INTRODUCING THE PV – LCOE FRAMEWORK

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- World-leading solar conversion efficiency
- >2.5 GW solar PV deployed
- Diversified portfolio: roofs to power plants
- More than 200 patents
- 6,000+ employees
- Strategic investment by Total: #11, F500
Question: Since 2007 how much have module prices decreased?
**Question:** Since 2007 how much has PV power plant LCOE decreased?
Question: When will PV power plants compete without subsidy?
Where are we with tracking PV power plant costs today?
Project scope differences make BOS comparisons and cost roadmapping challenging

BOS scope from 7 SunPower power plants: BOS cost difference between high and low project > 2x
Where are we with LCOE today?

- Different LCOE models across industry
- Different underlying assumptions complicate comparisons
- Tax and other regional factors limit global comparability
- Complexity can make LCOE analysis inaccessible to non-finance experts

A standardized, simplified model is desirable to track industry progress
Introducing the PV – LCOE Framework

- Capacity Factor
- Annual O&M
- PV Plant Cost
- Annual Degradation
- System Life
- Cost of Capital
Introducing the PV – LCOE Framework

PV - LCOE

Capacity Factor
Local Climate
System Configuration
Annual O&M
PV Basic Plant Cost
PV Power Block
PV Panel
Mounting System
DC Collection
AC Station
Power Block Assembly

Balance of Basic Plant

Cost Adders
Project Design
Site Civil & Electrical
Commissioning
Project Management & Indirect Costs

Development Costs

Land
Permitting
Transaction costs
Interconnection

Off-take risk
Technology risk
Weather risk

System Life
Cost of Capital

Annual Degradation

PV Plant Cost

Technology risk

Off-take risk
Weather risk

PV - LCOE
High-Level PV Power Plant Cost Categories

- PV Plant Cost
  - PV Basic Plant Cost
  - Cost Adders
  - Development Costs
The PV Basic Plant

Iberdrola
Alamosa – 30MW
The PV Basic Plant

PV basic plant assumptions:
1) System size of 10-100MW
2) Basic substation for connection to the transmission or distribution system
3) Medium voltage collection system for connection to a substation
4) 40 meters per second wind
5) Non-corrosive environment
6) No special landscaping
7) Flat site (+- 3 degrees)
8) Square site
9) Standard wages
10) No sales or VAT tax on components
11) Light snow conditions

Iberdrola
Alamosa – 30MW
High-Level PV Power Plant Cost Categories

PV Basic Plant

PV Power Blocks

Balance of Basic Plant

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SunPower Oasis 1.5MW PV Power Block
SunPower Oasis 1.5MW PV Power Block

**DC Collection**
- Array wire
- DC feeders
- Combiner boxes
- Conduit
- Trenching

**Mounting system**
- Tracker or fixed structure
- Mechanical controls
- Module attachment
- Foundations

**AC station**
- Inverters
- SCADA
- MV transformer
- AC conduit
- Equipment pad

**PV panel**

**PV Plant Cost**

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PV Power Block – AC Station

SunPower Oasis 1.5MW AC Station
PV Power Block – Mounting System

SunPower Oasis - T0 Tracking System
PV Power Block Assembly

SunPower Oasis – Power Block Assembly
Capacity Factor Drivers

\[ \text{Capacity Factor}_{AC} = \frac{\text{Plant Annual kWh}}{(\text{Plant kWp}_{AC \ POI} \times 8,760)} \]

**Major capacity factor drivers:**

- Panel performance
- Tracker or fixed
- Local climate
- Plant DC / AC ratio

**AC capacity POI** = maximum plant capacity at point of interconnection

**Plant DC/AC ratio** = an arbitrary plant design decision
Sample Capacity Factors

Approximate 1-axis horizontal tracker PV power plant capacity factors
## Discount Rate / Cost of Capital Drivers

<table>
<thead>
<tr>
<th>Off-take risk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Government FIT</td>
<td>Credit rating of the country providing a FIT guarantee</td>
</tr>
<tr>
<td>Utility PPA</td>
<td>Credit rating of the utility signing the PPA agreement</td>
</tr>
<tr>
<td>Merchant plant</td>
<td>Market price volatility in a wholesale power market</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance risk</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Weather risk</td>
<td>Weather materially differs from that modeled in the plant's</td>
</tr>
<tr>
<td></td>
<td>performance predictions</td>
</tr>
<tr>
<td>Technology risk</td>
<td>Technology underperforms relative to predictions</td>
</tr>
<tr>
<td>O&amp;M risk</td>
<td>Operations and maintenance costs exceed those forecasted in</td>
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<td></td>
<td>project financial model</td>
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<table>
<thead>
<tr>
<th>Property risk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage</td>
<td>System damaged by severe storm or seismic event</td>
</tr>
<tr>
<td>Theft</td>
<td>Theft of system components</td>
</tr>
</tbody>
</table>
Solar Resource Risk

PV power plants generate very consistent returns similar to a bond

For comparison a California investor owned utility 30-year bond ~5% return

Predicted power plant output based on measured annual weather data for Southern California power plant
Power Plant System Life

51% of USA generation older than 30 years
...and 73% of coal power plants are older than 30 years, why can’t PV achieve a similar lifetime?
The PV-LCOE Equation

- Capacity Factor
- Annual O&M
- PV Plant Cost
- Annual Degradation
- System Life
- Cost of Capital
The PV-LCOE Equation

PV - LCOE

Capacity Factor  Annual O&M  PV Plant Cost  Annual Degradation  System Life  Cost of Capital

30 years  7.5%
The PV-LCOE Equation

\[
PV - LCOE = \frac{0.085 \times \text{Capital Cost}_{\text{WAC}} + \text{Annual O&M}_{\text{WAC}}}{8.76 \times \text{Capacity Factor}_{\text{AC}} \times (1 - \text{Degradation Rate} \times 8.4)}
\]
## PV LCOE Sample Results

<table>
<thead>
<tr>
<th>Input Variables</th>
<th>DC/AC ratio</th>
<th>Munich fixed</th>
<th>Munich 1-axis</th>
<th>Spain fixed</th>
<th>Spain 1-axis</th>
<th>China fixed</th>
<th>China 1-axis</th>
<th>Phoenix fixed</th>
<th>Thai fixed</th>
<th>Thai 1-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost ($/Wdc)</td>
<td>2.60</td>
<td>2.70</td>
<td>2.60</td>
<td>2.70</td>
<td>2.50</td>
<td>2.70</td>
<td>2.15</td>
<td>2.60</td>
<td></td>
<td></td>
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<tr>
<td>Capital Cost ($/Wac)</td>
<td>3.25</td>
<td>3.38</td>
<td>3.25</td>
<td>3.38</td>
<td>3.12</td>
<td>3.38</td>
<td>2.69</td>
<td>3.25</td>
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<td></td>
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<tr>
<td>Yr 1 Capacity Factor</td>
<td>15%</td>
<td>17%</td>
<td>24%</td>
<td>28%</td>
<td>30%</td>
<td>31%</td>
<td>19%</td>
<td>24%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M/Wac/yr</td>
<td>0.023</td>
<td>0.025</td>
<td>0.023</td>
<td>0.025</td>
<td>0.023</td>
<td>0.025</td>
<td>0.021</td>
<td>0.023</td>
<td></td>
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</tr>
<tr>
<td>Annual Degradation</td>
<td>0.75%</td>
<td>0.75%</td>
<td>0.75%</td>
<td>0.75%</td>
<td>0.75%</td>
<td>0.75%</td>
<td>0.75%</td>
<td>0.75%</td>
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### PV-LCOE ($/kWh)

|               | 0.226 | 0.207 | 0.141 | 0.126 | 0.109 | 0.110 | 0.148 | 0.144 |

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Conclusion

- The need for a new cost and LCOE framework has been demonstrated
- A new PV-LCOE framework has been presented for organizing inputs to LCOE modeling
- A new cost taxonomy has been demonstrated with the concepts of basic power plant, cost adders, and power block introduced
- Key performance inputs into the PV-LCOE have been reviewed
- An equation has been presented to perform simple PV-LCOE computations
- Based on the tool, the first PV power plant markets below € 0.10 / kWh have been demonstrated
Acknowledgements

- Based on “CHARTING THE PROGRESS OF PV POWER PLANT ENERGY GENERATING COSTS TO UNSUBSIDIZED LEVELS, INTRODUCING THE PV – LCOE FRAMEWORK” by Matthew Campbell, SunPower Corporation. (including all equations)
- White paper available – conference organizers or email me at zachary.struyk@sunpowercorp.com
PV - sLCOE

- Capacity Factor
- Annual O&M (1% of plant cost)
- PV Plant Cost (0.75%)
- Annual Degradation (7.5%)
- System Life (30 years)
- Cost of Capital (7.5%)
PV - sLCOE

PV - sLCOE = \frac{0.0115 \times \text{Capital Cost}_{W,A,C}}{\text{Capacity Factor}}