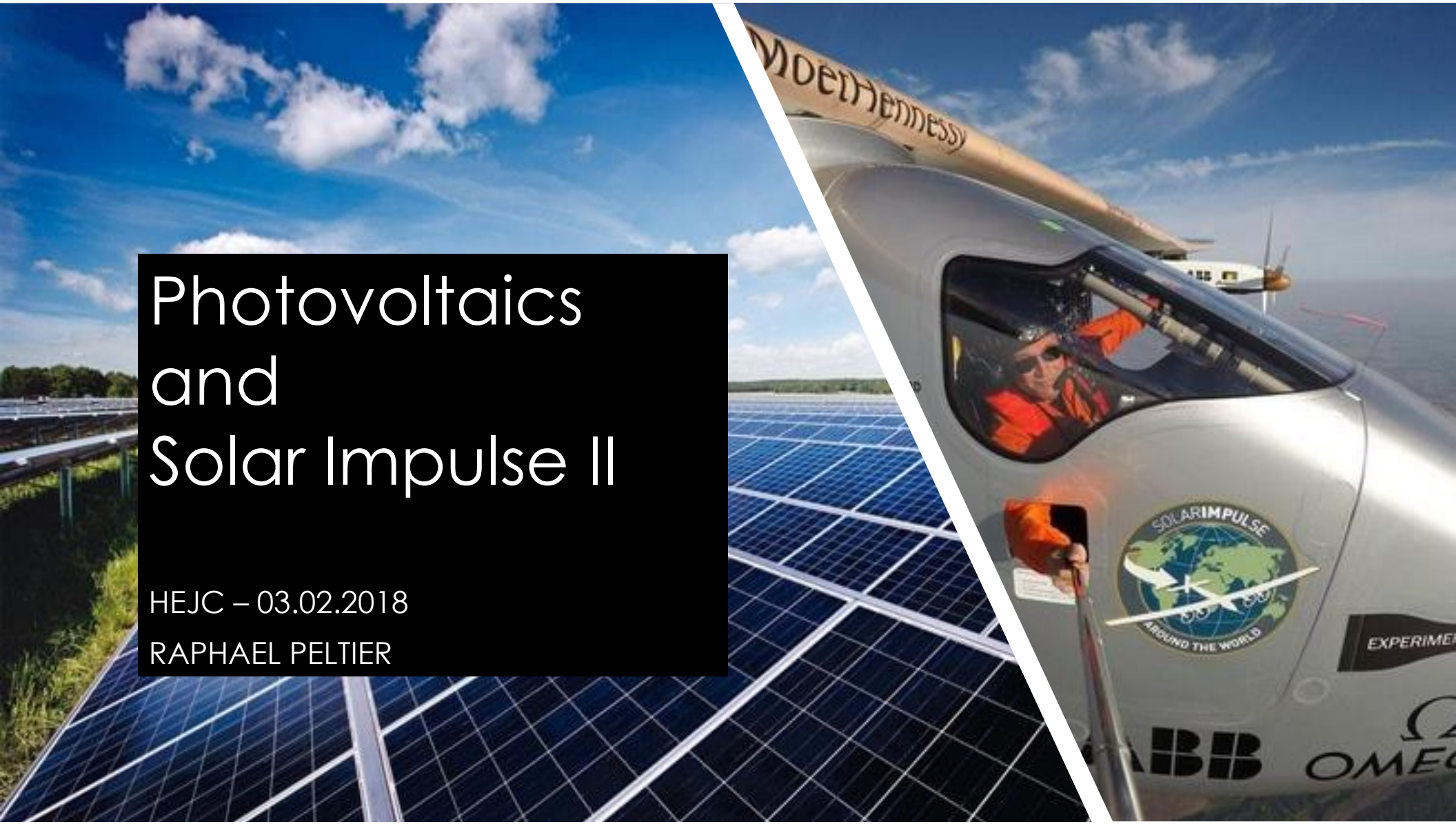


Photovoltaics and Solar Impulse II

HEJC – 03.02.2018

RAPHAEL PELTIER

Overview

I. Solar power – Status Quo
   i. Statistics
   ii. Policies

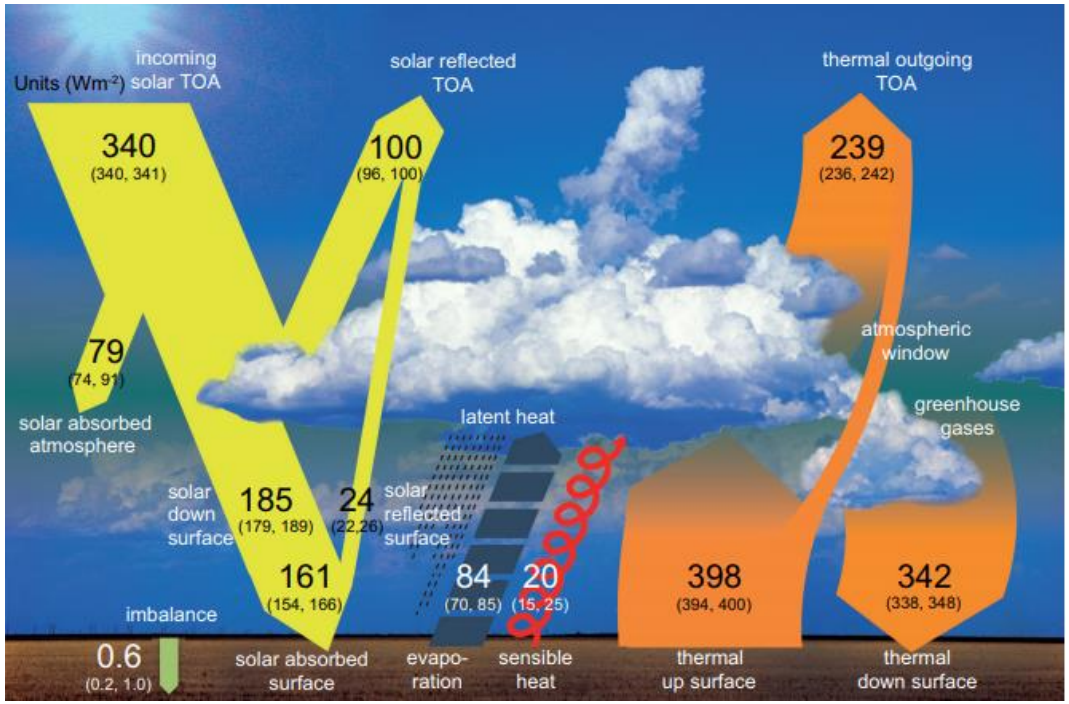
II. Photovoltaics
   i. Theory
   ii. True environmental costs

III. Solar Impulse II

Solar Power – Status Quo

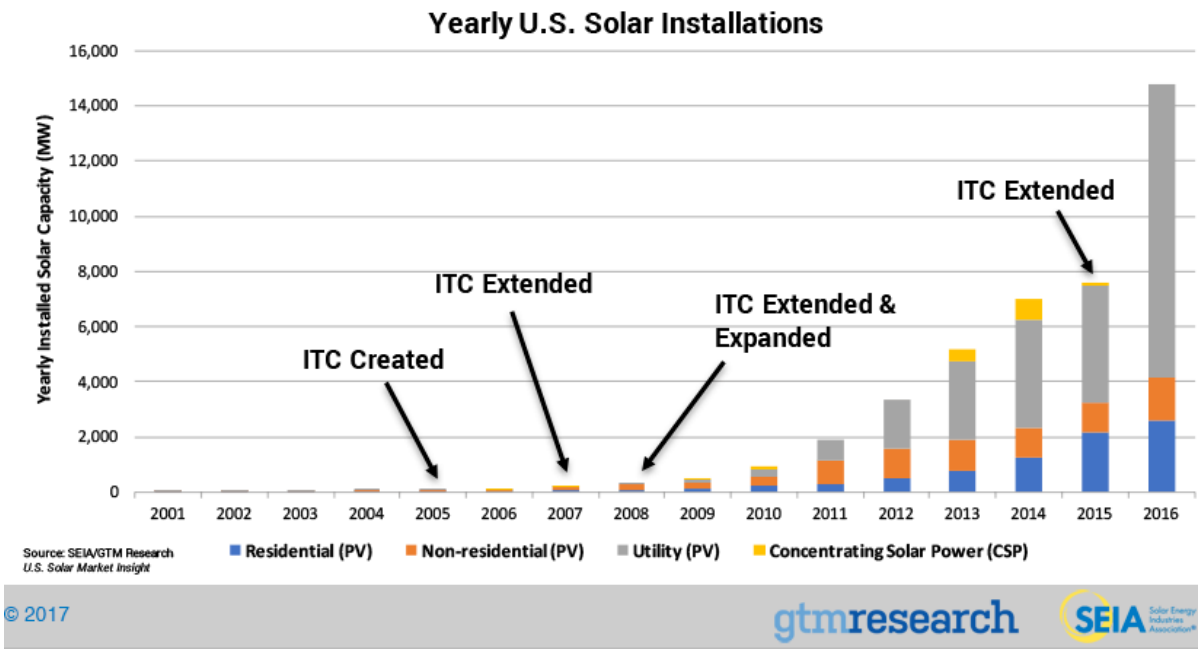
Powered by the Sun

- If the earth was a flat disk:
  - Energy by sun: 1 $\mathrm{kW/m^2}$
  - 100 PW (peta!) in total (100'000 TW)
  - >1'000'000 x total current world need
- Actually: 100 - 300 $\mathrm{W/m^2}$
  - Depending on location (poles vs. equator)
  - Not all energy above is usable!



IPCC Fifth Assessment Report, Technical Report UN World Energy Assessment: 2004 Update

Statistics - Installations



- Annual growth rate of **68%** on average all during the last decade

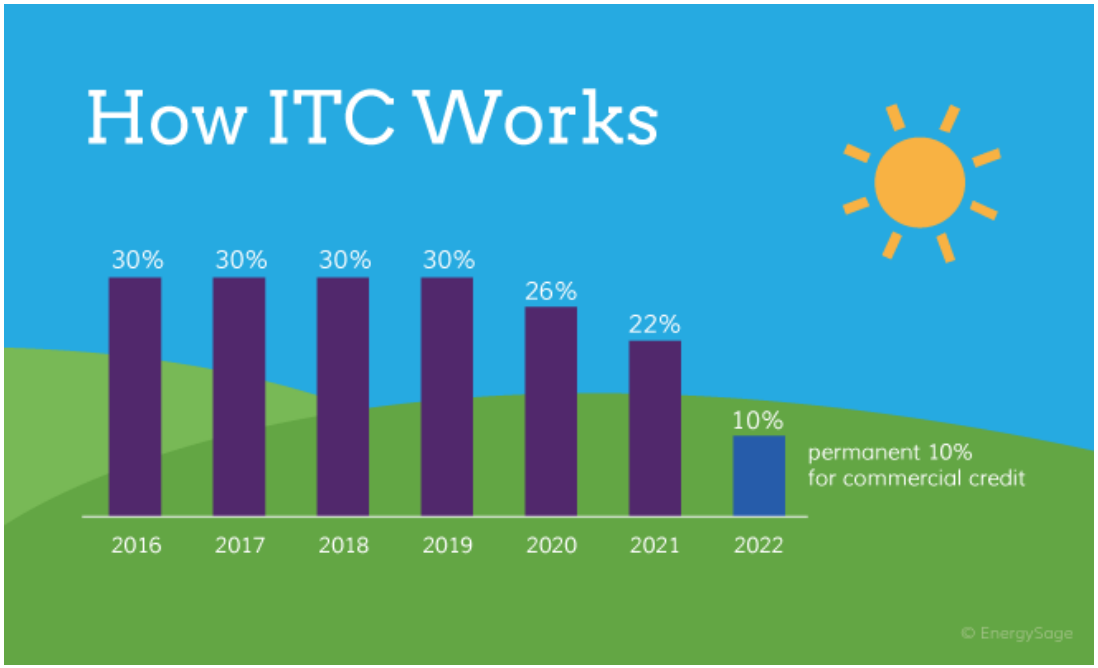
ITC – (Solar) Investment Tax Credit

I

- Deduct 30% of costs from taxes
- Reduction over time
- **2022:** only commercial credit left

- **1600% growth** since implementation (2006)

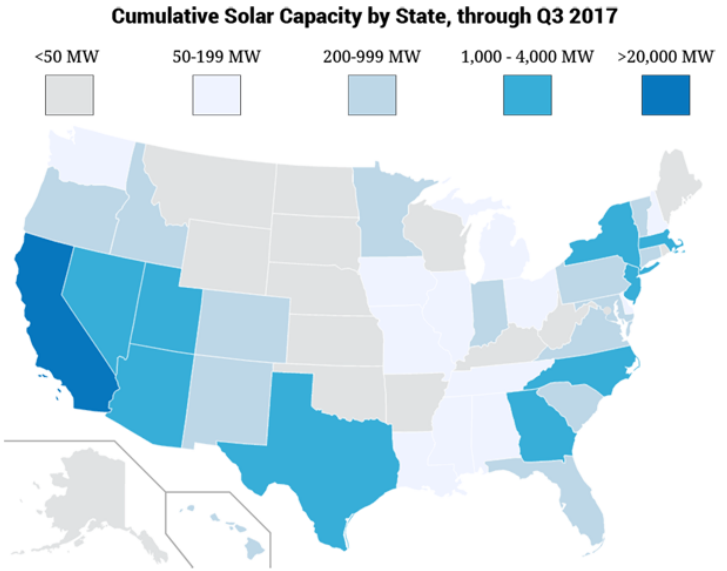
- Incentivise: **Prices** ↓
  Efficiency ↑



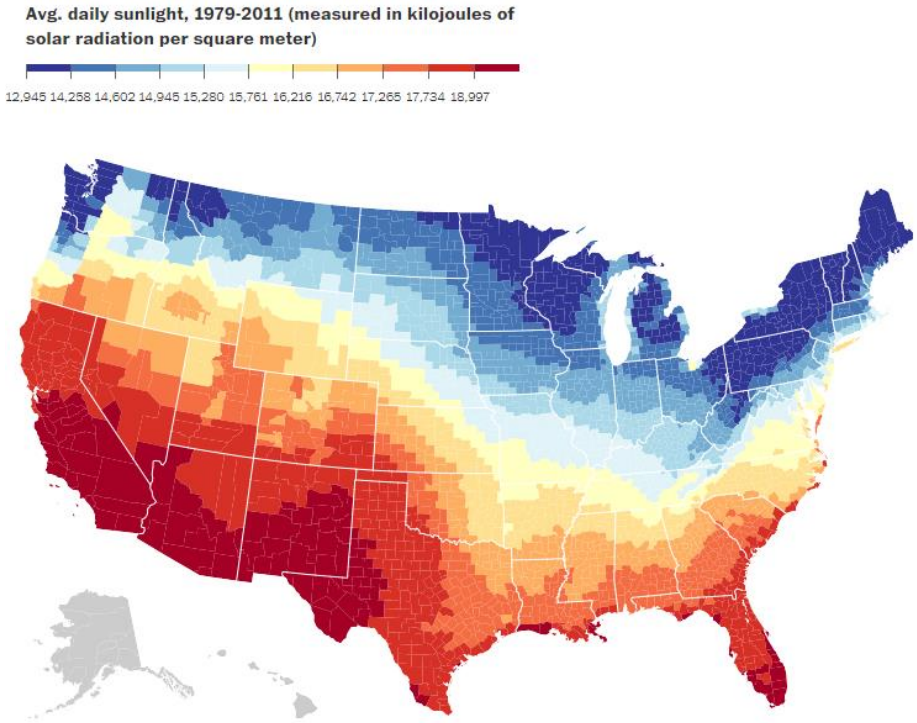
Statistics – 2016/2017

TOP 10 STATES

1. CA: 20,163 MW
2. NC: 3,785 MW
3. AZ: 3,336 MW
4. NV: 2,585 MW
5. NJ: 2,234 MW
6. MA: 1,898 MW
7. TX: 1,847 MW
8. UT: 1,566 MW
9. GA: 1,505 MW
10. NY: 1,176 MW

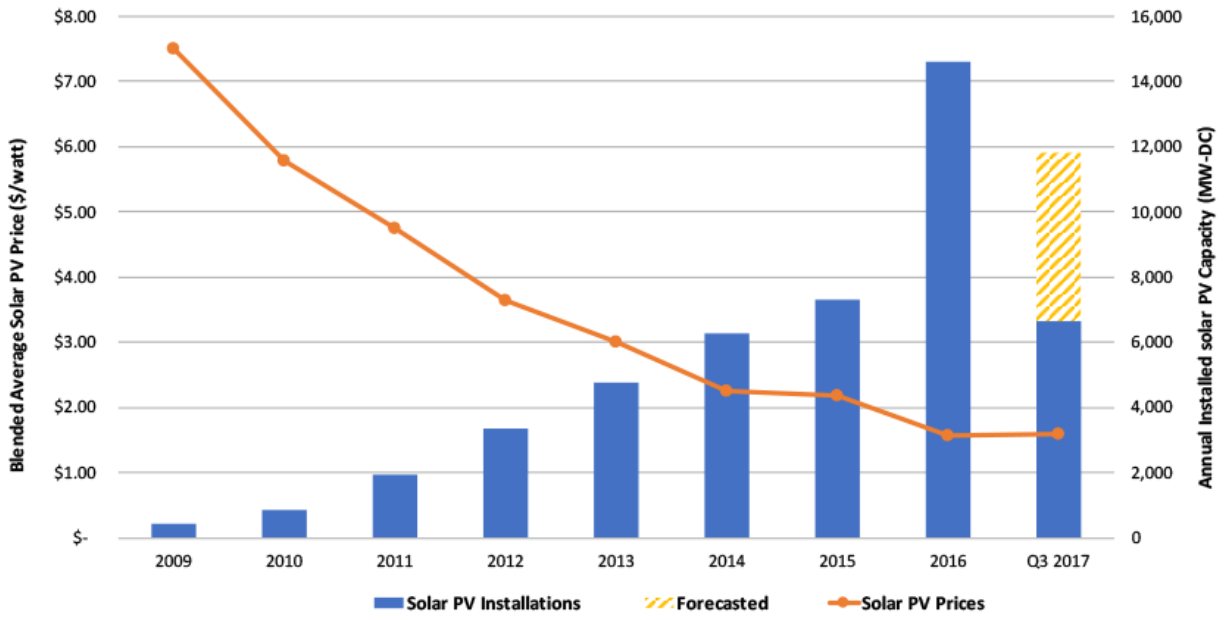


gtmresearch SEIA



https://www.washingtonpost.com/news/wonk/wp/2015/07/13/map-where-americas-sunniest-and-least-sunny-places-are/?utm_term=.83323b8527d6

Statistics - Prices



gtmresearch SEIA

Section 201 Solar Trade Case

I

- Jan 23rd Trump signs a proclamation for **tariffs on imported solar cells and modules** for a period of **four years**
- 9-months case study by U.S. international trade commission (ITC) after petitions from solar manufacturer **Suniva** and **SolarWorld**
- Effective date of the tariffs is **February 7, 2018**
- **Tariff level set at 30% (5% declining per year)**

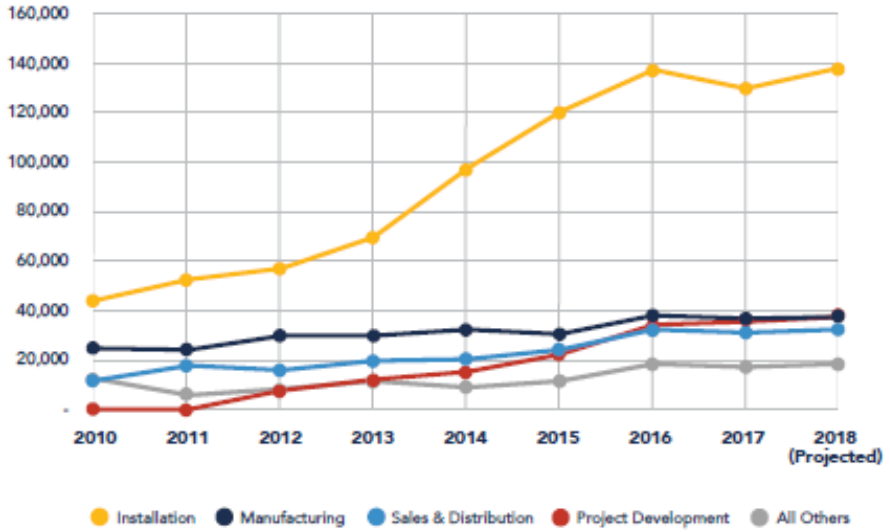
	Year 1	Year 2	Year 3	Year 4
Safeguard Tariff on Modules and Cells	30%	25%	20%	15%
Cells Exempted from Tariff	2.5 gigawatts	2.5 gigawatts	2.5 gigawatts	2.5 gigawatts

https://www.seia.org/research-resources/section-201-solar-tariffs

https://www.thewrap.com/donald-trump-got-his-eclipse-meme-from-a-guy-who-said-we-have-enough-of-these-jews/

Statistics – 2016/2017

- 2017: **250'271** solar workers in US
- Decline of **3.8%**, or 9'800 fewer jobs since 2016 due to:
  - Political challenges
  - Economical challenges
- **Section 201 Solar trade case** caused significant uncertainty



NOTE: *Projections are based on survey responses submitted prior to the trade case decision.*

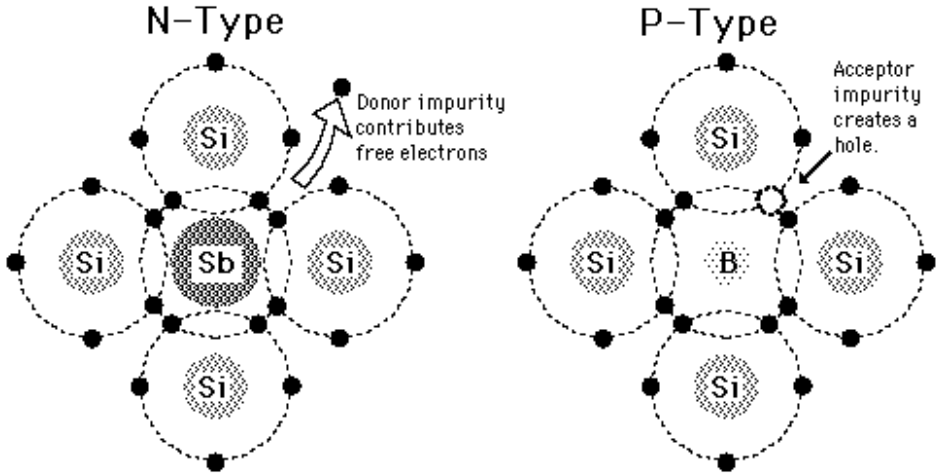
National Solar Jobs Census 2017, The Solar Foundation, available at: SolarJobsCensus.org

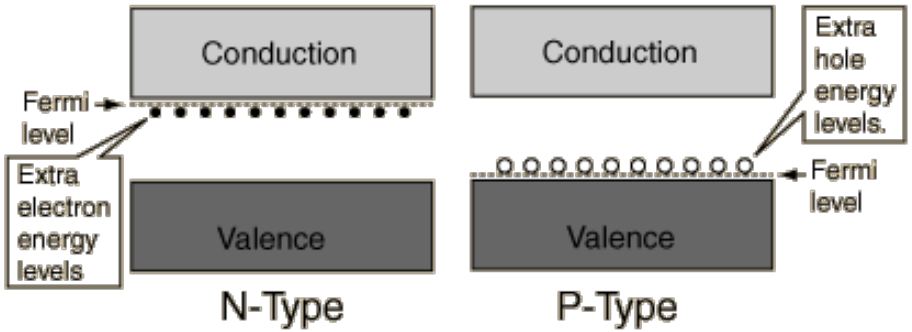
Open discussion – 5 min

- Incentive: stop importing from cheaper countries, innovate yourself
- Jobs: How long until USA can become competitive in price with cheap regions
- Cost vs. Profit: short term costs for potential long term benefits (employment, prices, innovation, etc.)

Photovoltaic Solar Cell

P- and N-type semiconductor



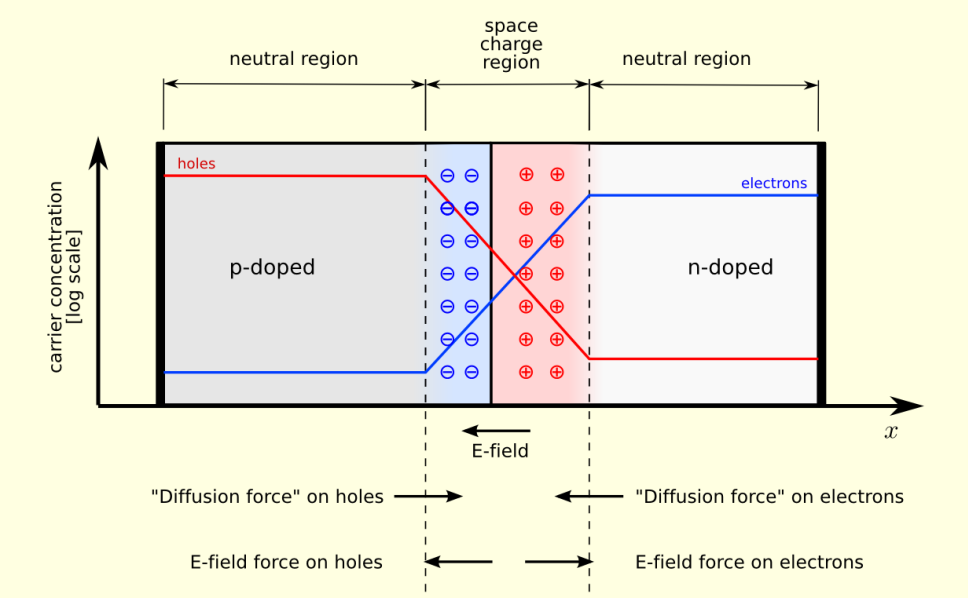


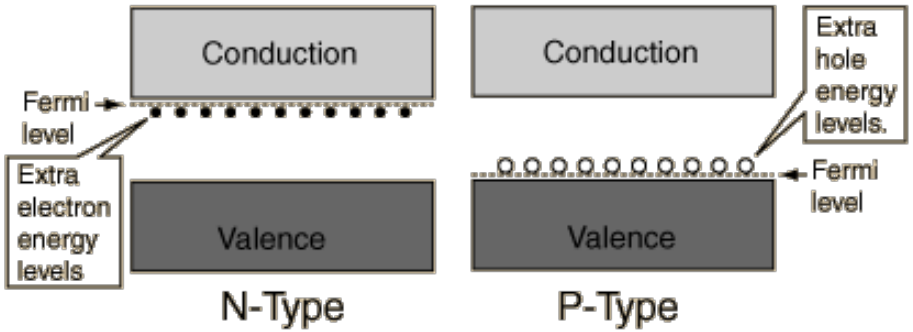
Around 1:1'000'000 are impurity

http://ummalqura-phy.com/HYPER1/dope.html

http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/dope.html

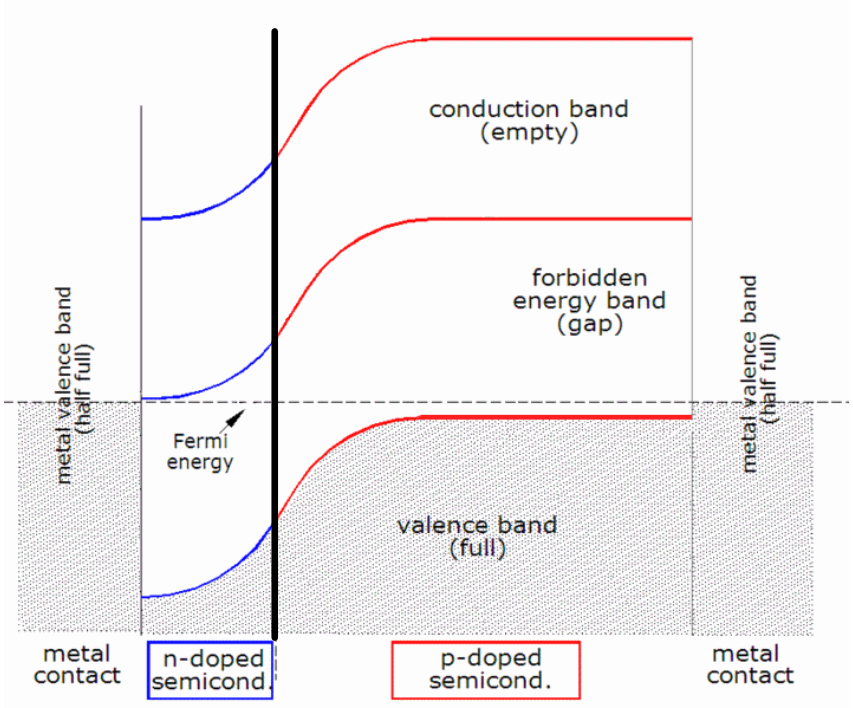
PN-Junction

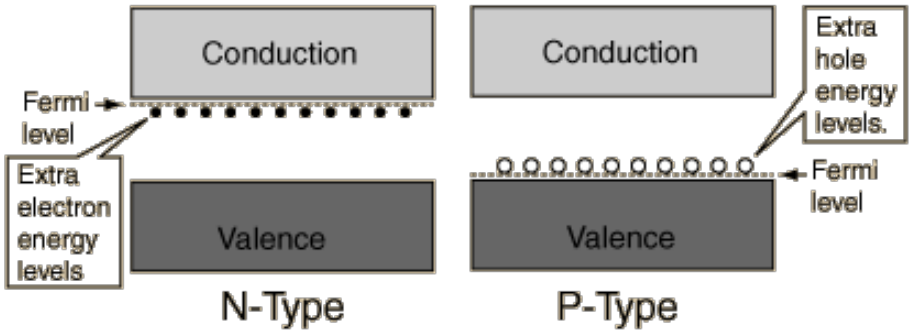




https://en.wikipedia.org/wiki/P%E2%80%93n_junction

PN-Junction

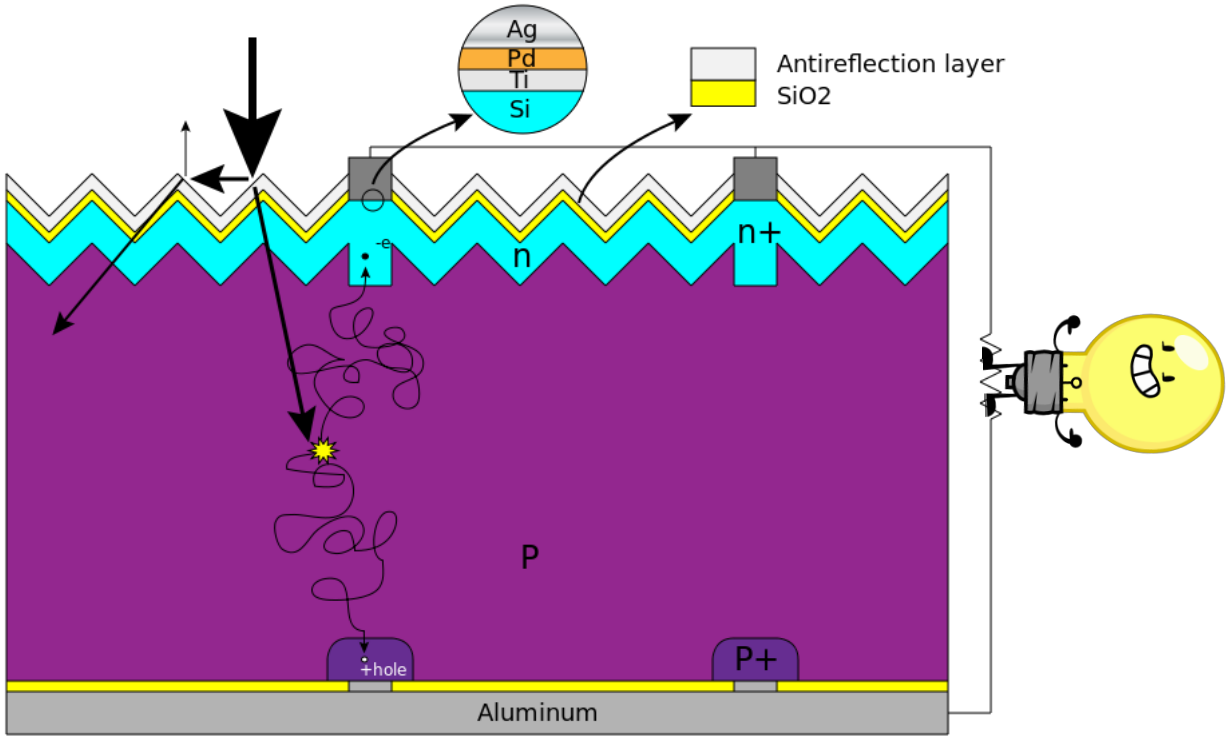




@ thermal equilibrium

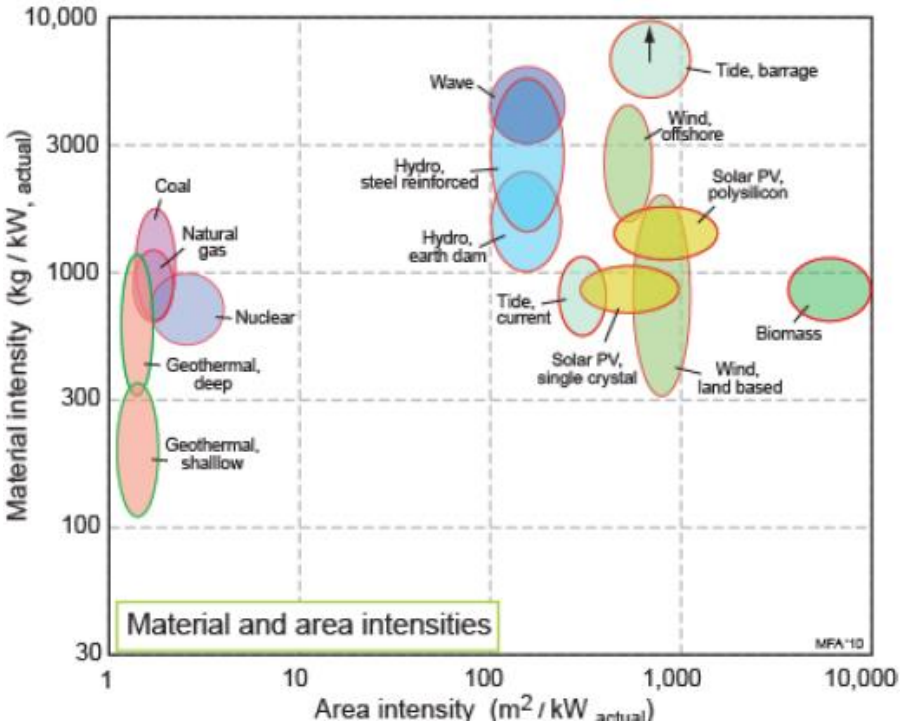
https://en.wikipedia.org/wiki/Theory_of_solar_cells

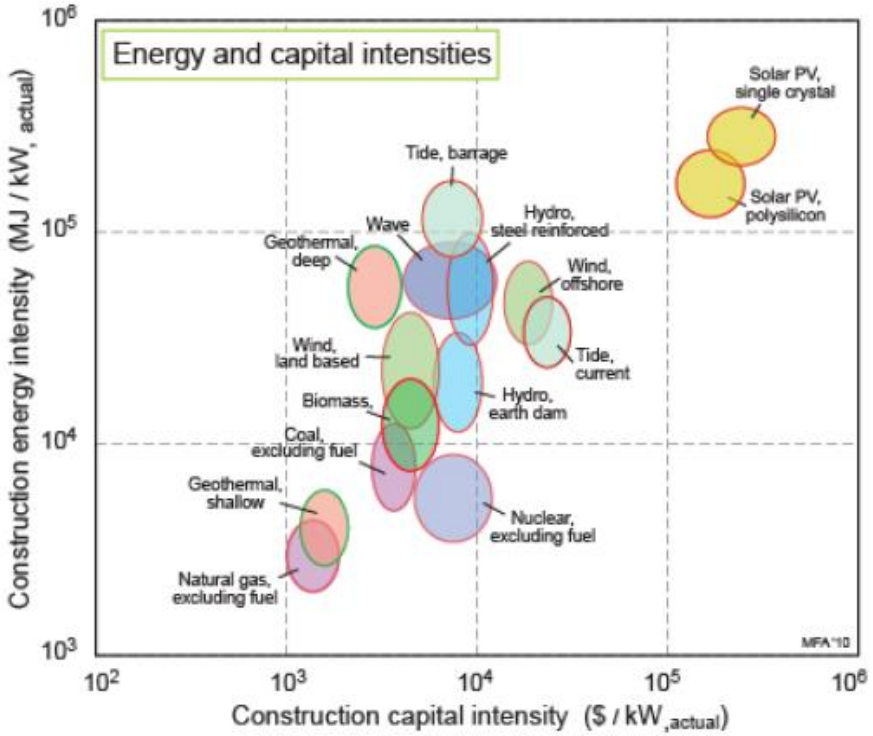
Photovoltaic cell



https://en.wikipedia.org/wiki/Solar_cell

Cost intensities





M. Ashby et al., White Paper Series Energy, Granta design 2012

Capacity factors

$$Capacity\ factor = \frac{power\ output\ over\ time}{max.power\ output\ over\ time}$$

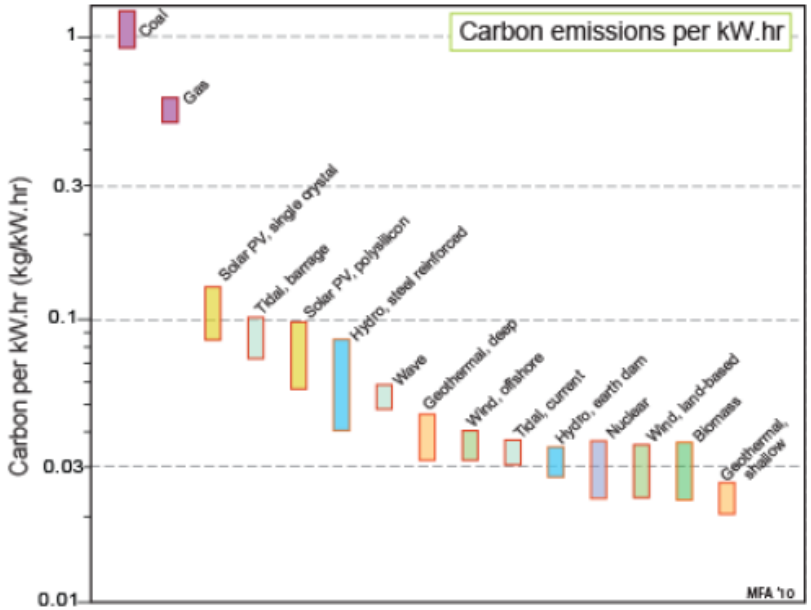
Power system	Capital intensity (k/kW_nom)	Area intensity (m2/kW_nom)	Material intensity (kg/kW_nom)	Construction energy intensity (MJ/kW_nom)	Construction carbon intensity (kg/kW_nom)	Capacity factor (%)
Conventional, gas	1–1.5	1-4	605–1080	1730–2710	111–211	75–85
Conventional, coal	2.5–4.5	1-4	520–1800	3580–9570	308–628	75–85
Nuclear, fission	3.5–6.4	1-3	170–625	2000–4300	105–330	45–55
Solar PV, single crystal	20.5–44.3	45–100	73–120	25,700–43,700	1,400–2200	8–12
Solar PV, poly-silicon	12.5–20.5	50-200	120 -220	23,700–33,700	630–1400	8–12
Wind, land-based	1.1–2.4	200–350	200–600	4380–9014	156–692	25–28
Wind, off-shore	5.5–8.0	200–330	1016–2000	12,000–20,000	840–1232	35–45
Hydro, earth dam	4.5–6.0	91–200	900–2000	7260–15,000	630–1100	45–65
Hydro, steel reinforced dam	5.5–7	80–150	1000–5700	30,000–66,000	2000–7000	50–70
Wave	1.2–4.4	42–100	1000–2000	22,950–31,540	1670–2070	25–40
Tidal, current	10–15	150–200	350–500	12,000–18,000	800–1130	35–50
Tidal, barrage	1.6–2.5	200–300	5,000–50,000	30,000–45,000	2400–3520	20–30
Geothermal, shallow	1.15–2	1–3	61–500	2400–3500	160–250	75–95
Geothermal, deep	2–3.9	1–3	500–1200	25,000 -65,700	1700–3900	75–95
Biomass	2.3–3.6	5,000–10,000	69–500	4,000–15,800	400–1800	50

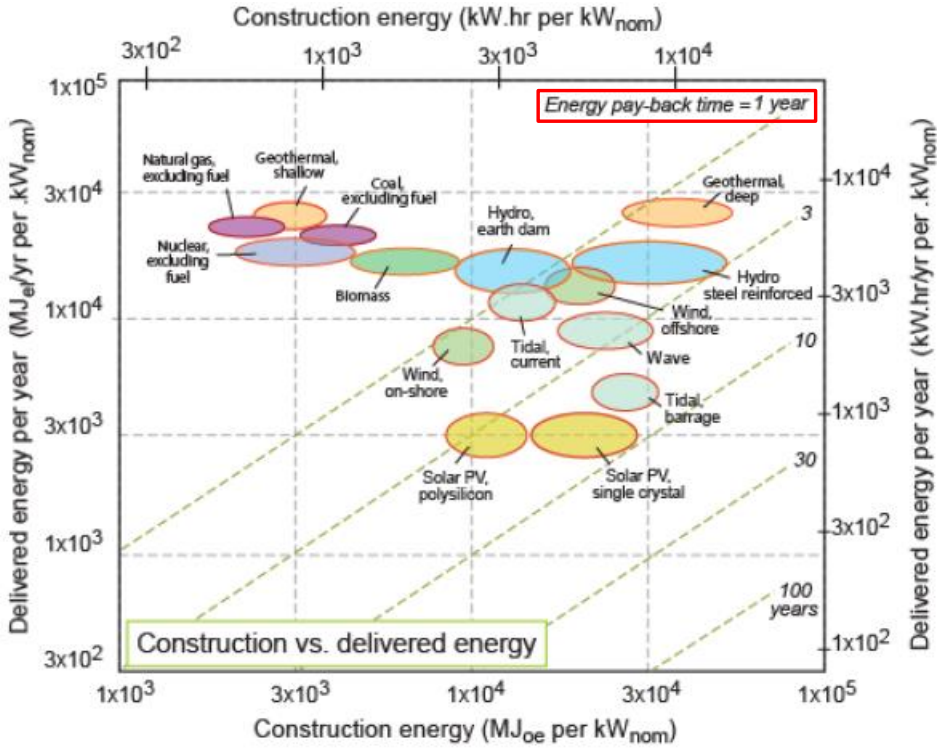
Table 2: Average approximate global resource intensities for power generating systems.

M. Ashby et al., White Paper Series Energy, Granta design 2012

Energy balance

For system life of 20 yrs





M. Ashby et al., White Paper Series Energy, Granta design

Critical materials

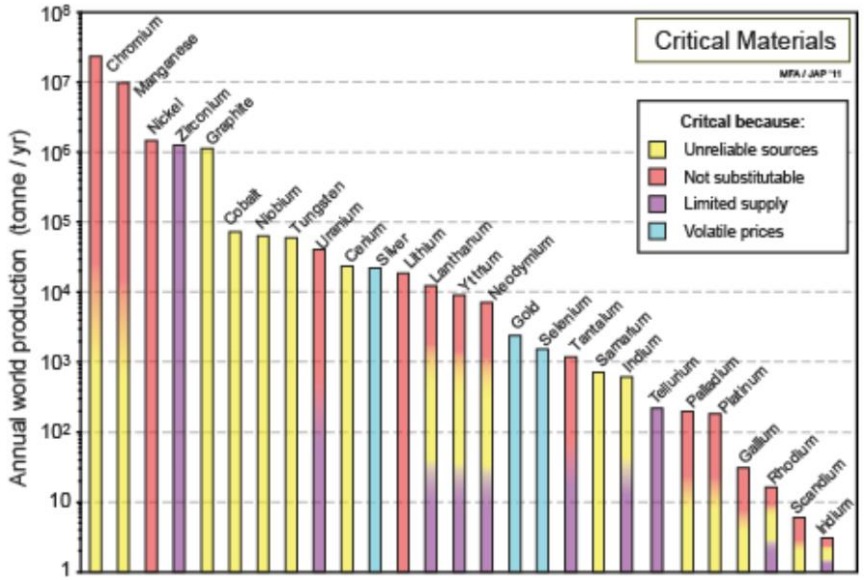


Figure 10. Current (2010) annual world production of 27 critical materials, highlighting the reasons for their being identified as critical.

Materials: PV power	Intensity (kg/kW_{nom})
Aluminum	62.32
Antimony (dopant)	0.10
Copper*	0.8
EVA	41.33
Gallium* (dopant)	0.50
Galvanized mild steel	40.67
Indium*	0.08
Lead tin solder	0.08
Silane (amorphous silicon)	0.49
Silver*	0.08
Stainless steel	18.70
Tellurium* (dopant)	0.10
Ytterbium* (dopant)	0.10
Total mass, all materials	**165**

Notes

- **These are masses per rated kW**
- **Starred * materials are strategic**

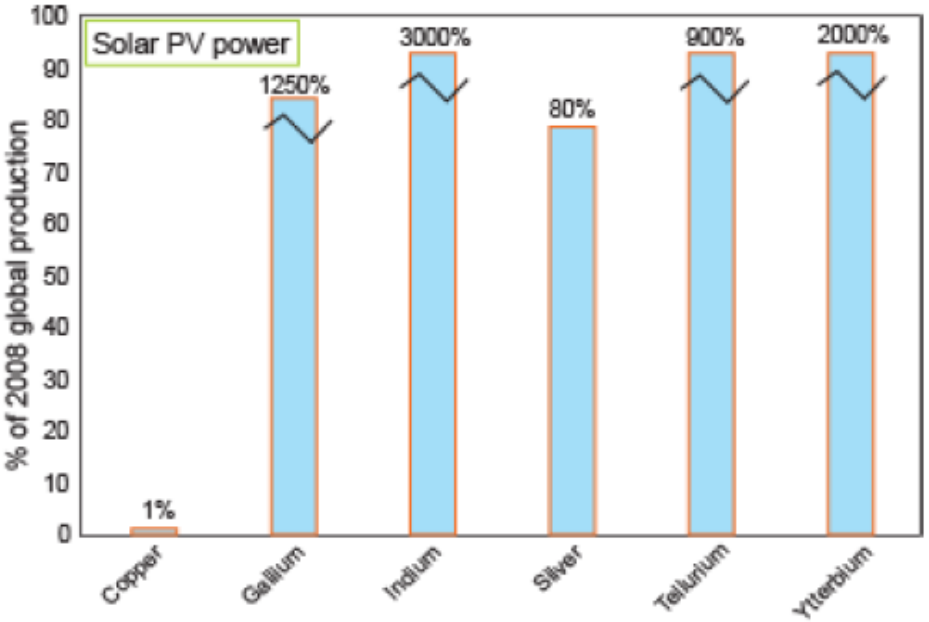
based on slides by M. Ashby

M. Ashby et al., White Paper Series Energy, Granta design 2012

Future production needs

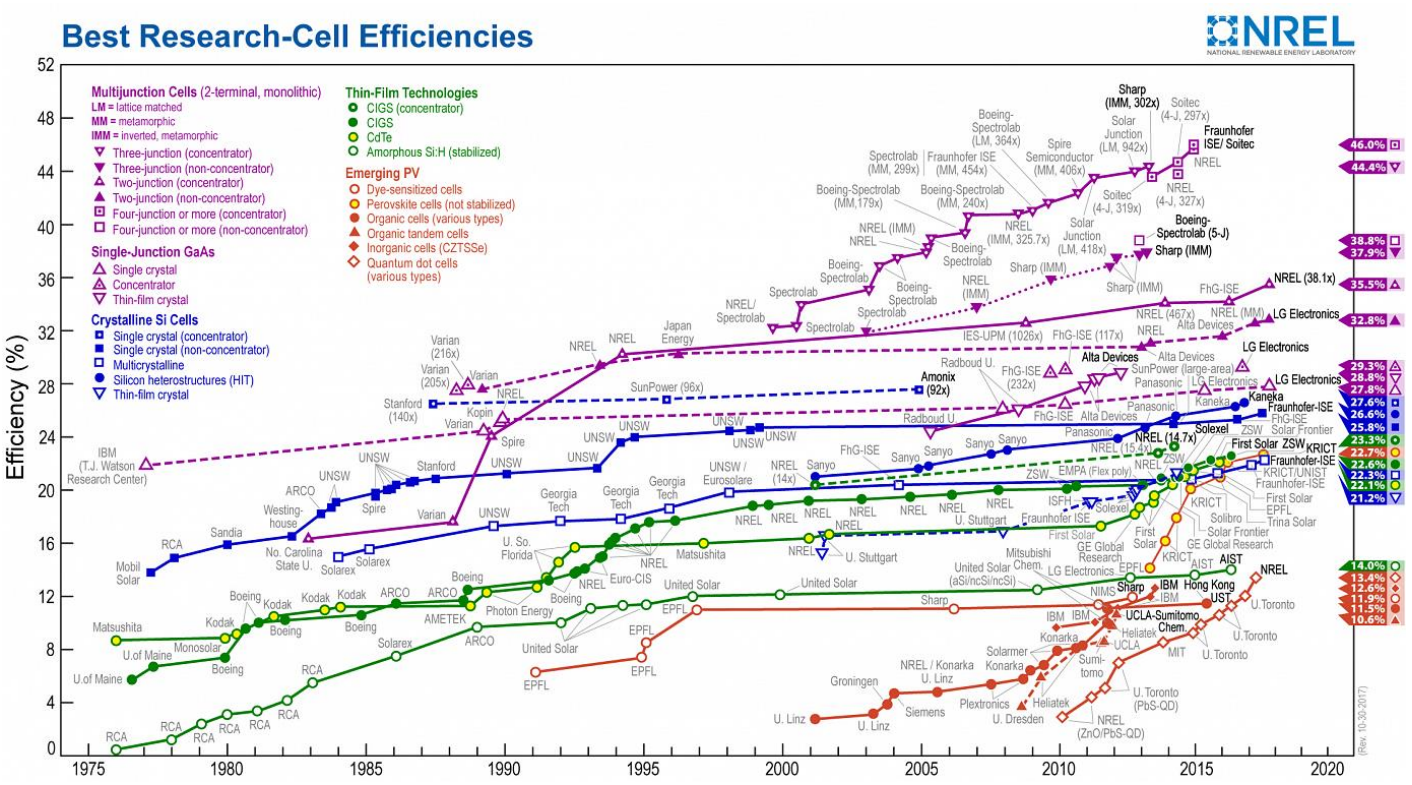
- **Scenario:** 2 TW of power from PV power system by 2020 (+ 10 hrs battery storage)
- Calculated fraction of current (2008) world production of critical material that would be required

- **Anticipating the demands is essential to plan future power supply!**



M. Ashby et al., White Paper Series Energy, Granta design 2012

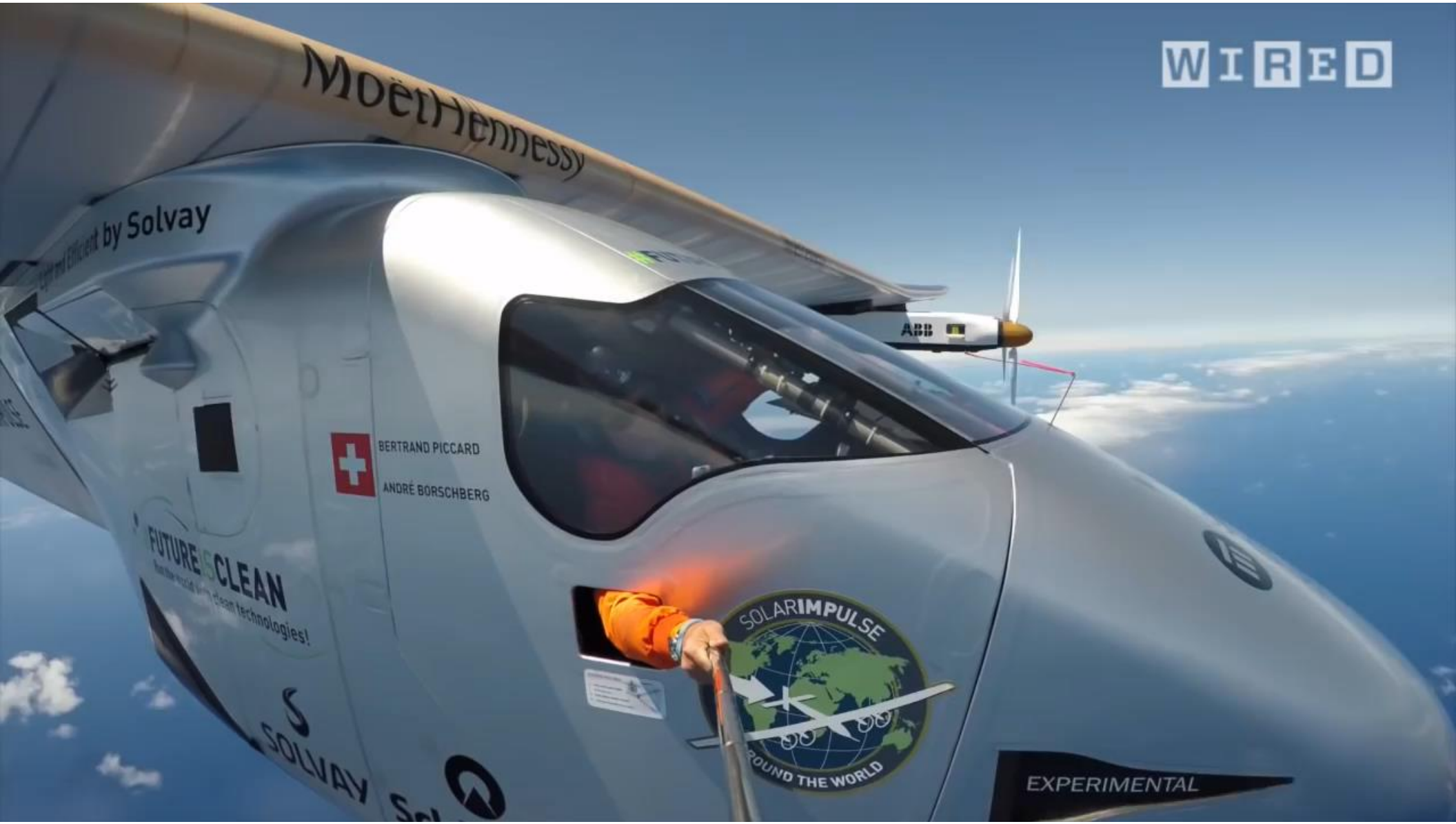
PV efficiencies



https://www.nrel.gov/pv/

III

Solar Impulse II


WIRED
Moët Hennessy
Light and Efficient by Solvay
ABB
BERTRAND PICCARD
ANDRÉ BORSCHBERG
FUTURE IS CLEAN
SOLVAY
SOLARIMPULSE
AROUND THE WORLD
EXPERIMENTAL

Solar Impulse II

III

Bertrand Piccard / André Borschberg

Solar Impulse II Team

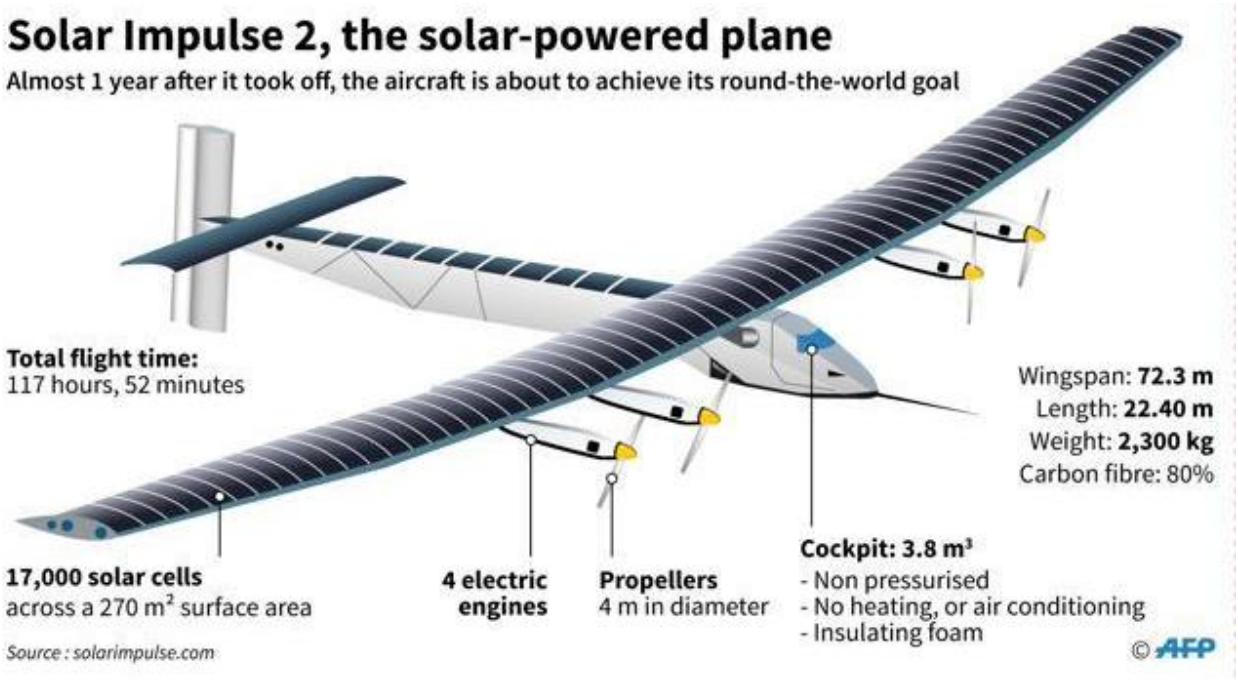
http://www.dailymail.co.uk/sciencetech/article-3162361/Solar-Impulse-2-ABANDONED-2016-Round-world-trip-stay-grounded-April-suffering-battery-damage.html

http://aroundtheworld.solarimpulse.com/pilots-team

Solar Impulse II

III

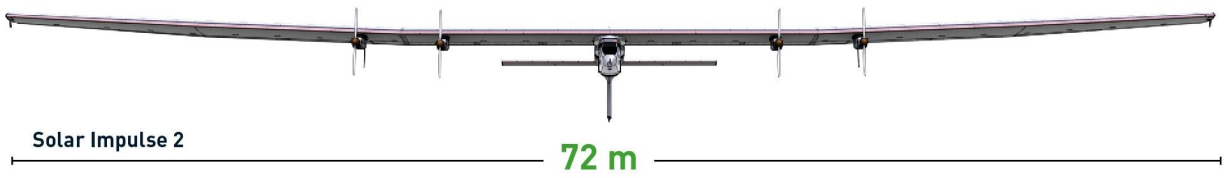
- Length: 21.85 m
- Wingspan: 63.4 m
- Wing area: 200 m^2
- Weight: 1600 kg (max. 2000 kg)
- Power: 4 x 13.5 kW (17.4 HP)
- Speed: 90 km/h
- Endurance: 36 hrs (3250 km)
- Service height: 8500 m



https://www.hindustantimes.com/world-news/in-pics-solar-impulse-2-takes-off-from-egypt-on-final-leg-of-world-tour/story-iTvSKP6LERYXimdC2jXi2N.html

Solar Impulse II

III



http://synergyfiles.com/2015/04/solar-impulse-1-vs-solar-impulse-2/

Solar Impulse II

Solar Impulse II

III

- 2003: Feasibility study at the École Polytechnique Fédérale de Lausanne (EPFL)
- 2004–2005: Development of the concept
- 2006: Simulation of long-haul flights
- 2006–09: Construction of first prototype (HB-SIA; *Solar Impulse 1*)
- **2009: First flight of *Solar Impulse 1***
- 2009–11: Manned test flights
- 2011–12: Further test flights through Europe and North Africa
- 2011–13: Construction of second prototype (HB-SIB; *Solar Impulse 2*)
- 2013: Continental flight across the US by *Solar Impulse 1*
- 2014: First flight of *Solar Impulse 2*
- **2015–2016: Circumnavigation of the Earth by *Solar Impulse 2*, conducted in seventeen stages over 16-1/2 months**

Solar Impulse II

III

- Frame: Carbon fiber and alveolate honey comb foam sandwich
  - fuselage, cockpit and spars
- Airframe: carbon fibre honeycomb sandwich
  - Upper surface encapsulated solar cells
  - Lower surface covered by high strength flexible skin
  - 140 Carbon fibre ribs spaced at 50 cm intervals
- Insultation: rigid polyurethane foam
- Windows: high performance polycarbonate

- **Efficiency: 23% for solar cells, 97% for the motors**

Solar Impulse II

III

Solar Impulse II

- Capacity: 1
- **Wing area: 200 m^2**
- **Weight: 1600 kg**

  Price: $170 mio

- **8 kg/m^2**

Jabiru J170

- Capacity: 1
- **Wing area: 9.56 m^2**
- **Weight: 600 kg**

  Price: $38'400

- **63 kg/m^2**

https://en.wikipedia.org/wiki/Jabiru_J170

Solar Impulse II

III