An Analysis of Techno-Economic Requirements for MOSAIC CPV Systems to Achieve Cost Competitiveness

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Incumbent Flat Plate PV Technology

- Flat-plate c-Si is > 90% of the PV market
- Module costs and prices have decreased rapidly and significantly
 - \$0.35/W ex-factory gate average price in 2017
- Single-junction devices have limits on efficiency
- Fixed-tilt systems suffer from cosine losses

CPV Concepts and the MOSAIC Program

Traditional HCPV Systems

- Myriad of different designs
- Thicker than traditional flat plate modules
- Require accurate 2-axis tracking
- Cannot collect diffuse sunlight

Micro-scale Optimized Solar cell Arrays with Integrated Concentration (MOSAIC)

- Myriad of different designs
- Form factor similar to flat plate technology: Approx. 2.5cm array height
- Either have relaxed tracking requirements or do not require external tracking
- Most able to collect some diffuse light

Techno-Economic Analysis Overview

- Conducted bottom-up cost analysis relevant to a range of MOSAIC designs, including fixed-tilt and tracked systems
 - Built a new bottom-up, engineering cost model of a dual-axis tracker for modeling tracked MOSAIC designs
 - Leveraged NREL's existing bottom-up system models of fixed-tilt rooftop and ground mount systems
 - Based on 2016 system costs
- Created a simplified LCOE calculator to use for “apples-to-apples”, technology-based comparisons
- Applied this modeling to:
 - Evaluate and validate program goals
 - Compare & contrast different module design aspects
 - Set cost and performance targets for specific module types in residential, commercial, and utility-scale markets
 - Assess different aspects of MOSAIC awardees designs and their potential competitiveness against incumbent technology

Harvest Efficiency

$$\eta_{Harvest,DC} = f_{DNI} \cdot g(\theta, \phi)_{DNI} \cdot \eta_{opt,DNI} \cdot \eta_{PV,DNI} \cdot F_{DNI} + (1 - f_{DNI}) \cdot g(\theta, \phi)_{DIFF} \cdot \eta_{opt,DIFF} \cdot \eta_{PV,DIFF} \cdot F_{DIFF}$$

- Currently, HCPV systems are rated using only direct normal irradiance (DNI) according to the IEC 62670-1 standard
- MOSAIC efficiency metric is harvest efficiency, which is based on total input irradiance

Potential Competitiveness of Internally-Tracked MOSAIC Systems in Different Markets

Theoretical MOSAIC System Aligns with MOSAIC Targets:

- Harvest efficiency: $\geq 30\%$ (30% of total insolation)
- Module production cost: \$0.41/W - \$0.58/W (\$0.50/W)
- Degradation rate: $<1\%$ /year (1%/year)

- Advantage of MOSAIC systems: ability to reach higher efficiencies and potentially have higher energy yields
 - Final energy yield that will be realized by MOSAIC systems is currently uncertain
- Residential rooftop systems have higher balance-of-system (BOS) costs, and so the advantage of higher efficiency is greater than for utility-scale
 - Advantage of MOSAIC systems will depend on the BOS cost structure at the time of commercialization

Effects of Module Efficiency and Price

- LCOE competitiveness depends on many factors
- Two primary drivers are module efficiency and price
- The potential for increased energy density associated with MOSAIC systems can provide additional value in space-constrained applications

Assumptions

- Phoenix, AZ
- Same degradation as mean value for c-Si (0.5%/year)
- 2,100 kWh/kW (compared to 1,800 kWh/kW for mono c-Si)

Mono c-Si LCOE for comparison

Modeled Two-Axis Tracker Costs in Phoenix, AZ

Curve varies depending on dimensions of tracker array, the size of the modules, and the location of installation

- Trackers with accuracies less than 0.5° are designed for stow conditions → little cost change
- For accuracies better than 0.3° , you may require additional structural reinforcement, incurring additional costs, specific to each module/system design
- Trade-offs for increasing tracker area
 - Wind and snow loading increases, driving up cost per tracker to maintain accuracy (higher increase with more stringent tracking requirements)
 - Watts per tracker increases, driving down overall installed cost per watt

Two-Axis MOSAIC versus Single-Axis Flat Plate System at Utility-Scale

- 80% of utility-scale installations in the US in 2016 used 1-axis tracking
- Higher energy yield requirements for MOSAIC because of increased cost associated with the dual-axis tracker, even with relaxed accuracy requirements
 - 2-axis trackers are earlier in the learning curve than 1-axis trackers

Comparison of System Characteristics to Achieve 5.2¢/kWh in Kansas City, MO

Technology	Module Efficiency	Module Price	Total Installed System Price	Degradation rate	Energy Yield to hit 5.2¢/kWh LCOE
Current CdTe, 1-axis tracking	16%	\$0.39/W _p	\$1.20/W	0.4%/year	1,966 kWh/kW _p (modeled energy yield for CdTe system)
Theoretical MOSAIC, 2-axis tracking: meets program targets	30%	\$0.50/W _p	\$1.46/W	1 %/year	2,438 kWh/kW _p (required to hit 5.2¢/kWh)
Theoretical MOSAIC, 2-axis tracking: exceeds program targets	40%	\$0.20/W _p	\$1.04/W	0.4%/year	1,829 kWh/kW _p (required to hit 5.2¢/kWh)

Planar micro-tracking LCOE modeling at Penn State

Technology Summary

- Fixed-tilt CPV panels, 300x concentration
- μ -scale 3J solar cells, ~42% efficient
- panel efficiency 35% of DNI

Annual energy generation

- Based on PV Watts TMY data & NREL SPA
- Comparison with 19% Si panel
- Metric: annual kWh/kWp(dc)

	19% Si	35% CPV
AZ	1830	1610
MO	1450	1160
NY	1350	1070

Conclusions

- CPV wins on install cost, Si wins on LCOE
- Key difference is 30 yr degradation rate
 - 0.4%/yr Si vs. 1%/yr CPV assumed

PennState

Residential LCOE & installation cost comparison

	AZ	MO	NY
Si			
LCOE (\$/kWh)	\$ 0.063	\$ 0.080	\$ 0.089
Install (\$/Wp)	\$ 2.67	\$ 2.66	\$ 2.84
CPV			
LCOE (\$/kWh)	\$ 0.073	\$ 0.100	\$ 0.113
Install (\$/Wp)	\$ 2.37	\$ 2.33	\$ 2.50

Analysis courtesy of Dr. N Giebank, Penn State University

Summary and Conclusions

- A bottom-up model created from NREL for MOSAIC is being used by awardees to assess their specific systems/designs
- MOSAIC systems could become cost-competitive with other PV technology, particularly in space-constrained applications
 - Residential and commercial BOS savings
 - We presented an example of this for a residential application and utility-scale application with Penn State's design
- However, this will depend on the specifics of the system, including:
 - Manufacturing cost per watt
 - Energy yield/harvest efficiency
 - System degradation
- Lower tracking accuracy requirements translate to lower tracker costs, to a point
- The modeled premium for two-axis trackers means high performance is required for CPV systems to break-even with existing technology on single-axis trackers in utility-scale markets

Thank you!

Questions?

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Simplified LCOE equation

$$LCOE = \frac{C_{upfront} + \sum_{n=0}^N \frac{O \& M_n}{(1+d)^n}}{\sum_{n=0}^N \frac{E_1(1-r)^n}{(1+d)^n}}$$

II. System Cost Model for MOSAIC

- The dual-axis tracked system cost model assumes a traditional pedestal architecture
- Fixed-tilt and 1-axis tracking architectures identical to those currently used for flat-plate designs
- Users input their specific module characteristics and get out system price and LCOE
- Can compare LCOE to existing technology in 3 locations: Phoenix, Kansas City, New York
- Simplified LCOE model and default financial inputs for easy use by scientific researchers and early-stage projects

II. System Cost Model for MOSAIC