

Spin-offs from space

Prof. Stuart Irvine



EGRD Workshop
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Birmingham 15th
June 2017



Swansea University
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UNED ENWROSGO
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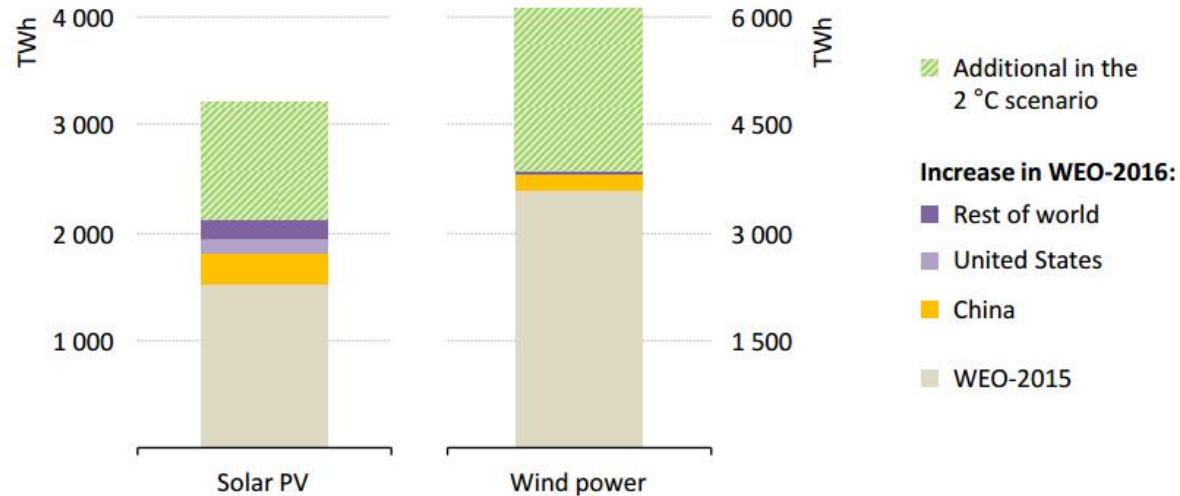


Umwylledh Cymru
Welsh Government

Greater policy support boosts prospects for solar PV and wind

World
Energy
Outlook
2016

Solar PV and wind generation, 2040



Stronger policies on solar PV and wind help renewables make up 37% of electricity generation in 2040 in our main scenario – & nearly 60% in the 2 °C scenario

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Global installed PV capacity in 2016

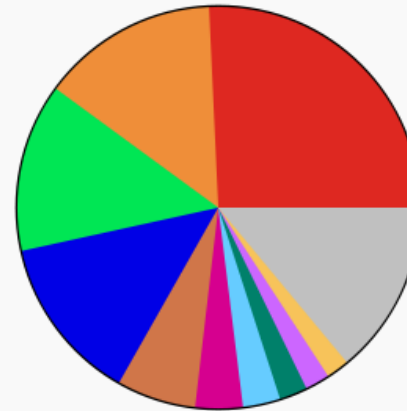
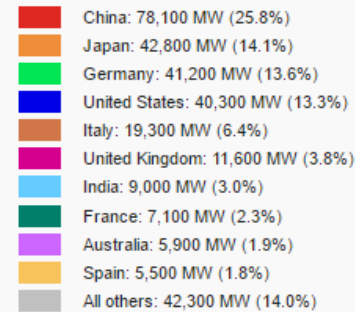
Installed PV Solar Power Capacity in 2016 (GW)^{[3][7]}

#	Nation	Total Capacity	Added Capacity
1	China	78.07	34.54
2	Japan	42.75	8.6
3	Germany	41.22	1.52
4	United States	40.3	14.73
5	Italy	19.28	0.37
6	United Kingdom	11.63	1.97
7	India	9.01	3.97
8	France	7.13	0.56
9	Australia	5.9	0.84
10	Spain	5.49	0.06
11	South Korea	4.35	0.85
12	Belgium	3.42	0.17
13	Canada	2.72	0.2
14	Greece	2.6	0
15	Thailand	2.15	0.73
16	Czech Republic	2.1	0
17	Netherlands	2.1	0.53
18	Switzerland	1.64	0.25
19	Chile	1.61	0.75

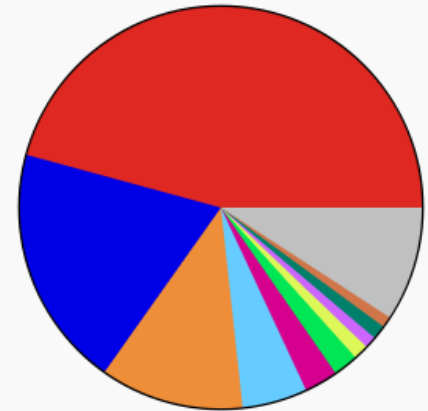
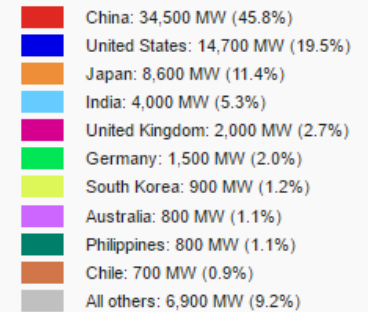
PV Watt per Capita (2016)^[3]

1	Germany	511
2	Japan	336
3	Italy	322

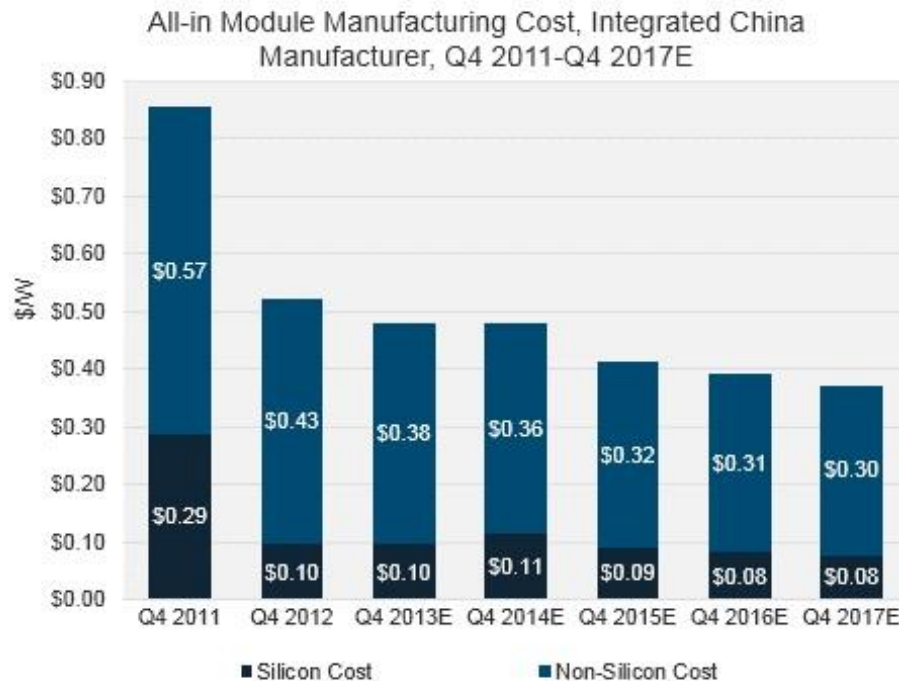
Top 10 countries in 2016 based on total PV installed capacity (MW)^[3]



Top 10 countries based on added PV capacity in 2016 (MW)^[3]

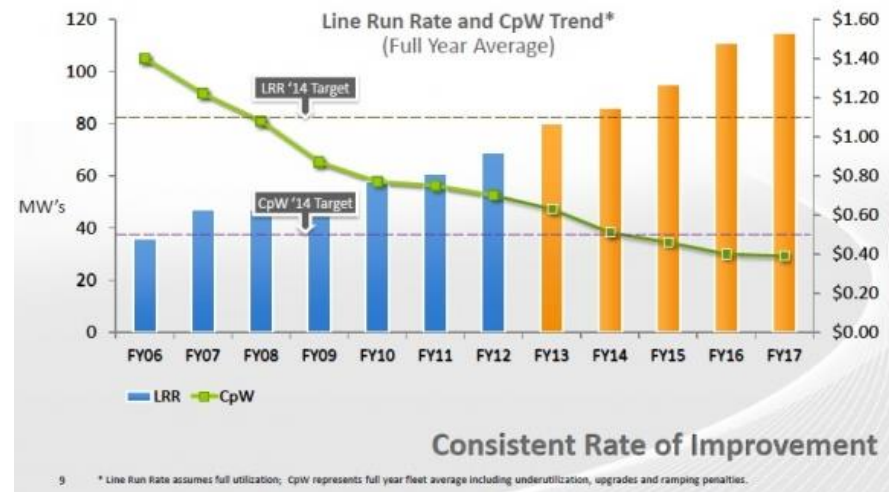


PV module prices continue to fall, driven by manufacturing scale and improving module efficiency

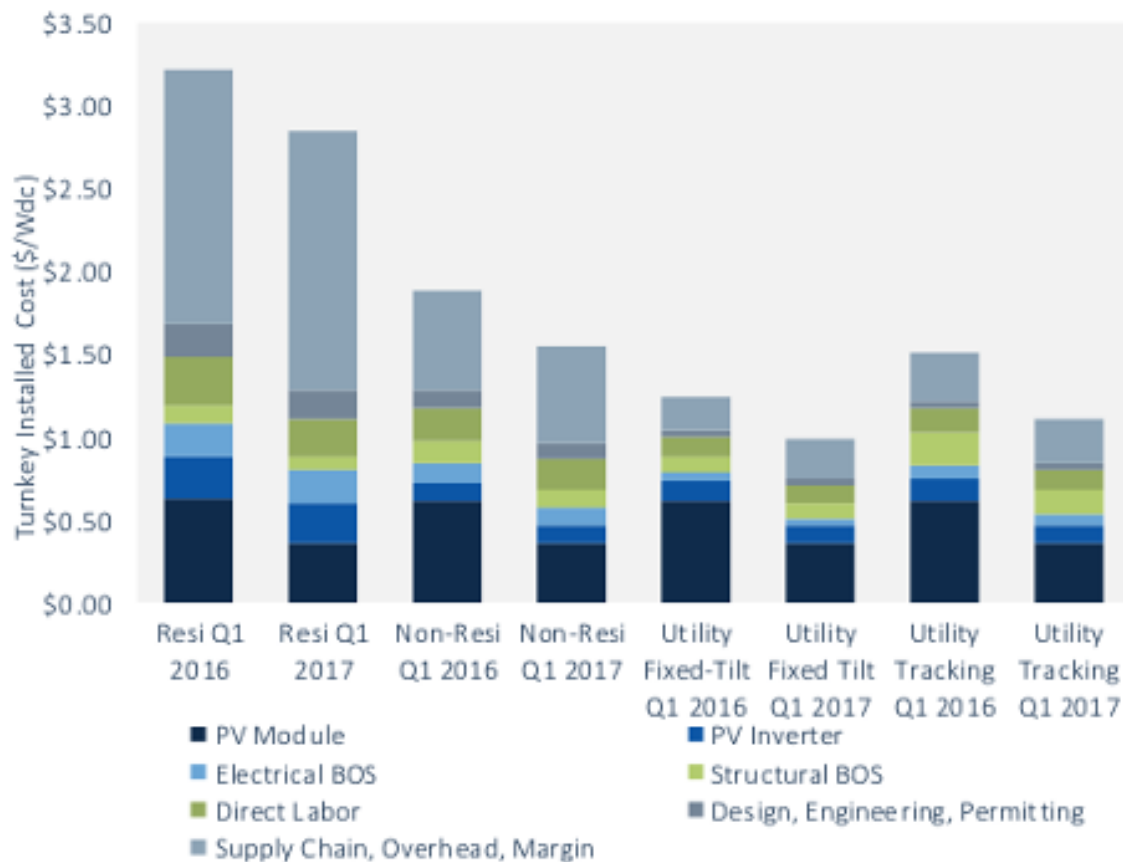


Includes depreciation, labor, consumables and overhead. Does not include SG&A, interest, shipping, or warranty expenses

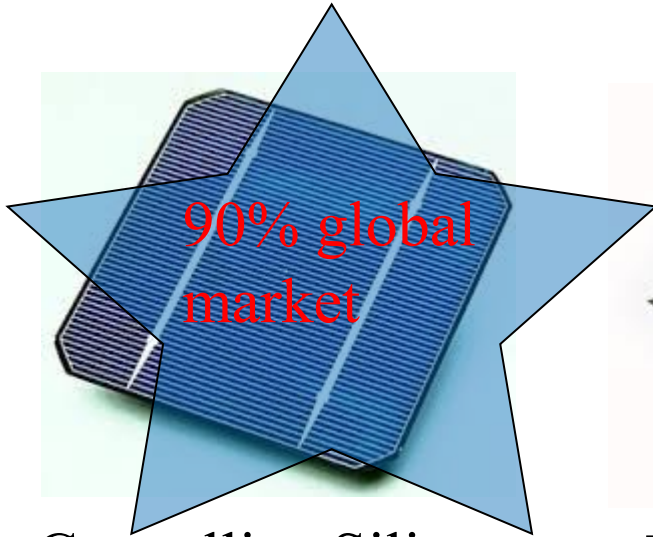
First Solar – thin film PV



Utility scale PV price falls below \$1 per Watt in US – PV Magazine



Different types of Solar Cells



Crystalline Silicon



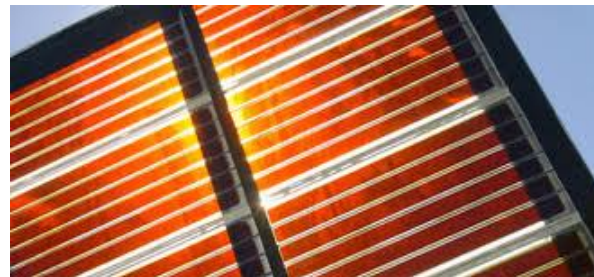
Thin film flexible



Multi-junction III-V



Organic



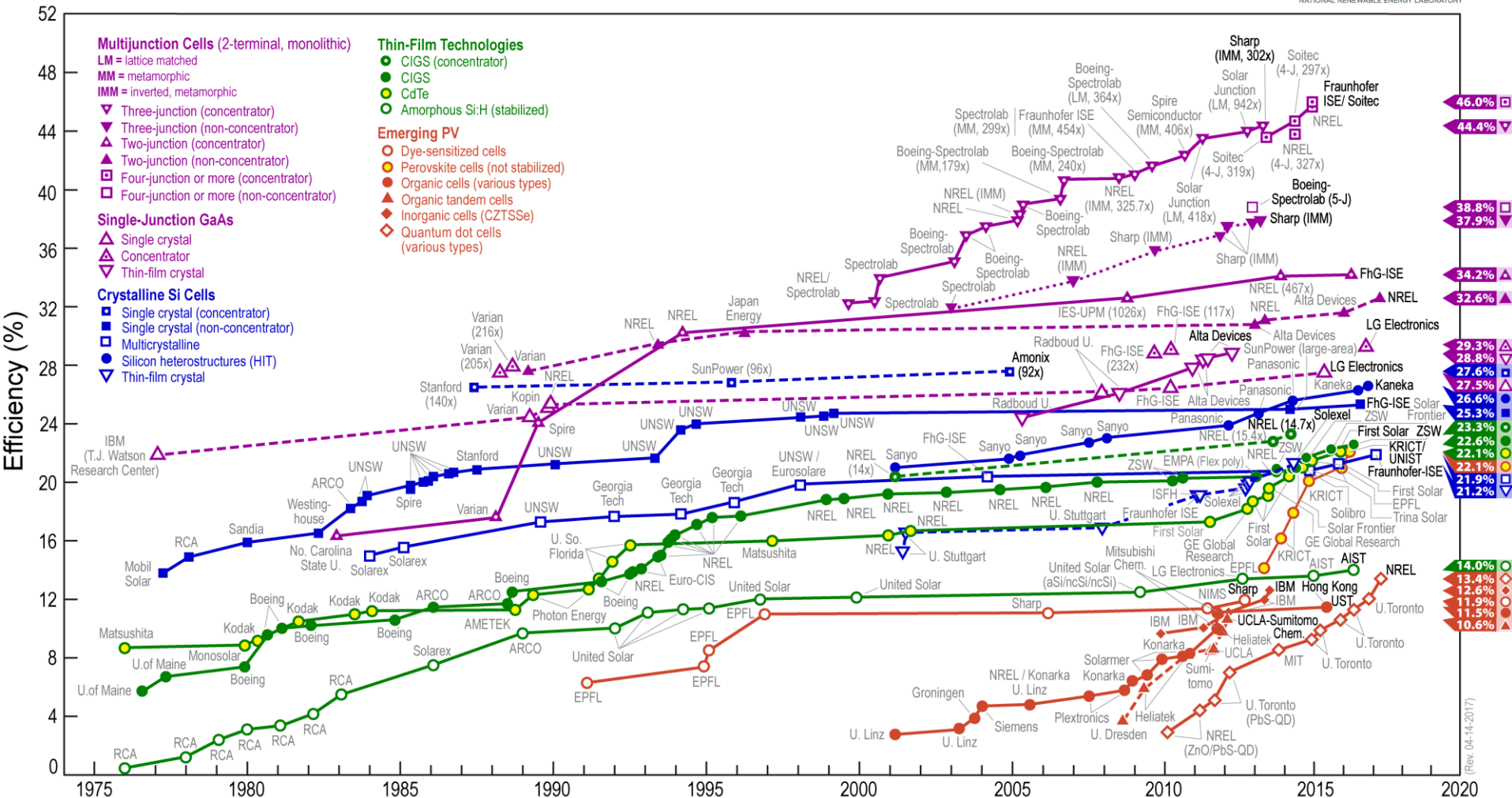
Dye sensitized



Perovskite



Best Research-Cell Efficiencies

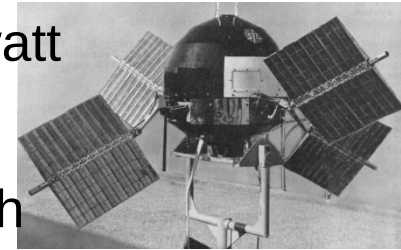


Solar cell applications in space – current and emerging

- 1839: Discovery of PV effect
- 1954: Bell Labs, the first silicon solar cell capable of converting enough of the sun's energy into power to run everyday electrical equipment.



- 1958: The first practical applications were satellites. Vanguard I space satellite <1 watt silicon array to power its radios
- 1959: Explorer VI satellite is launched with a photovoltaic array of 9600 silicon cells

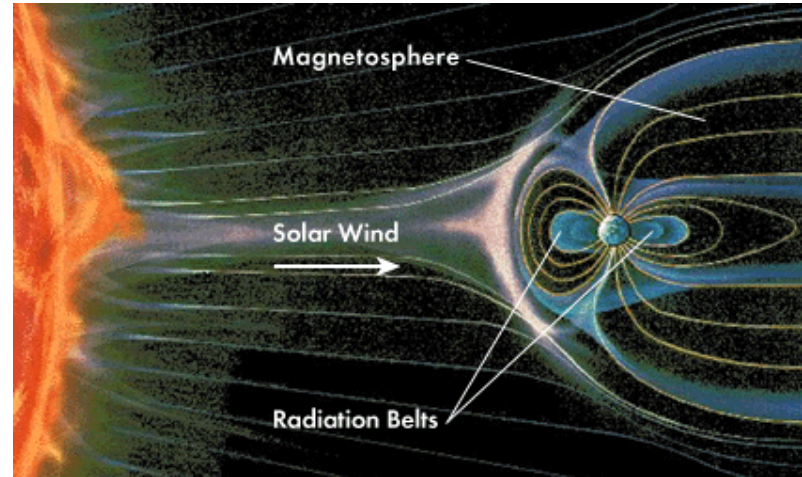
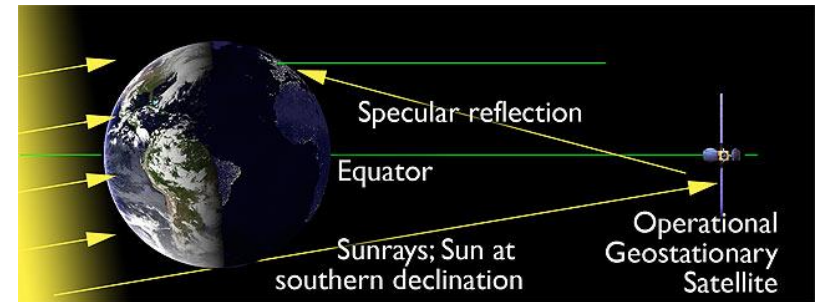


- 1980's: Terrestrial applications
- 1990's: multi-junction solar cells first used for space
- >2000: predominantly multi-junction (30% AM0)



Harsh Environment for Solar Cells in Space

- High intensity Ultraviolet
- Electron and proton irradiation
- Thermal gradients – front and back, in and out of eclipse (+100 to -200 °C)
- Storage/stowage
- Shock of launch and deployment



High performance, high specific power PV for terrestrial applications

- Current PV module supply designed for bolt-on to robust roofs and ground mount – specific power not an issue.
- High specific power is important for space (reducing launch weight) and BIPV on industrial roofs – require new solutions!



Flexible ultra-thin glass (UTG) for thin film PV



- Cover glass -protect solar cells in space from ultra-violet, electron and proton irradiation.
- QST UTG is cerium doped to prevent radiation damage to optical transmission.

Ultra-thin glass
 $\leq 100 \mu\text{m}$



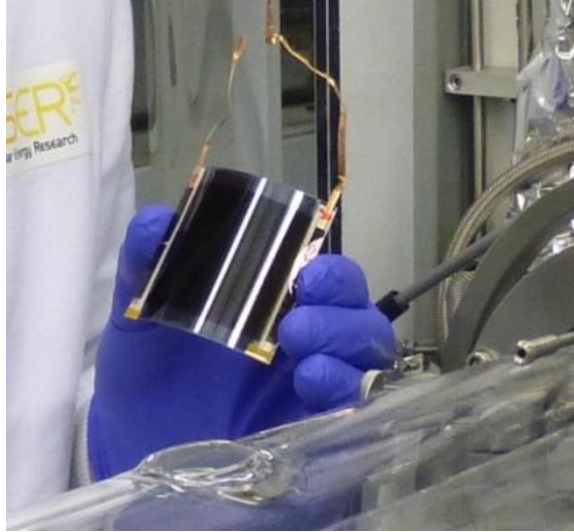
Schott ultra-thin glass

High specific
power for
space

Very low cost,
flexible, light
weight for BIPV



Thin film CdTe on Space PV glass

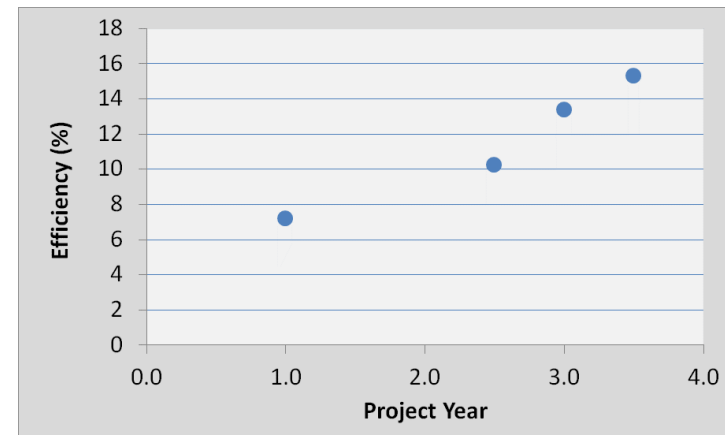


- First to report and publish TF PV directly onto cover glass
- Withstood thermal shock test (+80 °C to −196 °C)
- 0.5 MeV Proton irradiation tests >100 robustness of III-V solar cells

MOCVD deposited
AZO/ZnO/CdZnS/CdTe PV structure

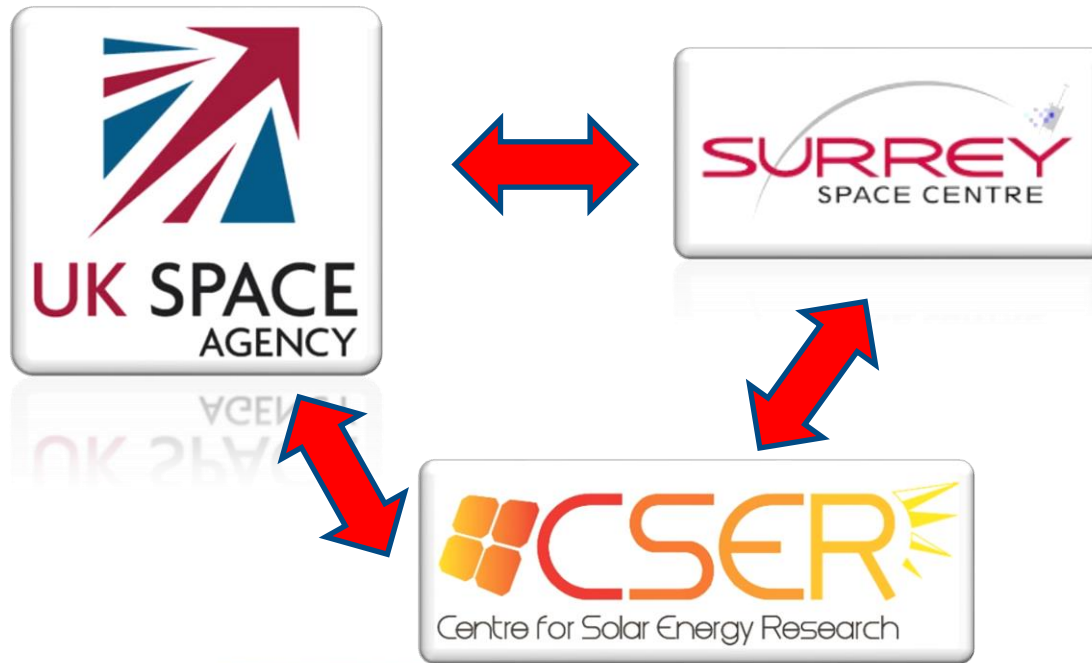
D. A. Lamb *et al.* “**High-Power, Low-Weight, Flexible CdTe Thin Film Photovoltaics For Space Application**”

Proceedings of the 28th European Photovoltaic Solar Energy Conference, Paris, (2013), pp.546–548.



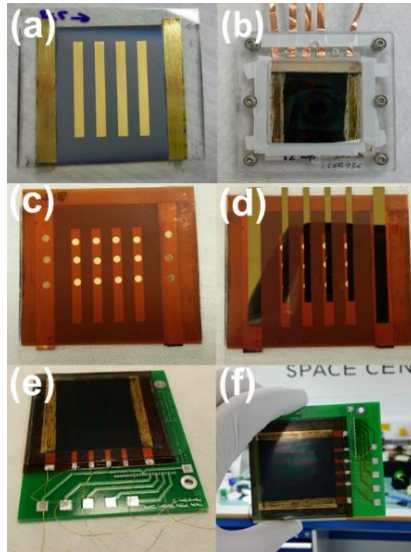
AlSat Nano mission – first space flight of thin film PV on cover glass – launch September 2016

- UK Space Agency's CubeSat mission
- AlSat Nano

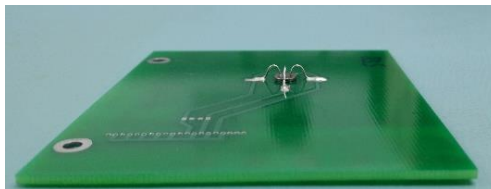


TFSC payload design

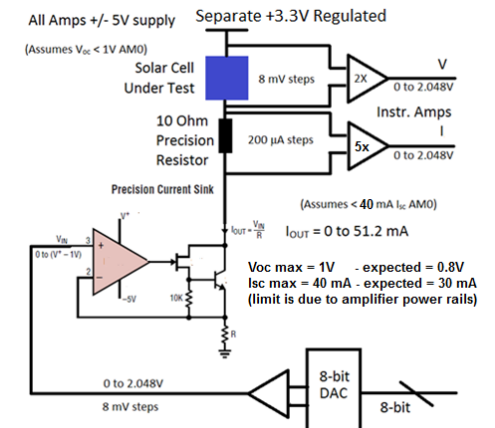
- Challenge
- Redundancy
- Encapsulation
- Electrical connection



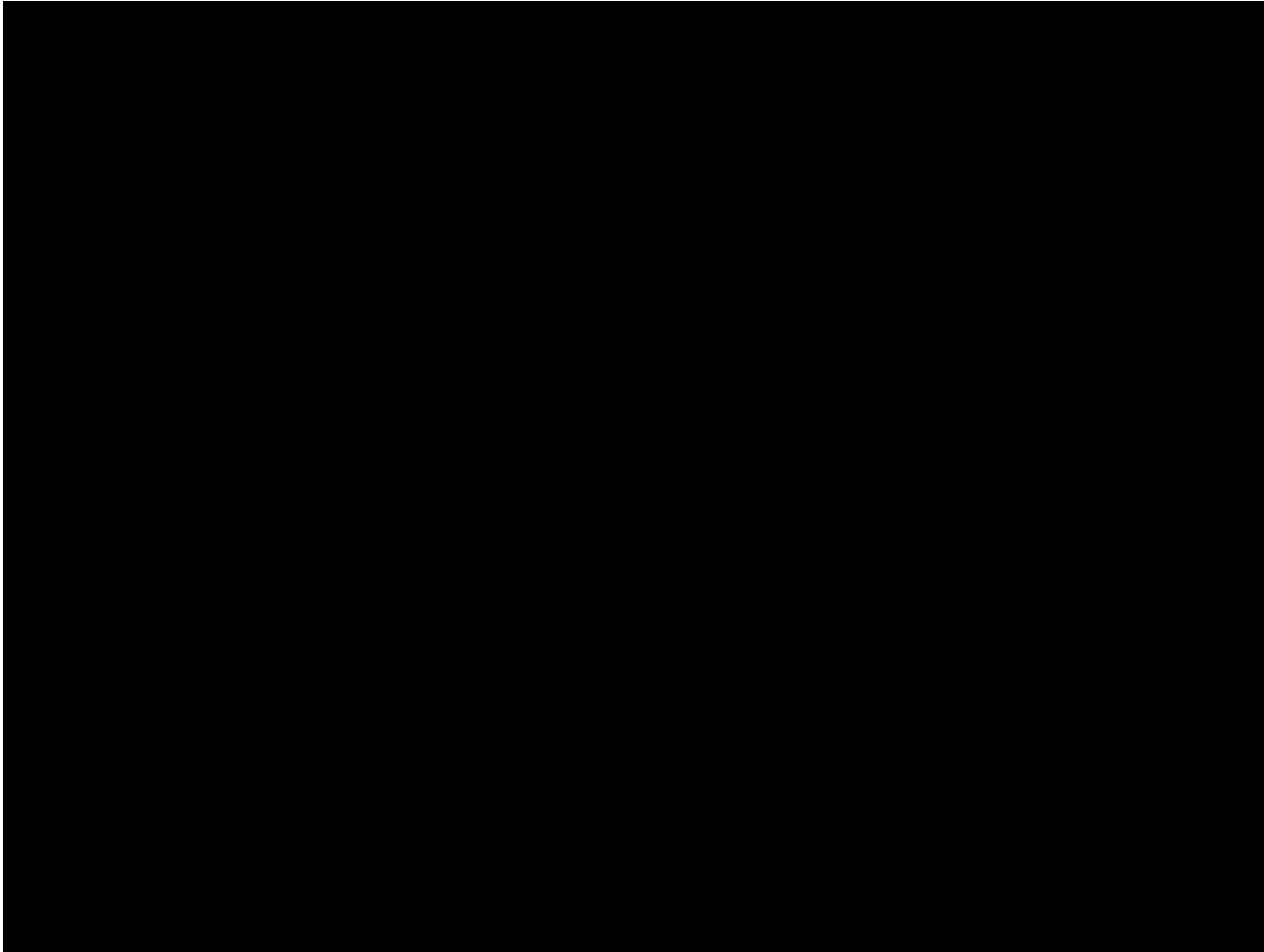
- LM35
- Cell temp °C



- Internal PCB
- processing electronics
- Controller-area-network (CAN) bus data interface to the satellite
- Measurement circuit
- 8-bit digital programmable precision current sink
- Protected against reverse bias by a diode strap
- In-house designed measurement software

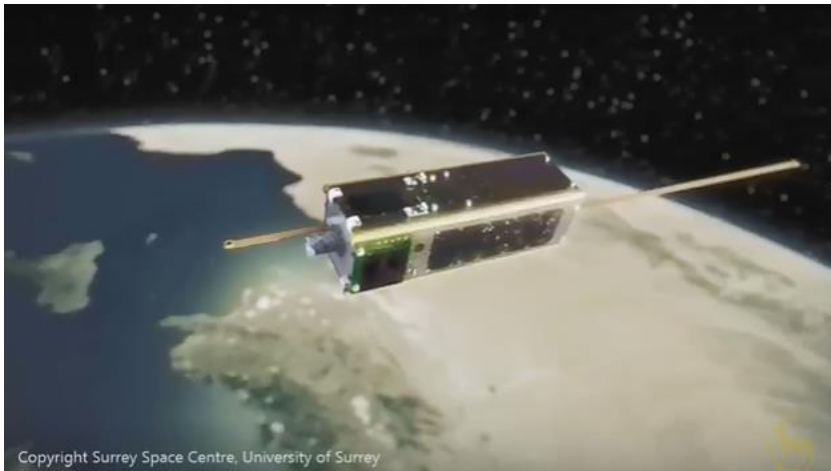
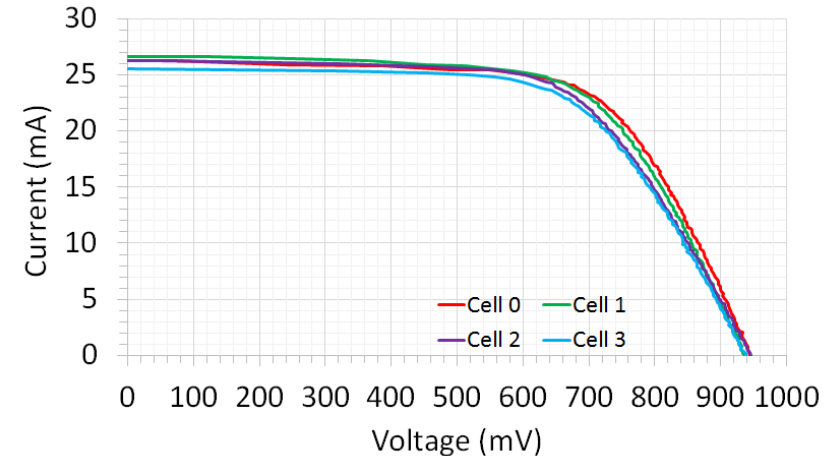


Launch & deployment



First data back from AlSat-Nano

- 1st expt. commissioned 08th Oct
- 05th Jan, better illumination
- Attitude stabilization
- Illumination level determined by TJ performance



- Illumination ~70%, Cell temp 4 °C

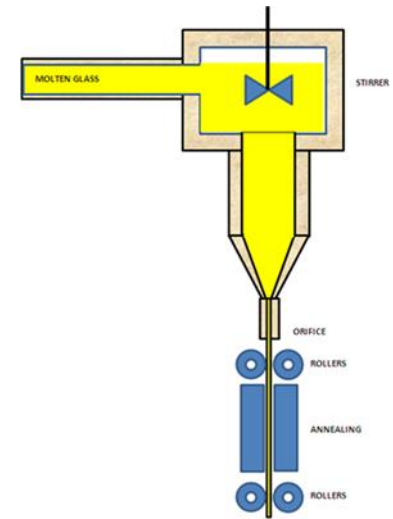
Cells	0	1	2	3
η %	17.0*	16.9*	16.4*	16.0*
I_{sc} (mA)	26.2	26.7	26.3	25.6
V_{oc} (mV)	945	938	946	938
FF %	66	64	63	64
R_s (Ω cm ²)	8.4	8.6	10.2	10.0

*high efficiencies are due to high V_{oc} and further work is required to explain the increase over the laboratory based measurements



How can thin film PV on UTG for space influence research into better solar cells for terrestrial power generation?

- High power to weight ratio PV for BIPV
- UTG glass can be produced in large volume and used in a roll to roll process.
- Flexible PV for lamination onto building materials – such as steel roofing and facades.
- During manufacture UTG is delicate but is strong when laminated.



Future potential for large scale PV power generation by integrating into buildings

- There are an estimated 250,000 hectares of south facing commercial roofs in the UK – *DECC UK PV Solar Strategy (2014)*
- New solutions needed that can integrate PV with building materials
- Achieve higher penetrations of solar PV into our energy supply



Is space PV totally different to terrestrial PV?

- Space environment produces different challenges for robust PV
- Space PV being driven more by cost and reducing launch weight
- New PV technologies developed for space require a lower volume than terrestrial – opportunity to develop manufacturing scale for new products
- Example of III-V concentrator PV for utility scale



Acknowledgements

Dan Lamb and CSER Team



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The ALSAT-1N flight opportunity
for the TFSC Payload was
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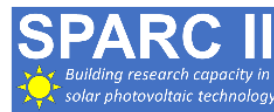


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