Solar Cell Technologies – Advanced Concepts in Photovoltaics

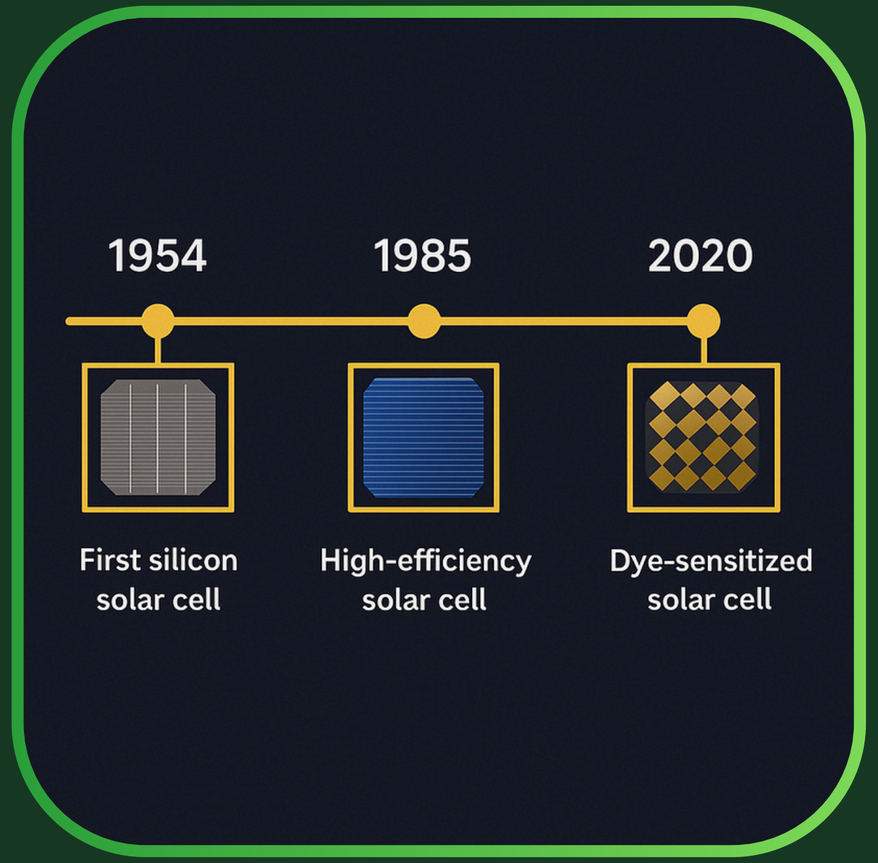
WEEK 2, DAY 1 ›››››

Objectives of the Session

- Understand the evolution and classifications of solar cell technologies.
- Examine material types: Crystalline Silicon, Thin-Film, III–V, Perovskite, Organic, Hybrid.
- Compare performance metrics: Efficiency, Cost, Maturity, Flexibility.
- Explore commercial adoption trends and future prospects.

A Short History of Solar Cells

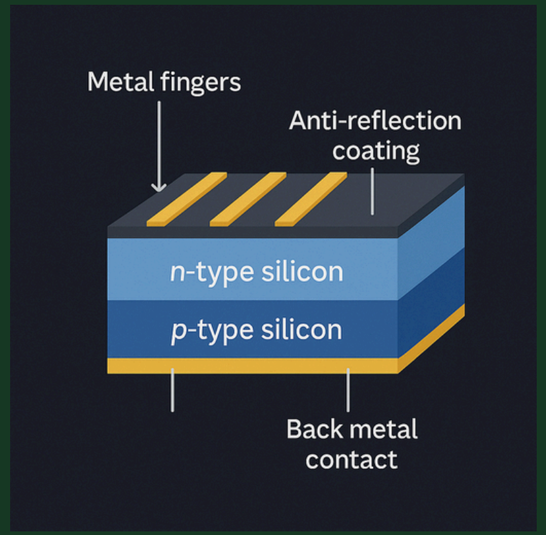
- 1839: Edmond Becquerel discovers the photovoltaic effect in a wet cell.
- 1954: Bell Labs develops the first practical silicon solar cell (~6% efficiency).
- 1970s–1990s: Commercialization of crystalline silicon modules; efficiencies reach ~15%.
- 2000s: Emergence of thin-film CdTe and CIGS technologies; efficiencies ~10–12%.
- 2010s–2020s: Rise of perovskite and organic cells; lab efficiencies exceed 25%.



Crystalline Silicon Solar Cells

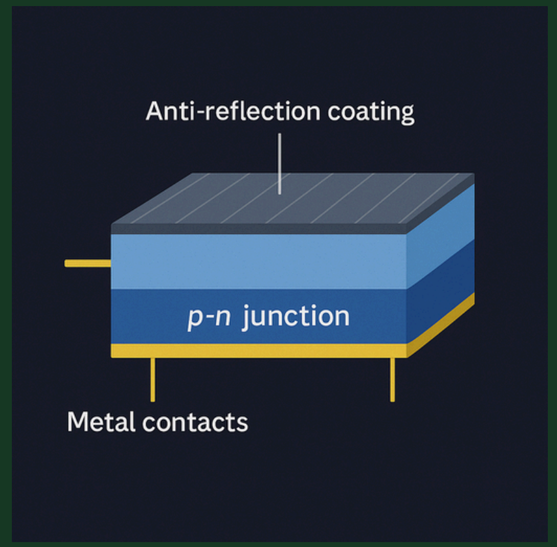
Monocrystalline Silicon

- Single-crystal wafers; uniform appearance.
- Commercial efficiencies: 18–22%.
- Higher cost due to wafer slicing.



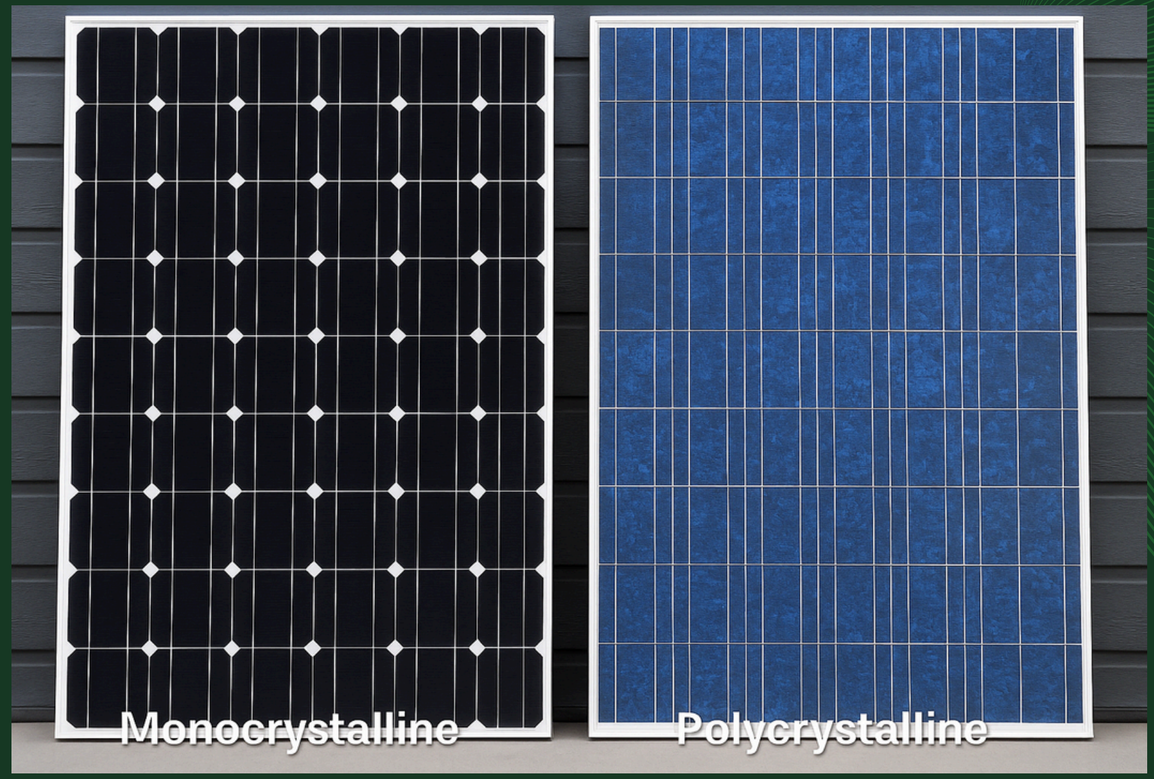
Polycrystalline Silicon

- Multiple crystal grains; grain boundaries.
- Efficiencies: 15–18%.
- Lower manufacturing cost.



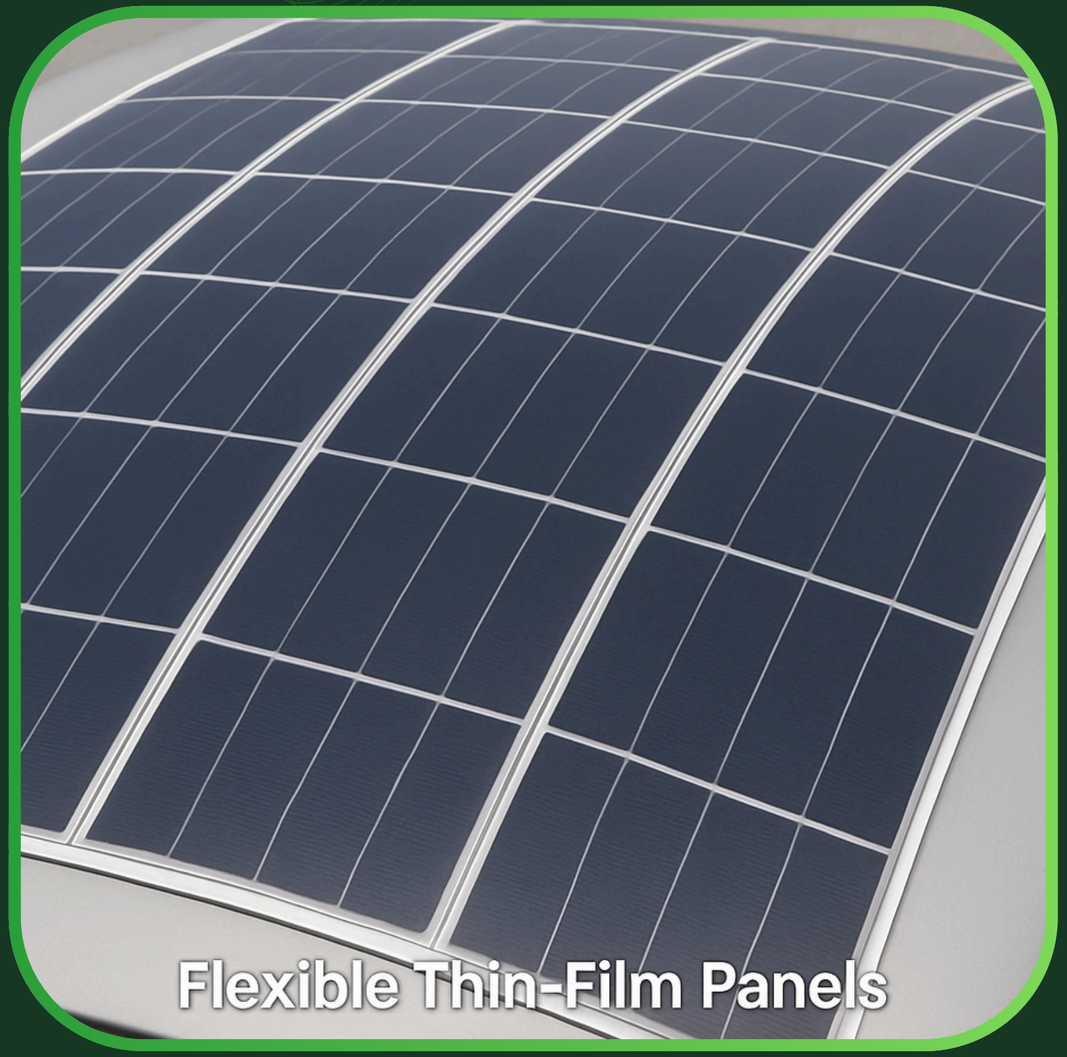
Mono-Si vs. Poly-Si Comparison

- Efficiency: Mono-Si ~22% lab, Poly-Si ~18% lab.
- Manufacturing Cost: Mono-Si higher due to precise crystal growth; Poly-Si less expensive.
- Appearance: Mono-Si smooth black; Poly-Si bluish with visible grains.
- Applications: Mono-Si for rooftop/residential; Poly-Si for utility-scale.
- Lifespan & Degradation: Both offer ~25–30 years; mono-Si slightly better performance retention.



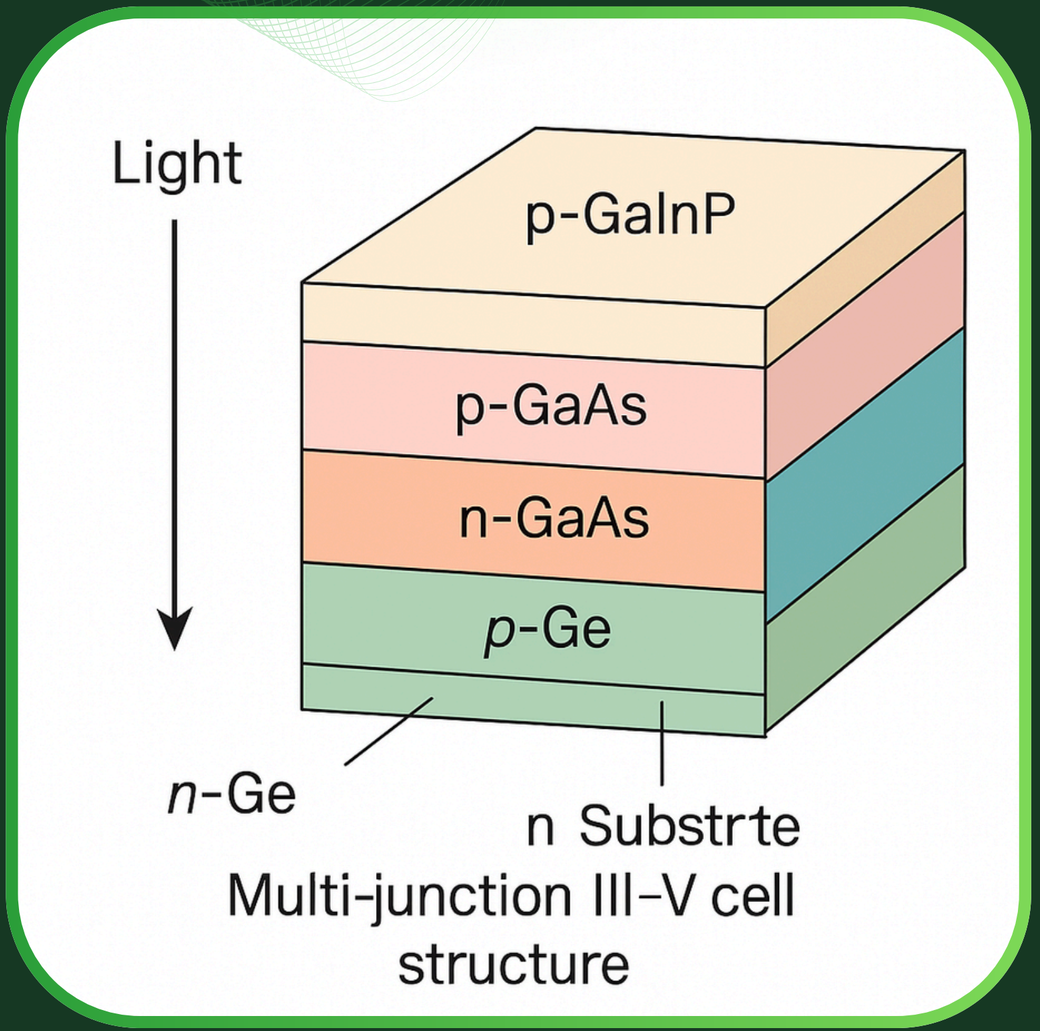
Thin-Film Technologies

- Cadmium Telluride (CdTe) : Low cost, moderate efficiency (10–16%), concerns over cadmium toxicity.
- CIGS (Cu–In–Ga–Se) : Efficiencies up to 20%; flexible substrates; complex manufacturing.
- Amorphous Silicon (a-Si) : Low efficiency (~8–10%), used in small electronics.
- Advantages : Lightweight, flexible, low-temperature processing.
- Drawbacks : Lower commercial efficiencies, potential environmental issues.



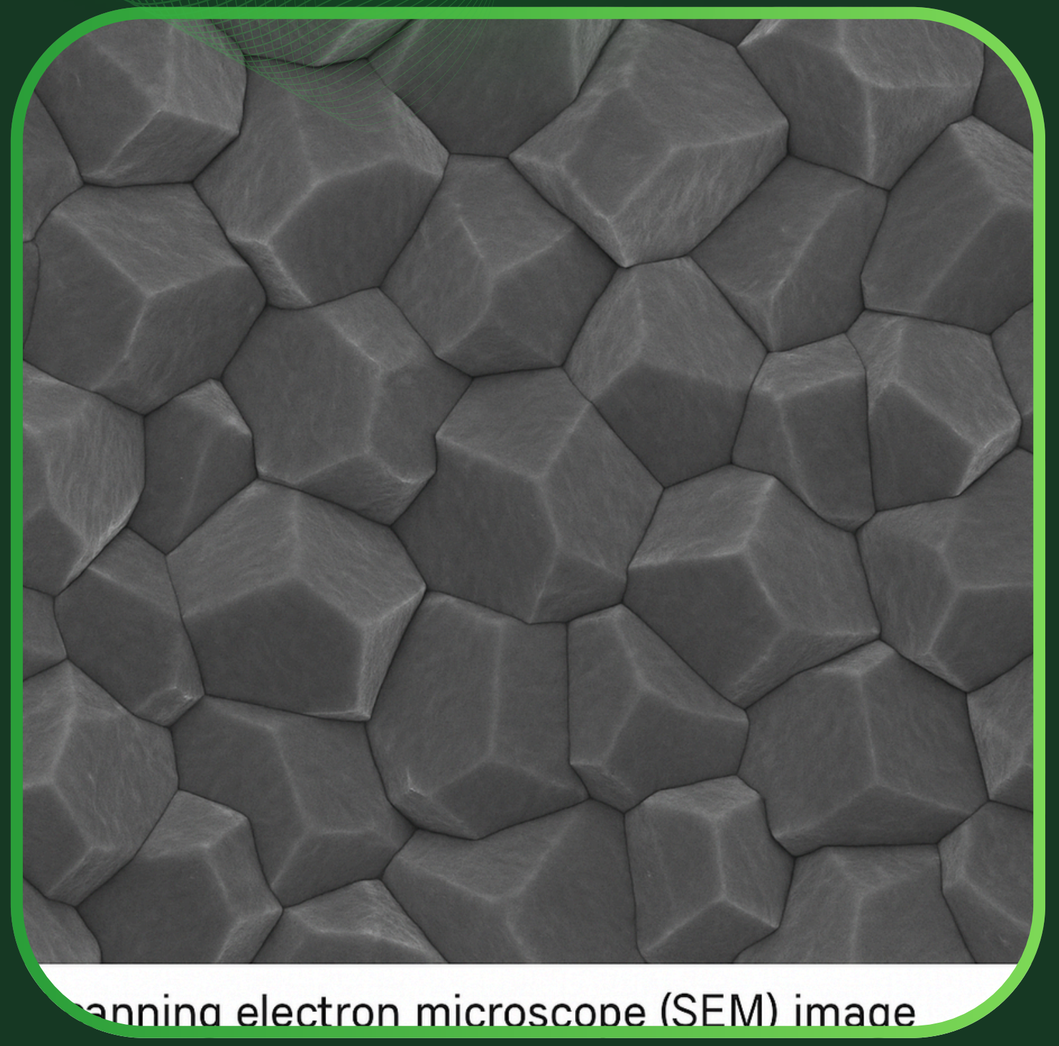
III–V Solar Cells

- Composed of group III and V semiconductors (e.g., GaAs, InP).
- Achieve >40% efficiency under concentrated sunlight in lab.
- Extremely high cost,used primarily in space and concentrator photovoltaics.
- Excellent radiation tolerance, stable performance in harsh environments.
- Research focus are multi junction stacks to capture broader spectrum.



Perovskite Solar Cells

- Organic–inorganic halide perovskites (e.g., MAPbI3) rapidly improved from ~3% to >25% efficiency (2012–2024).
- Benefits: Low-cost solution processing, tunable bandgaps, semi-transparency.
- Challenges: Long-term stability, lead toxicity, encapsulation techniques.
- Application potential: Tandem cells with silicon, flexible devices.


anning electron microscope (SEM) image

Organic & Hybrid Solar Cells

- Organic Photovoltaics : Carbon-based polymers/acceptors, flexible, printable, efficiencies (~10–15%.)
- Hybrid Cells : Combine organic layers with inorganic nanoparticles or perovskites, aim to improve charge transport.
- Advantages: Lightweight, low cost manufacturing, mechanical flexibility.
- Limitations: Faster degradation, lower efficiencies than inorganic cells.

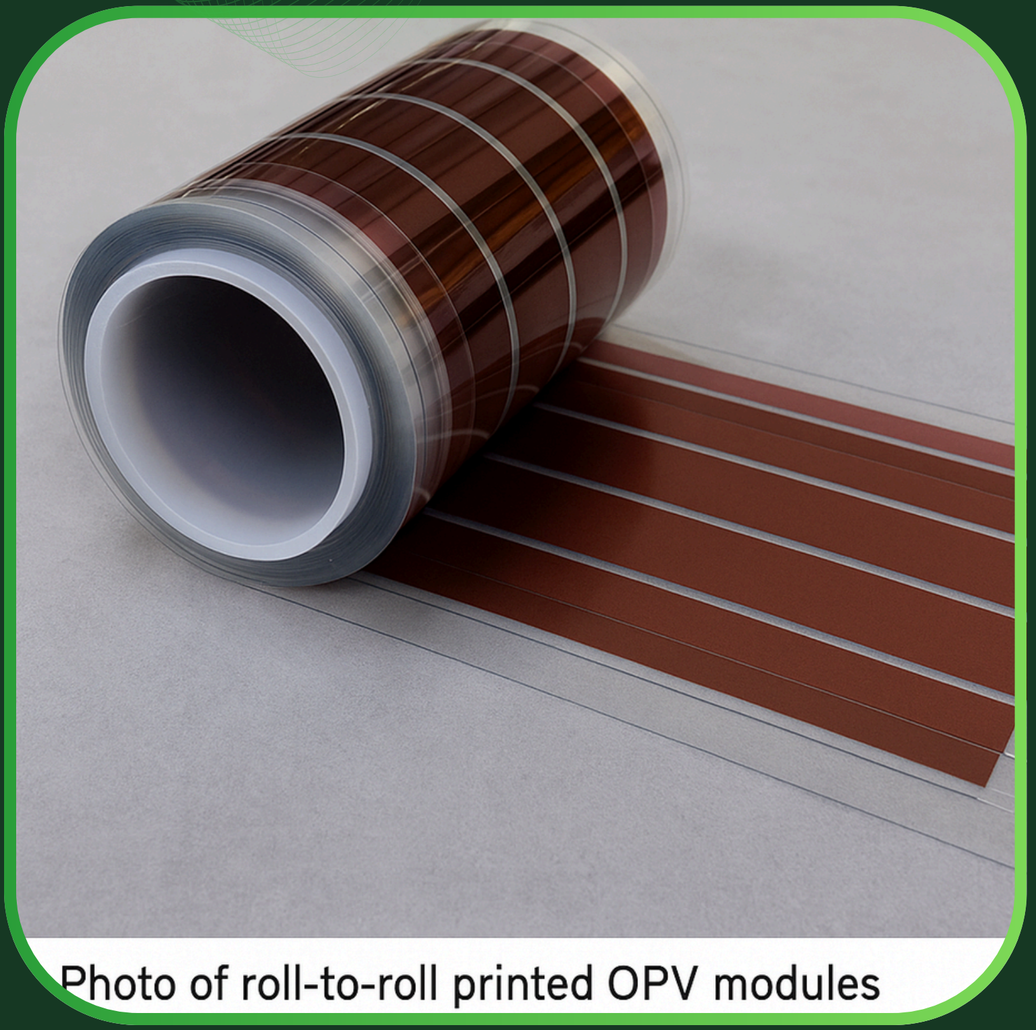


Photo of roll-to-roll printed OPV modules

Technology Comparison

Efficiency Range

Mono-Si (18–22%), Poly-Si (15–18%), CdTe (10–16%), CIGS (12–20%), Perovskite (>25%), OPV (10–15%), III–V (>40%).

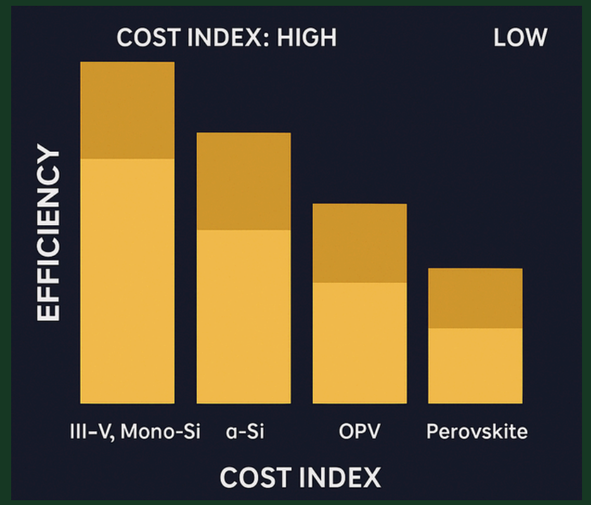
Maturity

Mature (Si, CdTe), Emerging (CIGS, Perovskite), Research (OPV, Hybrid).

Flexibility

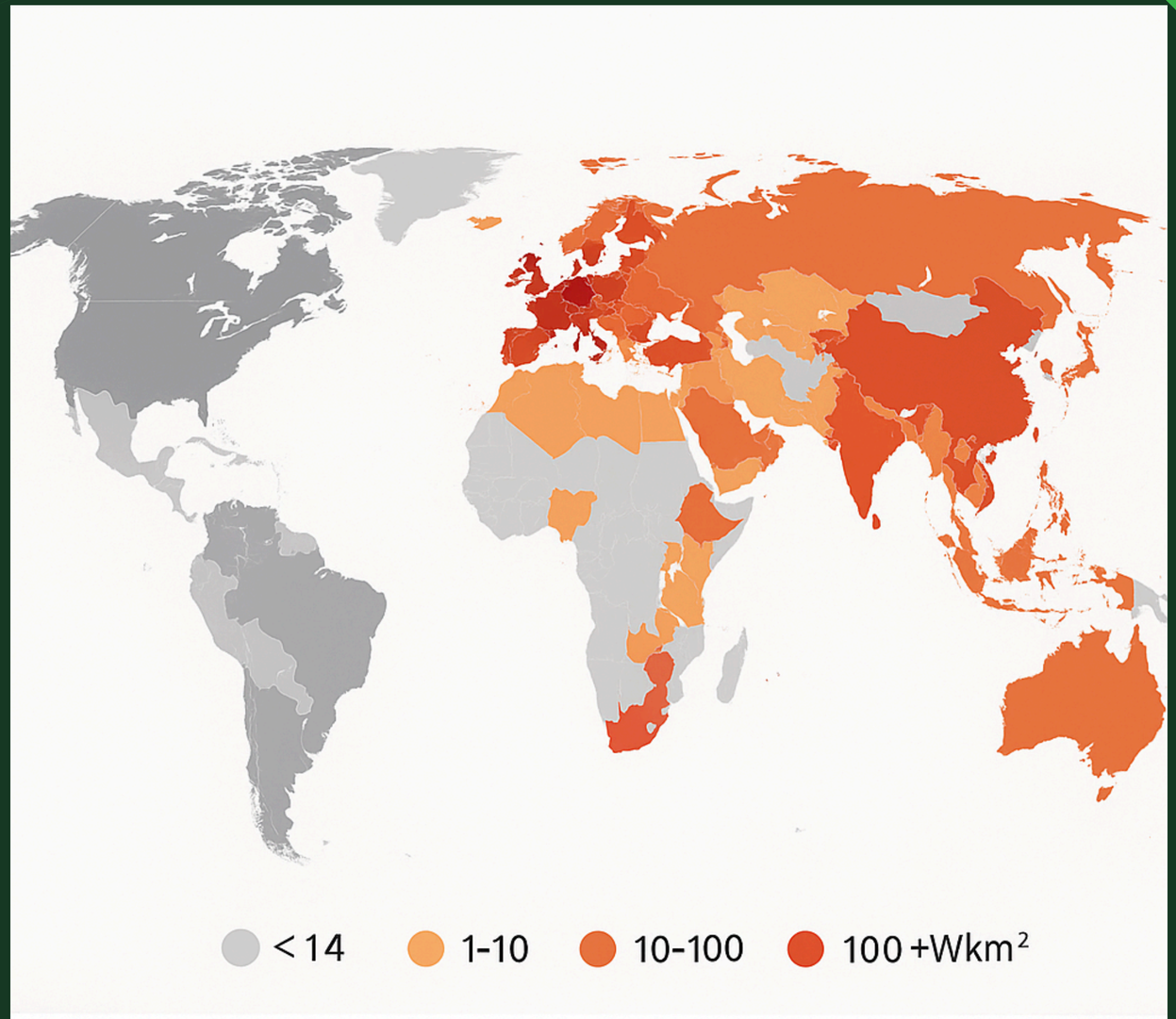
Rigid (Si, III–V), Flexible (Thin-film, OPV, Perovskite).

Cost Index



Commercial Adoption & Trends

- Market Share: Crystalline Si >90% of global installations (2024).
- Thin-film ~10% in specialized markets (BIPV, portable electronics).
- Perovskite tandems entering pilot production (2023–2025).
- Future focus: Bifacial modules, building-integrated PV, tandem architectures.



World map showing PV installation density

Review Questions :

Q1 : What trends are emerging in commercial solar cell adoption, and which technologies are likely to play a role in the future of photovoltaics?

Q2 : How have solar cell technologies evolved since the discovery of the photovoltaic effect in 1839? Identify at least three key milestones.

Q3 : Why are III–V solar cells not widely used in terrestrial applications despite their high efficiency?

Q4 : How do different material types (e.g., silicon, thin-film, III–V, perovskite, organic) compare in terms of efficiency, cost, and commercial maturity?

got any doubts

regarding the course?

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