UNIVERSITY OF OXFORD

Hoye Group

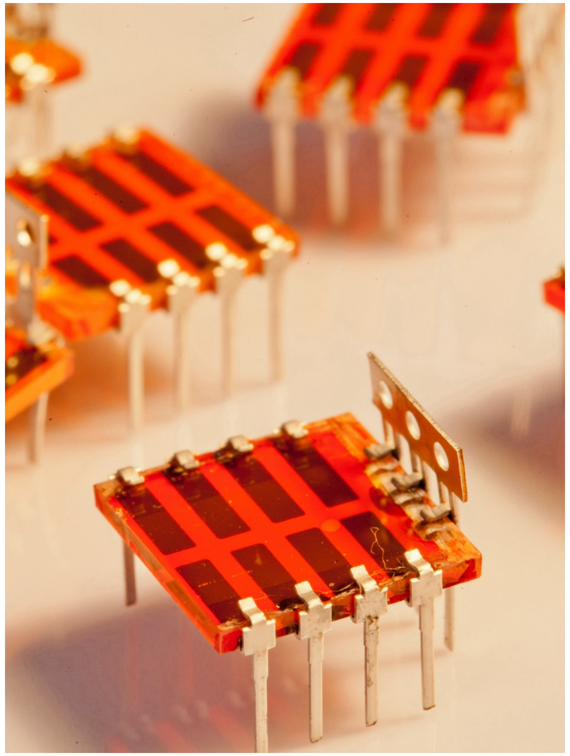
Chemistry of Sustainable Materials

Innovations in Photovoltaics: 2023 UK PV Roadmap

Prof. Robert Hoye

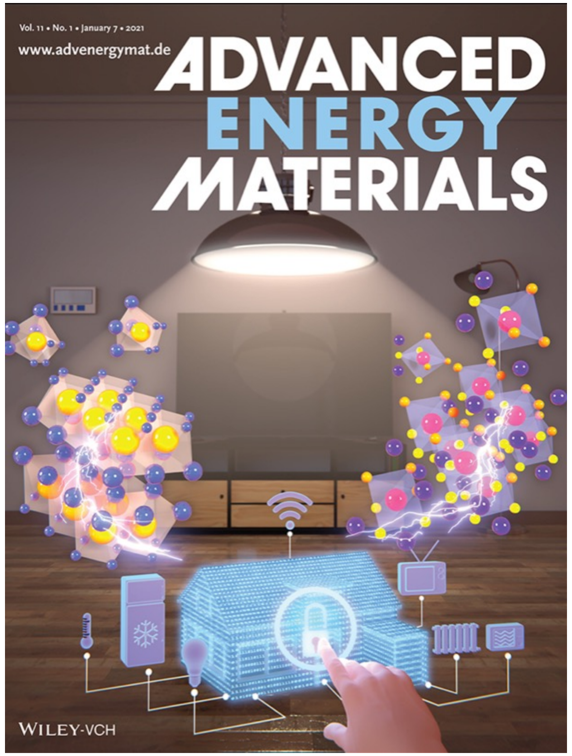
Hoye Group – Recent Works

Solar Cells



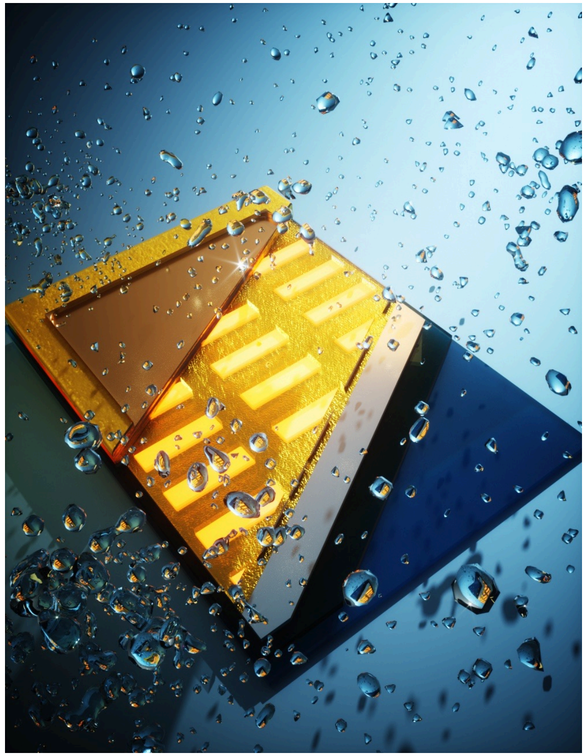
Hoye, *et al. Adv. Mater.* **29**, 1702176 (2017)

Energy Harvesting for IoT



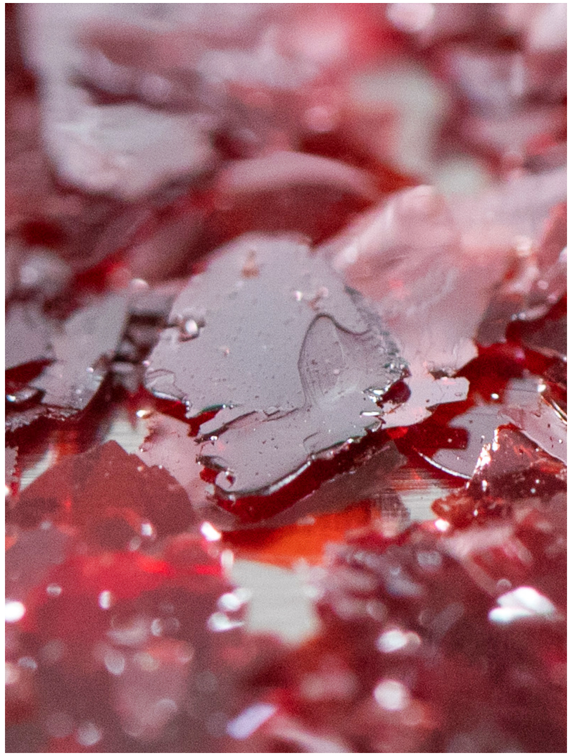
Adv. Energy Mater. **11**, 2002761 (2021)

Solar Fuels



Andrei, Jagt, …, Hoye, Reisner, *Nat. Mater.* **21**, 864 (2022)

Radiation Detection

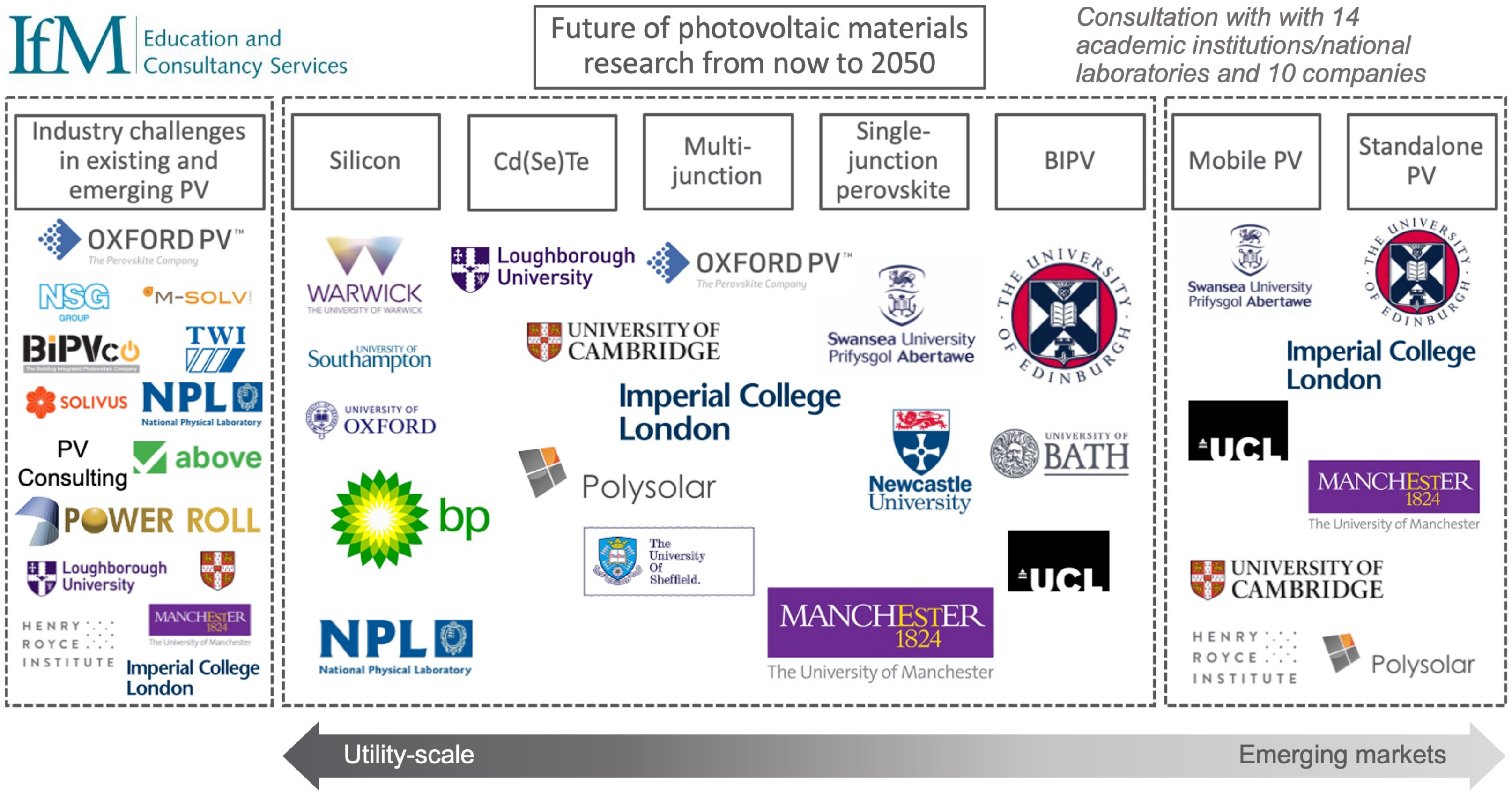


Jagt, Bravić…, Hoye, *Nat. Commun.* **13**, 4960 (2022)

2020 Materials for Photovoltaic Systems Roadmap

Roadmap with Henry Royce Institute

https://tinyurl.com/3jaaea2u



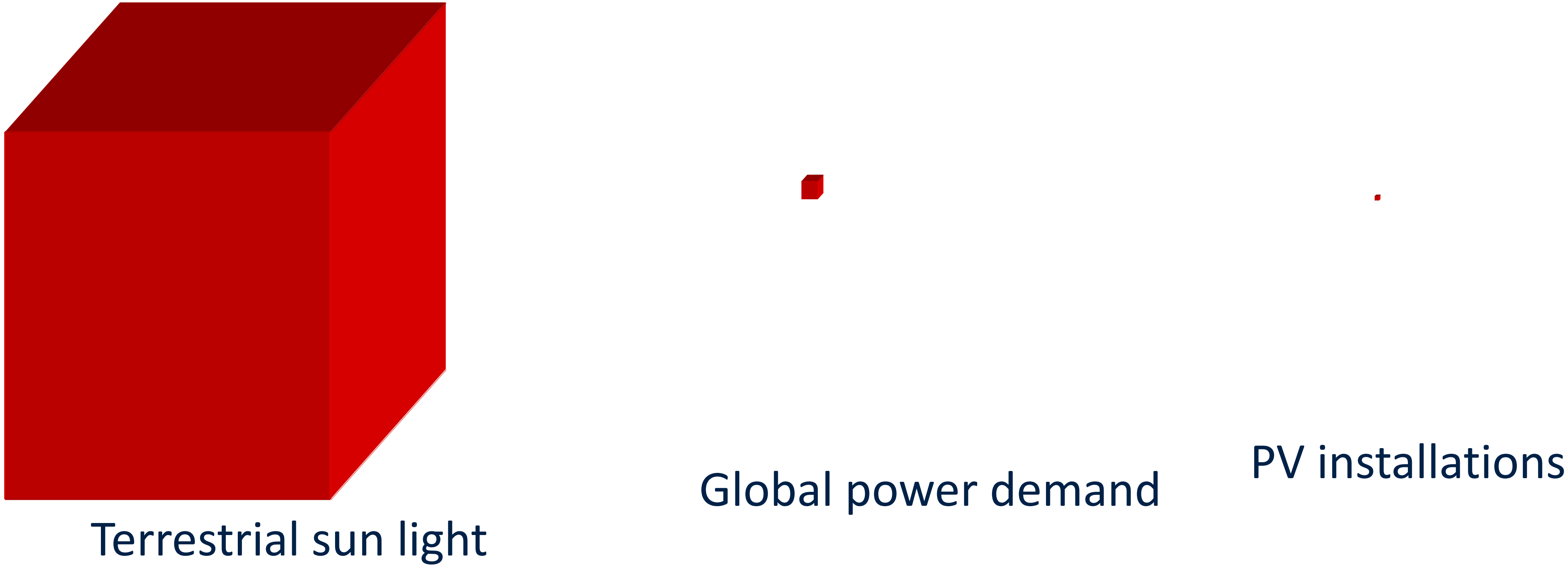
2023 Update

Article type: Roadmap

Roadmap on Photovoltaic Absorber Materials for Sustainable Energy Conversion

James C. Blakesley,[1,†] Ruy S. Bonilla,[2,†] Marina Freitag,[3,†] Alex M. Ganose,[4,†] Nicola Gasparini,[4,†] Pascal Kaienburg,[5,†] George Koutsourakis,[1,†] Jonathan D. Major,[6,†] Nakita K. Noel,[5,†] Bart Roose,[7,†] Ludmilla Steier,[8,†] Jae Sung Yun,[9,†] Simon Aliwell,[10] Pietro P. Altermatt[2,11] Tayebeh Ameri,[12] Virgil Andrei,[13] Ardalan Armin,[14] Diego Bagnis,[15] Jenny Baker,[16] Mathieu Bellanger,[10] Philippe Berrouard,[17] Jochen Blumberger,[18] Stuart A. Boden,[19] Hugo Bronstein,[13,20] Matthew J. Carnie,[21,22] Chris Case,[23] Fernando A. Castro,[1] Yi-Ming Chang,[24] Elmer Chao,[25] Tracey M. Clarke,[26] Graeme Cooke,[27] Pablo Docampo,[27] Ken Durose,[6] James R. Durrant,[4,21] Marina R. Filip,[5] Richard H. Friend,[20] Jarvist M. Frost,[4] Elizabeth A. Gibson,[2] Alexander J. Gillett,[20] Pooja Goddard,[28] Severin N. Habisreutinger,[23] Martin Heeney,[4] Arthur D. Hendsbee,[17] Louise C. Hirst,[20,29] M. Saiful Islam,[2] Imalka Jayawardena,[9] Michael B. Johnston,[5] Matthias Kauer,[10] Jeff Kettle,[30] Ji-Seon Kim,[31] Dan Lamb,[32] David Lidzey,[33] Jihoo Lim,[9,34] Roderick MacKenzie,[35] Nigel Mason,[36] Iain McCulloch,[37] Keith P. McKenna,[38] Sebastian B. Meier,[39] Paul Meredith,[14] Graham Morse,[40] John D. Murphy,[41] Jenny Nelson,[31] Chris Nicklin,[42] Thomas Osterberg,[43] Jay B. Patel,[5] Anthony Peaker,[44] Moritz Riede,[5] Martyn Rush,[45] David O. Scanlon,[26,46] Peter Skabara,[26] Franky So,[47,48] Henry J. Snaith,[5] Jarla Tiesbrummel,[5] Alessandro Troisi,[49] Craig Underwood,[50] Karsten Walzer,[51] Trystan Watson,[22] J. Michael Walls,[52] Aron Walsh,[53] Lucy D. Whalley,[54] Samuel D. Stranks[7,] and Robert L. Z. Hoye[8,53,*]*

Significant Potential of Solar Energy

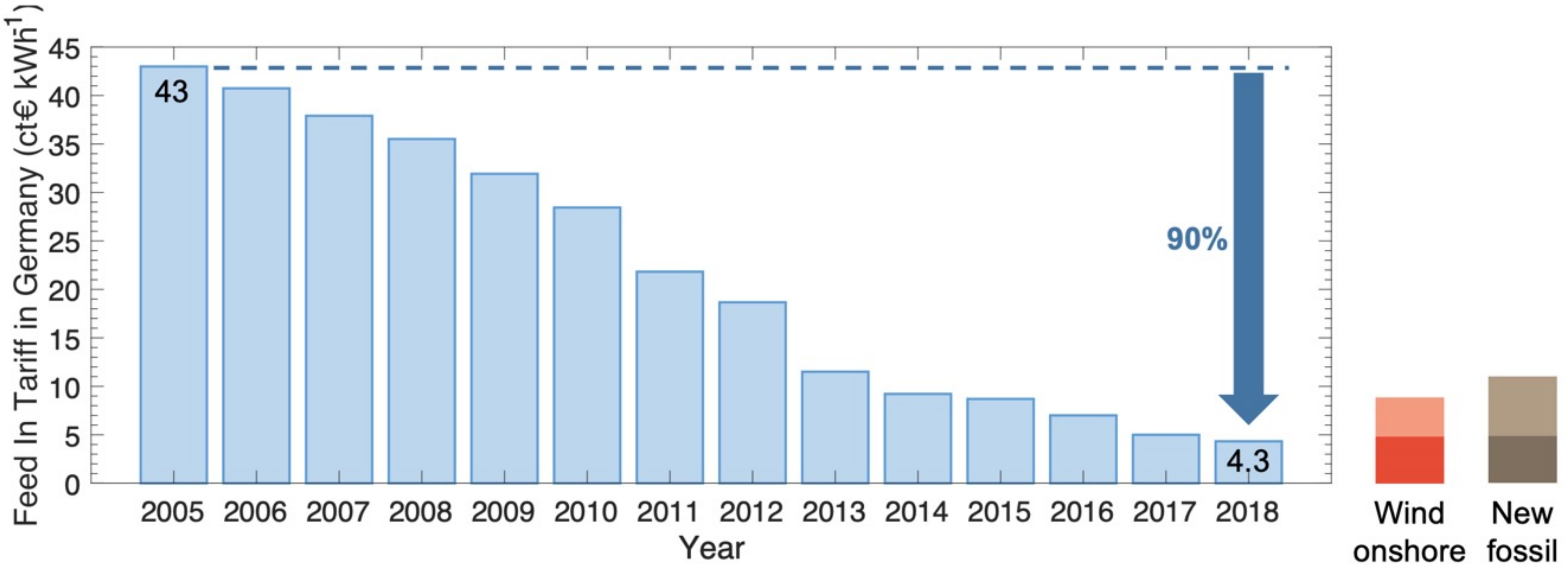


The Net-Zero Challenge

- IRENA: Staying within 2 °C of pre-industrial levels requires PV deployment to increase from 0.9 TW (2021) to 2.8 TW in 2030 and 8.5 TW in 2050
- IRENA: €6 trillion investment needed between now and 2050. Bring €150 trillion in benefits (health, subsidy and climate-related savings)
- Other models: up to 70 TW of PV worldwide by 2050
- UK PV deployment needs to increase from 14 GW (2021) to 70 GW by 2035 *

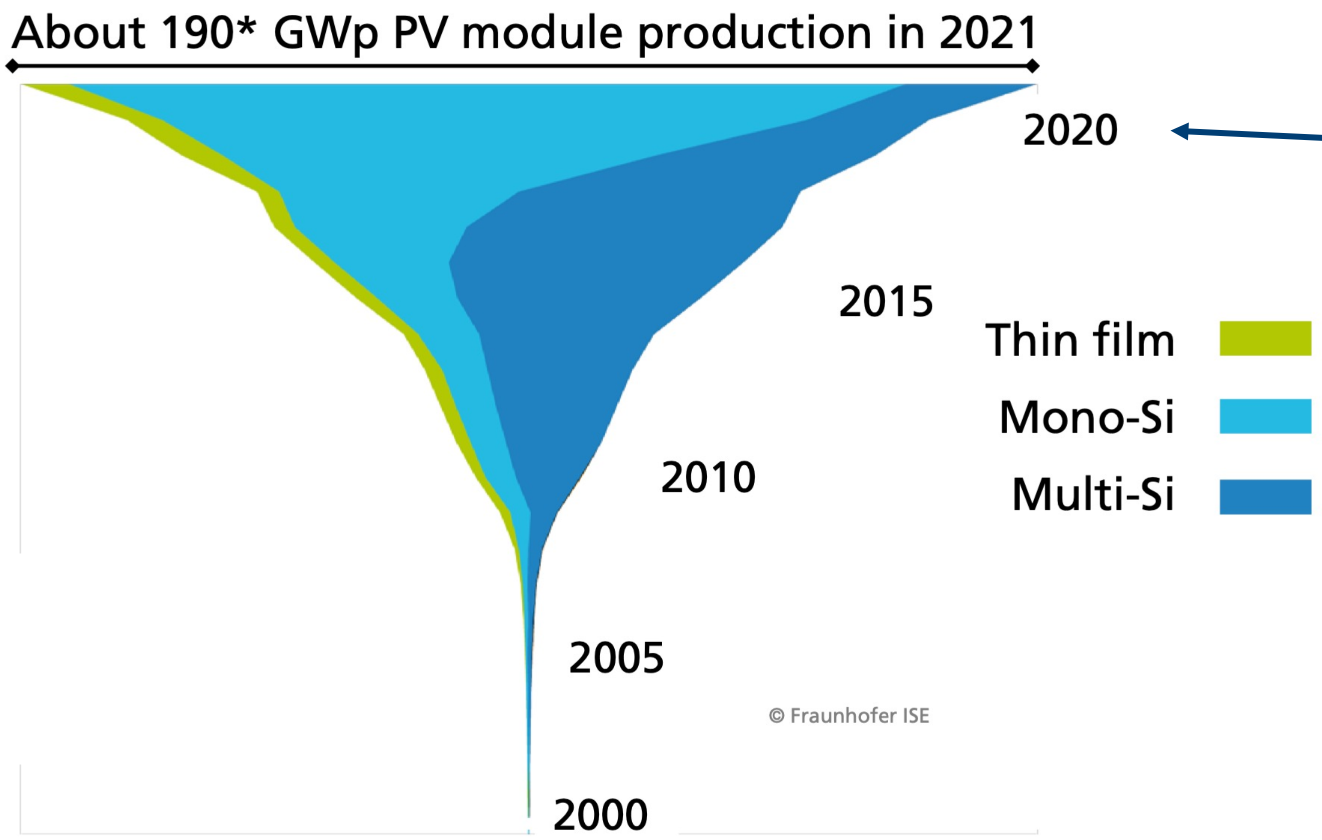
* UK Climate Change Committee, Progress in reducing emissions (2023)

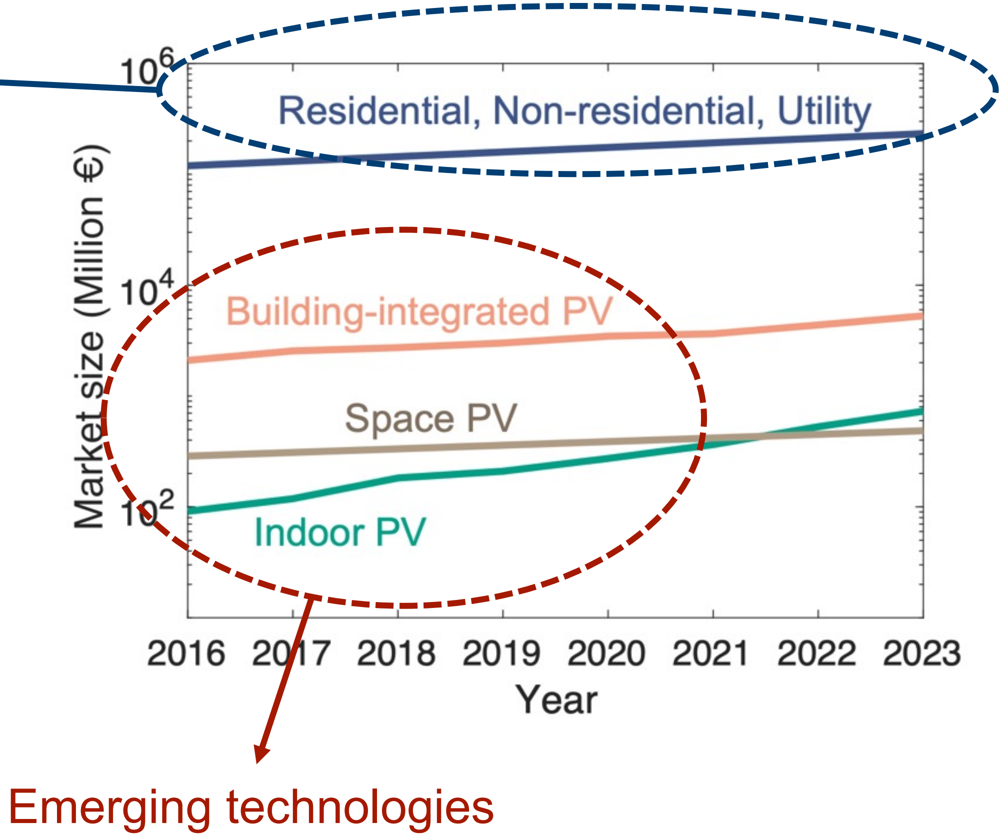
Rapid Decrease in Cost of Solar Energy



Fraunhofer Institute for Solar Energy, Photovoltaics Report (2023)

Photovoltaics Market





Fraunhofer Institute for Solar Energy, Photovoltaics Report (2023)

Outline

- Part 1: Key PV Technologies
- Part 2: Emerging Opportunities

Part 1

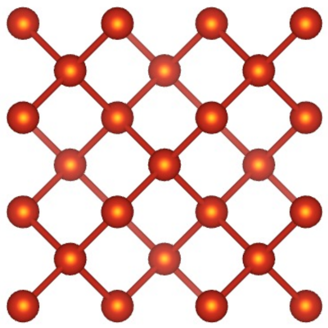
Key PV Technologies

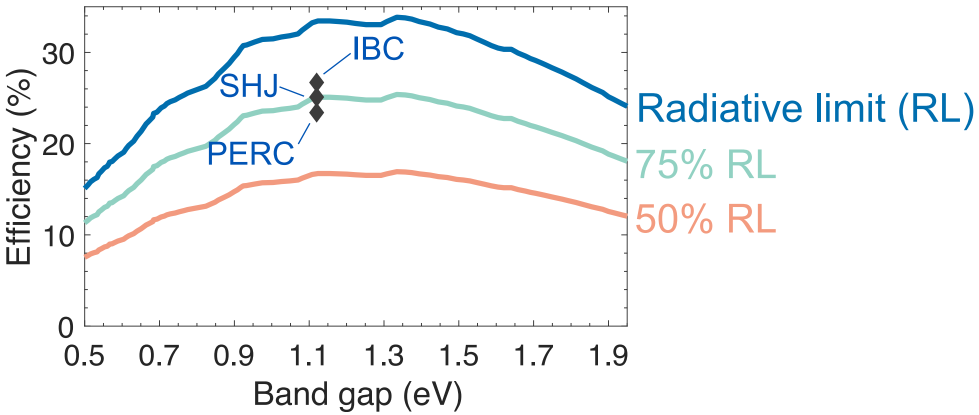
Key PV Technologies

- Silicon
- CdTe
- Lead-Halide Perovskite
- Organic Photovoltaics
- Dye-sensitized solar cells
- Emerging inorganic solar absorbers

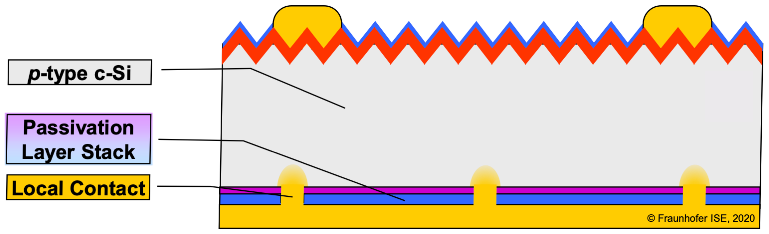
Silicon: Material and Status of Technology

c-Si





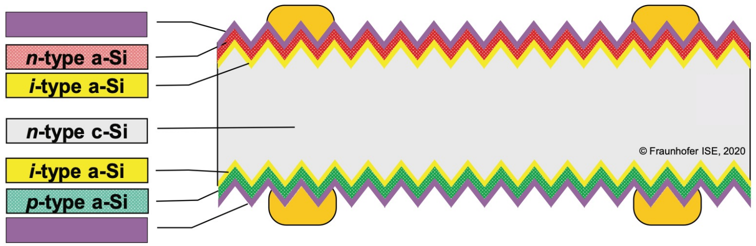
PERC



23.4%

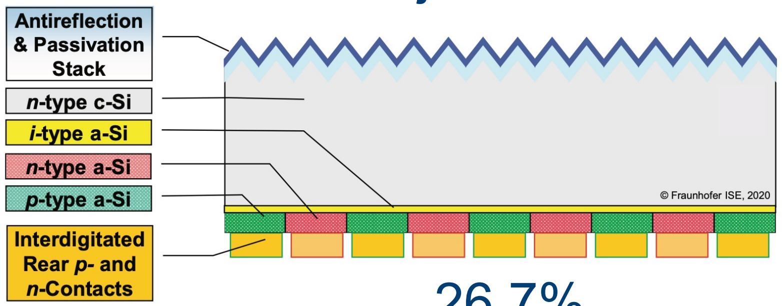
(predicted to saturate at ~24.5%)

Heterojunction cell (SHJ)



25.1%

Heterojunction IBC

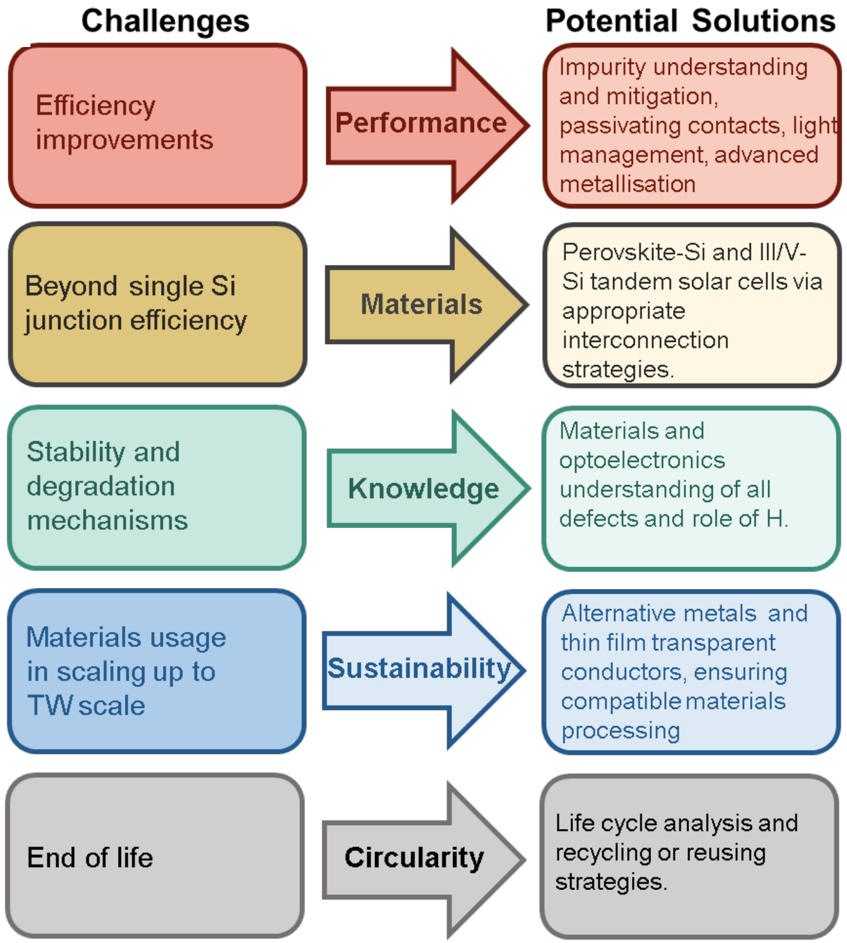


26.7%

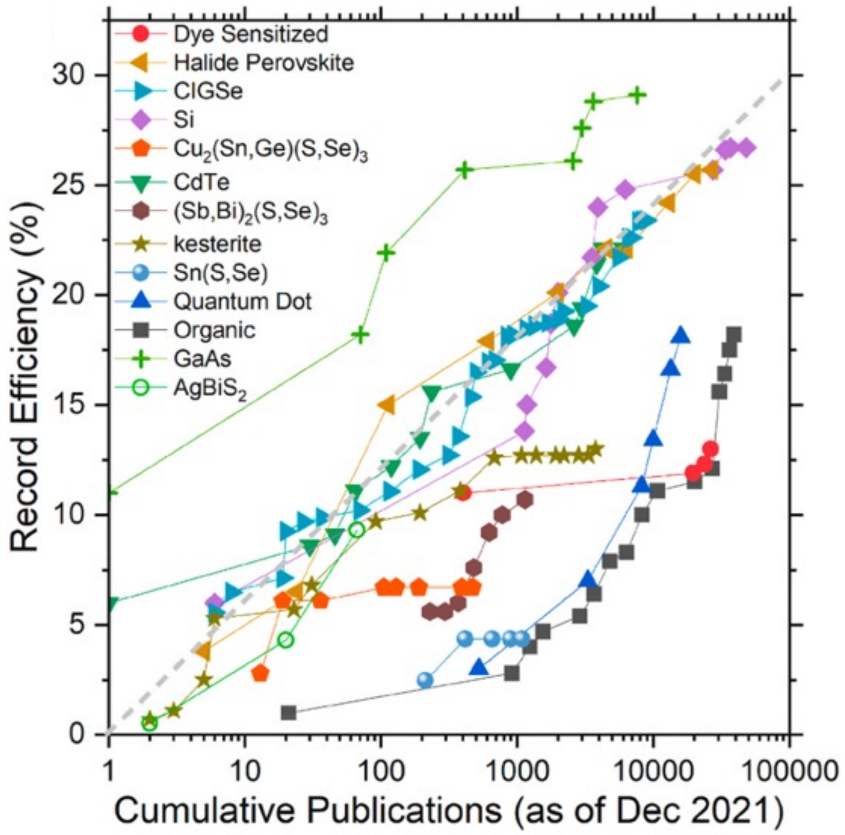
(practical limit of 27.1%)

J. Phys. D Appl. Phys, **2020**, *53*, 493001

Silicon: Pressing Challenges and Potential Solutions

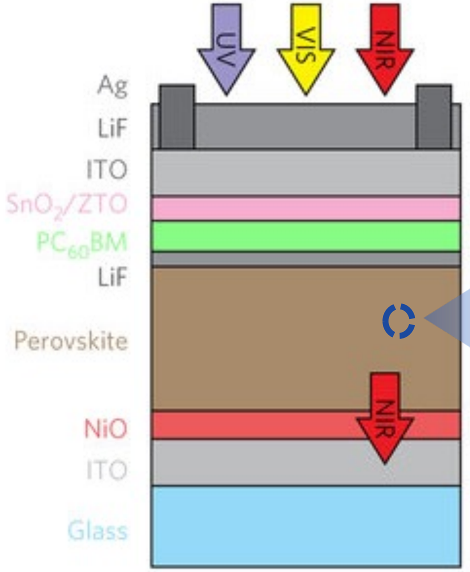


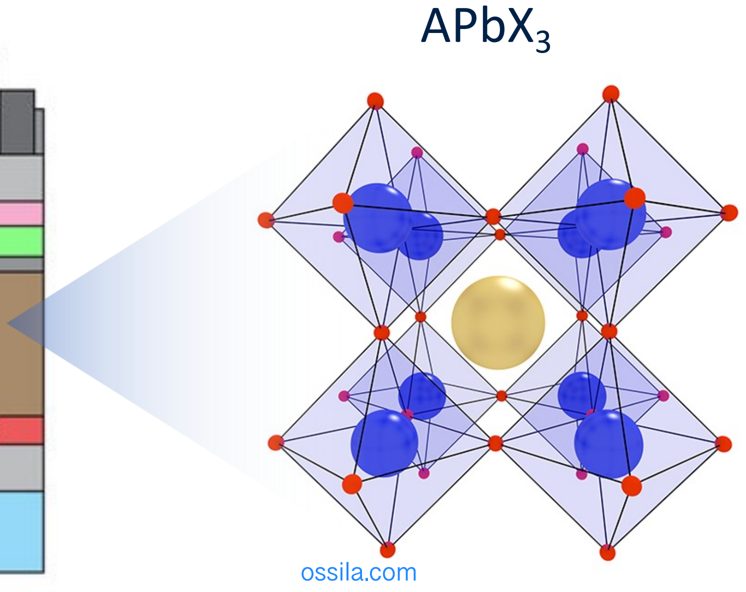
Rate of Learning of PV Technologies

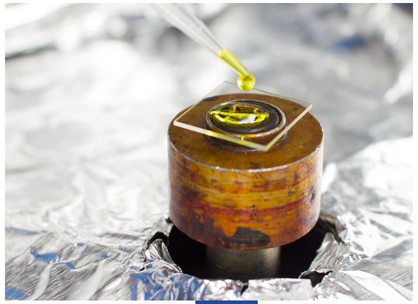


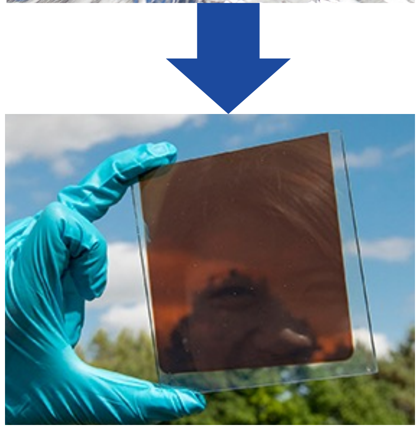
Sol. Energy Mater. Sol. Cells, **2023**, *251*, 112097

Lead-Halide Perovskites





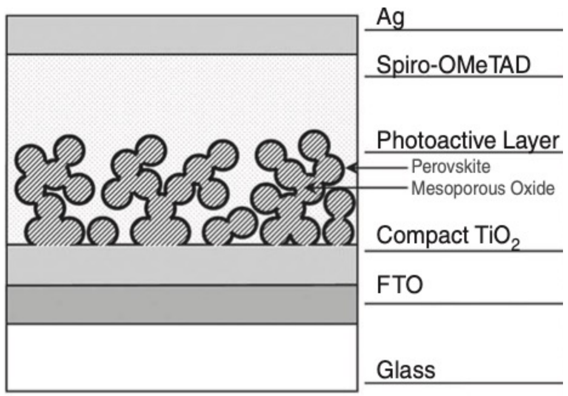




Nat. Energy, **2017**, 2, 17009

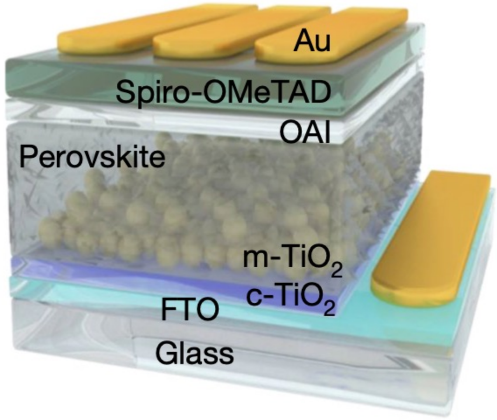
Status of Technology

Early structure (2012)



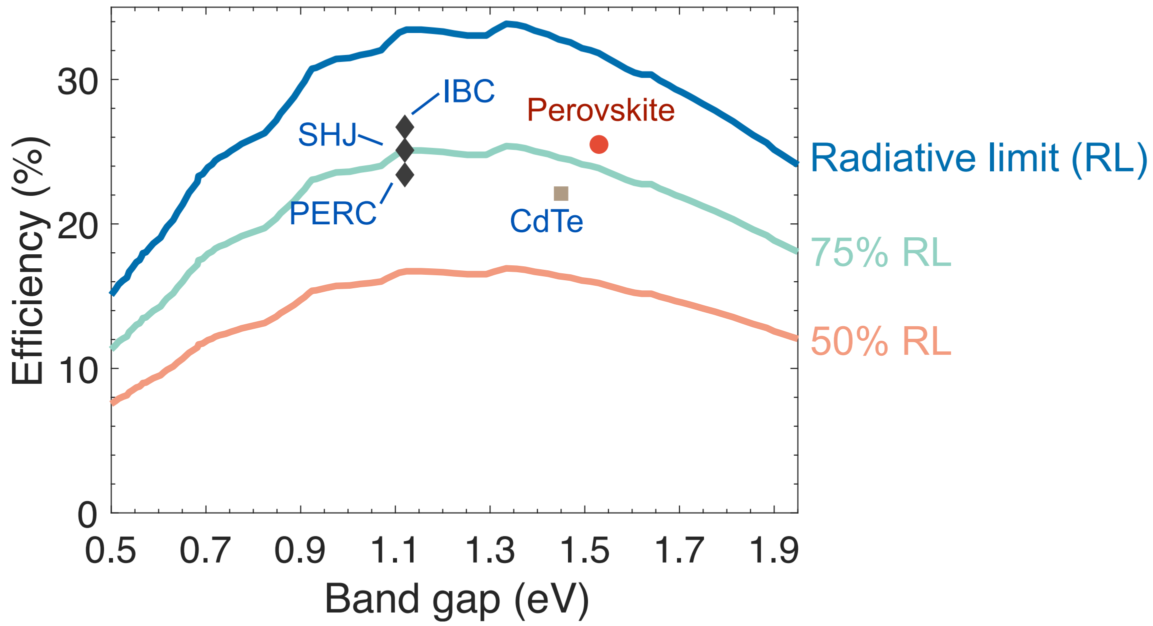
11%

Record PCE (2021)



25.6%

(25.2% certified)

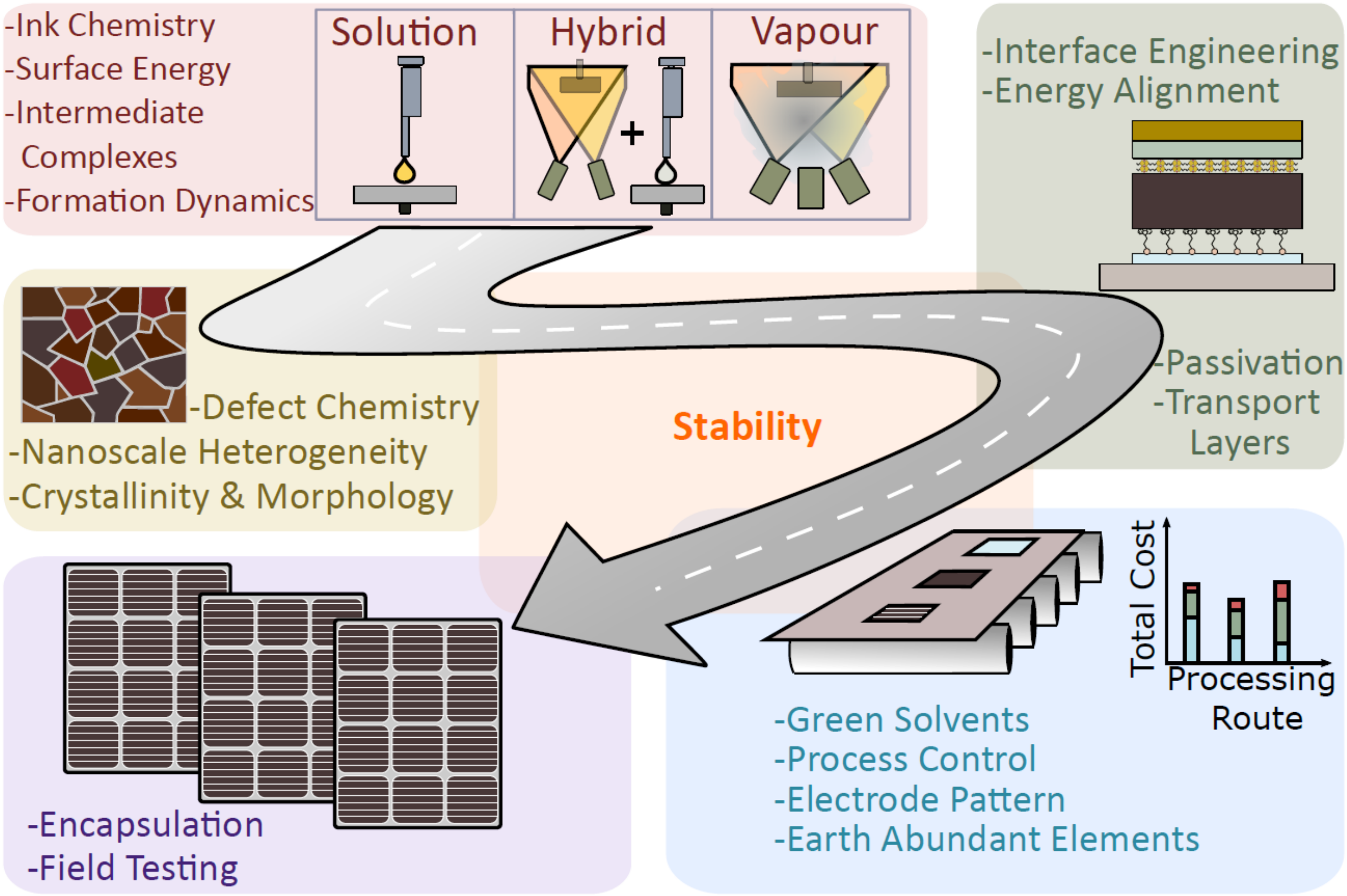


Science, **2012**, *338*, 643

Nature, **2021**, *592*, 381 (EPFL)

Nature, **2021**, *590*, 587 (KRICT/MIT)

Lead-Halide Perovskites: From Lab to Fab



Part 2

Emerging Opportunities

Motivation to Overcome Efficiency Limit of Silicon PV

Solar PV System Costs 2017

Module

Cost breakdown

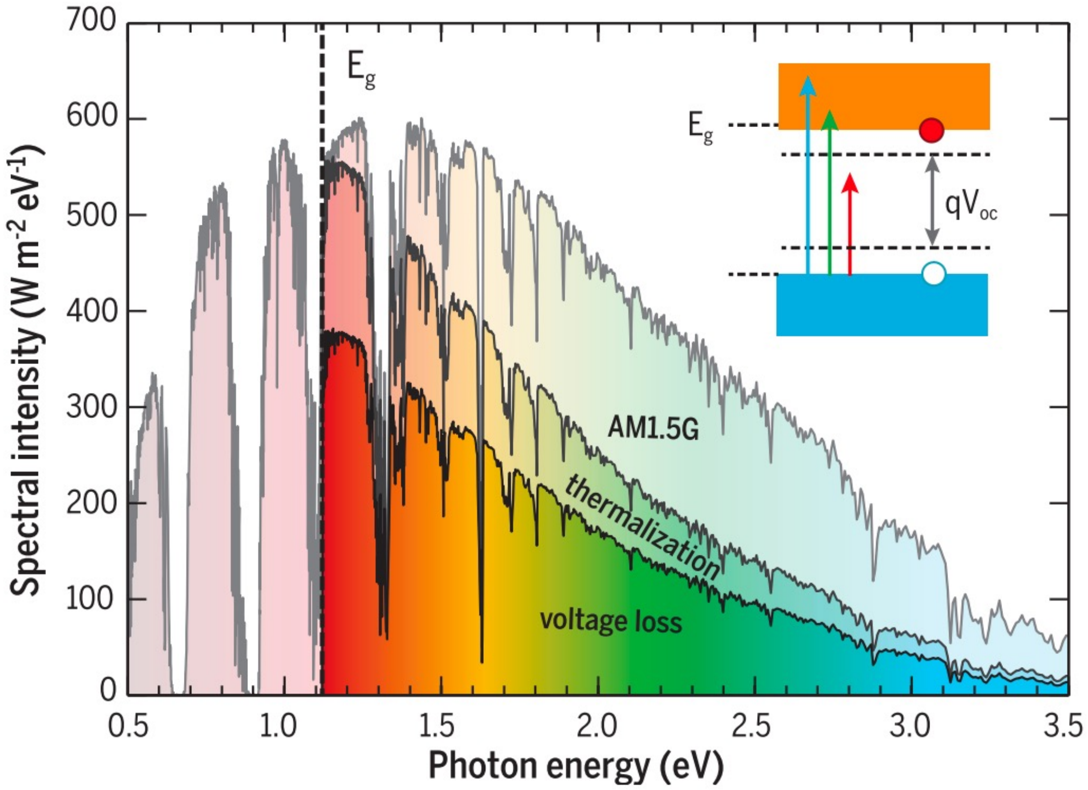
Itemized list

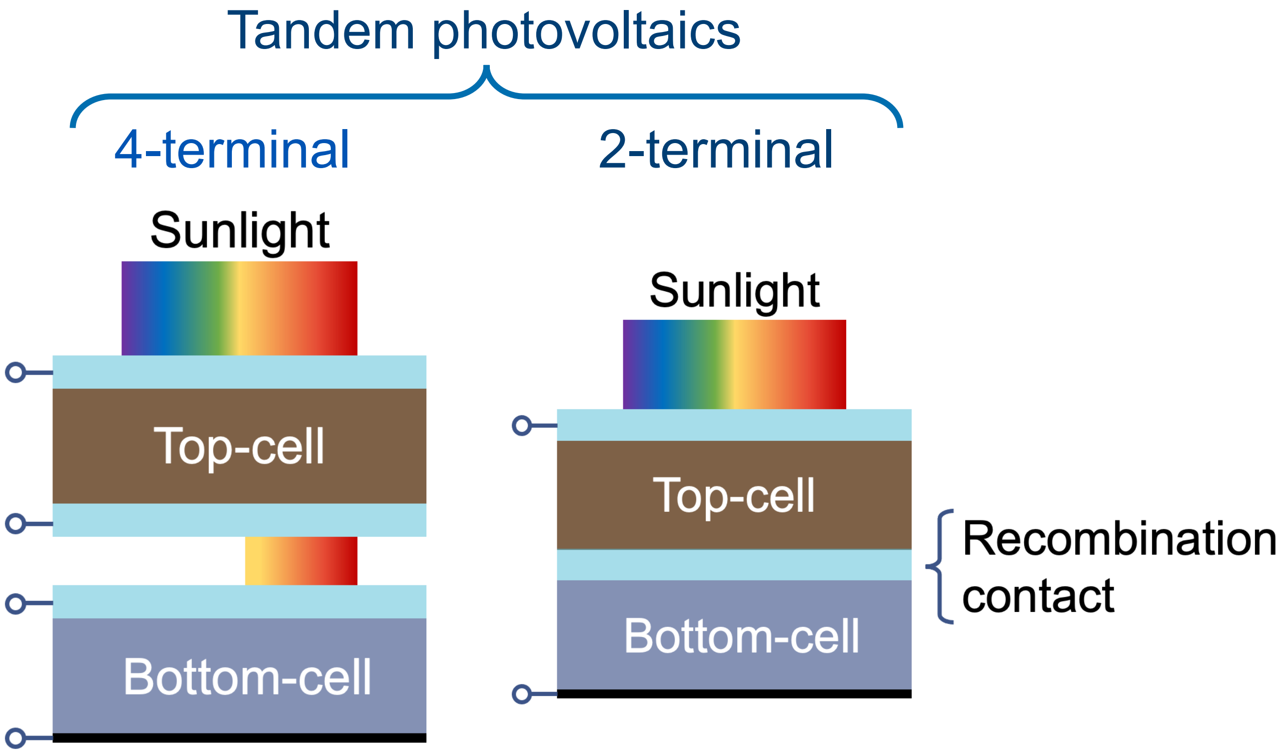
Item	Cost per watt	Legend
Profit	$0.34	
Overhead	$0.31	
Customer acquisition (Sales & Marketing)	$0.34	
Permitting, Inspection, Interconnection	$0.10	
Installation labor	$0.30	
Sales tax on equipment	$0.09	
Supply chain cost	$0.42	
Electrical BOS	$0.24	
Structural BOS	$0.11	
Inverter	$0.19	
Module	$0.35	
Total	**$2.80**	

Data Source: National Renewable Energy Laboratory, U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017 Benchmark

https://sunmetrix.com/cost-of-solar-panels/

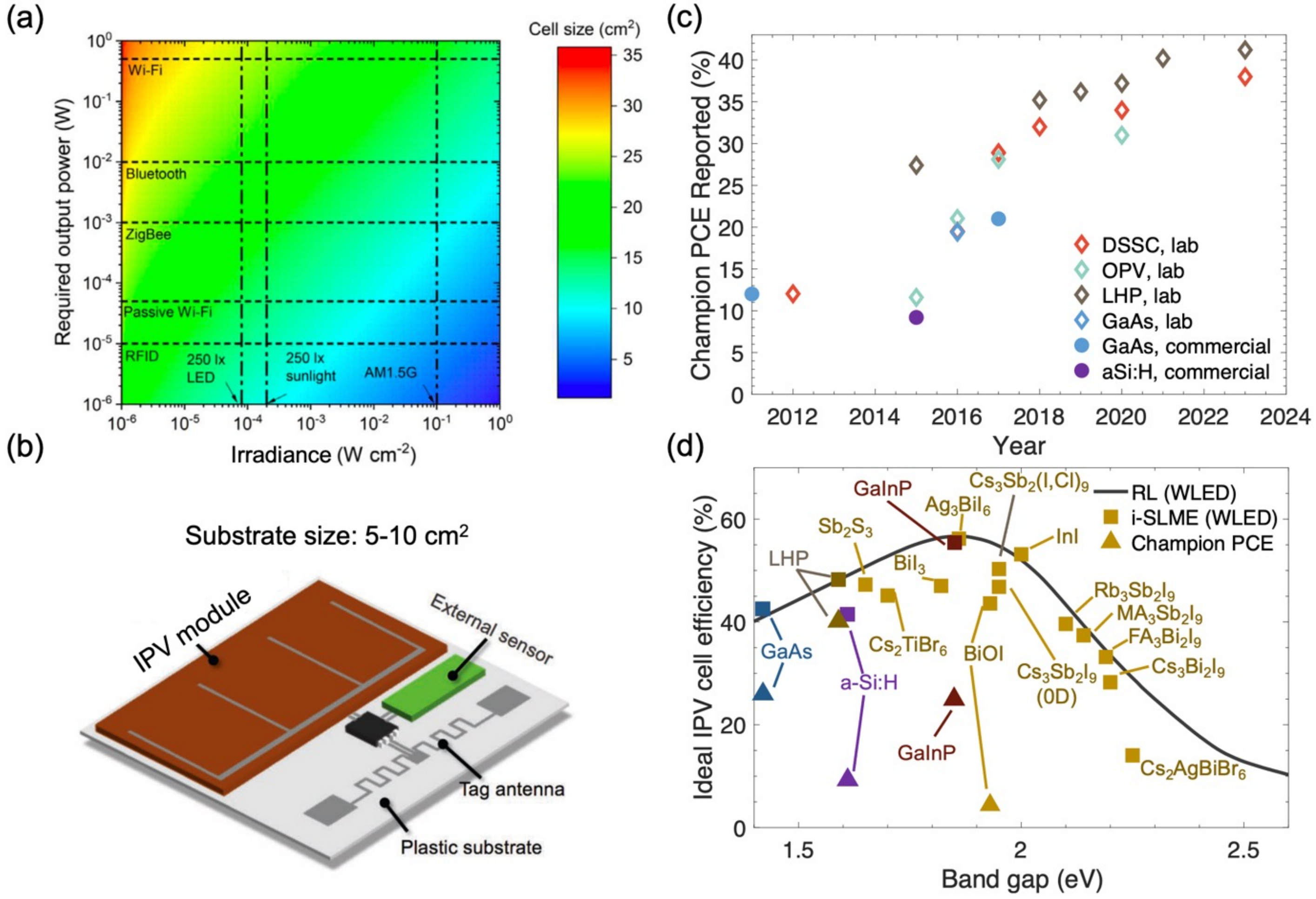
Perovskite-Based Tandem Photovoltaics



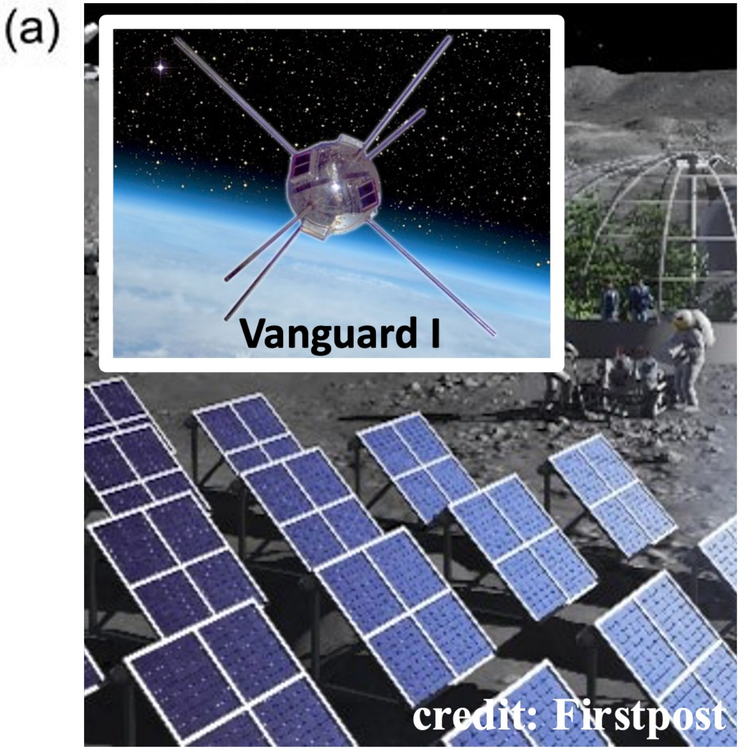


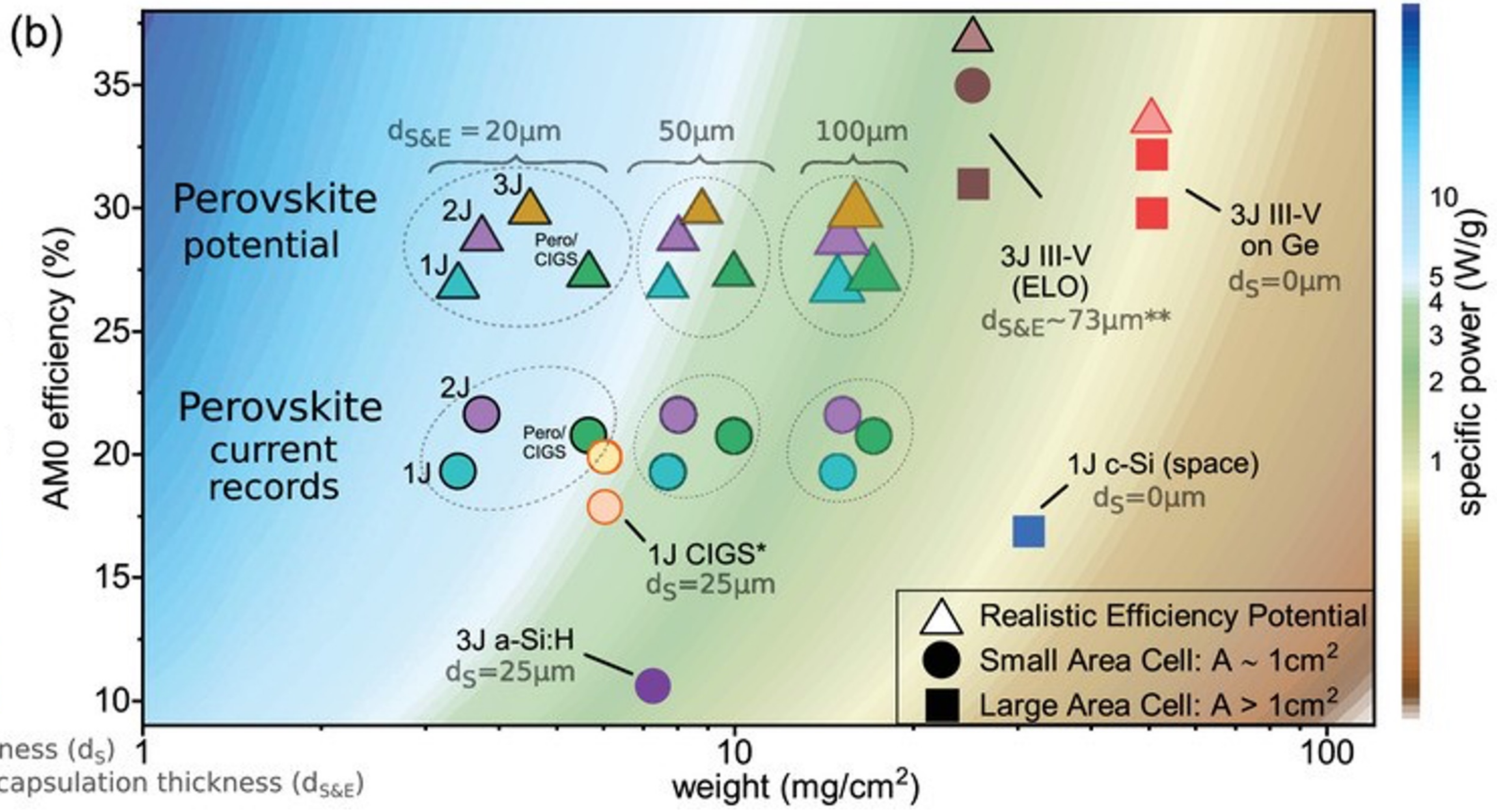
Science, **2016**, *352*, 307

Indoor Photovoltaics

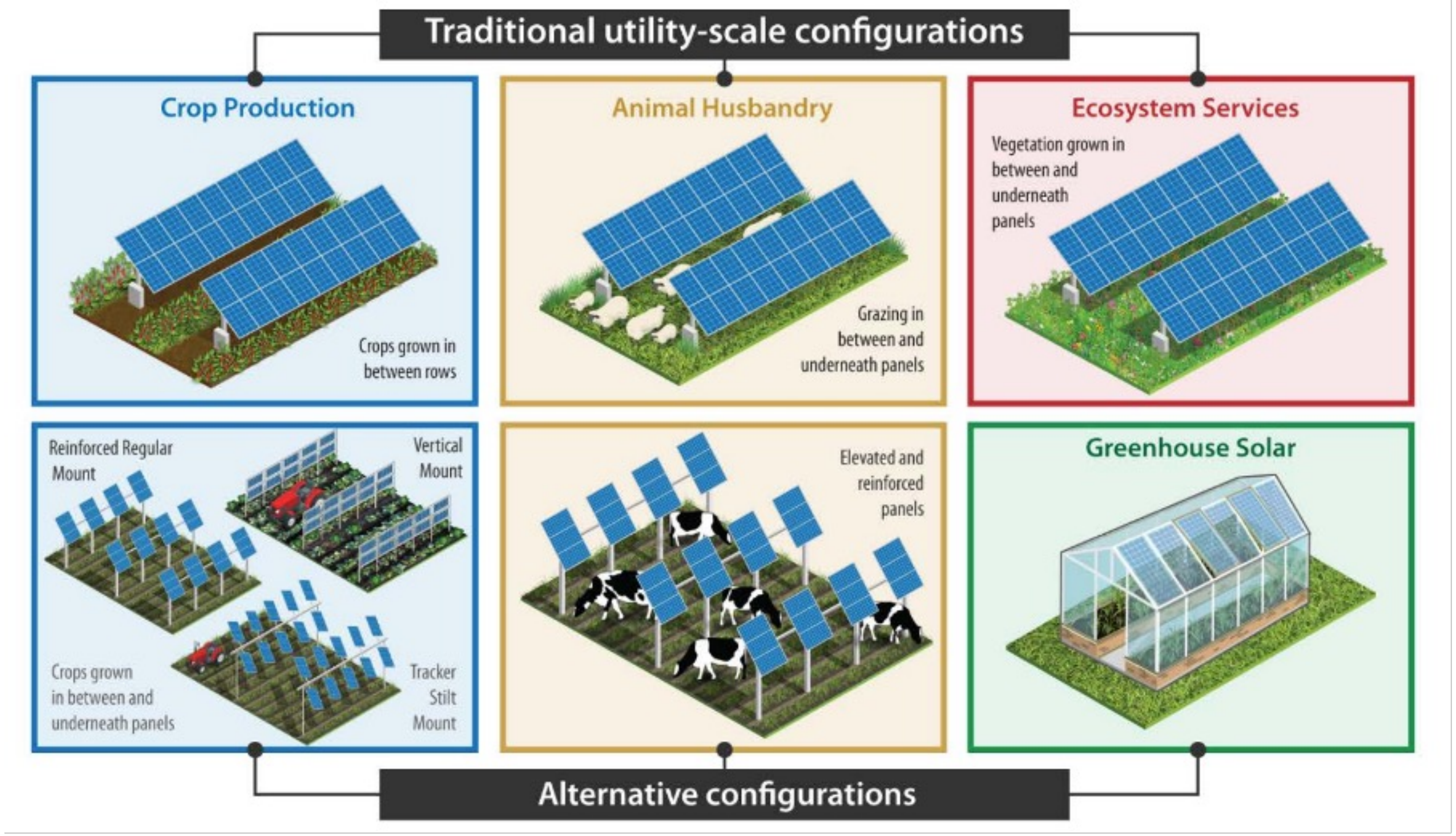


Space Photovoltaics





Agrivoltaics



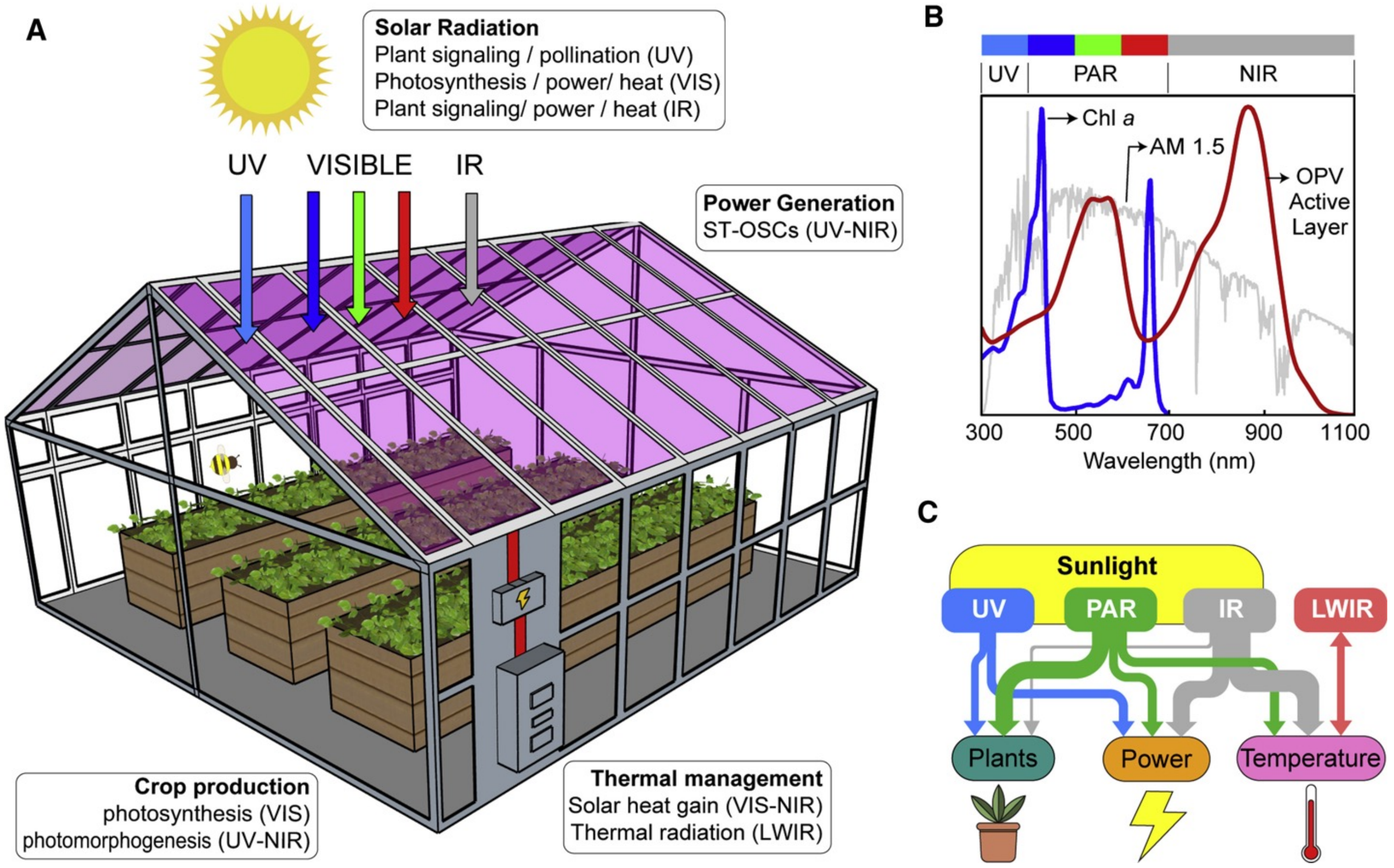
Challenges:

- Nascency in agrivoltaic systems
- Costs and incentives
- Regulatory factors

Requirements:

- Policy – greater incentives
- Sharing of best practice

Agrivoltaics – Organic PV



More work needed to understand the best combination of PV technology and plants

Other topics

- CdTe solar cells
- Organic photovoltaics
- Dye-sensitized solar cells
- Characterisation methods and standards
- Computational Materials Discovery
- PV and solar fuels
- Sustainability of PV as a system

Key Takeaways

- Increased investment in PV research and manufacturing essential
- UK needs to engage with challenge for TW-scale PV deployment. Important for **net-zero**, **energy security**, and take part in **multi-billion pound** supply chain
- More targeted collaboration and data sharing needed between academia and industry
- More efforts needed to close lifecycle in PV technology and consider end-of-life strategies for new PV technologies

Acknowledgements

Roadmap on Photovoltaic Absorber Materials for Sustainable Energy Conversion

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