SwiftSolar

Unlocking the full potential of solar energy

Role of Modeling in Swift Solar's Process Improvement & Tool Optimization

OzenCon 2026
March 10th, 2026
Mountain View, CA, USA

Reza Nazari, PhD
Staff Mechanical Engineer
Swift Solar

reza.nazari@swiftsolar.com

> Swift Solar Named One of the Top GreenTech Companies

> Swift Solar Overview

- **Founded 2017 as 3-way spinout from Stanford, MIT, NREL with exclusive IP rights**
- **~50 team members in San Carlos, CA**
- **Aim: produce high-efficiency cells and modules in US at GW scale. Raising the efficiency limit from 30-45%**
- **US pioneer in perovskite tandem PV technology**
- **Current status**
  - Raised >$50M in private capital
  - Prototyping and field testing
  - Scaling to first commercial production line ~2 years
  - Raising capital for first production line in the US

> Founded by the World's Top Perovskite Scientists

6 PhDs from MIT, Stanford, and Oxford

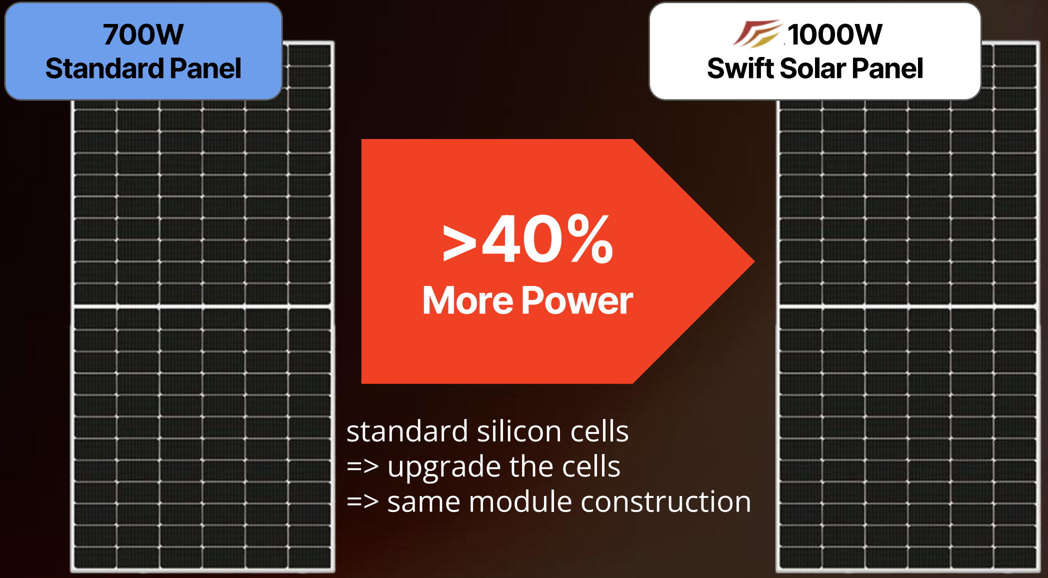
4 Forbes Under 30, 3 Top 1% Scientists, 2 NREL Scientists, R&D 100 Award

40 Patents, 300 Research Publications, 200,000 Citations (and counting)

1st Planar Perovskite Solar Cell, 1st Perovskite-Si Tandem, 1st All-Perovskite Tandem

Slide from Tobias Abzieher

> Swift Solar improves solar project economics



Better Product

- Similar form factor
- Higher energy density
- **Allows for Less:**
  land area, labor, racking, wire, O&M

Improved Project Economics

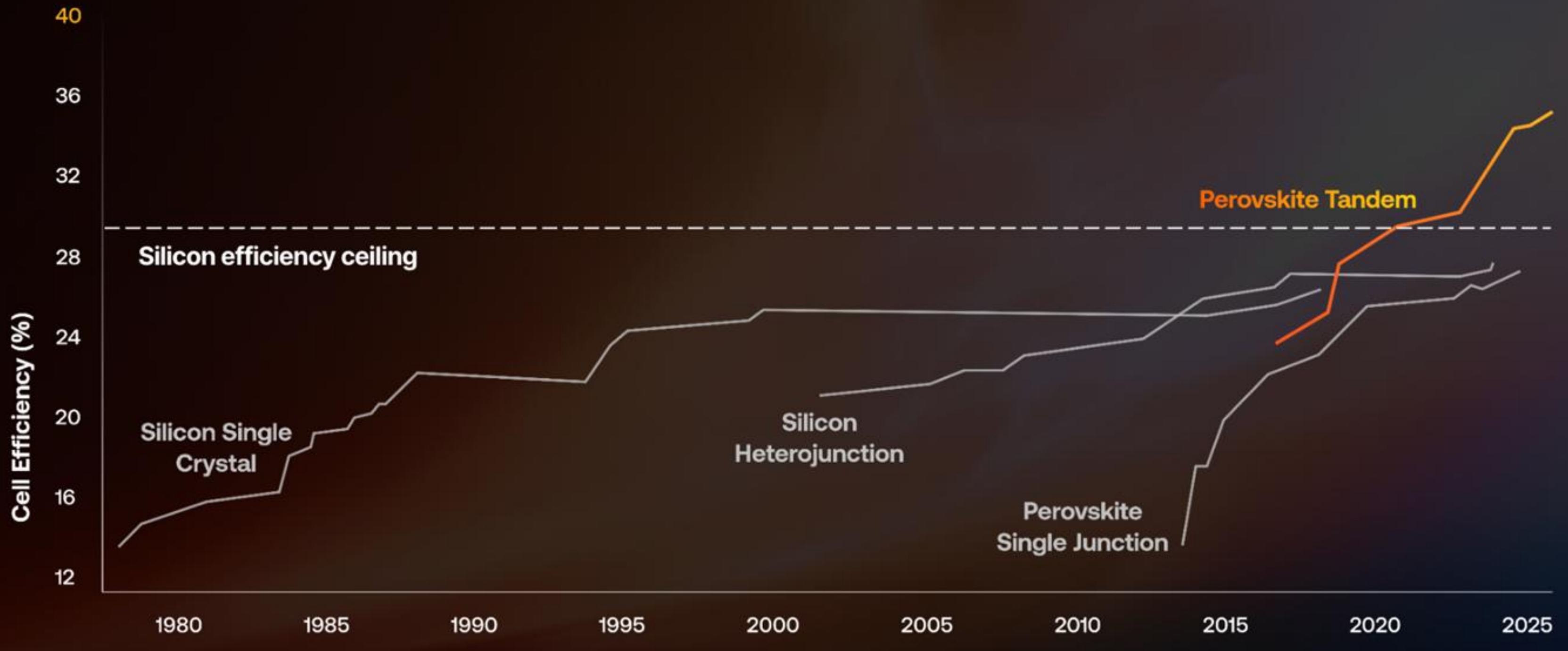
- Higher IRR (Internal Rate of Return) (2% increase from 5-8% baseline)
- Lower up-front system cost (13-20%)
- Lower O&M (Operations and Maintenance) costs (20-30%)
- Land optionality

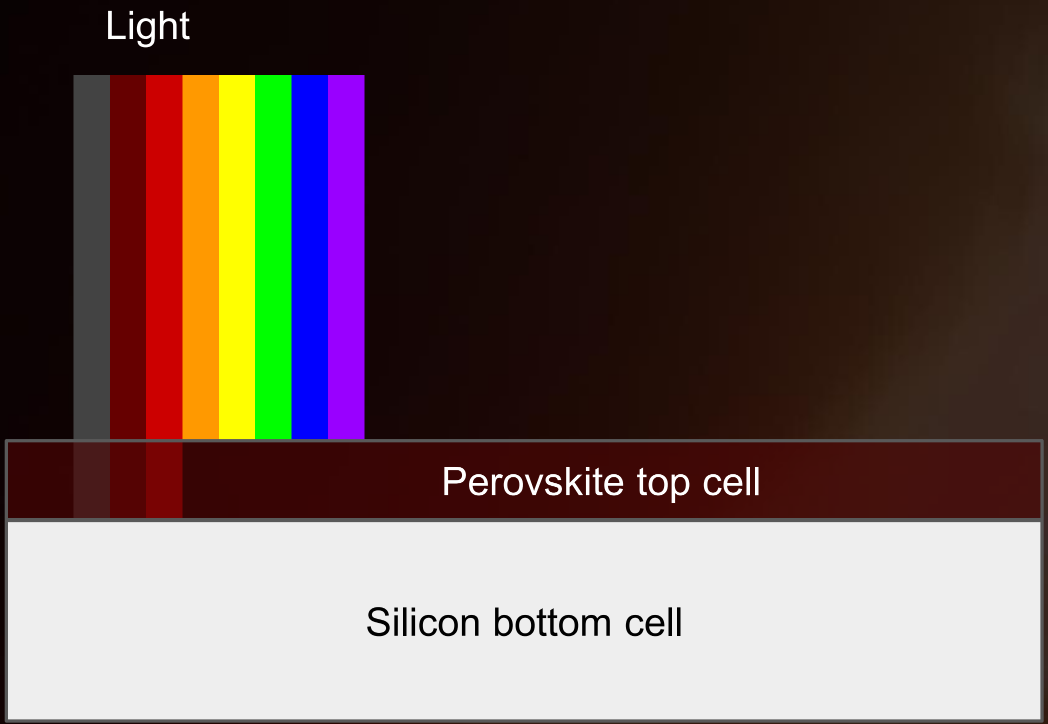
Each 5% increase in power

=> over $10B in US utility scale project value / yr

> Tandems are the best solar

Perovskite tandems are the first solar technology **ever** to outperform and undercut silicon



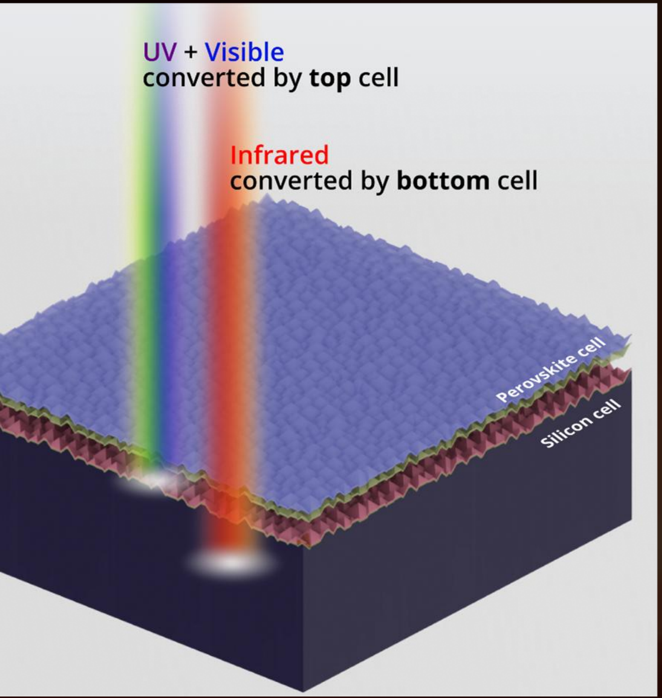


Tandem operating principle

- High energy light absorbed by perovskite (Swift Solar) top cell
- Low energy light absorbed by silicon
- Less energy wasted as heat
- Proven concept in space PV - but perovskite tandem technology is the first to do it at a relevant cost point.

> Unlocking the Full Potential of Solar Energy

The silicon solar cell efficiency is reaching its theoretical limit and modules cannot get much larger.
Swift Solar is addressing these challenges with unique tandem solar cell approaches in the U.S.



Vapor Processing of Perovskite	Monolithic Tandem Solar Cells[1]
mature on an industrial scale	higher system level output (+7%$_{rel}$)
simple scalability	lower TCO demand (- 5 ct W^{-1})
no solvent related hazards	reliability benefits
non-planar surfaces	technology potential
good controllability/reproducibility	market entry benefits

Slide from Tobias Abzieher

Swift Solar is the key to unlocking **4 megatrends**

Energy Dominance

US energy security—and national security—starts with **domestic** solar manufacturing

AI Demand

AI will double data center energy by 2030—only PV can **scale** fast enough

Space Economy

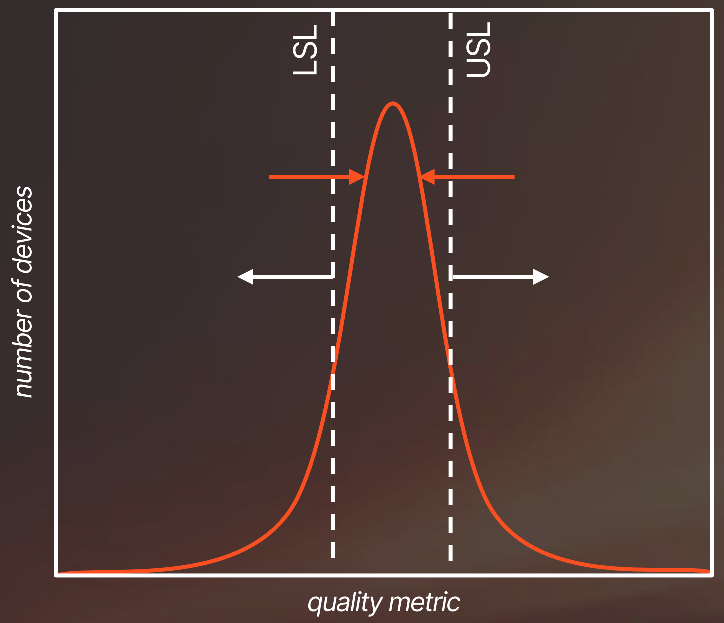
Every next-gen satellite and space mission demands **more efficient**, lightweight, and affordable solar

Climate Change

Decarbonizing the planet will take terawatts of **ultra-low-cost** electricity from solar and other sources

> Key Challenge: Narrow Process Windows

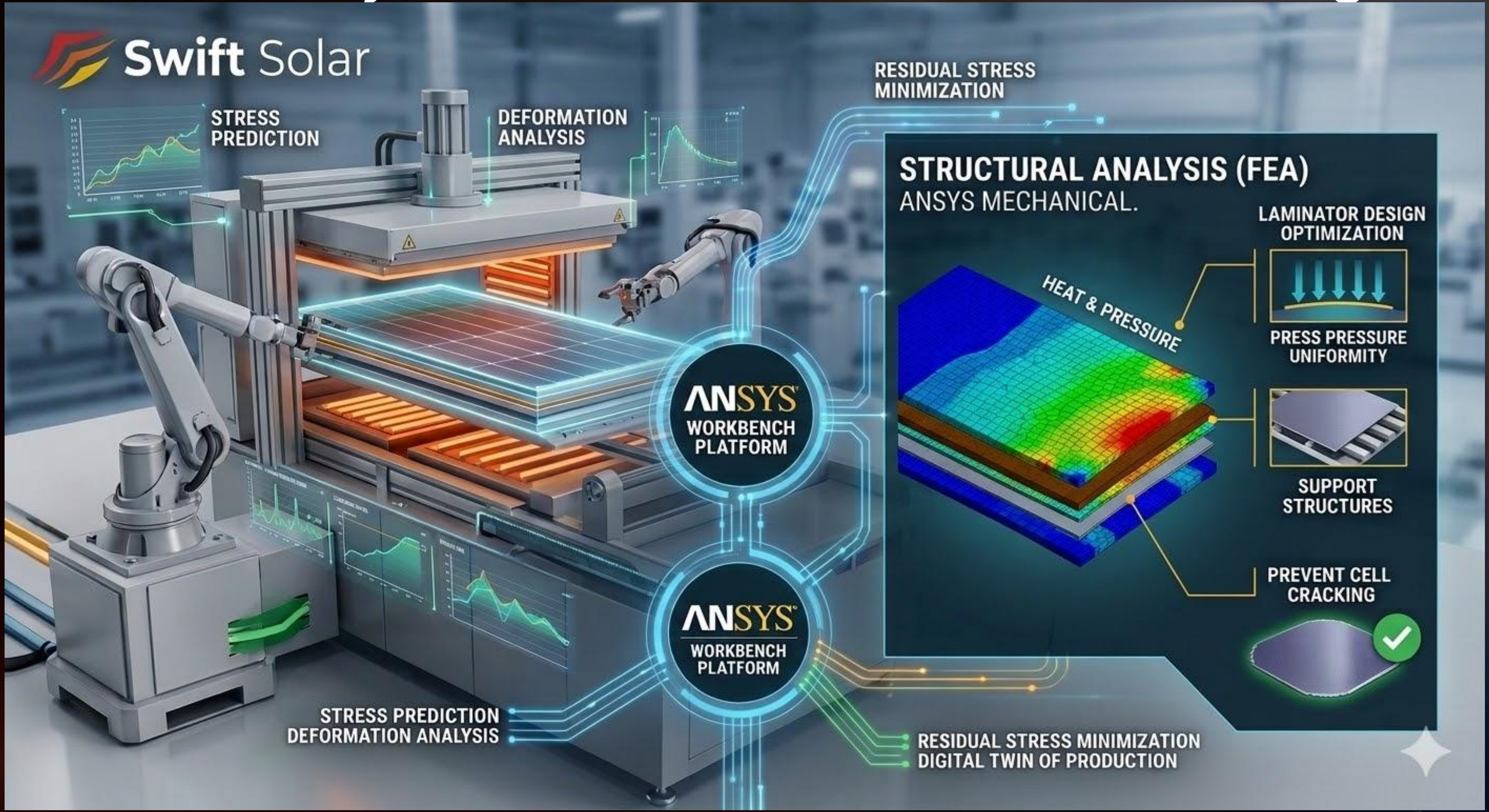
Process window (e.g. compositional window) of vapor processed perovskite absorbers are rather narrow, especially when it comes to operation stability, requiring special attention to process specification and control limits.



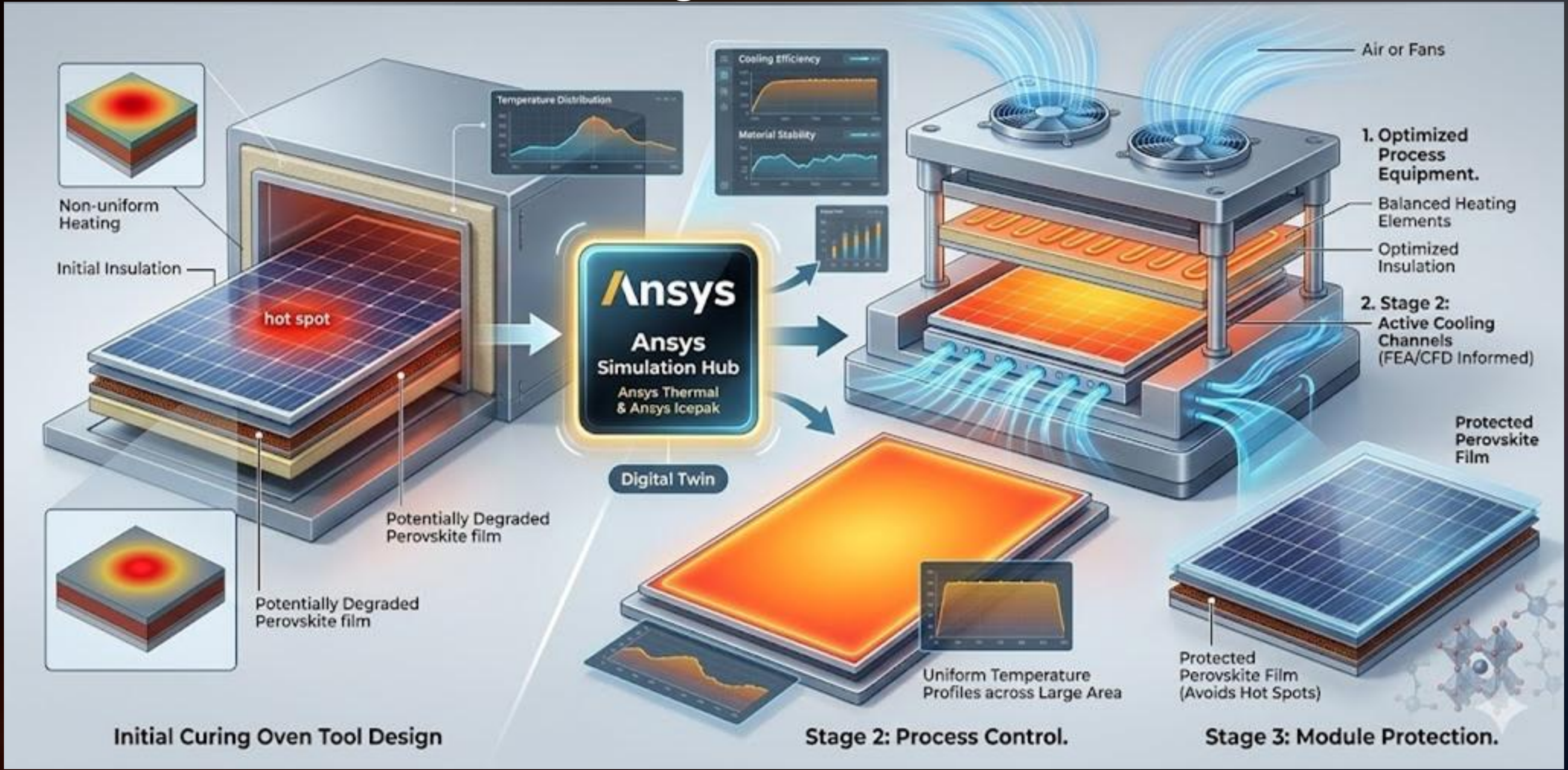
Narrow Control Limits	Widen Specification Limits
source uniformity	composition
deposition consistency	phase purity
monitoring accuracy	film formation route
substrate consistency	additives
deposition drifts	annealing protocol

Slide from Tobias Abzieher

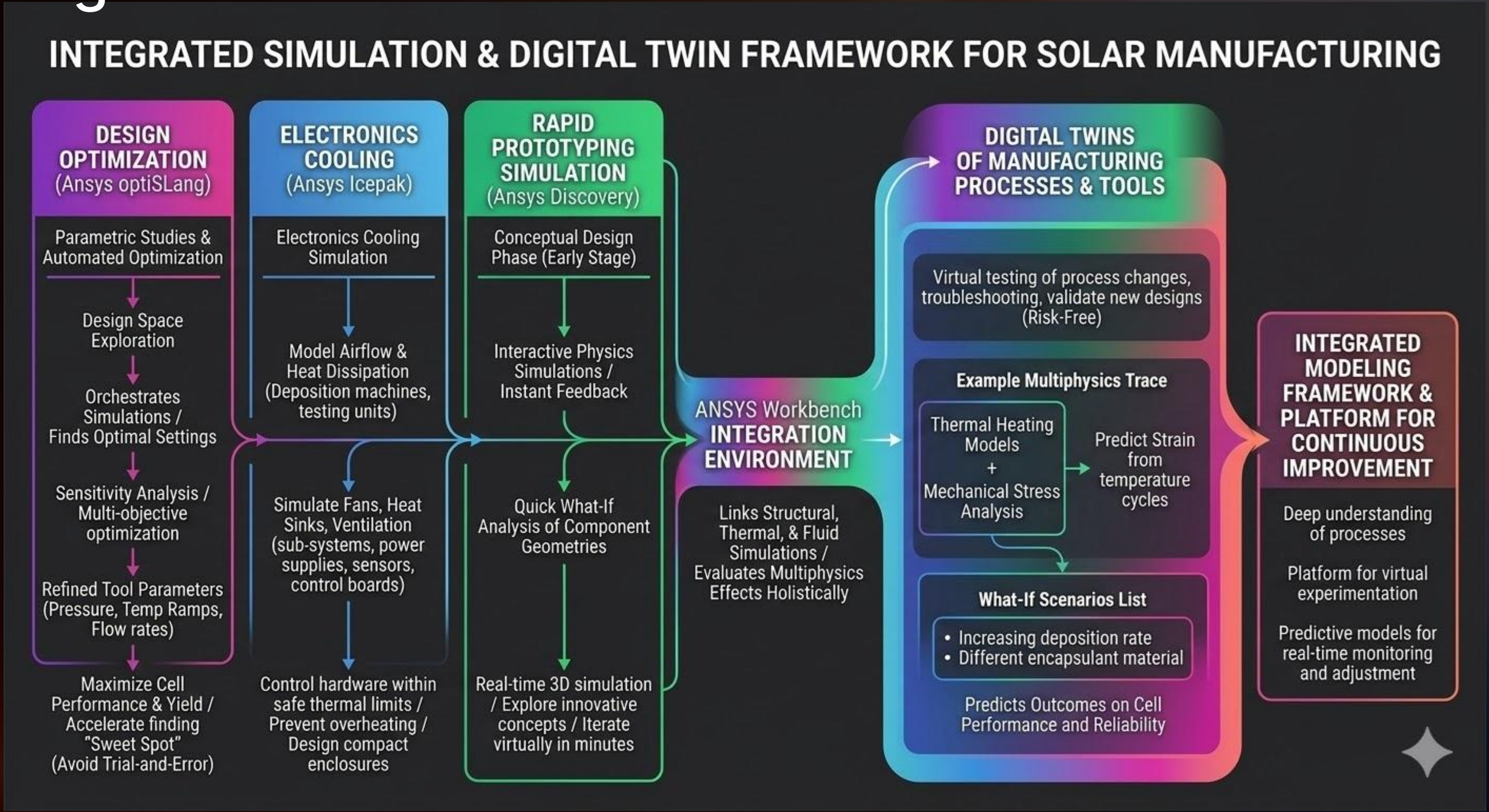
> Structural Analysis (FEA) of Solar Cell Manufacturing



> Precision Thermal Management

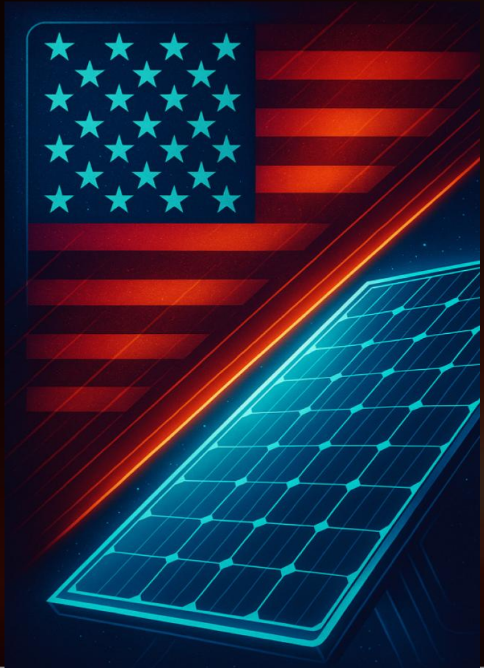


> Integrated Simulation



> GreenTech for Utility-Scale PV and Beyond

Swift Solar is delivering **American-made** advanced solar for space, defense, AI, and more



3 LOI signed,
solar cells flown on 3 missions

6 DoD R&D contracts awarded

$3M grant from CEC,
LOI from top 10 global EV OEM

partnership with communication infrastructure company

Slide from Tobias Abzieher

> First Deployments of Swift Solar's Technology

AMERICAN TOWER®

strategic partnership to evaluate the deployment of perovskite-based tandem solar cells

driven by the surge in energy demand from AI data centers and the limitations due to grid constraints

American Tower operates 42,000 communications sites in the U.S. and over 149,000 sites globally

Slide from Tobias Abzieher

> Roadmap | The path forward for Swift

2017
Swift Solar launched

2023–24
Series A financing

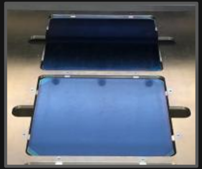
2026
Series B financing

2027–28
Fab0 in US 10–100 MW/yr

2029–30
Fab1 in US >1 GW/yr

Fab2-FabN Globally

R&D proof of concept at 1 cm^2



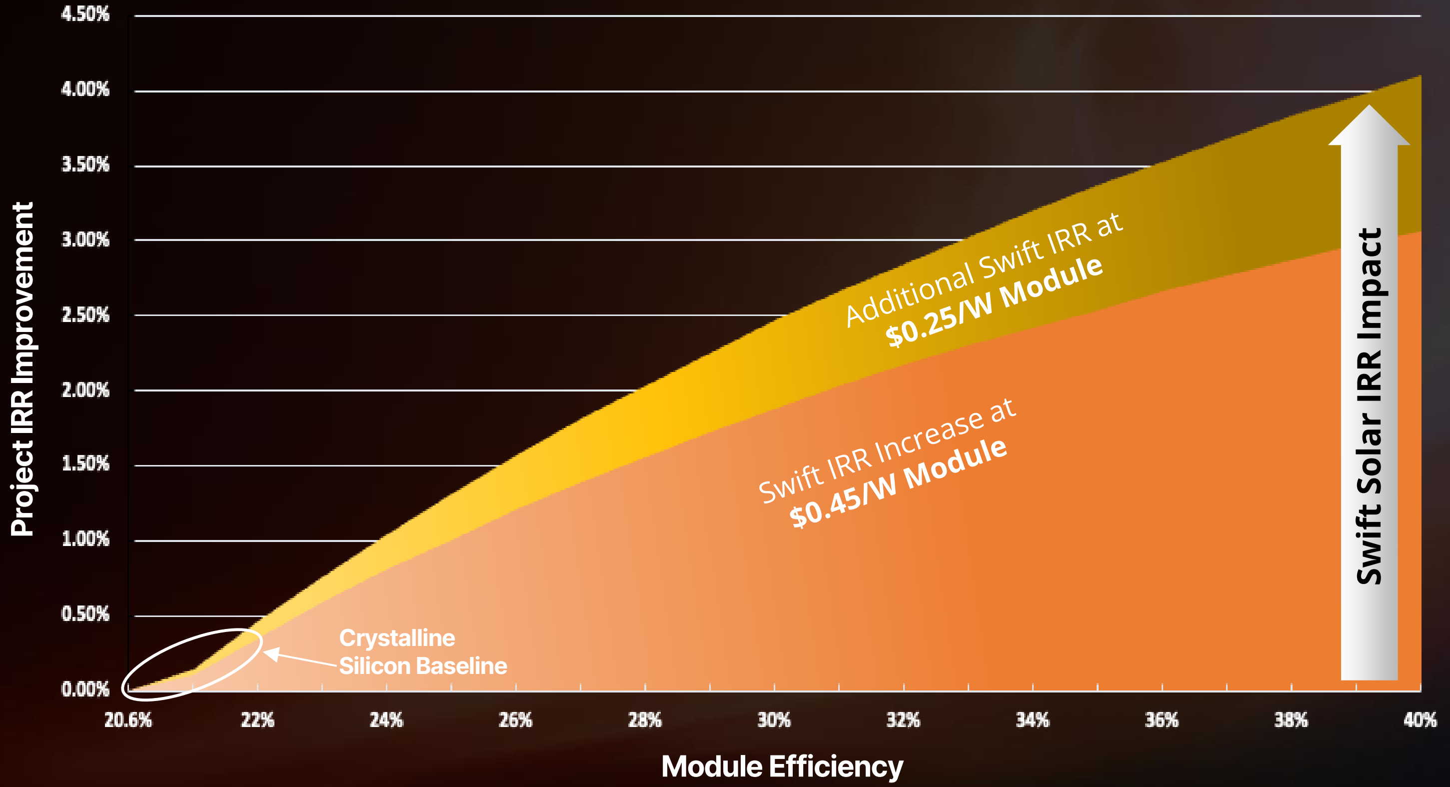
- Technology readiness
- Manufacturing readiness
- Market traction
- Field testing of prototypes
  - DoD, Utility partners
- >$50M raised cumulatively

- Financing for first production plant
- Tool purchases / facility preparation
- Customer pilots
- Exploring re-shoring c-Si supply chain

- Ramp production
- MW-scale pilot projects with select partners

- Product access for preferred deployment partners

> Swift Solar | project economics increase by over 200bps



Driven by reductions in

Up-front **Balance of System** (BOS) costs

Annual **Operations & Maintenance** (O&M) costs

*Swift's IRR estimates ates based on a DOE specified 100MWdc single-axis tracker project with 20.6% PCE reference modules price at $0.336/W. All system cost and O&M cost estimates come directly from DOE PV System Cost Model (PVCSM) 2024. Module pricing is held constant for this analysis in this presentation, assuming that Swift Solar will be at cost-parity with the market at GW scale.

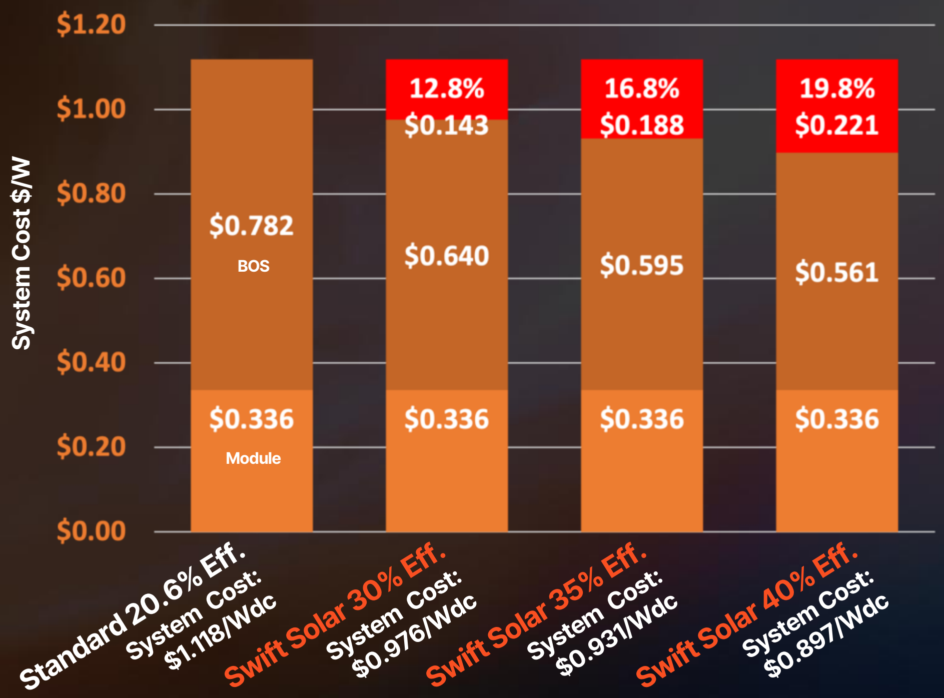
> BOS savings | higher module efficiencies significantly reduce build cost

***Total system costs are reduced by ~13% to 20% due to smaller project footprint**

- Less racking & equipment per MW
- Less wire per MW
- Less shipping per MW
- Less labor per MW
- Less sales tax per MW

- ~$0.143-$0.221/Wdc system cost savings
- ~$14-22M total savings (100MW project)
- ~160-270 bps of project IRR

Total System Cost by Module Efficiency: 100MWdc System



*Swift's IRR estimates ates based on a DOE specified 100MWdc single-axis tracker project with 20.6% PCE reference modules price at $0.336/W. All system cost and O&M cost estimates come directly from DOE PV System Cost Model (PVCSM) 2024. Module pricing is held constant for this analysis in this presentation, assuming that Swift Solar will be at cost-parity with the market at GW scale.

SwiftSolar

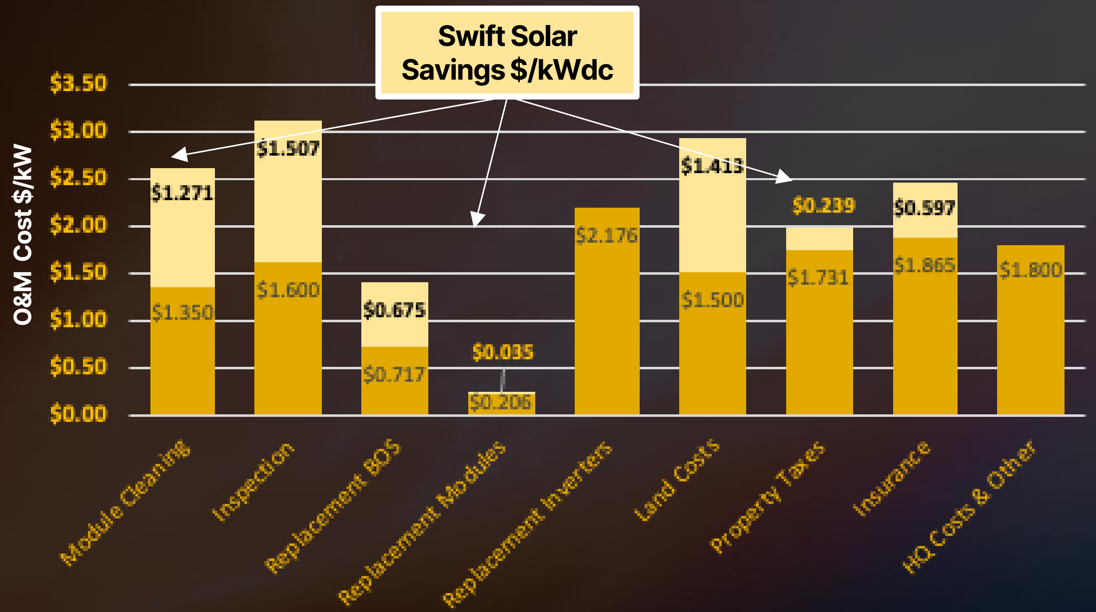
> OPEX savings | cost reductions drive annual operational gains

***O&M costs reduced by ~20% to 30% due to smaller project footprint**

- Less cleaning per MW
- Less inspecting per MW
- Less BOS replacement per MW
- Less module replacement per MW
- Less land costs per MW

- Annual savings of $370k to $500k per 100 MW
- NPV of $6M to $10M over 30 year life
- 55 to 90 bps of added project IRR

Total System O&M Costs by Scope of Work: 100MWdc System



*Swift's IRR estimates ates based on a DOE specified 100MWdc single-axis tracker project with 20.6% PCE reference modules price at $0.336/W. All system cost and O&M cost estimates come directly from DOE PV System Cost Model (PVCSM) 2024. Module pricing is held constant for this analysis in this presentation, assuming that Swift Solar will be at cost-parity with the market at GW scale.

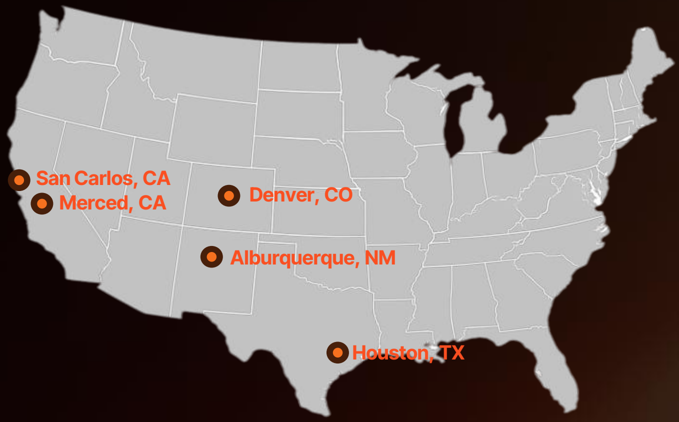
> Thank You for Your Attention

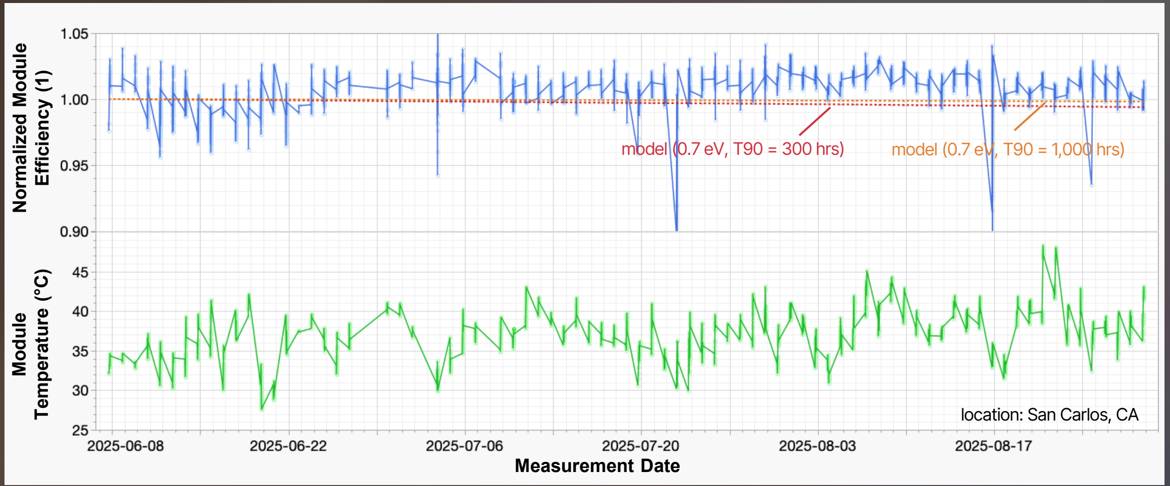
Visit our website:
www.SwiftSolar.com

Feel free to reach out:
reza.nazari@swiftsolar.com

> Key Challenge: Durability in Real-World Operation

Swift Solar's early development efforts prioritized accelerated indoor heat and light stability testing, complemented by outdoor performance evaluations in demanding climatic environments.





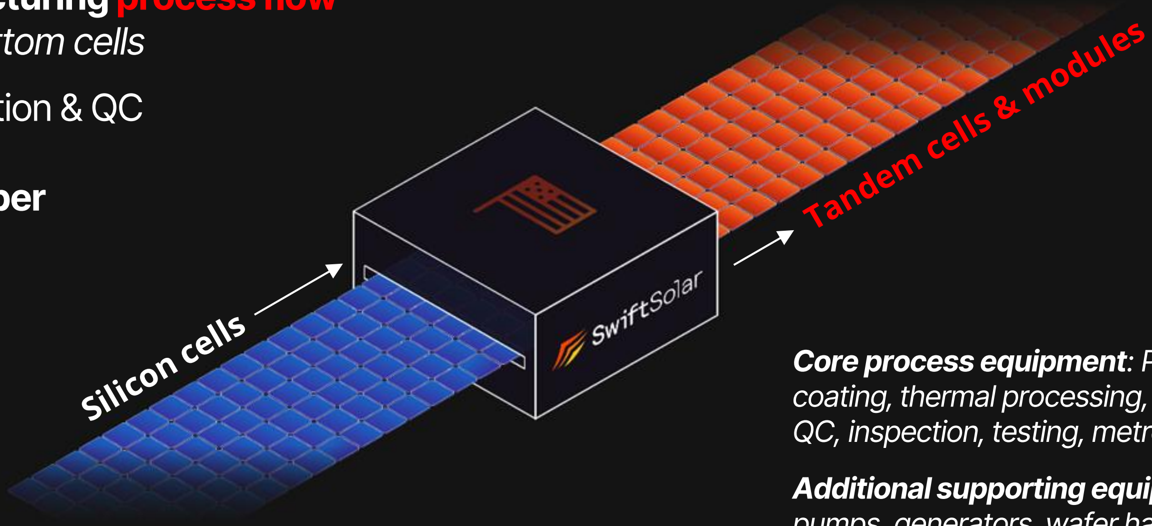
- mechanically stable charge transport layers
- process and control windows
- composition and secondary phases
- lamination and encapsulation
- passivation
- film formation route
- bottom cell design

Slide from Tobias Abzieher

> Overview | Swift perovskite–Si tandem manufacturing

Tandem cell manufacturing process flow
***Substrate: Silicon** bottom cells*

- Bottom cell inspection & QC
- Contact layer 1
- **Perovskite absorber**
- Contact layer 2
- Top electrode
- Metallization
- Test & sort
- Module Assembly



***Core process equipment**: PVD/CVD and wet coating, thermal processing, precursor prep and QC, inspection, testing, metrology*

***Additional supporting equipment**: chillers, pumps, generators, wafer handling systems, buffer stations, AGVs, cranes, forklifts, MES*

Compatible with HJT and TOPCon silicon cells, p-type and n-type

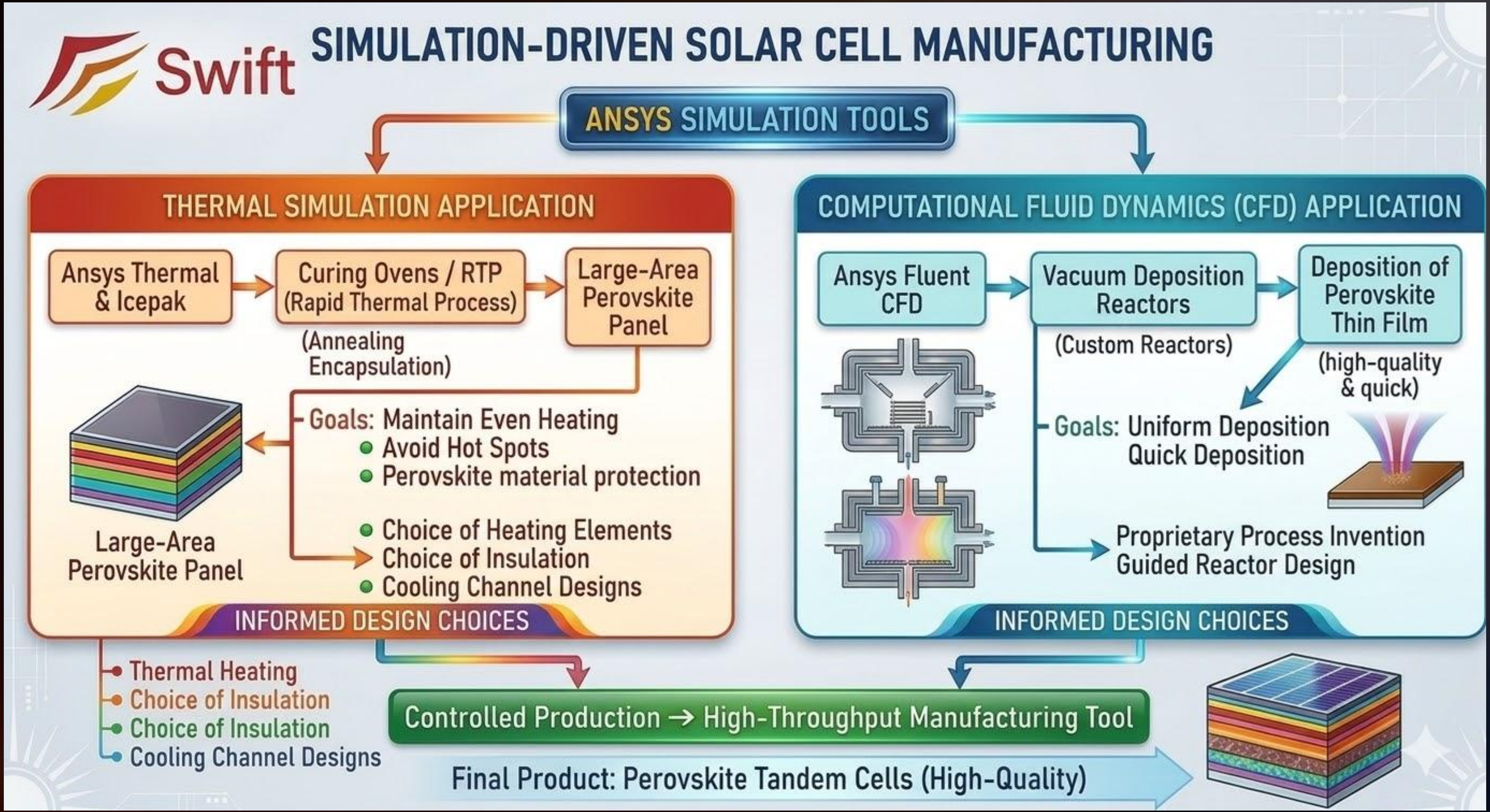
Uniquely positioned to deliver the future of solar: >35% Si-free PV

01 Swift has a distinct pathway to delivering a new class of all-thin-film modules, unlocking efficiencies above 35%

02 Swift's proprietary deposition methods and 2T device architectures enable all-perovskite multijunctions by allowing stacking of perovskite cells without damaging underlying layers

03 Swift is the US leader in 2T perovskite technology—the long-term winner for high-efficiency, low-cost solar—with a roadmap to GWs by 2030 and TWs by 2050

> Simulation-Driven Process Design



> Swift's Key Differentiators

Two-terminal (2T) tandem architecture

High-speed vapor deposited perovskite

> 2 Terminal (2T) vs 4 Terminal (4T)

Key Questions:

Which architecture delivers best final PV module product?

Highest efficiency?

Longest lifetime?

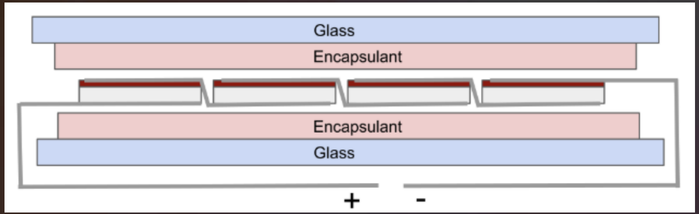
Lowest cost?

> Swift's 2T architecture outperforms 4T competitors

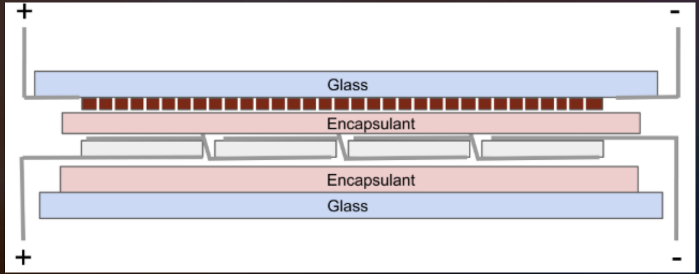
2T tandems enable the highest power potential

Characteristics	Preferred	Reasons
Performance *Efficiency & yield*	2T	~7% relative higher module efficiency and annual energy production
Cost	2T	~$0.05/W lower cost due to less TCE requirements
Reliability *Lifetime & degradation rate*	2T	- Superior lifetime reliability due to continuous barrier layers, conductive front electrodes and series-connected structure - Better shading tolerance
Market Entry	2T	- Faster and more capital-efficient - Higher production yields
Technology Potential	2T	Enables triple-junction modules with future efficiencies over 40%

2T cross-section



4T cross-section



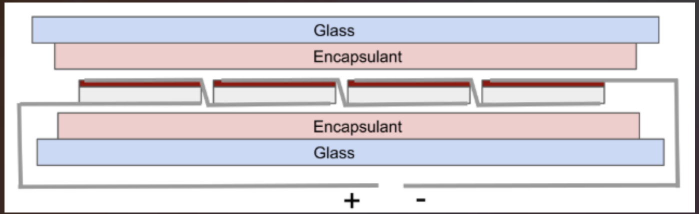
https://www.swiftsolar.com/news/2t-is-the-true-tandem

> Swift's 2T architecture outperforms 4T competitors

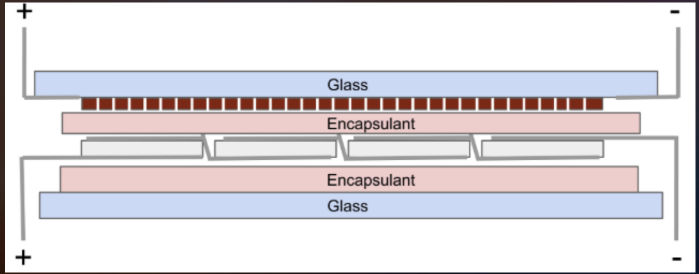
2T tandems enable the highest power potential

Characteristics	Preferred	Reasons
Performance *Efficiency & yield*	2T	~7% relative higher module efficiency and annual energy production
Cost	2T	~$0.05/W lower cost due to less TCE requirements
Reliability *Lifetime & degradation rate*	2T	- Superior lifetime reliability due to continuous barrier layers, conductive front electrodes and series-connected structure - Better shading tolerance
Market Entry	2T	- Faster and more capital-efficient - Higher production yields
Technology Potential	2T	Enables triple-junction modules with future efficiencies over 40%

2T cross-section

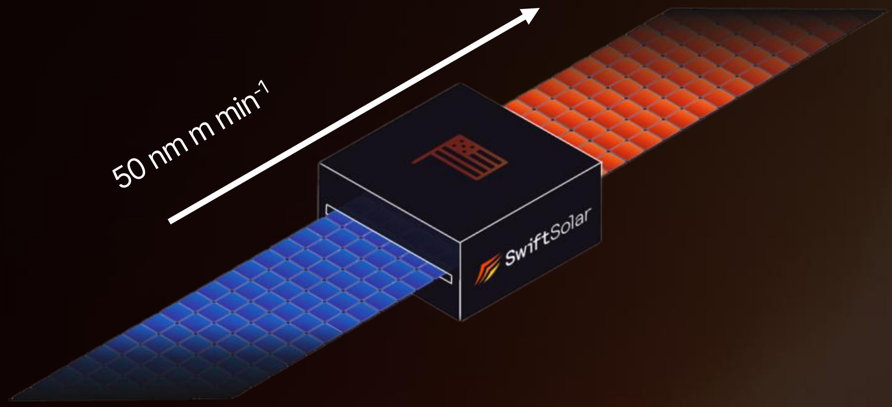


4T cross-section



https://www.swiftsolar.com/news/2t-is-the-true-tandem

> Swift Solar's Absorber Deposition Approach



cycle times of 45 sec for M10 wafers are achieved with Swift Solar's unique vapor deposition approach

depending on source width one linear source set is sufficient to fabricate between 320 (800 mm) and **1,250 wafers per hour** (3,200 mm)

uniform and consistent

simple to scale-out

lower in-line monitoring demands

less decomposition of organic molecules

simple deposition characteristics

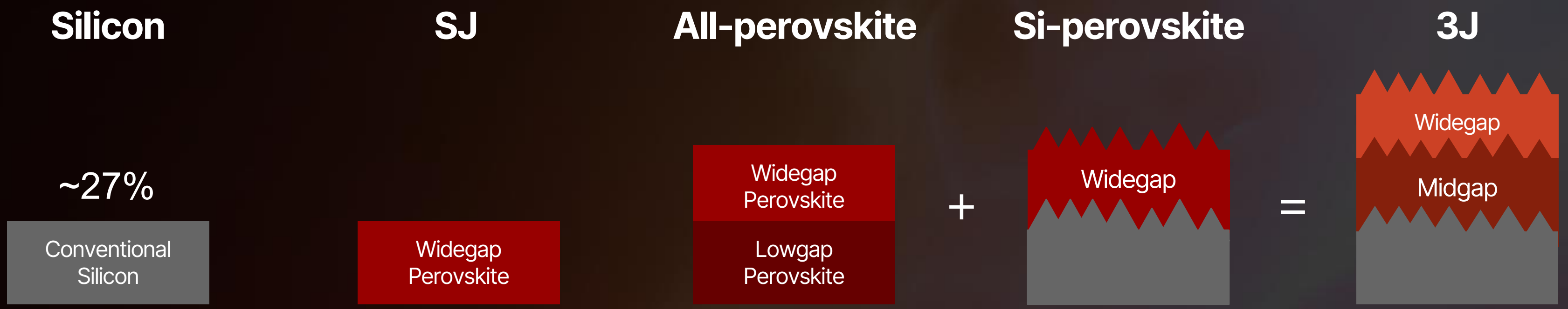
various deposition configurations possible

> Swift's Key Differentiators

Two-terminal (2T) tandem architecture

High-speed vapor deposited perovskite

> Proprietary high-speed perovskite vapor deposition



Process Method	Practical Efficiency Limits			
Vapor	~30%	~34%	~39%	~44%
Solution	~30%	Difficult	~37%	Very difficult

Vapor processing unlocks a higher efficiency roadmap

10× faster than OTS dry methods

> Swift Solar's Absorber Deposition Approach

low deposition speeds of vapor processing are the key challenge for commercialization

scale-out to 1,000 M10 wafers per hour will require 21 linear sources (made up of 5 point sources each)

Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

PERSPECTIVE

View Article Online
View Journal | View Issue

Check for updates

Cite this: *Energy Environ. Sci.*, 2024, 17, 1645

Vapor phase deposition of perovskite photovoltaics: short track to commercialization?†

Tobias Abzieher, *[a] David T. Moore, *[a] Marcel Roß, [b] Steve Albrecht, [b] Jared Silvia,[c] Hairen Tan, [d] Quentin Jeangros,[e] Christophe Ballif,[ef] Maximilian T. Hoerantner,[g] Beom-Soo Kim, [h] Henk J. Bolink, [i] Paul Pistor, [jk] Jan Christoph Goldschmidt, [l] Yu-Hsien Chiang,[mn] Samuel D. Stranks, [mn] Juliane Borchert,[op] Michael D. McGehee, [q] Monica Morales-Masis, [r] Jay B. Patel, [s] Annalisa Bruno [t] and Ulrich W. Paetzold *[u]

While perovskite-based photovoltaics (PV) is progressing toward commercialization, it remains an open question which fabrication technology – solution-based, vapor-based, or combinations – will pave the way to faster economic breakthrough. The vast majority of research studies make use of solution-processed perovskite thin films, which benefit from a rapid optimization feedback and inexpensive to procure tools in modern research laboratories, but vapor phase deposition processes dominate today's established thin-film manufacturing. As research and development of vapor phase processed perovskite thin films are still strongly underrepresented in literature, their full potential is yet to be identified. In this collaborative perspective of academic influenced by industrial views, we convey a balanced viewpoint on the prospects of vapor-based processing of perovskite PV at an industrial scale. Our perspective highlights the conceptual advantages of vapor phase deposition, discusses the most crucial process parameters in a technology assessment, contains an overview about relevant global industry clusters, and provides an outlook on the commercialization perspectives of the perovskite technology in general.

Received 27th September 2023,
Accepted 2nd January 2024

DOI: 10.1039/d3ee03273f

rsc.li/ees

EES Solar

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal | View Issue

Check for updates

Cite this: *EES Sol.*, 2025, 1, 404

Industrialization of perovskite solar cell fabrication: strategies to achieve high-throughput vapor deposition processes†

Julian Petry, *[a] Viktor Škorjanc, [b] Alexander Diercks, [c] Thomas Feeney, [c] Amedeo Morsa, [d] Sara Rose Kimmig, [ef] Jens Baumann,[g] Frank Löffler,[g] Stefan Auschill,[h] Joshua Damm, [a] Daniel Baumann, [a] Felix Laufer, [c] Jona Kurpiers, [b] Michael Müller, [d] Lars Korte, [b] Steve Albrecht, [bi] Marcel Roß, *[b] Ulrich W. Paetzold *[ac] and Paul Fassl *[ac]

Vapor phase deposition processes hold great potential for industrializing the deposition of perovskite-based absorbers, offering a pathway to commercialization. Specifically, the scalability, ability to produce conformal coatings, and established use in industrial processing of optoelectronic devices lead to the assumption that thermal sublimation is inherently suitable for commercial-scale perovskite solar cell production. However, ensuring economic viability requires a detailed assessment of achievable production throughputs, a key factor in achieving cost-effective large-scale manufacturing. This work bridges the gap between research focus and industry needs by introducing and analyzing three strategies to increase production throughput in an industrial context: (1) we investigate the thermal stability of key perovskite precursor materials to provide guidelines for safe operation by mitigating decomposition risks. (2) We critically evaluate the industrial feasibility of common deposition modes, including co-deposition and sequential deposition, as scaling from laboratory to industrial production introduces new challenges in terms of material utilization and compositional material homogeneity. In addition, we analyze the static deposition rate profiles of key perovskite precursor materials and use this

> Structural Analysis (FEA) of Solar Cell Manufacturing using Ansys Mechanical

SwiftSolar

Unlocking the full potential of solar energy

Join our Team:

R&D Engineer/Scientist
Technicians
and more to come...

www.swiftsolar.com/careers

Reza Nazari, PhD

reza.nazari@swiftsolar.com