EnerHarv 2024

PSMA International Workshop | 26-28 June, 2024 | Perugia, Italy

COMMERCIAL SPONSORS

EnerHarv 2024 Workshop:

Roadmap on Energy Harvesting Materials

Presented By –

Thomas m. Brown, PhD

CHOSE, Tor Vergata University of Rome

thomas.brown@uniroma2.it

Thursday, June 27, 2024

ORGANIZER

HOST

MEDIA SPONSORS

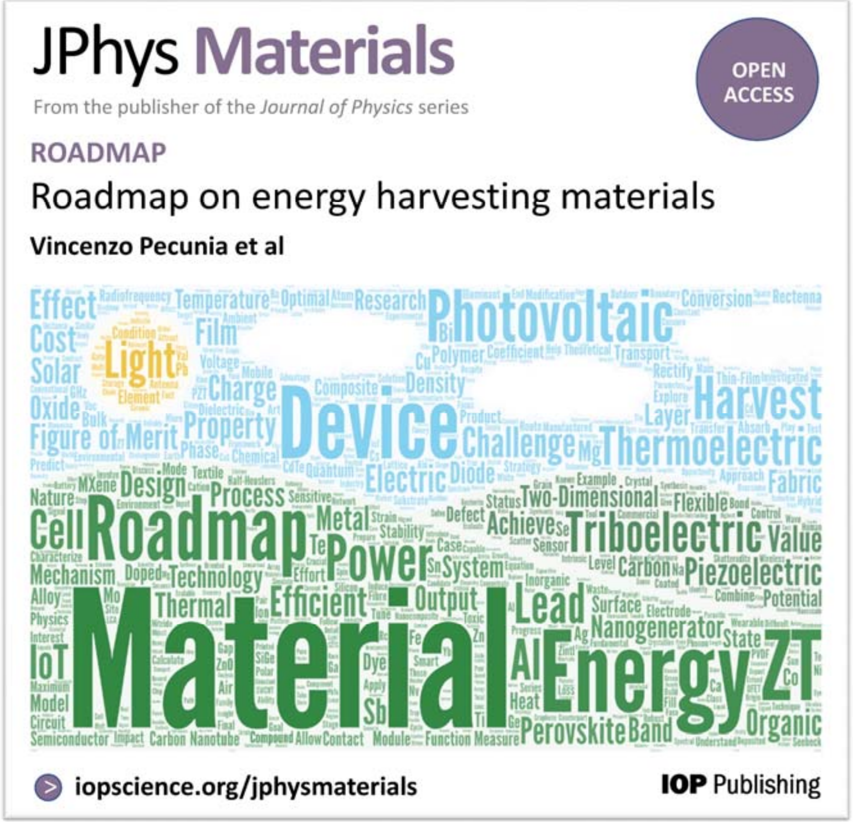
TECHNICAL SPONSORS

OVERVIEW

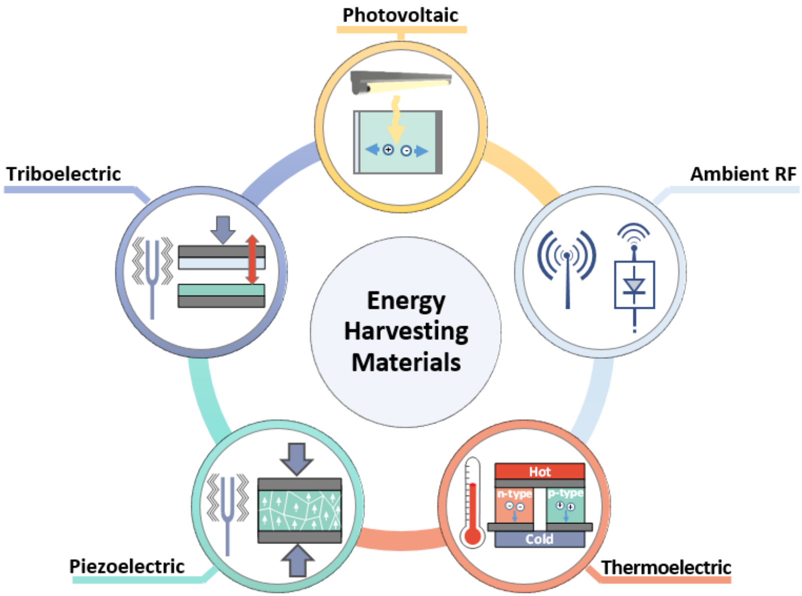
- **Roadmap on Energy Harvesting Materials: organization of article**
- **Different types of energy harvesting**
- **Status and challenges**

‘Roadmap on Energy Harvesting Materials’

- Milestone publication charting the course for energy harvesting materials to deliver clean energy anytime, anywhere
- Collaborative endeavour organized by **prof. Vincenzo Pecunia, Simon Fraser University (Canada),** bringing together 116 leading experts from around the world

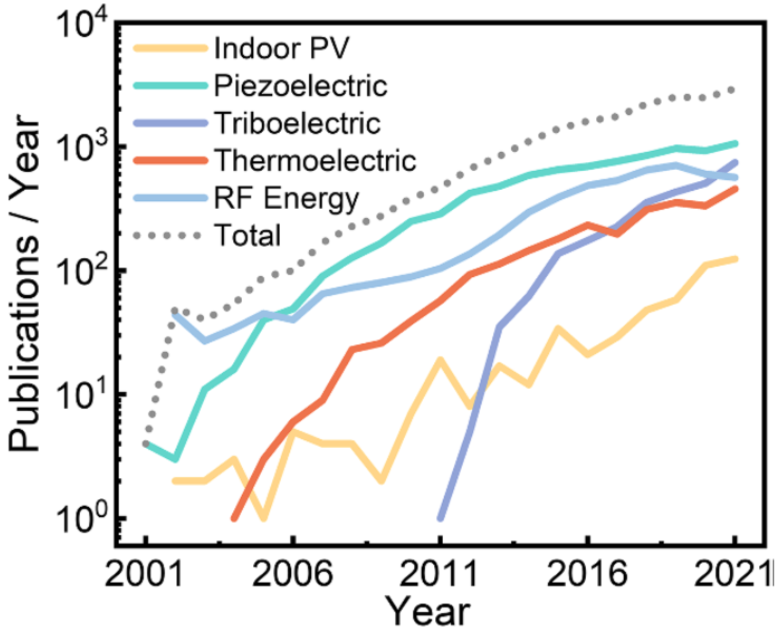


Roadmap on energy harvesting materials



52 section articles organized in:

- **Status**
- **Current and future challenges**
- **Advances in science and technology to meet challenges**
- **Concluding remarks**



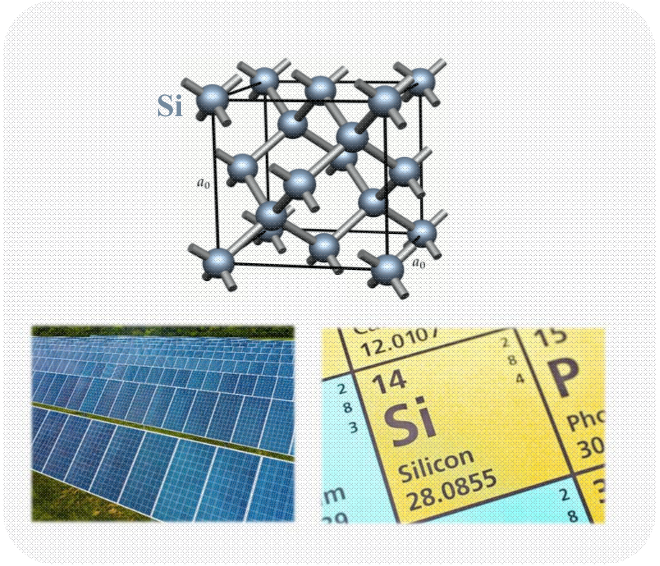
Publications per year for the various energy harvesting technologies covered in Roadmap

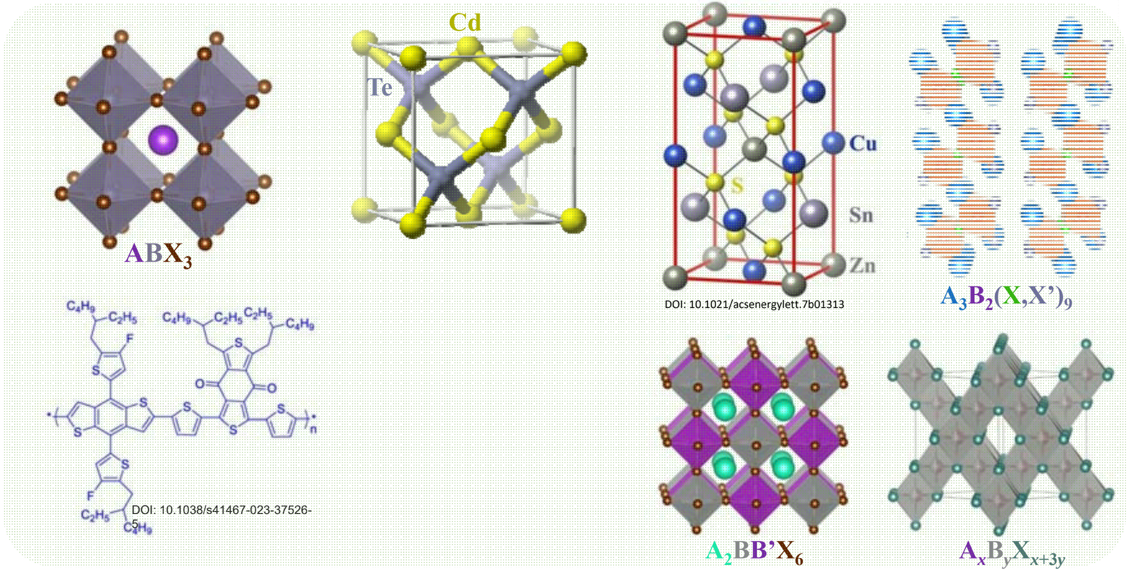
Roadmap on energy harvesting materials, V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

Why look at the status of energy harvesting materials?

Let’s look at photovoltaics as an example:

- The most widespread photovoltaic technology is based on silicon
- But a much wider range of technologies, based on a variety of materials, are being developed to realize next-generation photovoltaics

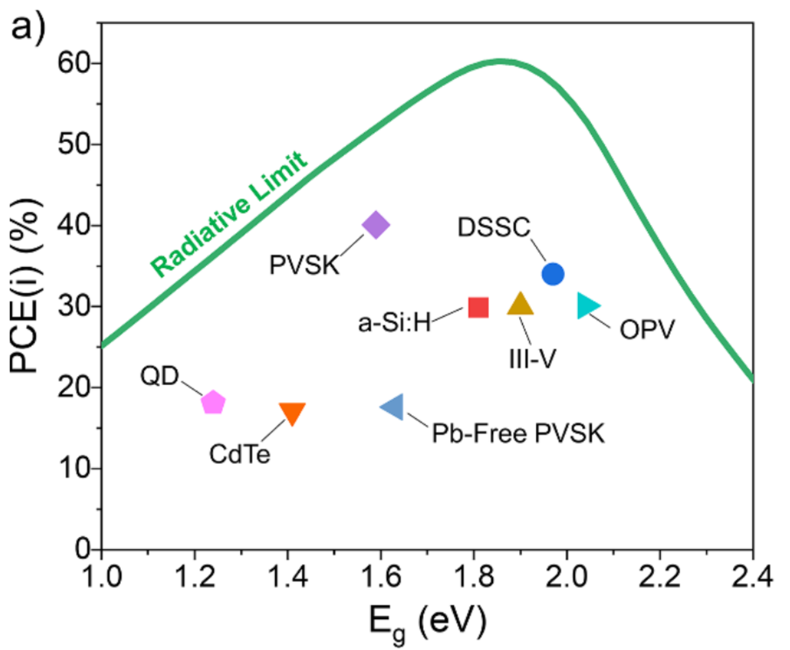




Materials for indoor photovoltaics

IOP Publishing J. Phys. Mater. 6 (2023) 042501

Contents



Indoor PCE of champion devices of PV technologies indoors for illuminance ~1000 lx. Perovskite Solar cells at ~ 40%

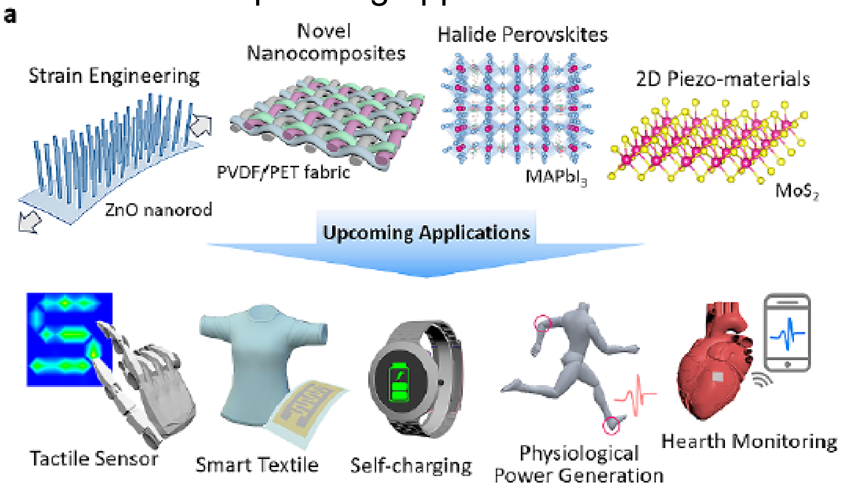
There is space to improve & many challenges ahead!

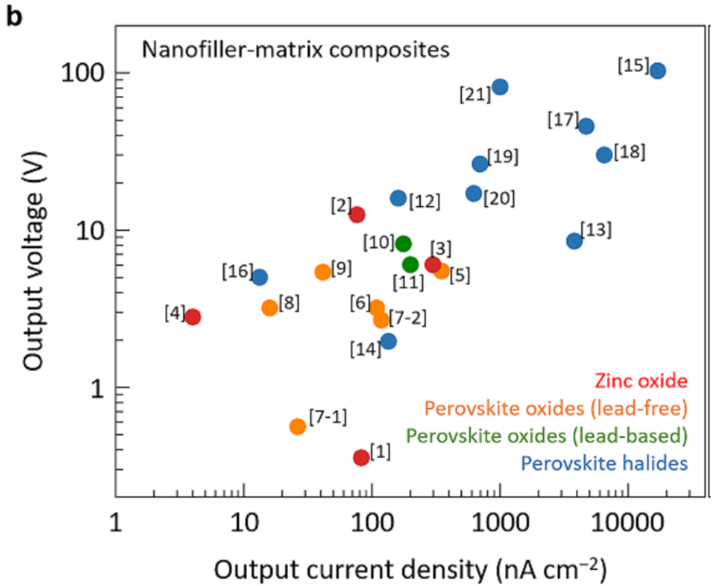
Roadmap on energy harvesting materials, sect. 2.1 V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

Materials for piezoelectric energy harvesting

3. Materials for piezoelectric energy harvesting
3.1. Introduction to piezoelectric energy harvesting—lead-based oxide perovskites
3.2. Lead-free oxide perovskites for piezoelectric energy harvesting
3.3. Nanostructured inorganics for piezoelectric energy harvesting
3.4. Nitrides for piezoelectric energy harvesting
3.5. Two-dimensional materials for piezoelectric energy harvesting
3.6. Organics for piezoelectric energy harvesting
3.7. Bio-inspired materials for piezoelectric energy harvesting

upcoming applications

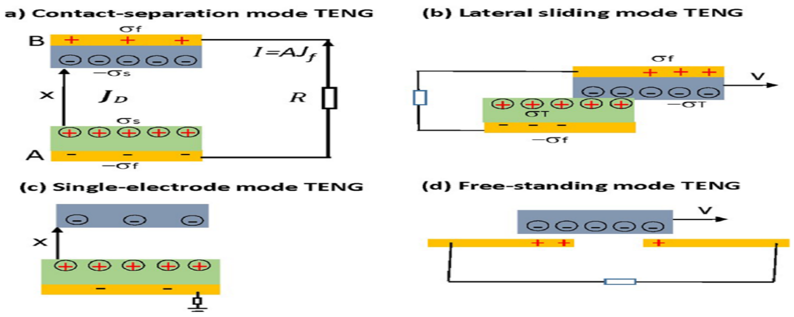




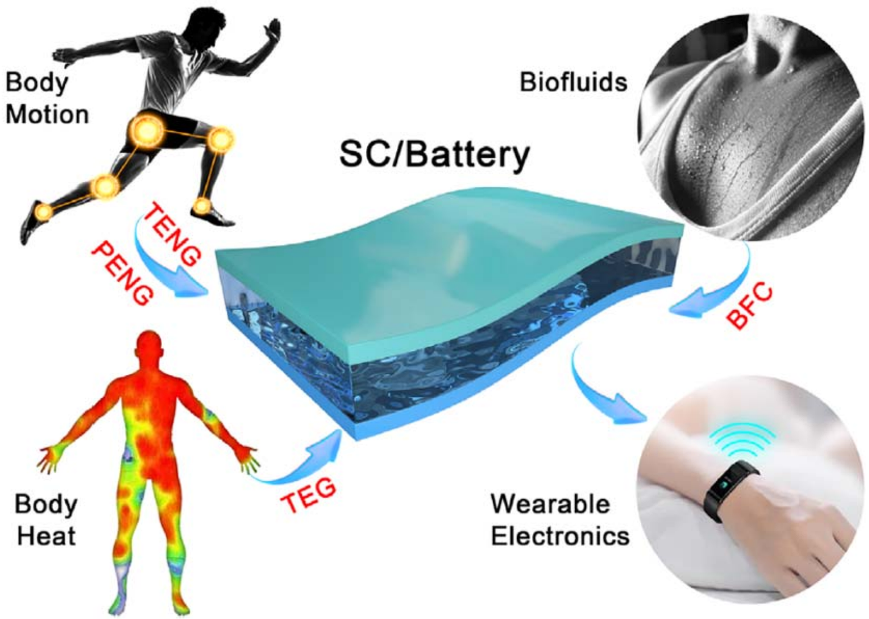
output voltage and current density values reported for the nanocomposites

Roadmap on energy harvesting materials, sect. 3.3, V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

Materials for triboelectric energy harvesting



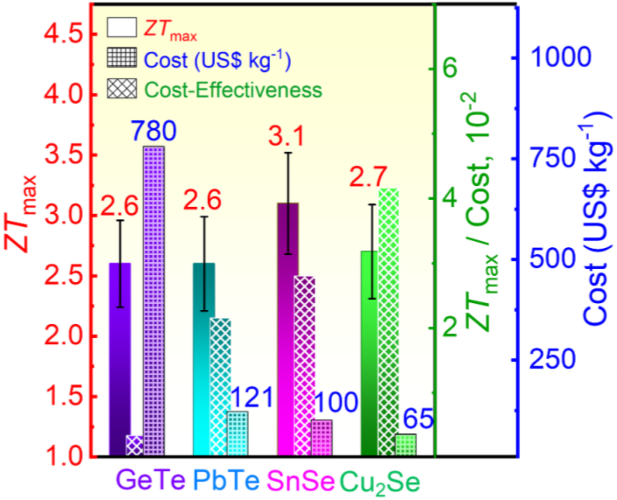
operational modes of triboelectric nanogenerators



A wearable energy storage system via self-charged human-body bioenergy, including body motions, heat, and biofluids.

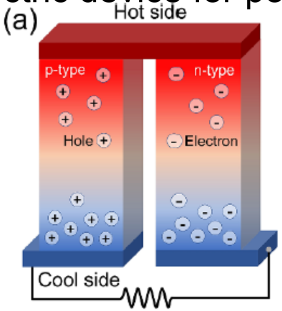
Roadmap on energy harvesting materials, sect. 4, V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

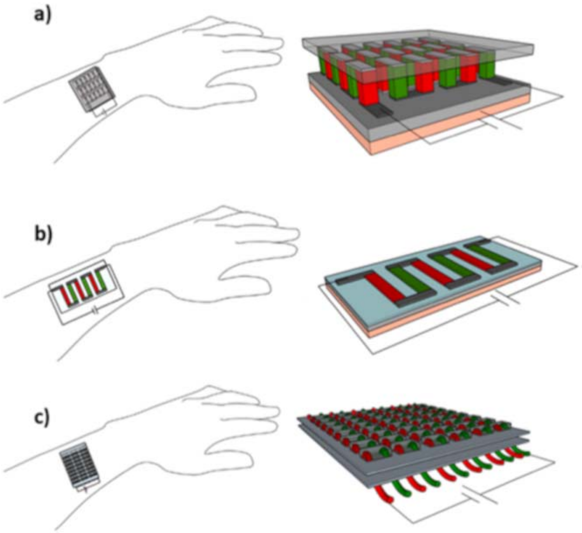
Materials for thermoelectric energy harvesting



Comparison of their maximum ZT, cost, and cost-effectiveness of typical chalcogenides

thermoelectric device for power generation

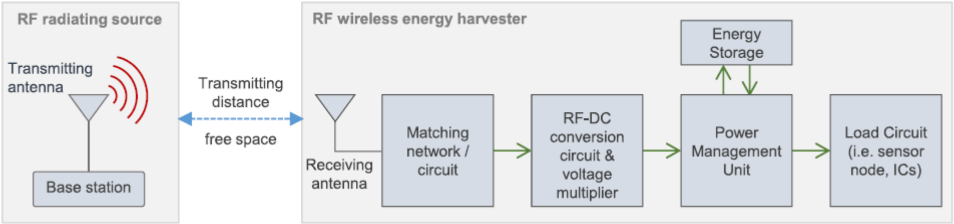


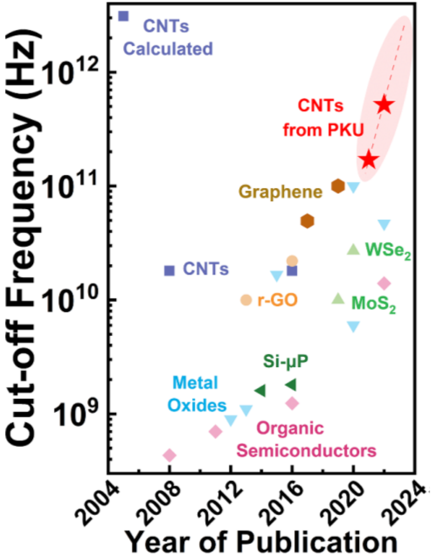


different configurations in wearable thermoelectric generators:

Roadmap on energy harvesting materials, sect. 5, V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

Materials for radiofrequency energy harvesting



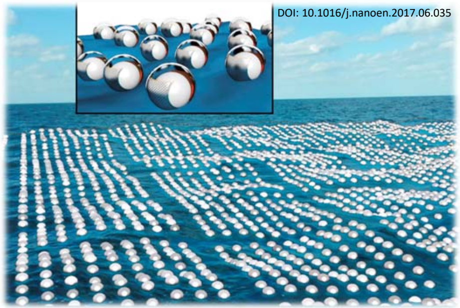


cut-off frequency of state-of-the-art rectifying devices based on carbon nanotubes and other materials

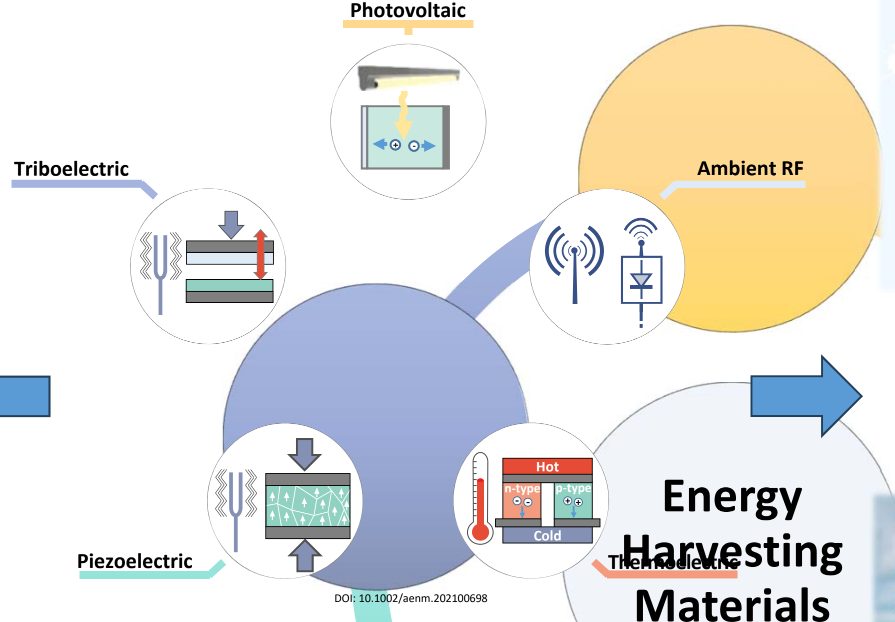
The evolution of large-area rectennas:

Roadmap on energy harvesting materials, sect. 6, V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

Energy Harvesting for Sustainable Development



Clean electricity through large-scale installations to meet rising energy demand



Compact, sustainable power sources for Internet-of-Things sensor nodes

Energy harvesting materials research is key to developing clean energy solutions toward net-zero

Roadmap on Energy Harvesting Materials

- **Key challenges:**
  - **Efficiency**
  - **Stability**
  - **Manufacturability**
  - **Environmental Sustainability**
  - **Cost**
  - **Form Factors**

7. Sustainability considerations on energy harvesting materials research

- Our recent roadmap provides guidance on key challenges and promising directions to unlock the potential of next-generation energy harvesting materials.

JPhys Materials

From the publisher of the *Journal of Physics* series

OPEN ACCESS

IOP Publishing | J. Phys. Mater. 6 (2023) 042501 | https://doi.org/10.1088/2515-7639/acc550

Journal of Physics: Materials

OPEN ACCESS

RECEIVED 18 August 2022

REVISED 7 February 2023

ACCEPTED FOR PUBLICATION 17 March 2023

PUBLISHED 7 August 2023

ROADMAP

Roadmap on energy harvesting materials

Vincenzo Pecunia, S Ravi P Silva, Jamie D Phillips, Elisa Artegiani, Alessandro Romeo, Hongjae Shim, Jongsung Park, Jin Hyeok Kim, Jae Sung Yun, Gregory C Welch, Bryon W Larson, Myles Creran, Audrey Laventure, Kezia Sasitharan, Natalie Flores-Diaz, Marina Freitag, Jie Xu, Thomas M Brown, Benxuan Li, Yiwen Wang, Zhe Li, Bo Hou, Behrang H Hamadani, Emmanuel Defay, Veronika Kovacova, Sebastjan Glinsek, Sohini Kar-Narayan, Yang Bai, Da Bin Kim, Yong Soo Cho, Agnė Žukauskaitė, Stephan Barth, Feng Ru Fan, Wenzhuo Wu, Pedro Costa, Javier del Campo, Senentxu Lanceros-Mendez, Hamideh Khanbareh, Zhong Lin Wang, Xiong Pu, Caofeng Pan, Renyun Zhang, Jing Xu, Xun Zhao, Yihao Zhou, Guorui Chen, Trinny Tat, Il Woo Ock, Jun Chen, Sontyana Adonijah Graham, Jae Su Yu, Ling-Zhi Huang, Dan-Dan Li, Ming-Guo Ma, Jikui Luo, Feng Jiang, Pooi See Lee, Bhaskar Dudem, Venkateswaran Vivekananthan, Mercouri G Kanatzidis, Hongyao Xie, Xiao-Lei Shi, Zhi-Gang Chen, Alexander Riss, Michael Parzer, Fabian Garmroudi, Ernst Bauer, Duncan Zavanelli, Madison K Brod, Muath Al Malki, G Jeffrey Snyder, Kirill Kovnir, Susan M Kauzlarich, Ctirad Uher, Jinle Lan, Yuan-Hua Lin, Luis Fonseca, Alex Morata, Marisol Martin-Gonzalez, Giovanni Pennelli, David Berthebaud, Takao Mori, Robert J Quinn, Jan-Willem G Bos, Christophe Candolfi, Patrick Gougeon, Philippe Gall, Bertrand Lenoir, Deepak Venkateshvaran, Bernd Kaestner, Yunshan Zhao, Gang Zhang, Yoshiyuki Nonoguchi, Bob C Schroeder, Emiliano Bilotti, Akanksha K Menon, Jeffrey J Urban, Oliver Fenwick, Ceyla Asker, A Alec Talin, Thomas D Anthopoulos, Tommaso Losi, Fabrizio Viola, Mario Caironi, Dimitra G Georgiadou, Li Ding, Lian-Mao Peng, Zhenxing Wang, Muh-Dey Wei, Renato Negra, Max C Lemme, Mahmoud Wagih, Steve Beeby, Taofeeq Ibn-Mohammed, K B Mustapha and A P Joshi

iopscience.org/jphysmaterials

IOP Publishing

Q & A

EnerHarv 2024

PSMA International Workshop | 26-28 June, 2024 | Perugia, Italy

Thanks very much for your time and attention!

Questions/comments???

TECHNICAL SPONSORS

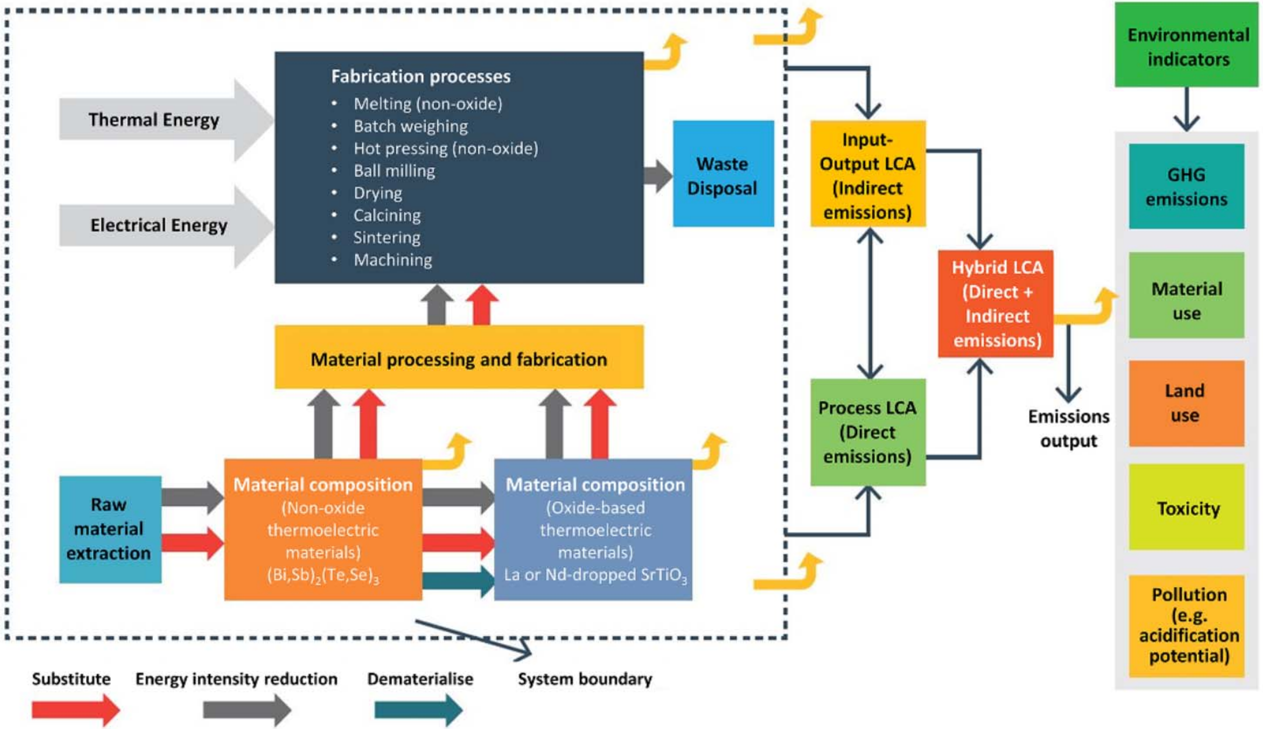
ORGANIZER

HOST

COMMERCIAL SPONSORS

MEDIA SPONSORS

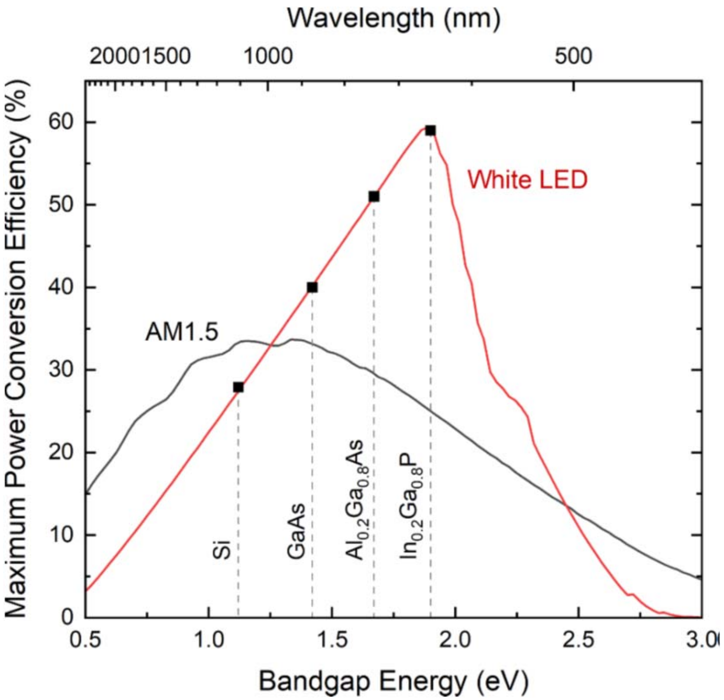
Sustainability considerations on energy harvesting materials research



system boundary defined for the LCA of two thermoelectric modules.

Roadmap on energy harvesting materials, sect. 7, V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

III–V compound semiconductors for indoor photovoltaics

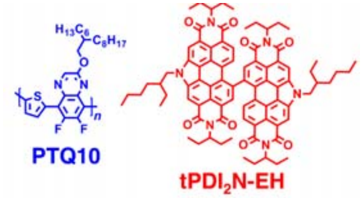


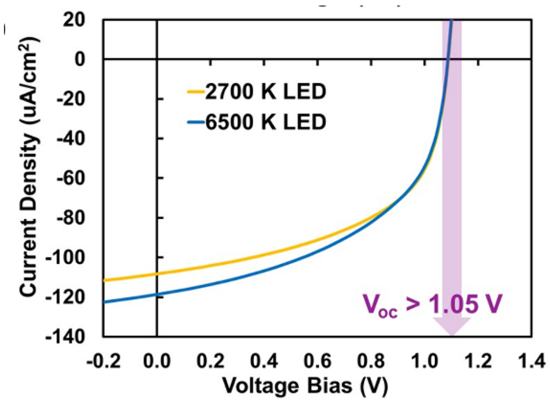
Calculated max efficiency versus bandgap energy for photovoltaic cells under AM1.5 and white light-emitting-diode illumination.

- PCEs > 20% have been reported for AlGaAs
- PCEs >30% for InGaP
- Cost-effective approaches to realize III–V photovoltaics are a current research challenge but different from large area PV

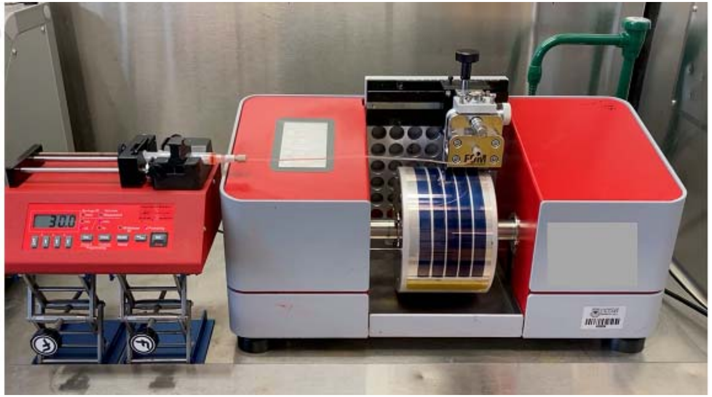
Roadmap on energy harvesting materials, sect. 2.2, J.D. Phillips, in V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

OPV for indoor photovoltaics





- Control of the chemical structure of molecules allows for tailoring of optoelectronic properties to match spectrum. High Voc.

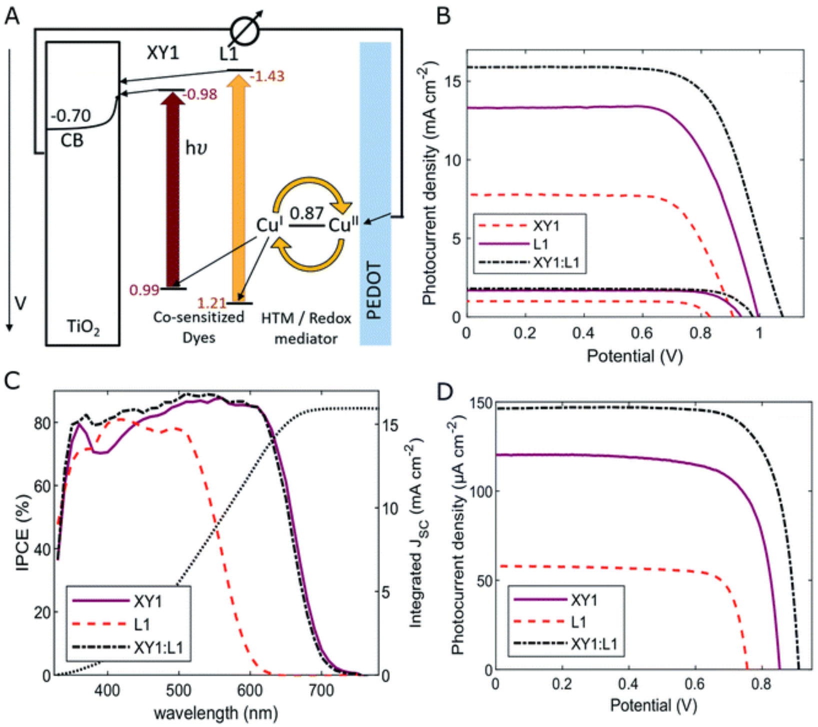


- PCEs ≥ 25% at 1000 lx.

- Cost-effective deposition via coating & printing techniques

Roadmap on energy harvesting materials, sect. 2.2, G,.C. Welch et al., in V. Pecunia et al. J. Phys. Mater. 6 (2023) 042501

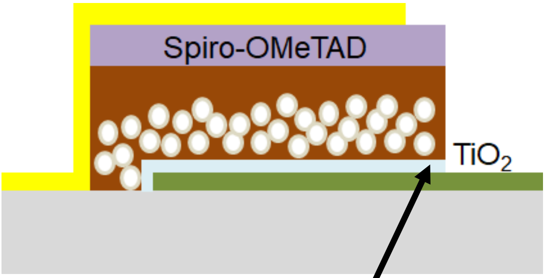
Dye Sensitized Solar Cells for indoor photovoltaics



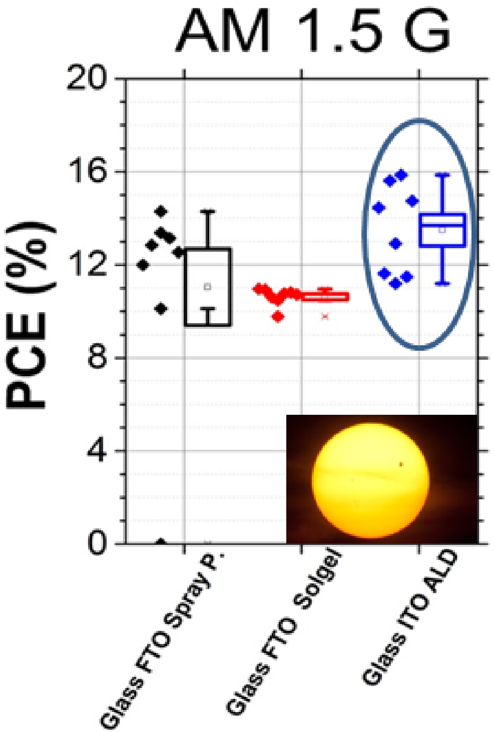
https://pubs.rsc.org/en/content/articlelanding/2020/sc/c9sc06145b

- PCE of 28.9% reached at 1000 lx [Cu(tmby)2]2+/1+ redox coupled with TiO2 films co-sensitized with the dye D35 and XY1
- panchromatic dyes, alternative hole transport materials 13% under AM1.5G conditions and 34% under indoor light.
- Cost-effective deposition via coating & printing techniques; questions about electrolyte use.

Perovskite Photovoltaic Cells for Indoors



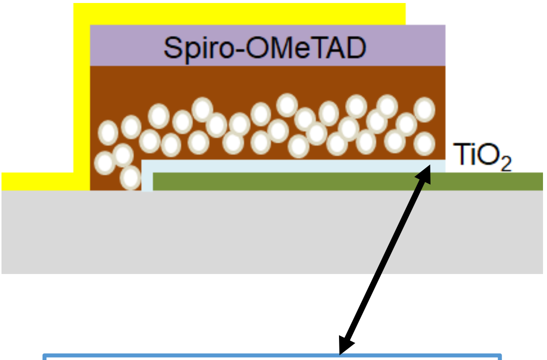
- Spray Pyrolysis (450°C)
- SolGel spin coating (500°C)
- ALD (150°C)



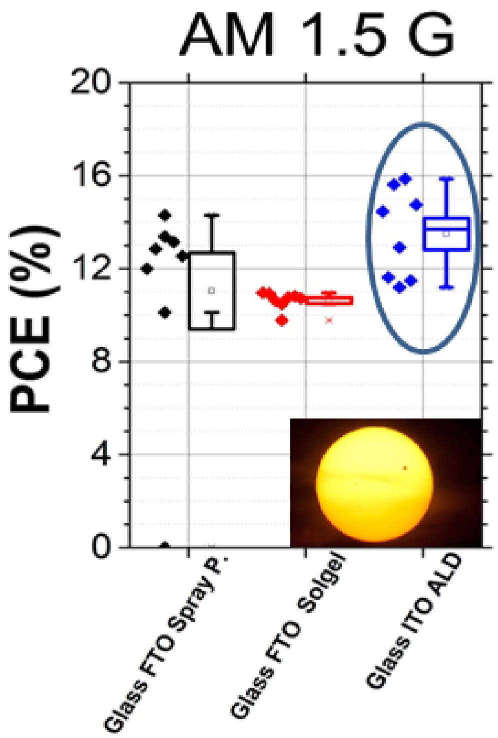
- Much higher efficiency indoors
- Performance indoors more sensitive to film & interface quality

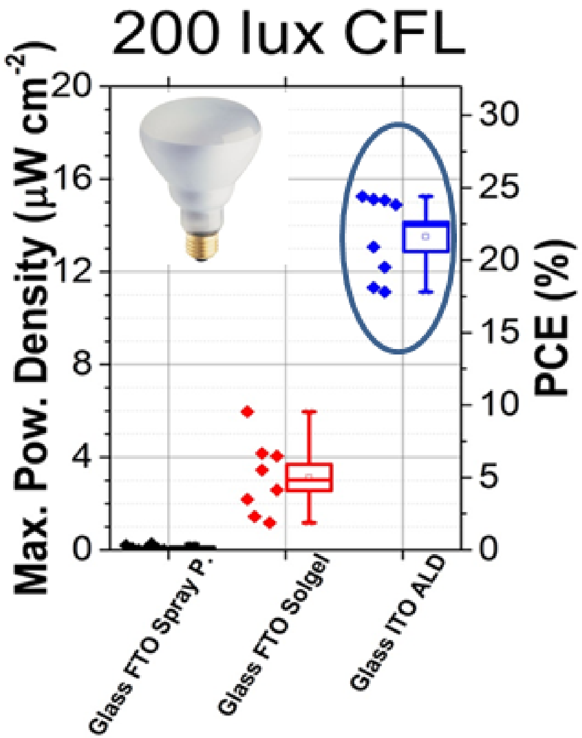
F. Di Giacomo, Nano Energy 30, 460 (2016)

Perovskite Photovoltaic Cells for Indoors



- Spray Pyrolysis (450°C)
- SolGel spin coating (500°C)
- ALD (150°C)

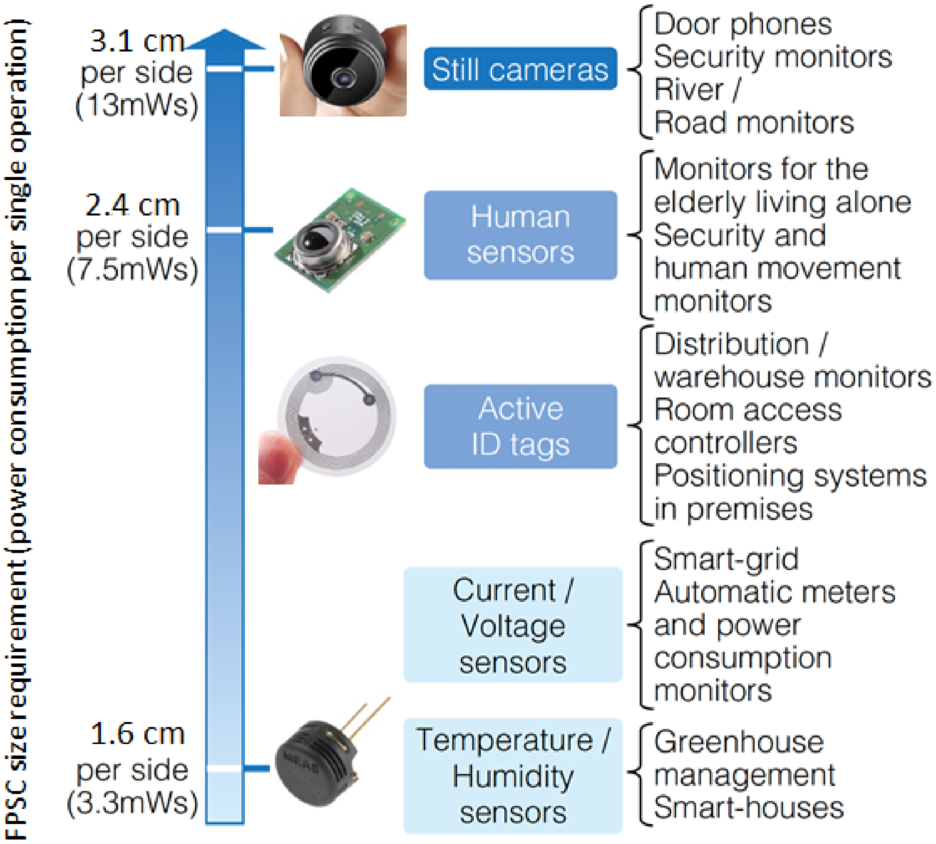




- Much higher efficiency indoors
- Performance indoors more sensitive to film & interface quality

F. Di Giacomo, Nano Energy 30, 460 (2016)

III–V compound semiconductors for indoor photovoltaics



Calculation conditions:

1000 lux illumination

Power output of PV:
127.8 μW/cm^2 for cells with ~30% PCE at 1000 lx

Operation cycle:
every 10s

Fujikura Technical Review, 2013. *F. De Rossi et al., Applied Energy, 2015, 156, 413.*

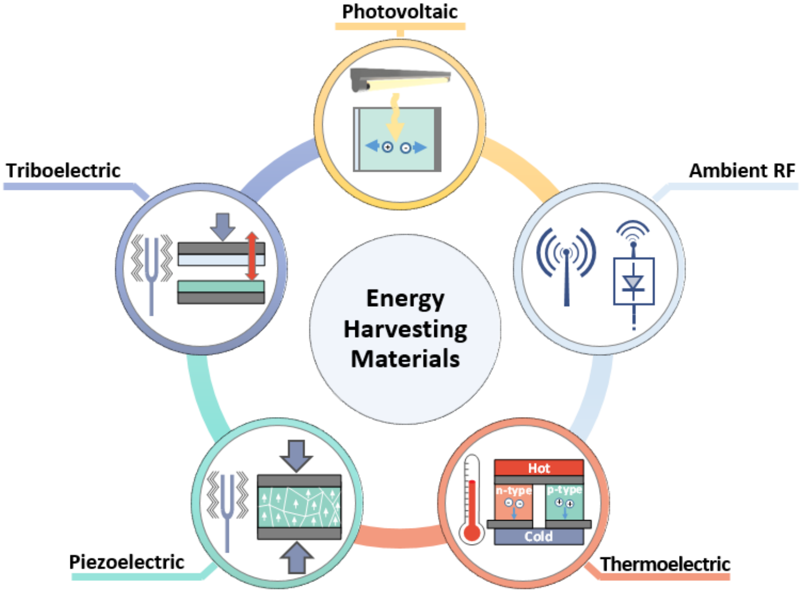
Why look at the status of energy harvesting materials?

- Emerging photovoltaic materials have the potential to facilitate cheaper, eco-friendlier, and lighter photovoltaics, fostering broader deployment → cheaper, more abundant clean electricity

- The same trend generally holds for all other energy harvesting technologies

⇓

Energy harvesting materials research is key to developing clean energy solutions toward net-zero



DOI: 10.1002/aenm.202100698