

Pathway Towards Low-Cost, High-Efficiency Solar Cells by Dynamic Hydride Vapor Phase Epitaxy

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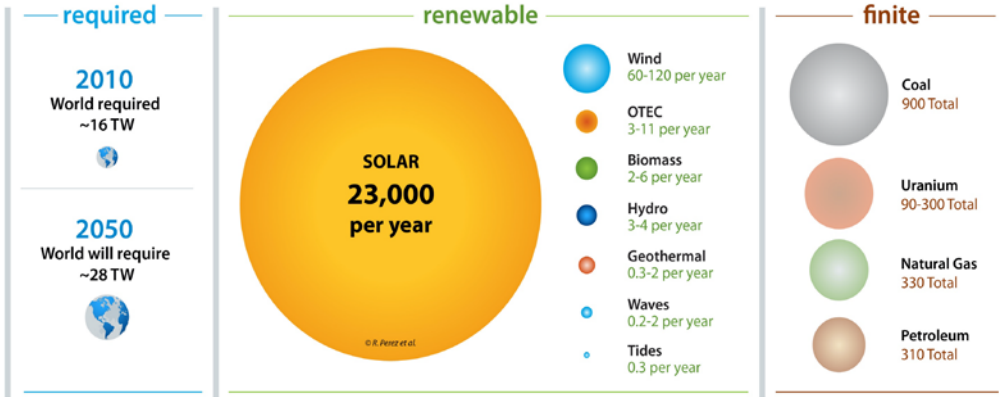
Renewable Energy



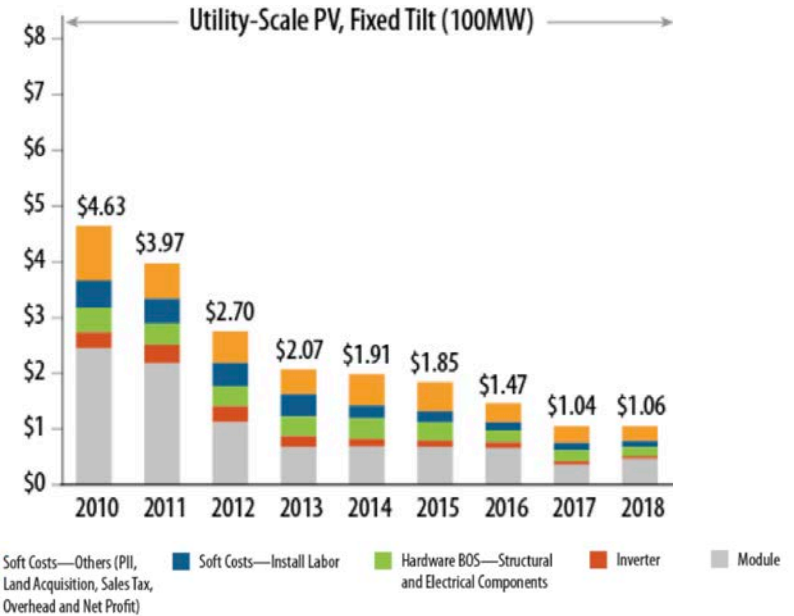
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Introduction: Why Solar?

World Energy Resources (TW)



23,000 TW are incident on the earth from the sun per year – three orders of magnitude more than the projected global consumption for 2050



Meanwhile, the cost of solar panels has substantially decreased in the last decade

III-V Materials for Solar Applications

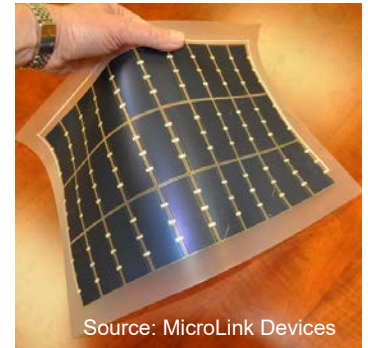
	<u>Silicon</u>	vs.	<u>III-Vs</u>
Power conversion efficiency	18-21%		26-34%
Power output per weight	260 W/kg		1100 W/kg
Power output per area	200 W/m ²		300 W/m²
Flexibility	Rigid		Rigid or flexible
Market share	95%		<1%
Cost	<\$1/W		\$61/W

13 IIIA 3A	14 IVA 4A	15 VA 5A
5 3.2,1 B Boron 10.811	6 4.3,2,1,-1 -2,-1,-4 C Carbon 12.011	7 5.4,3,2,1,0 -1,-2,-3 N Nitrogen 14.007
13 3,1 Al Aluminum 26.982	14 4.3,2,1,-1 -2,-1,-4 Si Silicon 28.086	15 5.4,3,2,1,0 -1,-2,-3 P Phosphorus 30.974
31 3.2,1 Ga Gallium 69.732	32 4.3,2,1 Ge Germanium 72.61	33 5.3,2,-3 As Arsenic 74.922
49 3.2,1 In Indium 114.818	50 4.2,-4 Sn Tin 118.71	51 5,3,-3 Sb Antimony 121.760
81 3,1 Tl Thallium 204.383	82 4,2 Pb Lead 207.2	83 5.3,1,-3 Bi Bismuth 208.980
113 7 Uut Ununtrium unknown	114 2 Fl Flerovium (289)	115 3,1 Uup Ununpentium unknown



III-V Materials for Solar Applications

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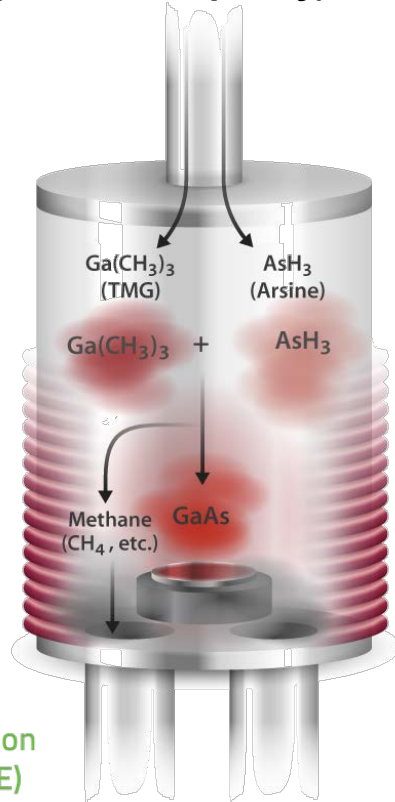
Solar cells can be made from a variety of materials including silicon and III-Vs.

III-V materials have higher solar cell performance than silicon, but are more expensive. If their cost could be reduced, III-Vs could enable many applications that are difficult now.

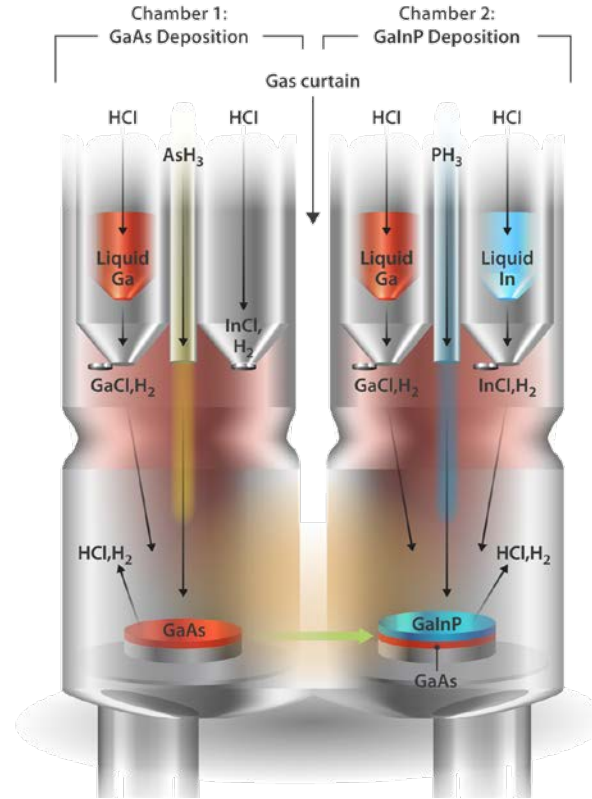
III-V Epitaxy Methods

The Incumbent Method (Organometallic Vapor Phase Epitaxy)

- ✓ Reliably produces high-quality, complex solar cells
- ✗ Low growth rates typically used in industry
- ✗ Expensive organometallic precursors (\$1/g for the Ga precursor)



The Alternative Method (Dynamic Hydride Vapor Phase Epitaxy)



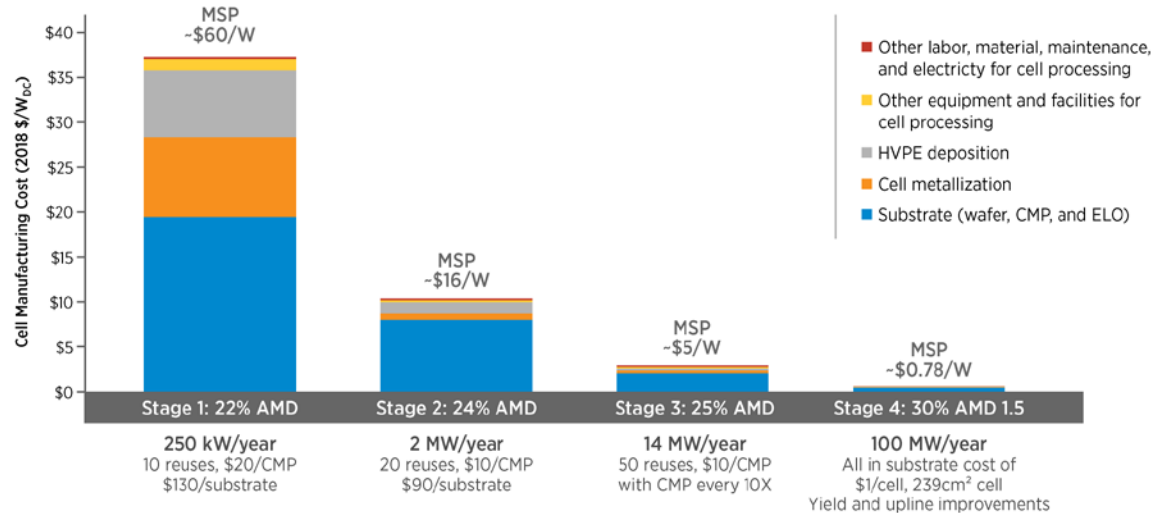
- ✓ Fast growth rates > 0.5 mm/h
- ✓ Lower-cost precursors (\$0.21/g for the elemental Ga precursor)
- ✓ More efficient use of precursors
- ✗ Only research scale so far
- ✗ Uses flammable hydrogen gas

Objective

Our objective is to maintain III-V solar cells with very high efficiency while exploring methods to reduce the cost

This poster discusses the enabling role of nitrogen carrier gas to reduce HVPE deposition costs

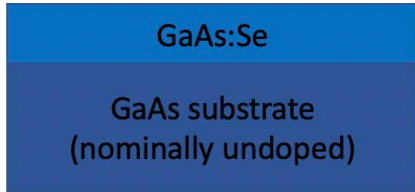
The Roadmap to Low-Cost, High-Output III-V Solar Cells



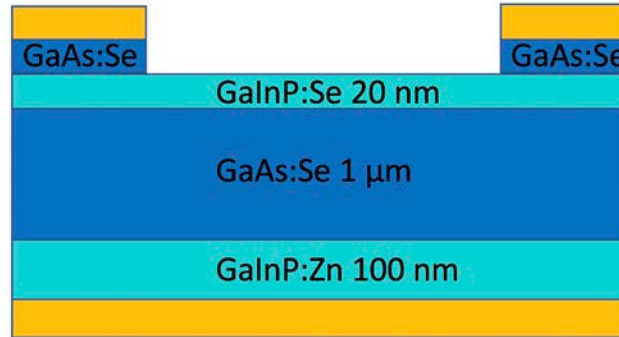
Methods: D-HVPE Growth

We grew GaAs test structures to determine the growth rate with a **nitrogen carrier gas**, which is safer and cheaper than hydrogen carrier gas that is typically used

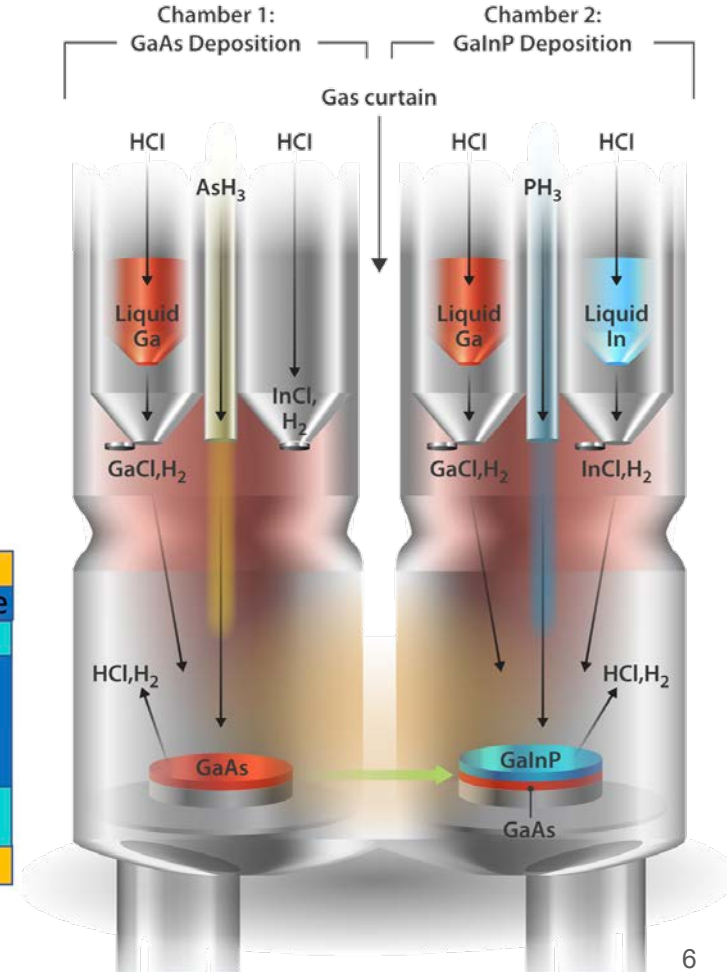
We then developed solar cells to confirm that they still maintain high efficiency at high growth rates with nitrogen



- 1) Test structure for growth rate calibration



- 2) Solar cell growth

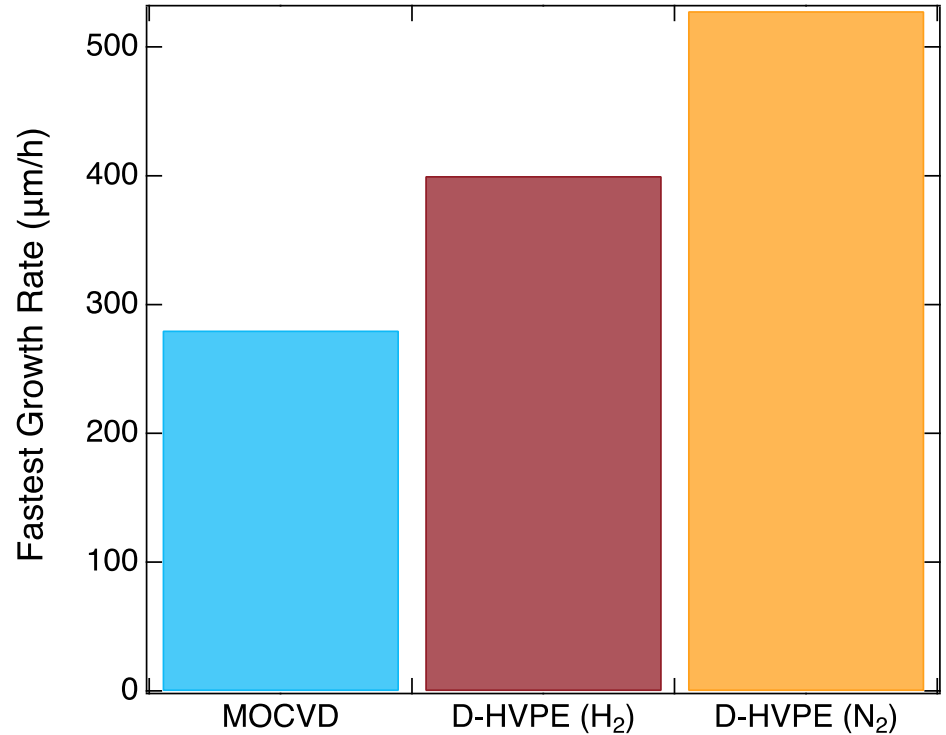


Results: Growth Rate Enhancement

We used the maximum AsH_3 flow and increased the GaCl flow to compare the influence of carrier gas on growth rate

We observed a growth rate of **528 $\mu\text{m/h}$** using **nitrogen carrier gas** and 400 $\mu\text{m/h}$ using hydrogen carrier gas

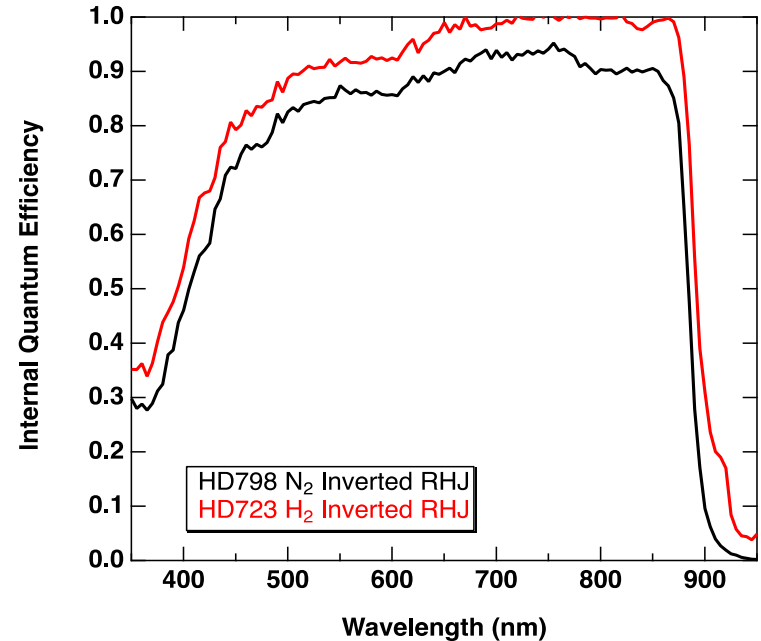
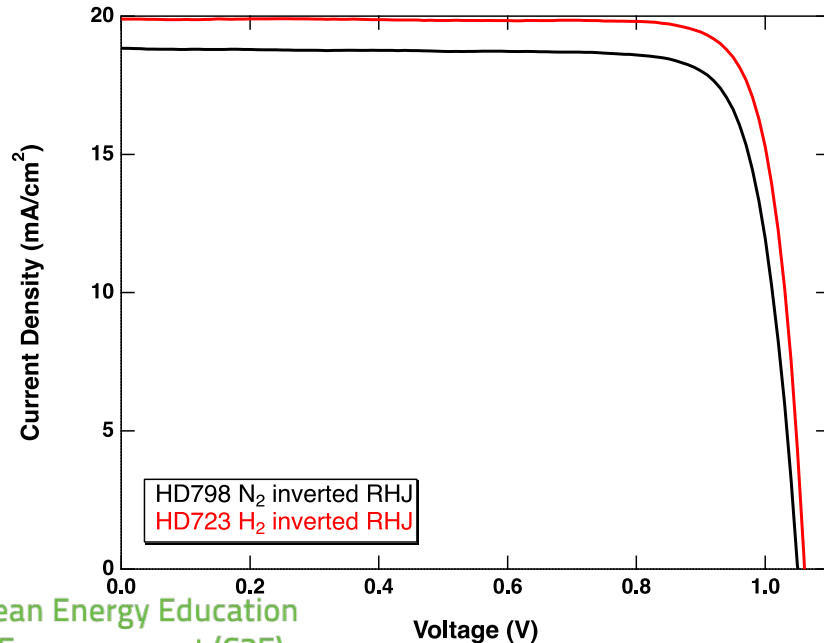
This growth rate enhancement could improve throughput in industrial-scale reactors, while utilizing a carrier gas that is **cheaper and safer** than the current standard



Results: Solar Cell Performance

Estimated **24% power conversion efficiency** with an antireflection coating at a growth rate of 30 $\mu\text{m}/\text{h}$

The open circuit voltage (which predicts material quality) is within 20 mV of the hydrogen baseline with almost no optimization. The difference in the short-circuit current density is due to a difference in layer thickness.

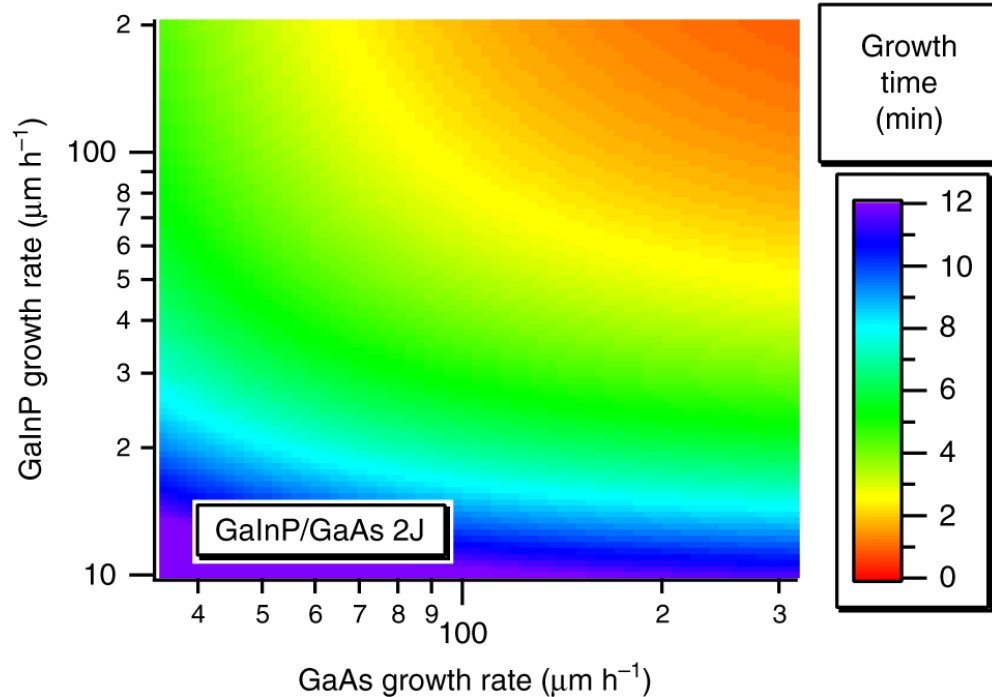


Conclusions

Higher growth rate can lead to lower time to grow a single-junction or multijunction III-V solar cell

We found that using nitrogen carrier gas improves the growth rate compared to hydrogen carrier gas, and has additional benefits such as being cheaper and safer

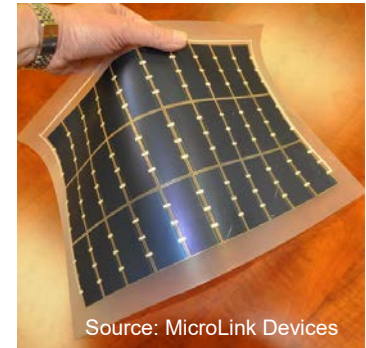
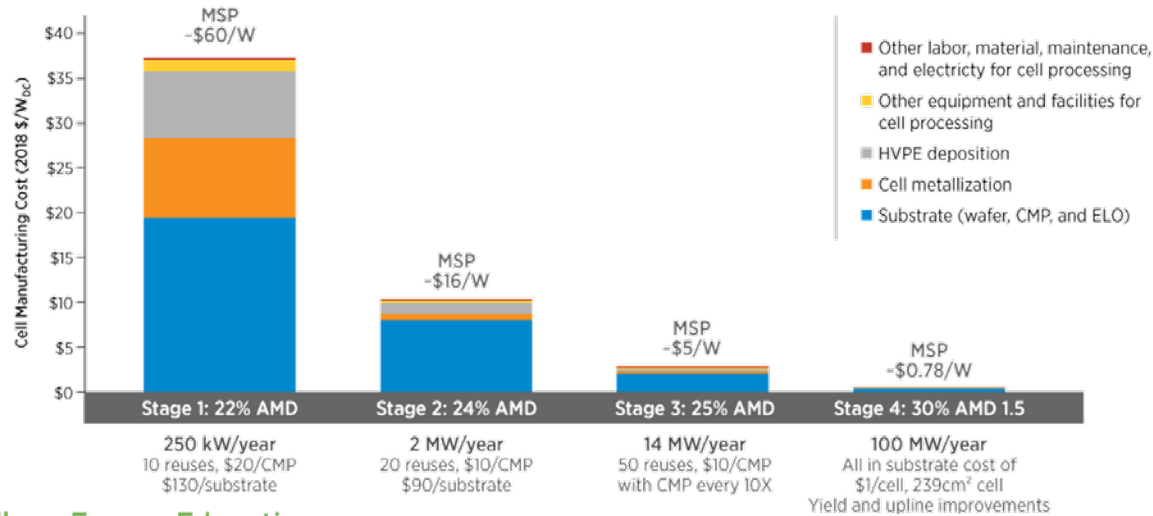
Improvements in throughput decrease the cost associated with epitaxy



Impact

This work combined with continued scaling of D-HVPE reactors and techniques to reduce the cost of metallization and substrates will enable a pathway for III-V solar cells in many future technologies like **efficient, light-weight solar modules on cars** or **flexible and portable solar mats, tiles, and backpacks**

The Roadmap to Low-Cost, High-Output III-V Solar Cells



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Thank you!

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