

The New Era of Solar Cells; From Rooftops to Space Applications

Tara P. Dhakal

Director, Center for Autonomous Solar Power (CASP)
Professor, Electrical and Computer Engineering,
Binghamton University, Binghamton, NY 13902, USA

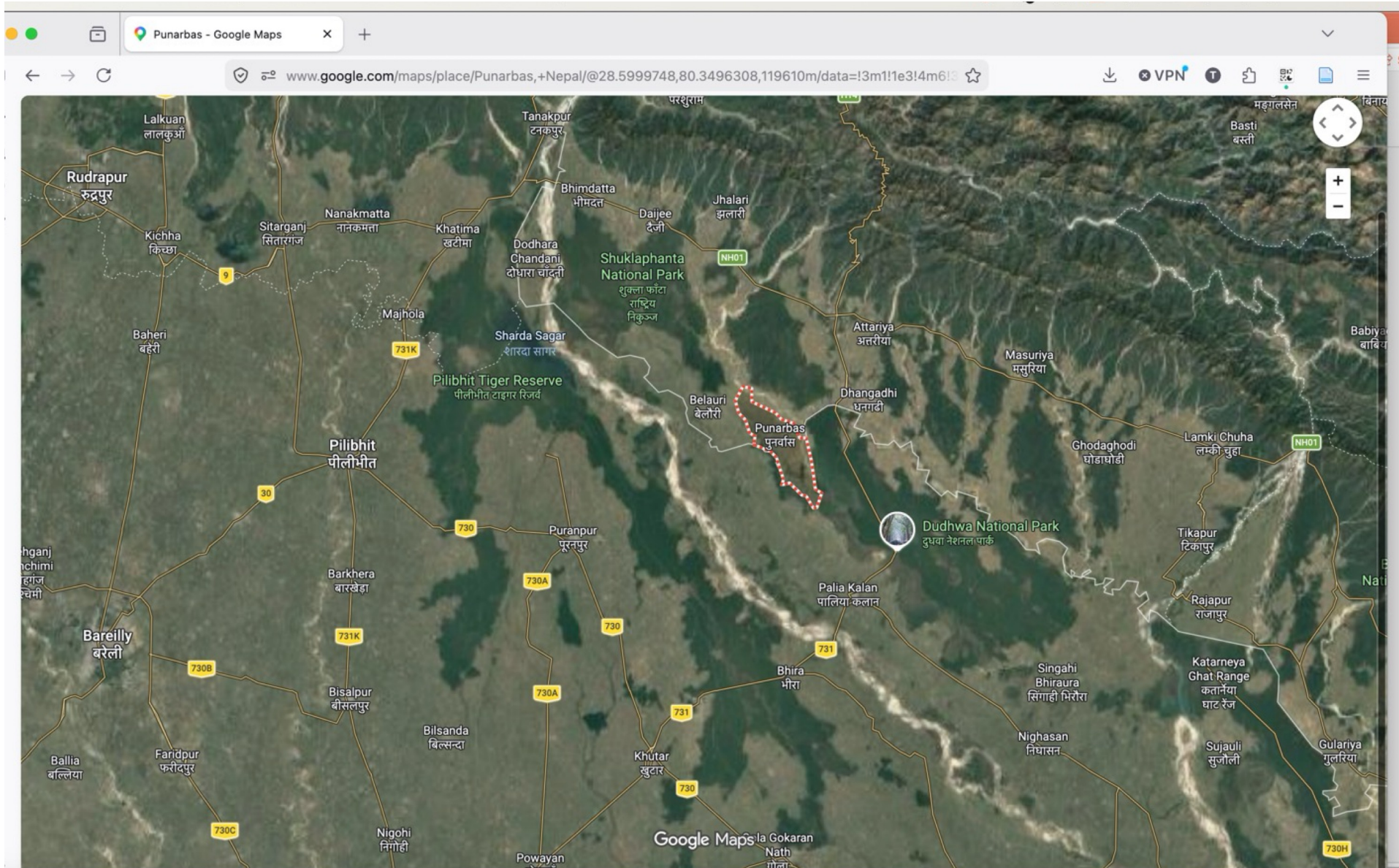
Contact E-mail: tdhakal@binghamton.edu

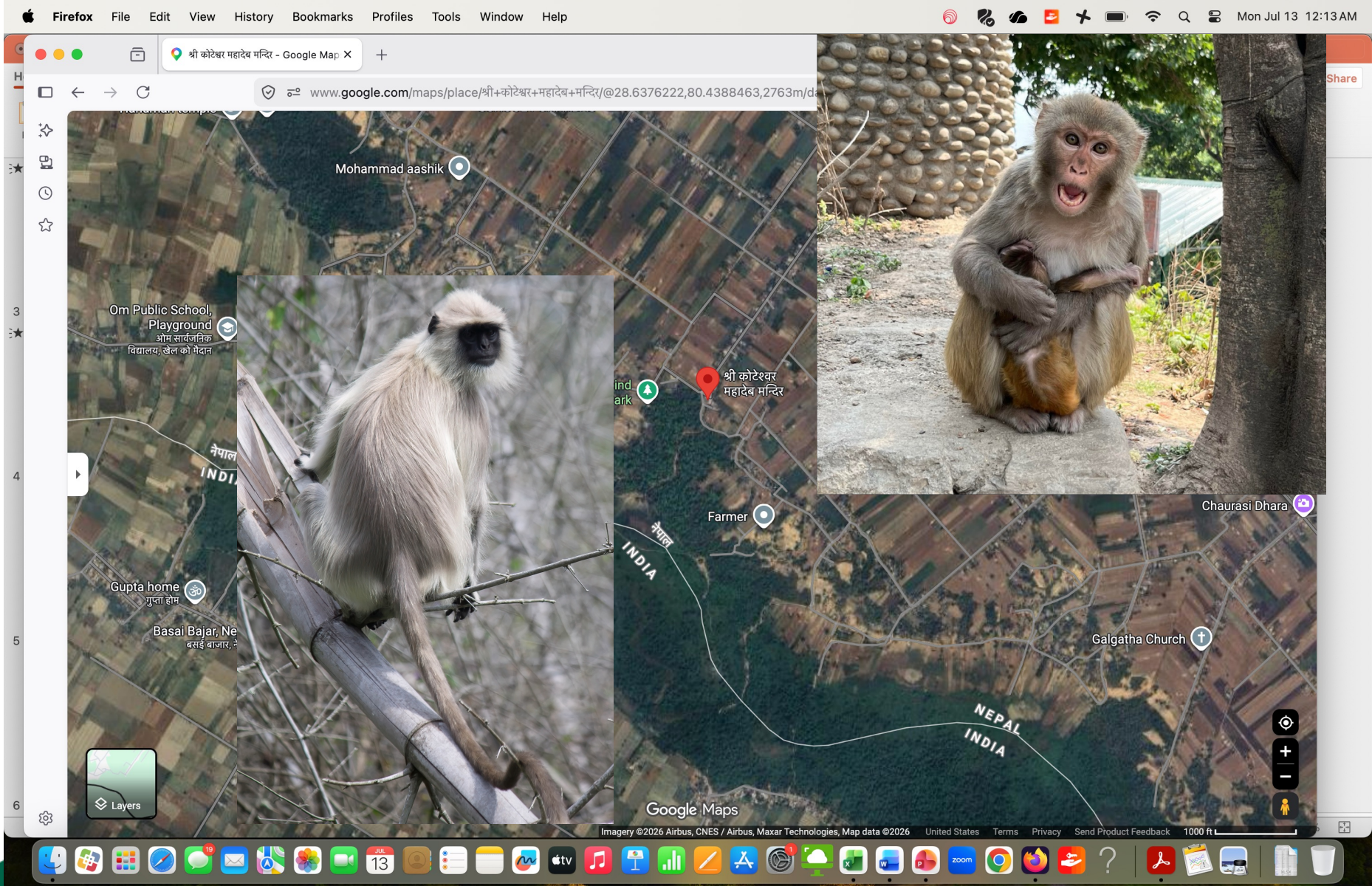
Where is NEPAL ?



Punarbass







About Me

- BSc, Tribhuvan University, Kathmandu, Nepal
 - Valedictorian (Board top, Gold medal from King Birendra)
- MS: Shimane University, Japan (Monbusho Scholarship)
- PhD, University of Florida, Gainesville, FL
- Professor: ECE Department, Binghamton University, NY
 - <https://www.binghamton.edu/electrical-computer-engineering/people/profile.html?id=tdhakal>
- Director: Center for Autonomous Solar Power (CASP)
 - Under the umbrella of a New York Center of Excellence known as Small Scale Systems Integration and Packaging (S³IP):
<https://www.binghamton.edu/s3ip/index.html>



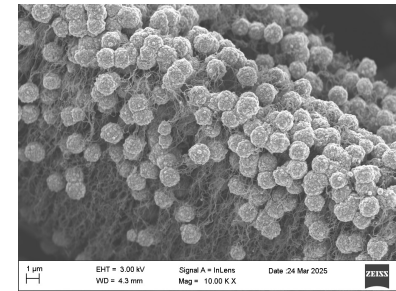
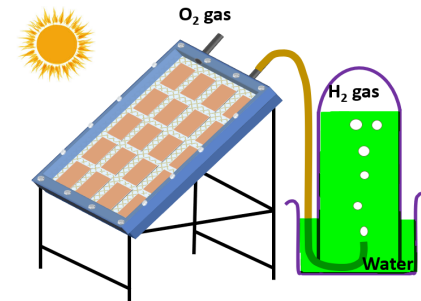
Contact information: tdhakal@binghamton.edu

A New York State Center of Excellence

BINGHAMTON UNIVERSITY

My projects

- Manufacturing Perovskite Solar Modules
- Perovskite based low toxicity solar technology
- Perovskite powered hydrogen production using low-cost catalysts
- Energy Storage: Batteries and supercapacitors



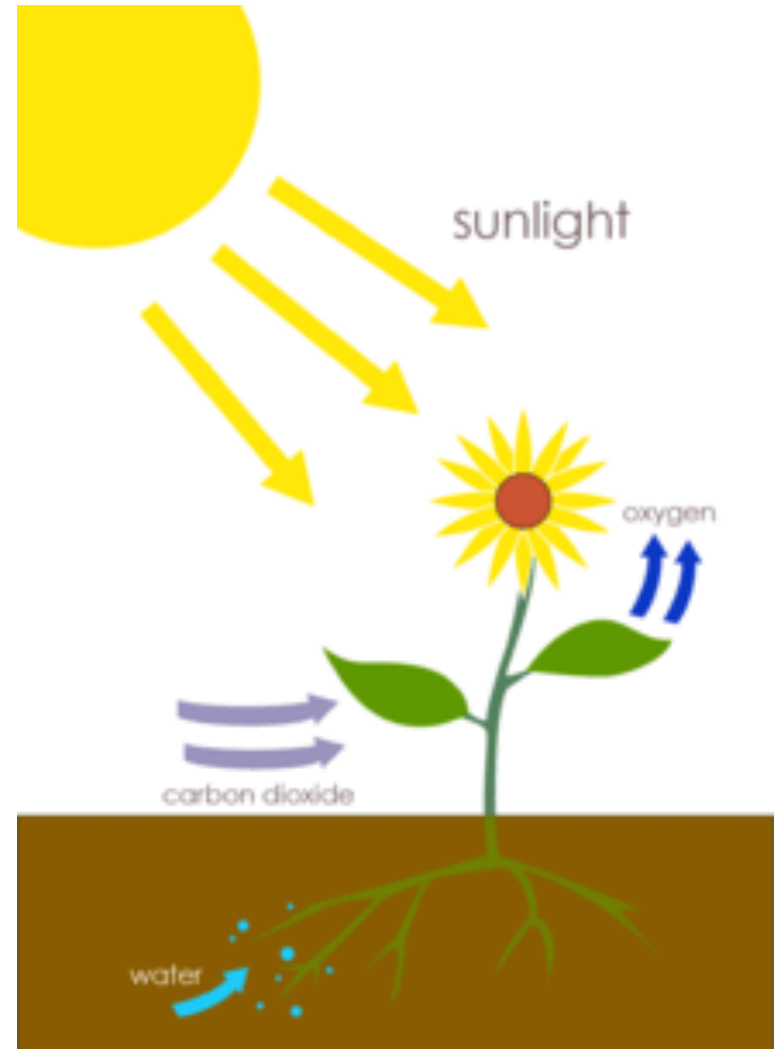
Supercapacitors on CNTS

Why Solar Cells?

Life-sustaining values of sunlight

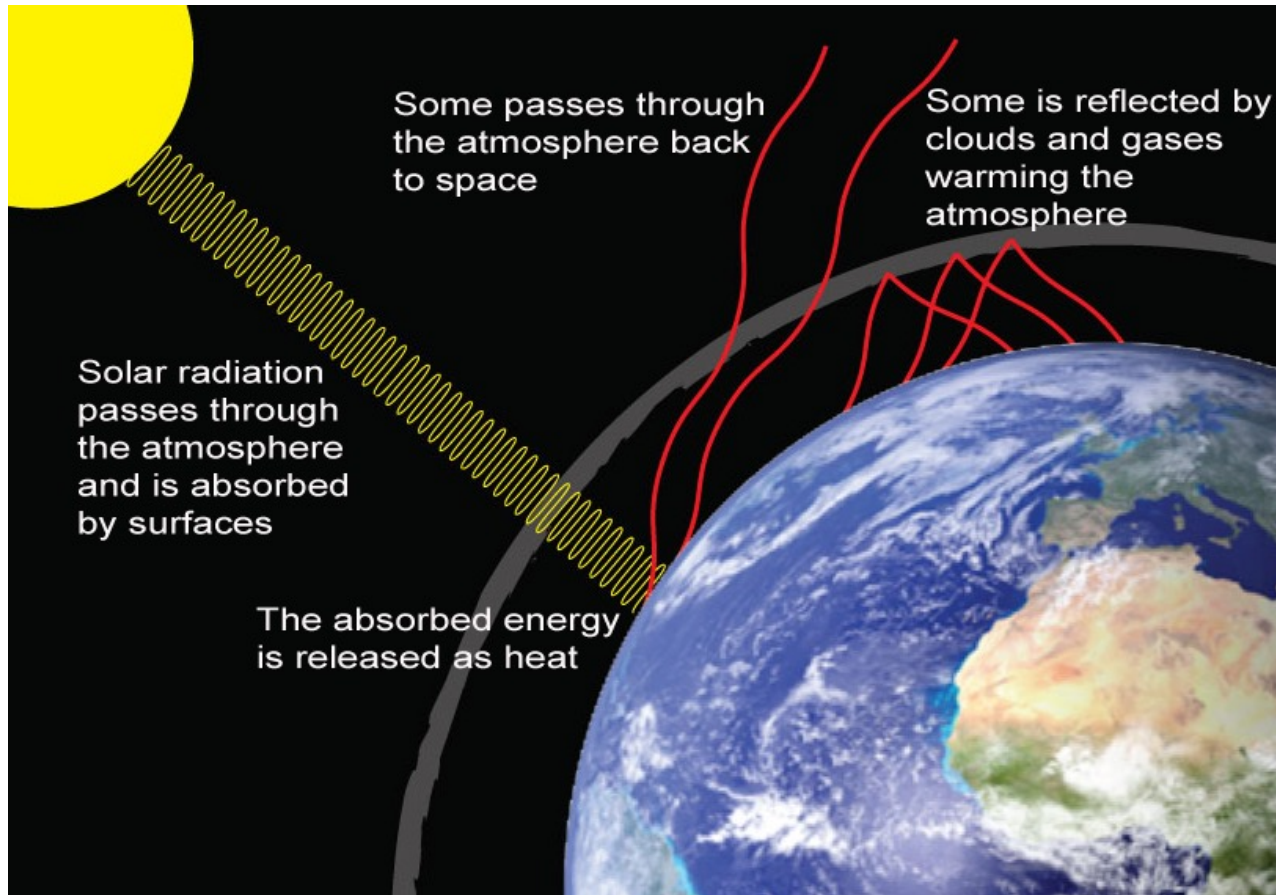
Photosynthesis process:

- The oxygen available to us today is due to the photosynthesis process that happened over millions of years
- Burning Carbon will produce CO_2 and consume oxygen
- The Photosynthesis process is too slow to catch up with the burned oxygen
- CO_2 trapped in our atmosphere will warm the Earth through the greenhouse effect



Motivation for Renewable Energy

Greenhouse effect:



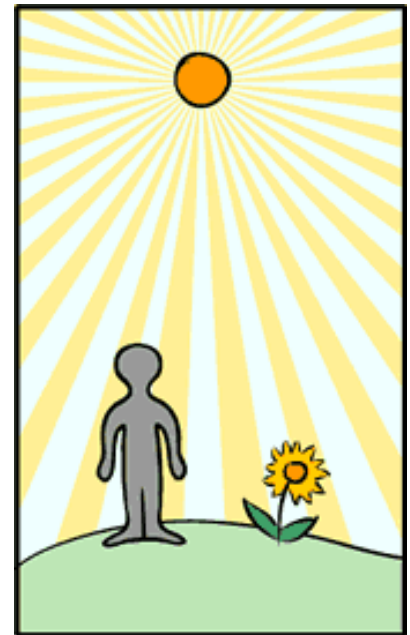
What We Learned So Far?

❑ We can not burn all Carbon:

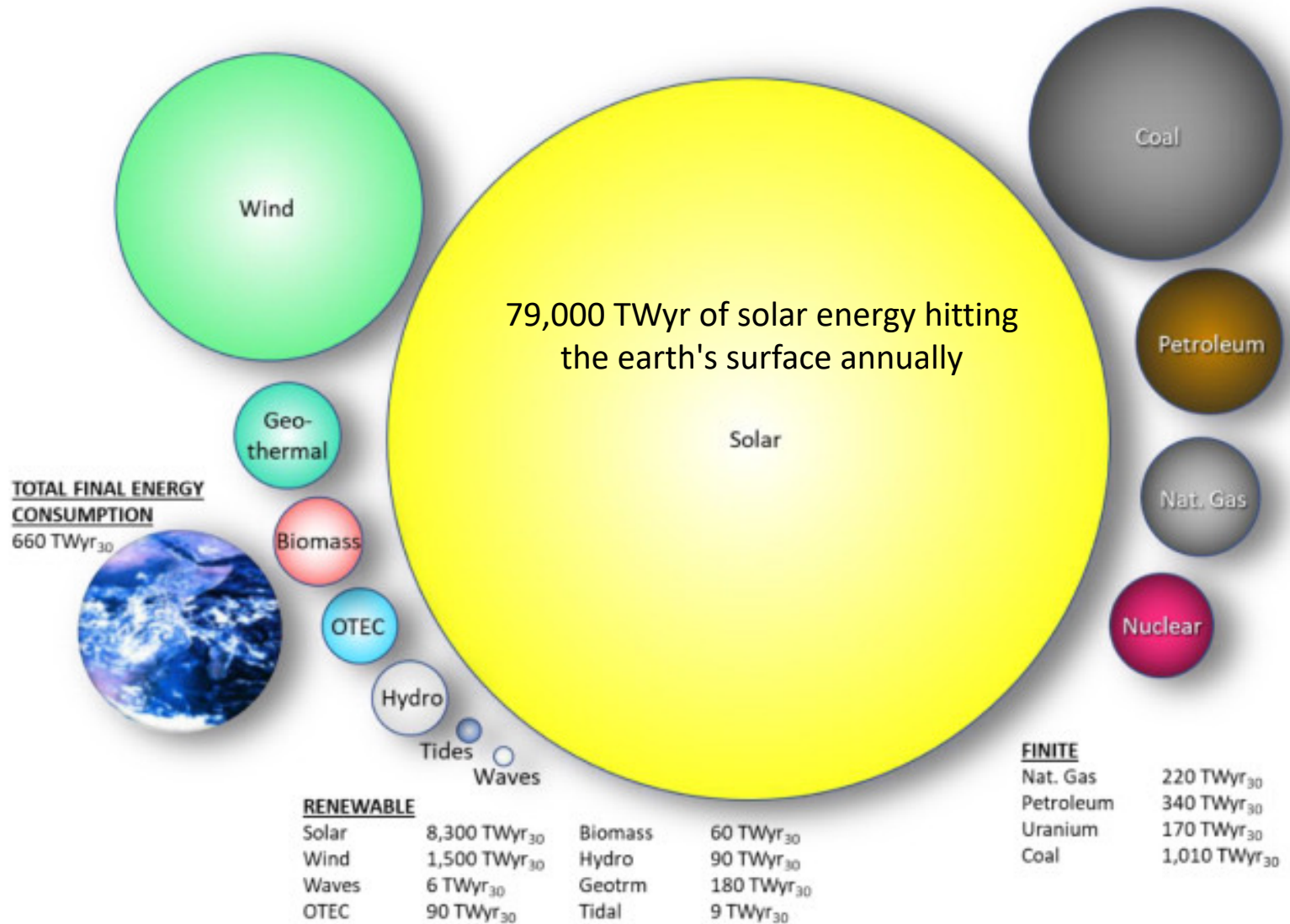
- Leaves a footprint (CO_2) causing greenhouse effect
- Will deplete O_2 produced by photosynthesis process

❑ We need to look for clean and non perishable source of energy:

- Sun has vast amount of energy
- Solar energy never runs out
- Solar Cells can convert sunlight into electricity



The Case for Solar Energy

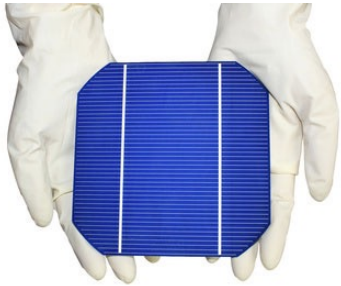


Solar Cells are Emerging Everywhere



How Solar Cells are Deployed?

How Solar panels are made?



Cells

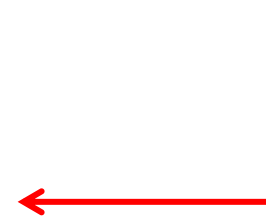
Connect the Cells
in series



Cells placed like tiles on
your bathroom floor

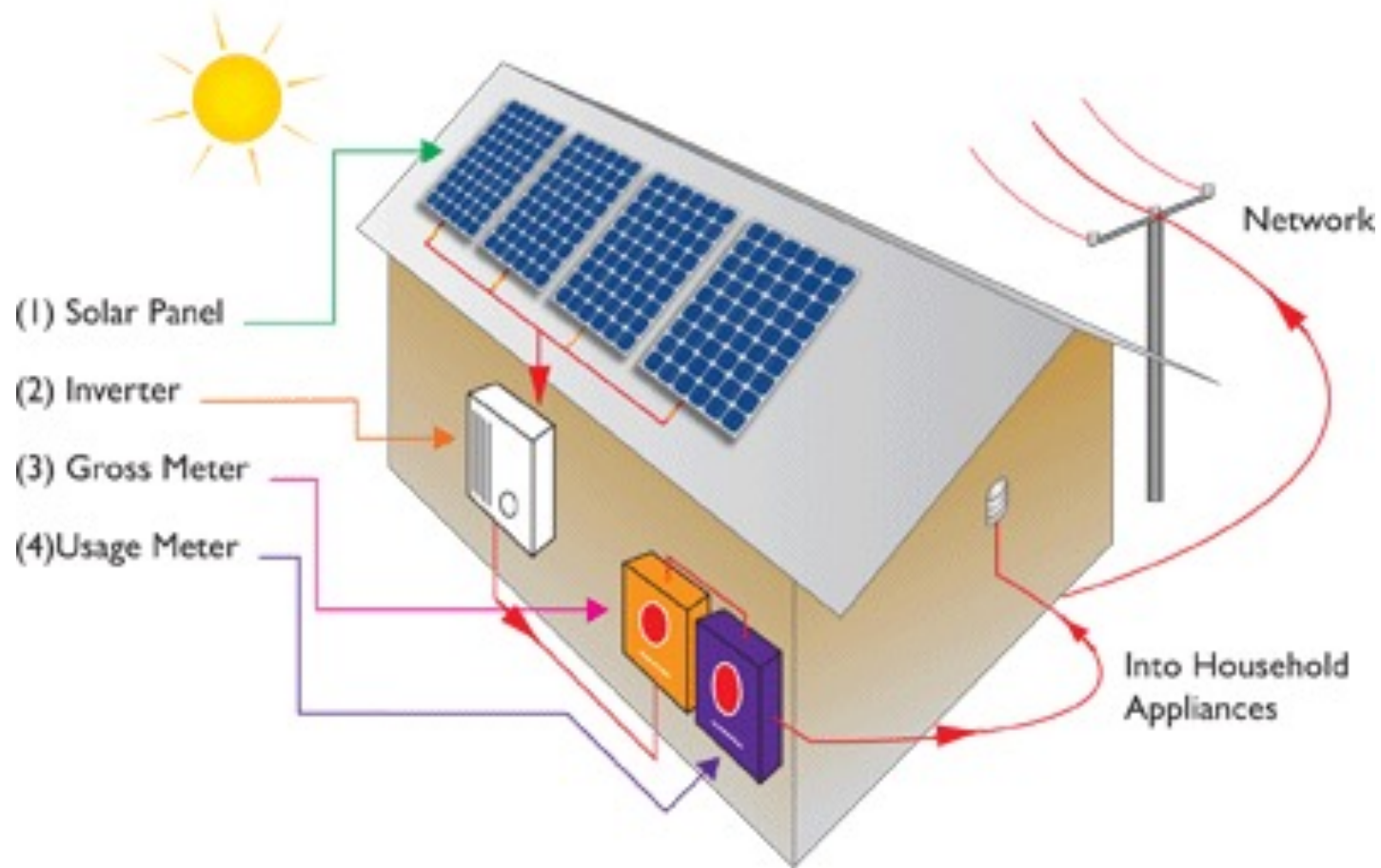


Module (Panel)



Deployed on the roof or the field (Array)

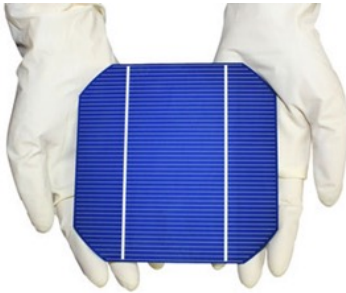
Solar panels at home



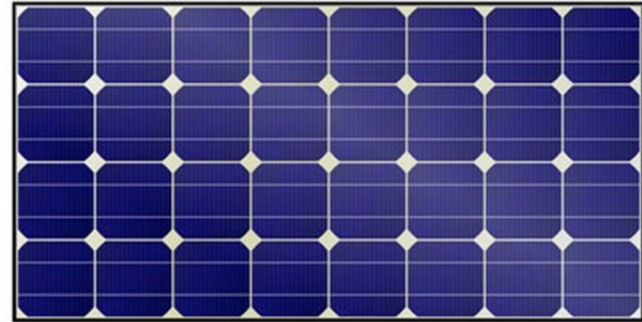
Types of Solar Cells

Types of solar cells

1. Silicon solar cells (They are quite thick, and brittle)



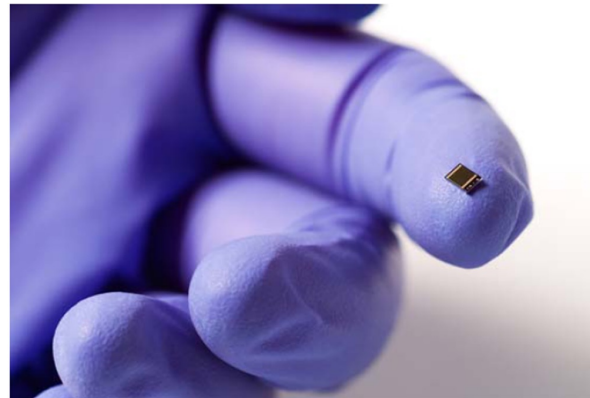
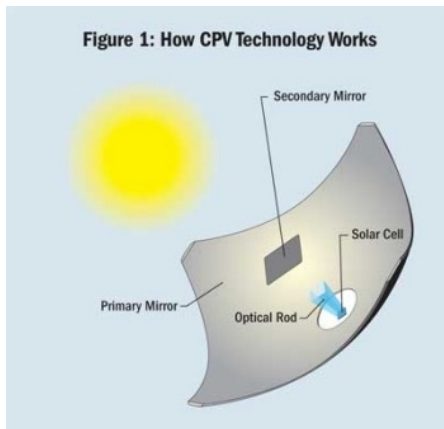
c-Si ~ 0.2 mm



- Very efficient (~27%)
- Robust
- Expensive

Types of solar cells

2. CPV (Concentrator Photovoltaics); III-Vs normally used, e.g. GaAs

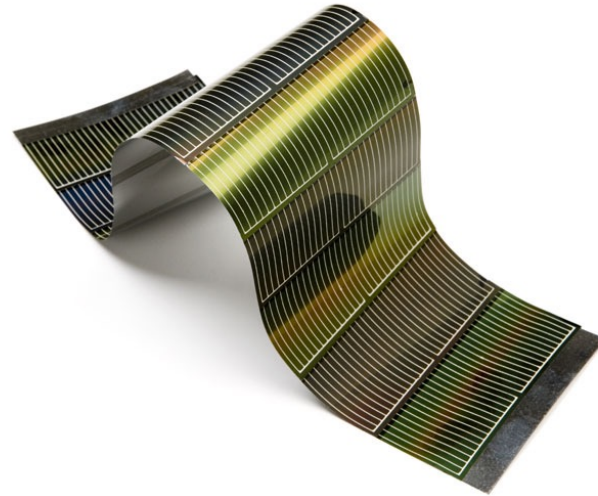
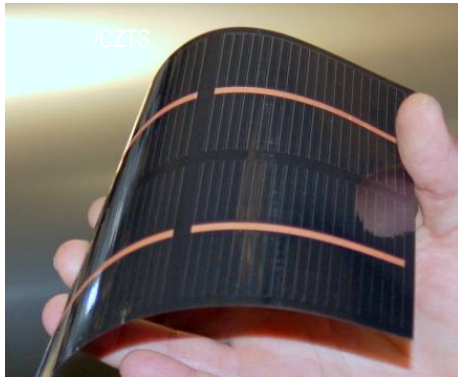


World record solar cell with 44.7% efficiency, made up of four solar subcells based on III-V compound semiconductors for use in concentrator photovoltaics.
©Fraunhofer ISE

- High quality, very efficient
- 45% efficiency
- Expensive

Types of solar cells

3. Thin film solar cells

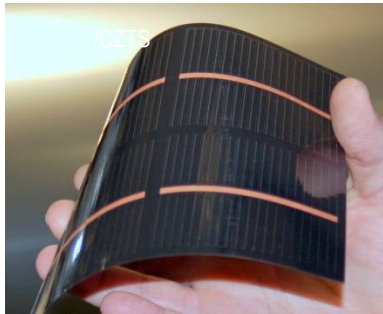


Cu(In,Ga)Se_2 (CIGS) ~ 1-2 μm

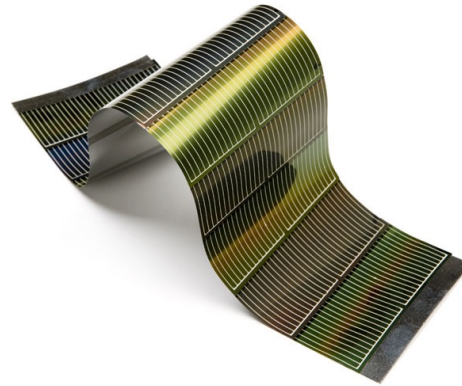
- They are quite thin, and flexible
 - 100 times thinner than hair diameter
- Cheaper but not so efficient (20-25%) and not very reliable
- Some contain toxic materials
- However this could be the future of solar cell technology

What we are doing?

3. Thin film solar cells



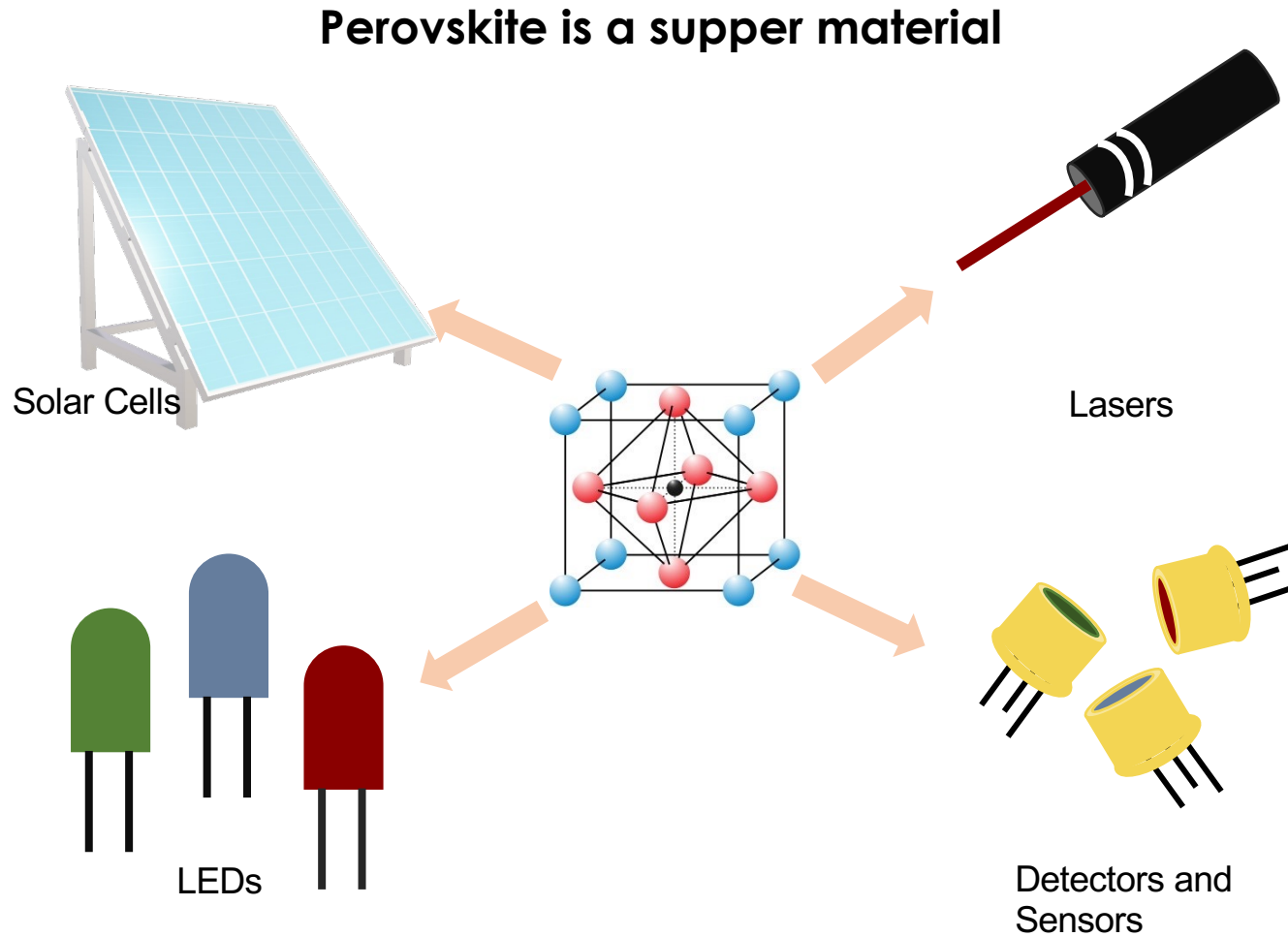
Cu(In,Ga)Se_2 (CIGS) ~ 1-2 μm



- They are quite thin, and flexible
 - 100 times thinner than hair diameter
- Both organic and inorganic types are available
- Cheaper but not so efficient (20-25%) and not very reliable
- Some contain toxic materials
- However, this could be the future of solar cell technology

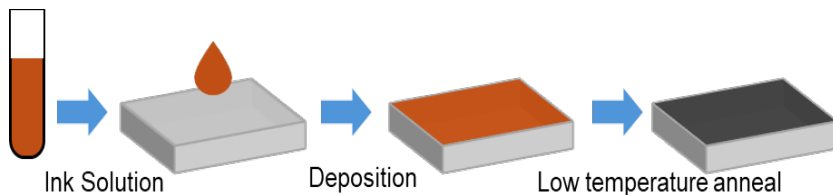
Perovskites are
thin film solar cells

Applications of Perovskite Materials



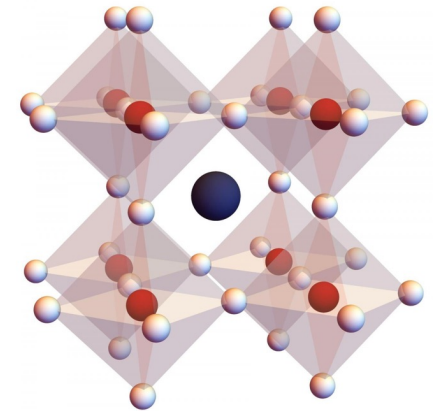
Exciting Newcomer (?): Perovskite Solar Cells

- Organic-metal halide perovskites
- Perovskites named after Russian mineralogist [L. A. Perovski](#)
- Not used for solar until 2009
 - Rocketed from 3% to 26% in 2024
- Chemical formula:
 - ABX_3
- Simple solution processing
- Low temperature process

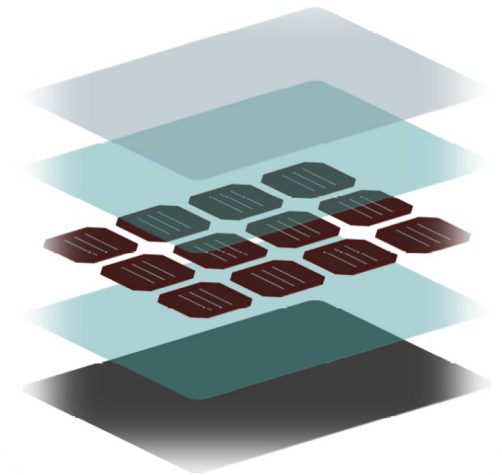


Progress on Perovskite Solar Cells

- The Performance of Perovskite Solar Cells improved to 23.26%
- Scaling up perovskite solar cells through support from National Science Foundation SBIR/STTR grant
- A spinoff is established for perovskite commercialization



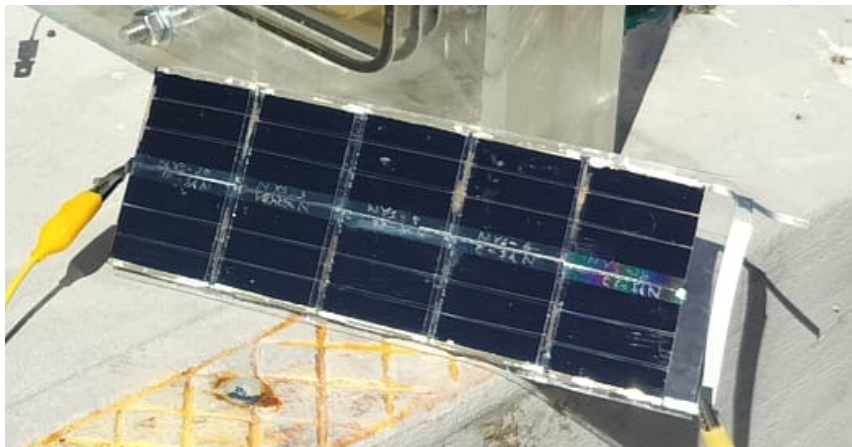
Perovskite Structure



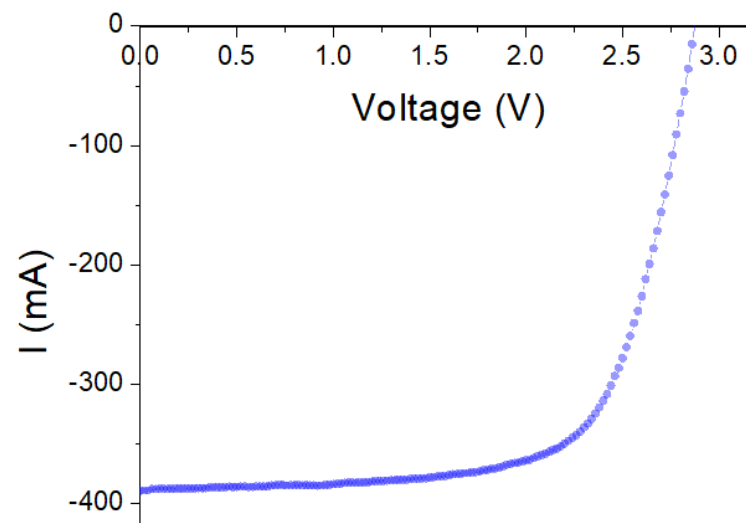
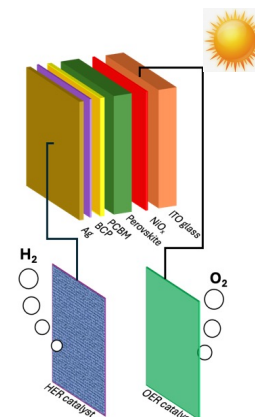
Pinwheel Solar Cell Structure

Perovskite Solar Cell Powered Hydrogen Production Using Low-Cost Catalysts

Perovskite minimodule with 10 PV devices in parallel

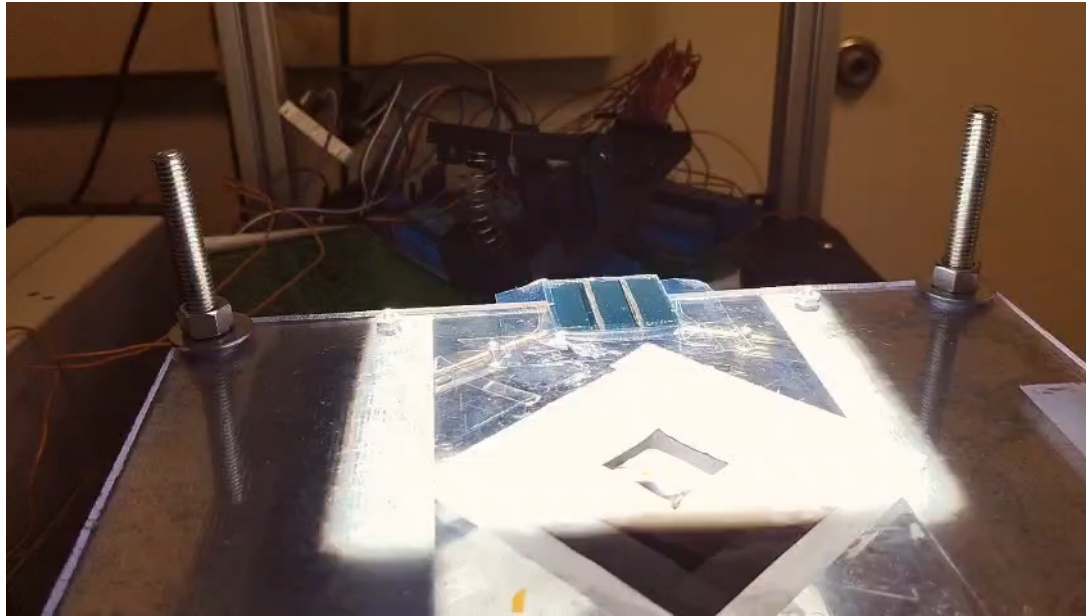


This minimodule has been employed to water splitting for hydrogen production

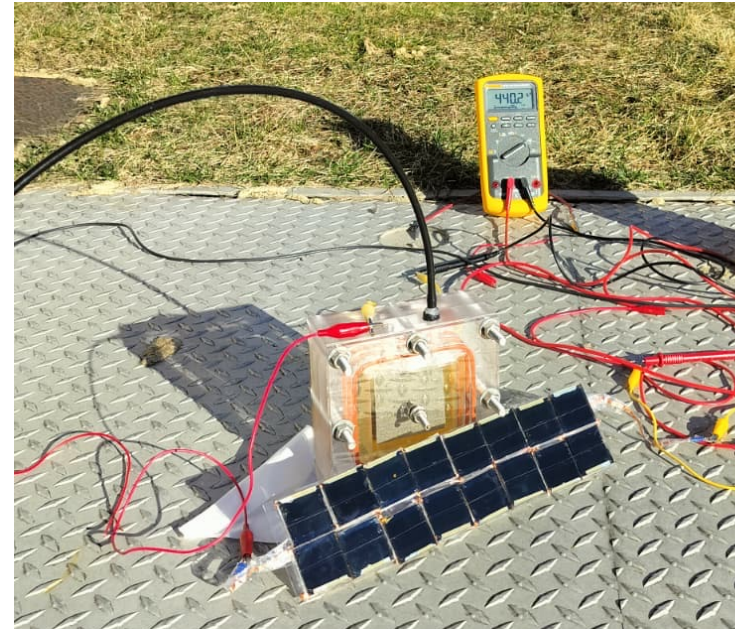


Isc (mA)	389.18
Voc (V)	2.87
Fill factor	0.69
Efficiency (%)	17.12%

Application of Perovskite Solar Cells for Water Splitting



Video demonstration of water splitting
using perovskite solar cells



Water splitting using PSCs: Outdoor
demonstration

Perovskite for Space

The Orbital Arenas: Solar Challenges

Orbit Type	Altitude / Lifespan	Unique Space Challenge	Ideal Cell Choice
LEO (Low Earth Orbit)	160 – 2,000 km (~5-7 Years)	Massive thermal swings (90-min cycles), Atomic Oxygen	Silicon (low cost) or Perovskites
MEO (Medium Earth Orbit)	2,000 – 35,000 km (~10 Years)	Passing directly through intense Van Allen Belts	Radiation-hardened III-V
GEO (Geostationary Orbit)	~35,786 km (15-20+ Years)	Extreme long life needed, cosmic rays, solar storms	Ultra-high-efficiency III-V

Perovskite's armor: Self-healing properties

Silicon's weakness:

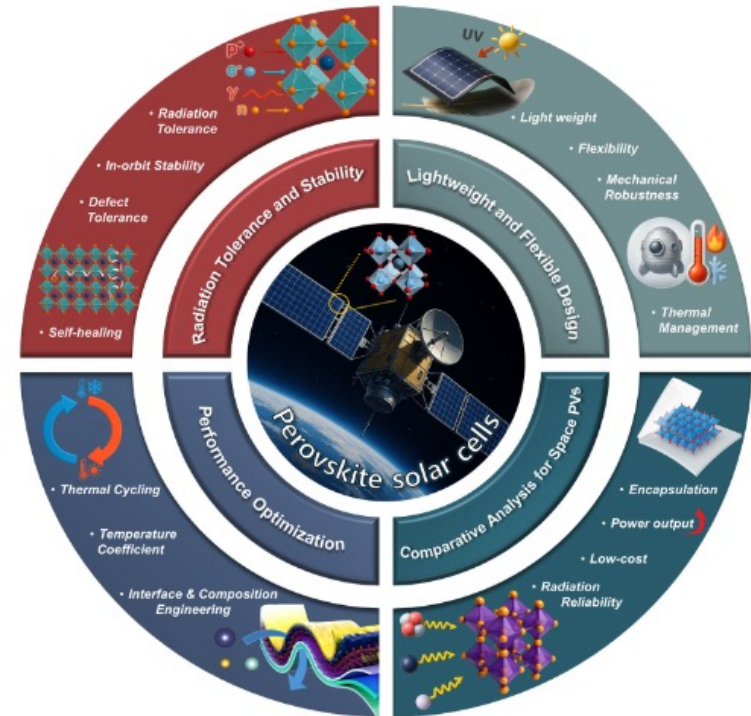
- When high-energy cosmic radiation hits a traditional silicon panel, it permanently breaks its crystalline order. Over time, the panels lose power, slowly "dying" in orbit.

Perovskite's Secret

- Because of their soft, organic molecular structure, perovskites have a superpower: Self-healing. The atoms can dynamically shift back into their perfect crystalline order after being disrupted.

Weight is Everything

- Getting heavy payloads into space is incredibly expensive. Every gram counts when you're launching a rocket!
- Perovskite solar films can produce up to **30 watts of power per gram**, compared to just **2 watts** for traditional silicon space arrays.



Perovskite's Radiation Exposure Resistance

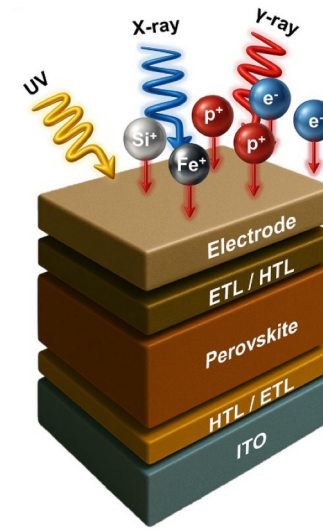
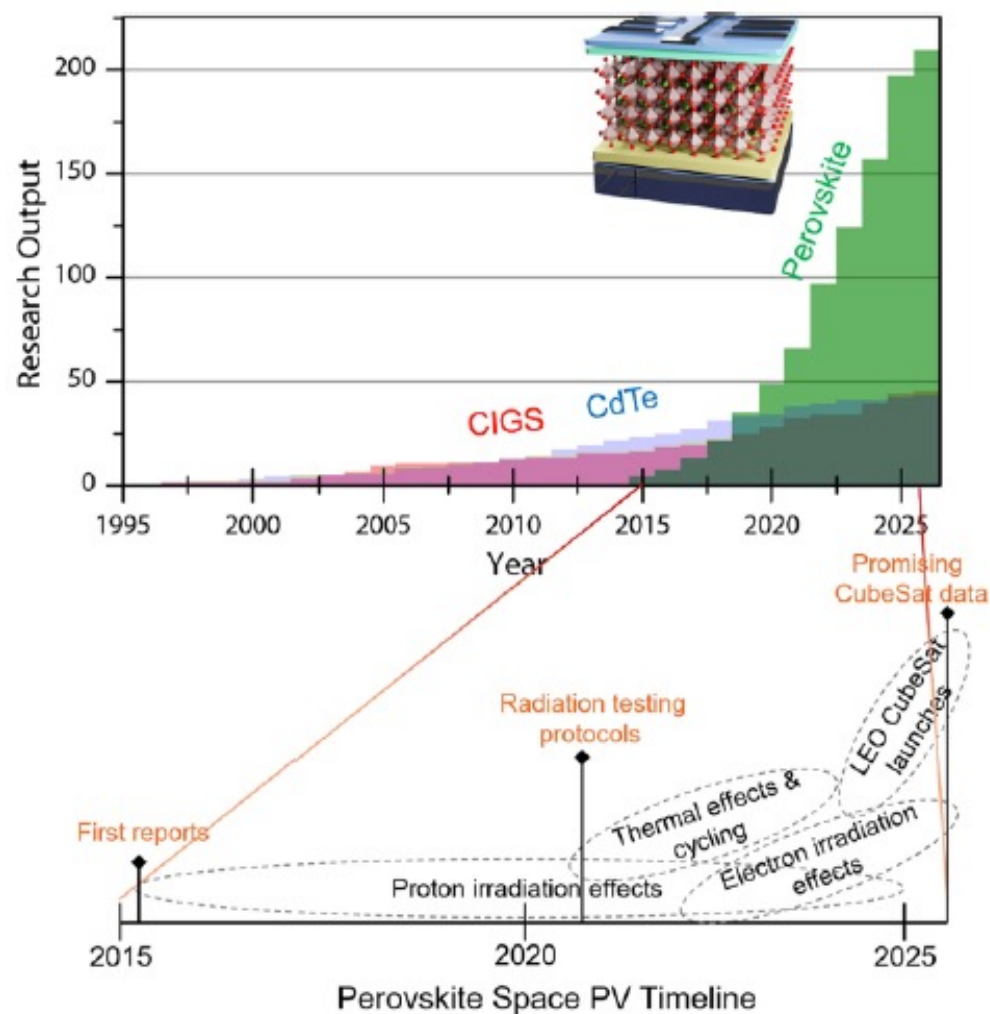


Table 1. Quantitative comparison of photovoltaic (PV) technologies for space applications

PV technology	Initial efficiency (%)	Specific power (W g ⁻¹)	Radiation tolerance	10-year performance retention ¹	Manufacturing cost (USD W ⁻¹)	TRL ^[186] ²
c-Si	22-27 ^[167]	0.1-0.4 ^[158]	Low (severe degradation > 10 ¹² p cm ⁻²) ^[23]	70%-85% ^[157]	0.2-0.4 ^[174]	9
III-V (GaAs, multi-junction)	30-39 ^[168]	0.3-1.5 ^[57]	Medium (significant degradation > 10 ¹³ p cm ⁻²) ^[155]	80%-90% ^[157]	150-1,000 ^[173]	9
Perovskite	25-27 ^[166] ; 34.8 ^[14] (tandem)	2-50 ^[159]	High (tolerant up to ~10 ¹⁶ p cm ⁻²) ^[28]	Unvalidated	< 0.1 (target) ^[176]	4, 5

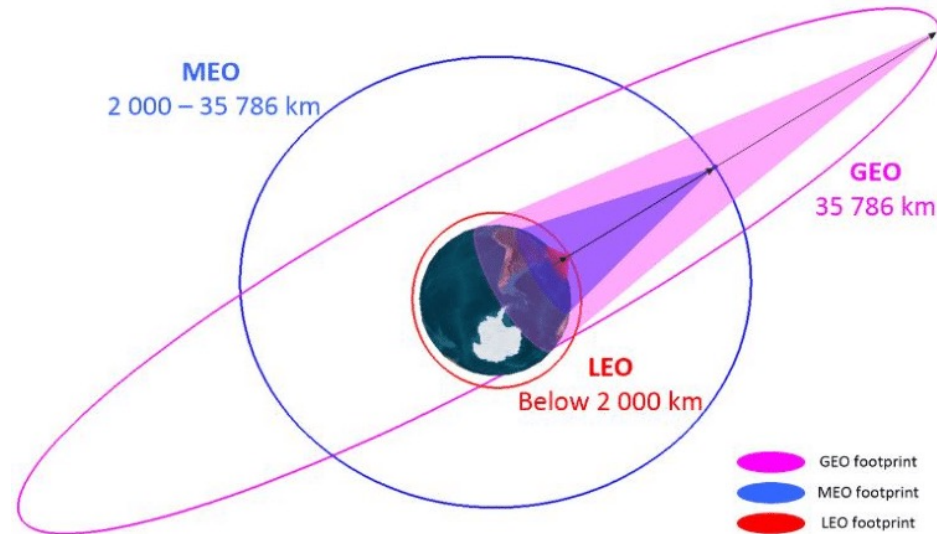
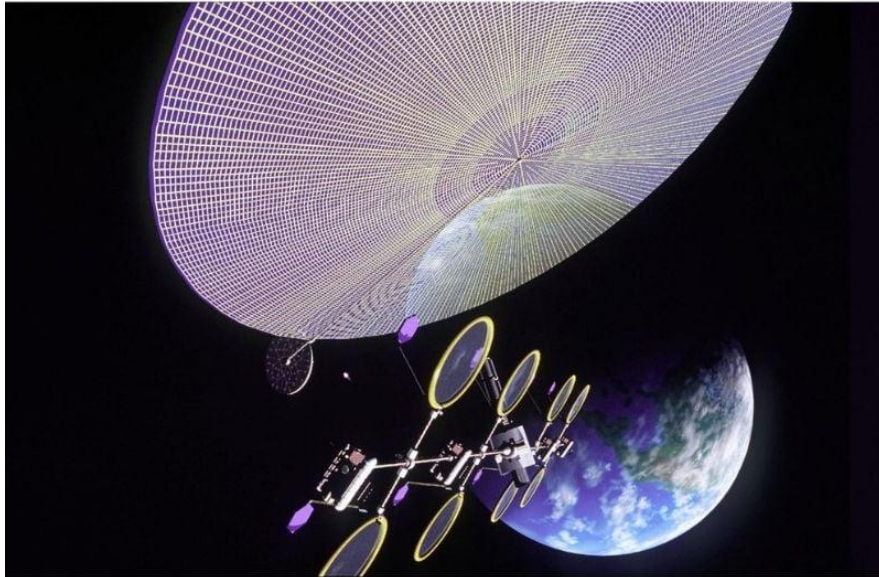
¹Representative in-orbit performance retention values from satellite telemetry; ²Technology Readiness Level (4: component or breadboard validation in laboratory environment, 5: component or breadboard validation in relevant environment, 9: actual system “flight prove” through successful mission operations).

Perovskites (green) space PV research over time



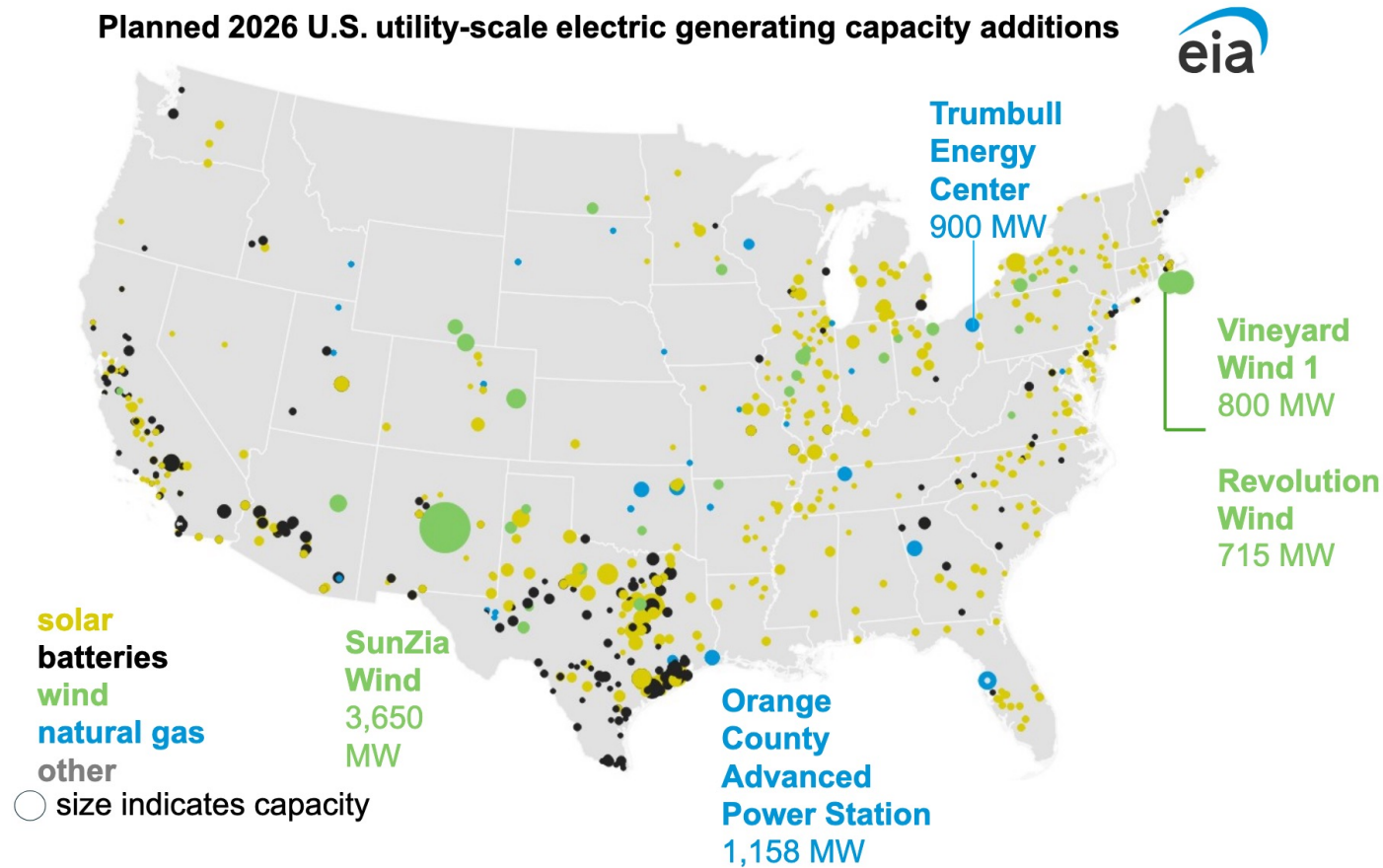
Could perovskite solar cells power the entire Earth from Orbit?

A solar panel in geostationary earth orbit (GEO) receives sunlight uninterrupted day and night



- Human civilization uses about 20 TW of average power
- A future perovskite-based solar blanket with 30% efficiency and 200 g/m² mass
- Ultralight perovskite or tandem perovskite arrays powering satellites, lunar bases, and eventually space-based solar power stations.
- **Challenge: 20-30 year stability** under UV radiation, charged particles, atomic oxygen, and thermal cycling in space.

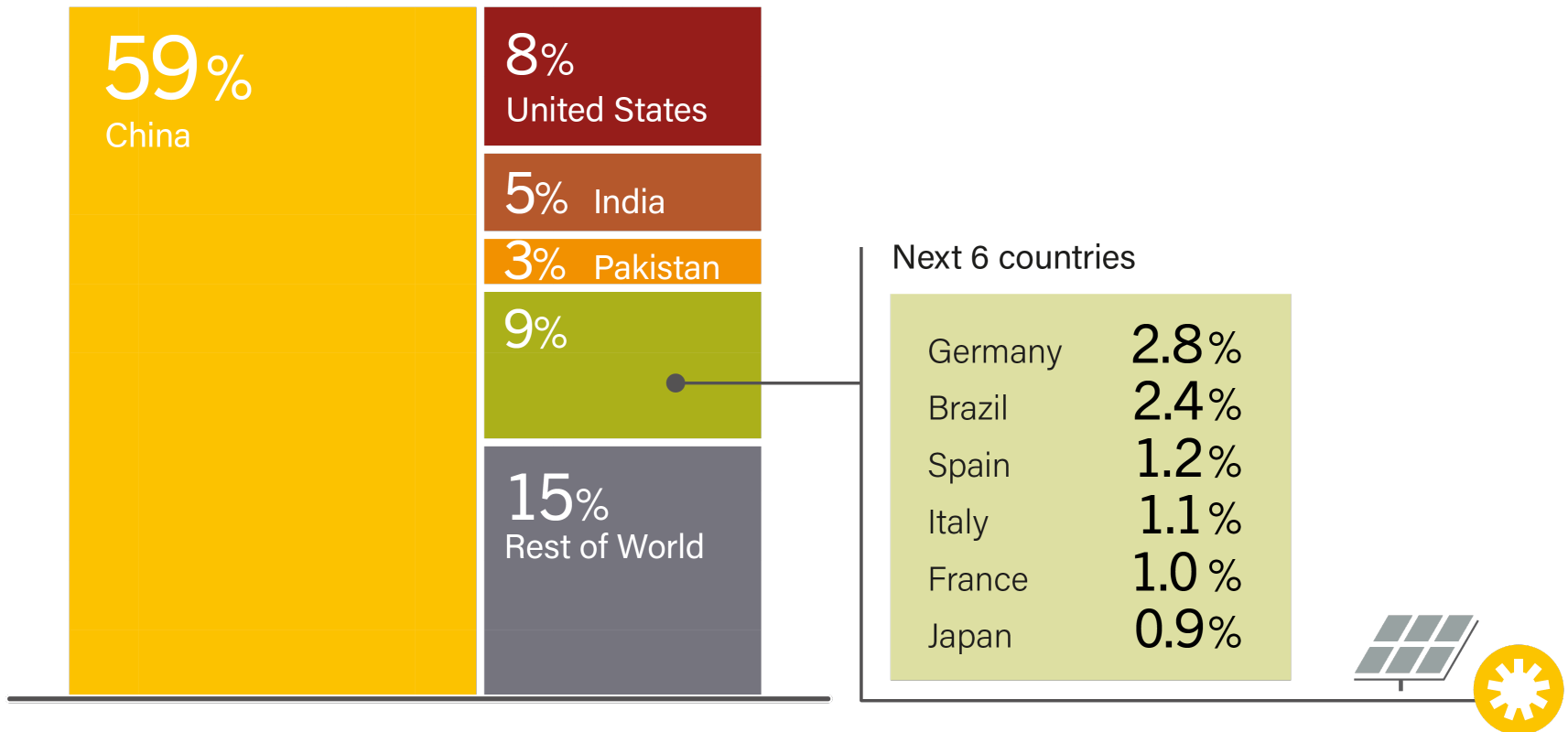
What is the status of Solar PV module installation in the US and Worldwide?



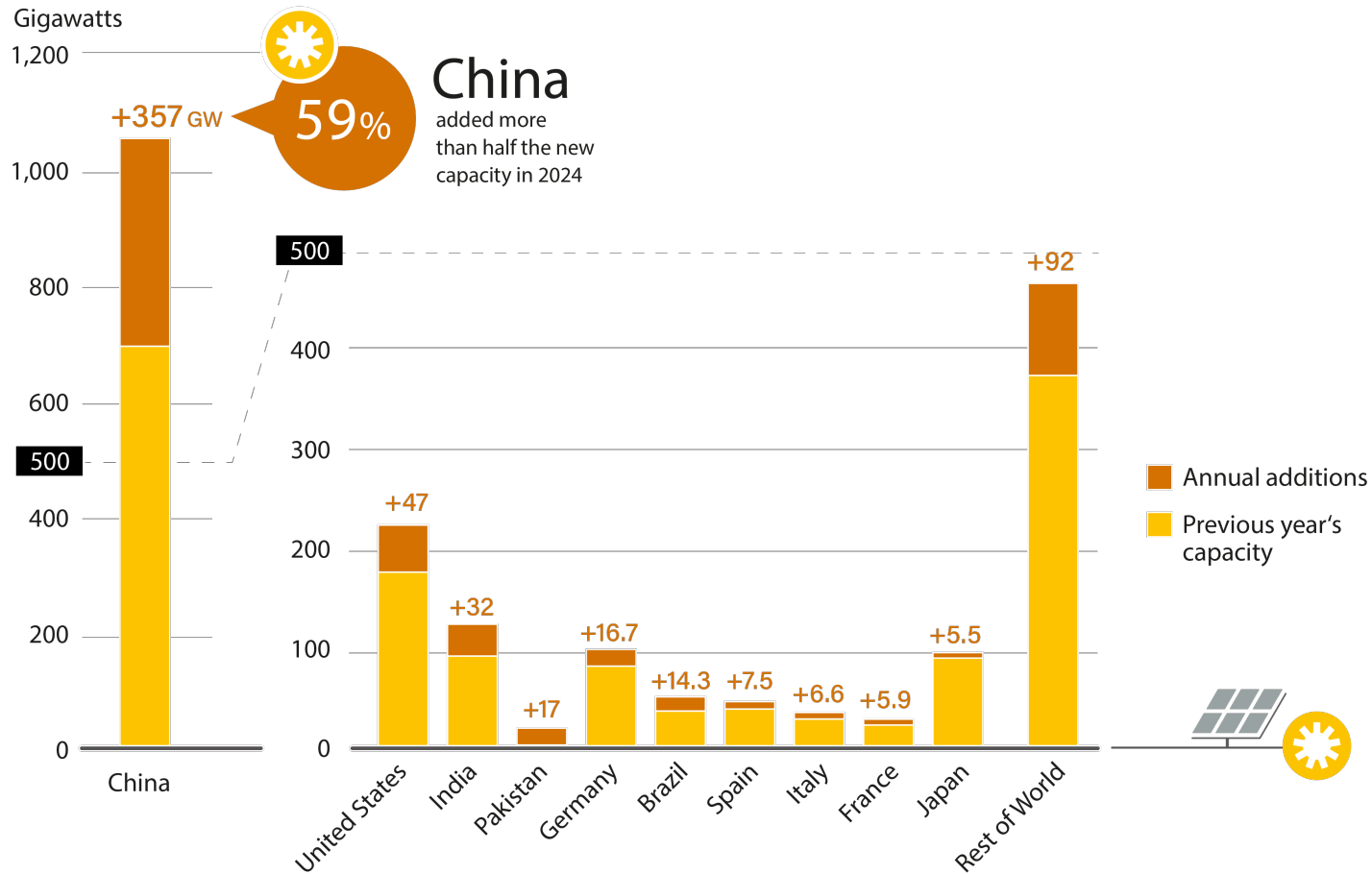
Data source: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*, December 2025
Note: MW=megawatts

Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2024

Solar PV Global Additions 2024: **602 GW**

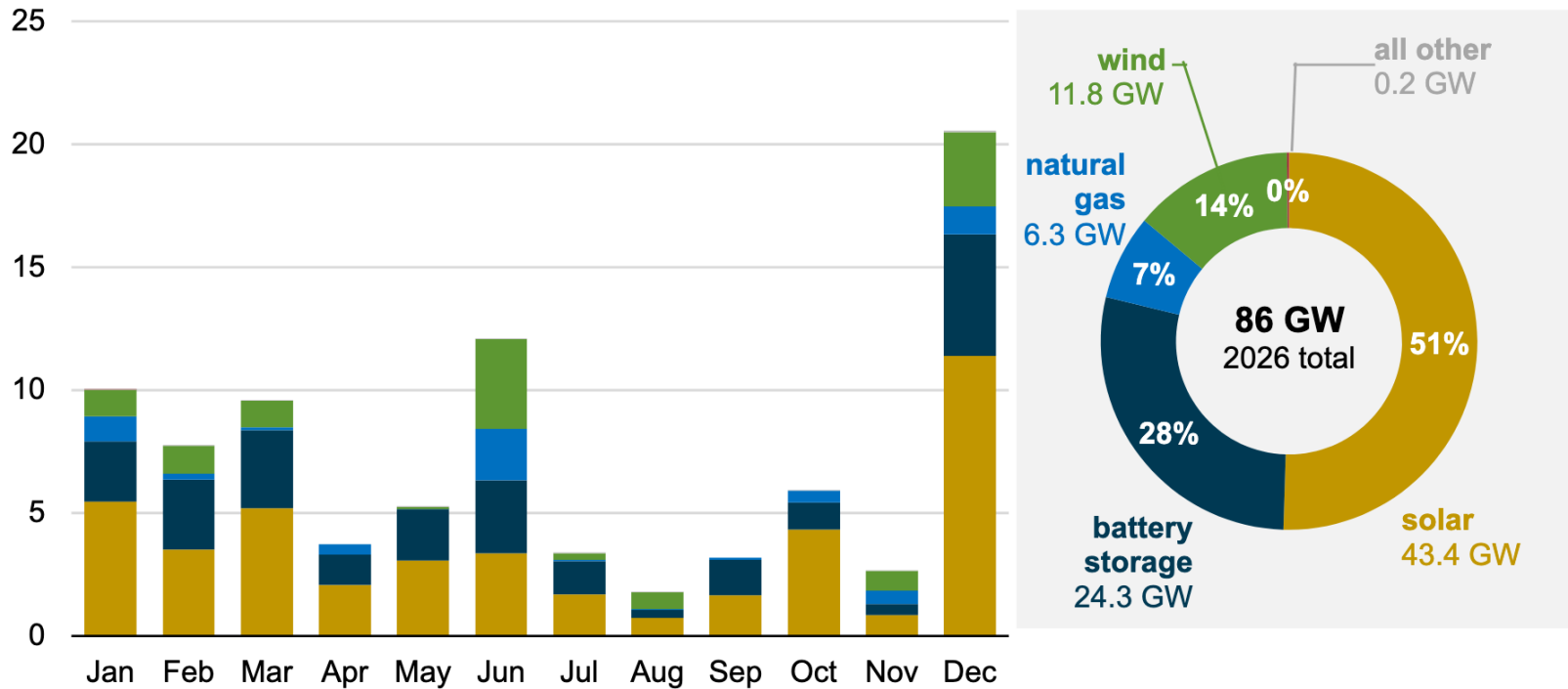


Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2024



New U.S. electric generating capacity expected to reach a record high in 2026

U.S. planned utility-scale electric generating capacity additions (2026)
gigawatts (GW)



Utility-Scale vs. Rooftop Trends

- **Utility-scale solar PV** installations surged by approximately 380 GW in 2024 – a 43% year-on-year increase – and made up almost two thirds of global solar addition
- **220GW Rooftop solar PV** capacity grew by around 23% in 2024, adding nearly 220 GW globally – with major growth in Germany, Brazil, India and Pakistan.



Solar manufacturing jobs

- ❖ By end-2023, the global solar PV sector employed an estimated **7.2 million** people, with China accounting for nearly two-thirds of these jobs.
- ❖ In the United States, employment in solar PV reached approximately **280,000**, with the manufacturing segment gaining momentum due to the Inflation Reduction Act (IRA)

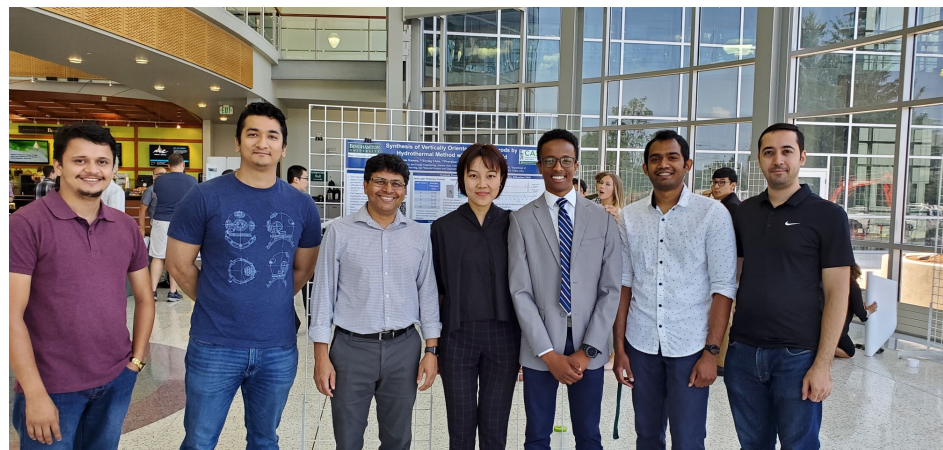


Dhakal Research Group



Contact: Tara P Dhakal
E-mail: tdhakal@binghamton.edu

<https://www.binghamton.edu/casp/>
<https://www.binghamton.edu/electrical-computer-engineering/people/profile.html?id=tdhakal>



Stand-Alone Solar Tracking System

Solar for Community

Solar and battery integrated system



System Features

- Tracks the Sun (40-50% more) power than south facing panels
- Electricity stored in the batteries
- Inverter used: 3 Outlets for charging phone and laptops
- Good to be installed in schools and colleges for power and education
- Electric stove

Acknowledgments



Thank you for listening 🙏