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CHARTING THE PROGRESS OF PV POWER PLANT ENERGY GENERATING COSTS TO UNSUBSIDIZED LEVELS

INTRODUCING THE PV – LCOE FRAMEWORK

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June 6, 2012

SunPower 2012

- 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?

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Question: Since 2007 how much has PV power plant LCOE decreased?

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Question: When will PV power plants compete without subsidy?

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Where are we with tracking PV power plant costs today?

PV

BOS

Project scope differences make BOS comparisons and cost roadmapping challenging

			Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7
Panel		PV Panel	Yes	Yes	Yes	Yes	Yes	Yes	Yes
BOS	Power block	Tracker	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		DC collection system	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Inverter station	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Basic plant	MV collection system	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Civil work - fence, roads, drainage	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Substation	No	Customer	Yes	Customer	Customer	Yes	Yes
		Prevailing wage	Yes	No	No	No	No	Yes	Yes
		Hilly site	No	No	Yes	No	No	Yes	No
		O&M building	Yes	Customer	Yes	No	Customer	Yes	Yes
		Sales tax	Yes	No	No	No	Yes	Yes	Yes
		Endangered species	No	No	No	No	No	Yes	No
		High wind conditions	No	Yes	Yes	No	No	No	No
		Snow conditions	No	No	No	Yes	No	No	Yes
		Landscaping for visual mitigation	Customer	No	Yes	No	No	Yes	Yes

BOS scope from 7 SunPower power plants: BOS cost difference between high and low project > 2x

Where are we with LCOE today?

PV

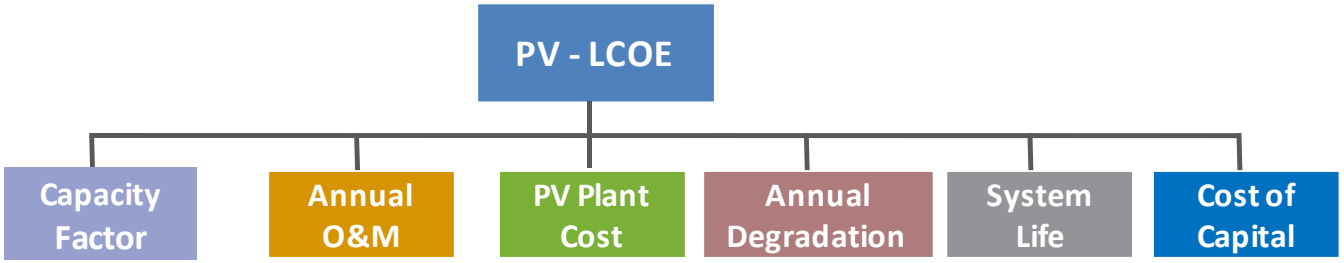
BOS

LCOE

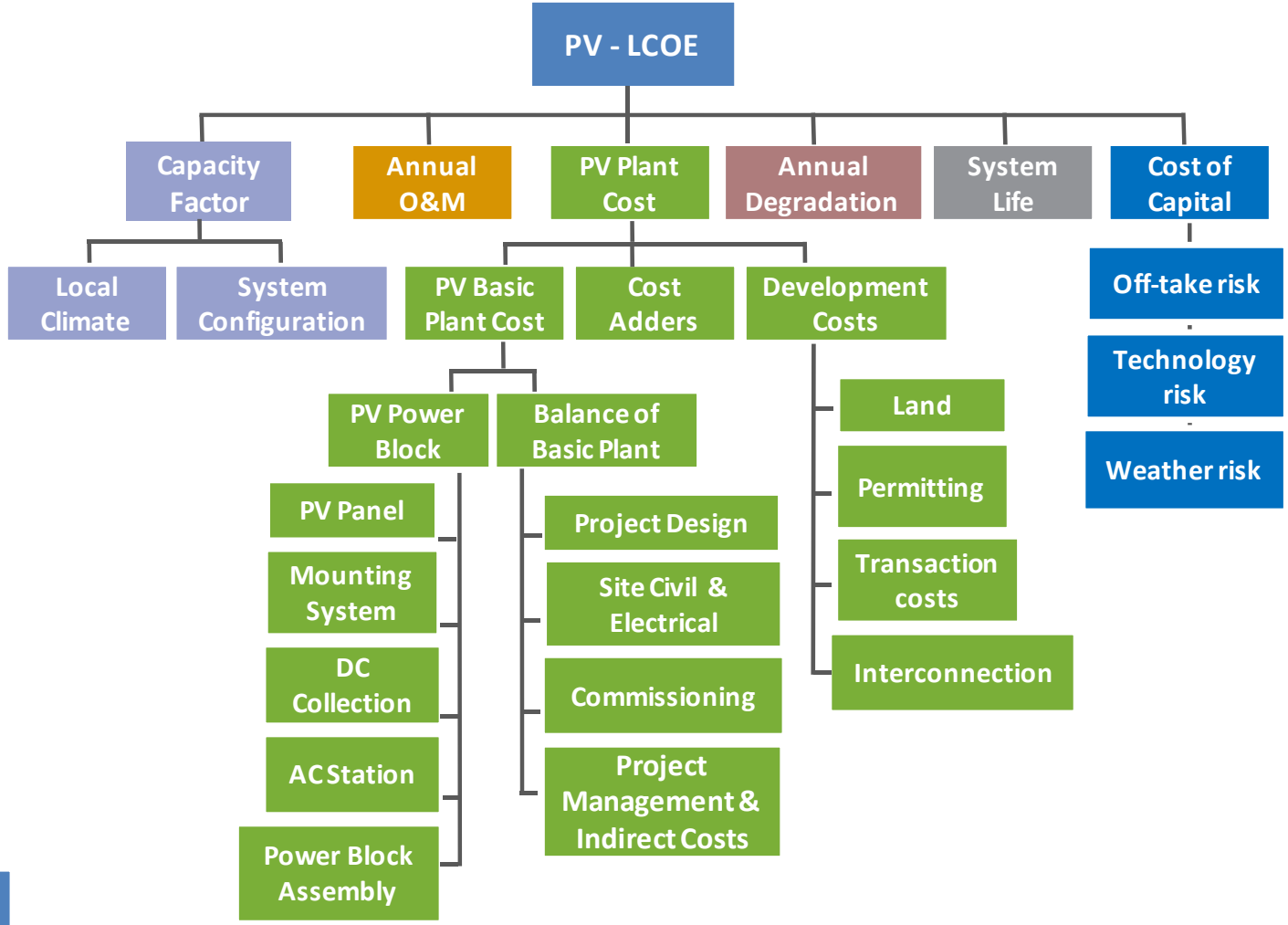
- Different LCOE models across industry
- Different underlying assumptions complicate comparisons
- Tax and other regional factors limit global comparability
- Complexity can make LCOE analysis inaccessible to non-finance experts

A standardized, simplified model is desirable to track industry progress

Introducing the PV – LCOE Framework

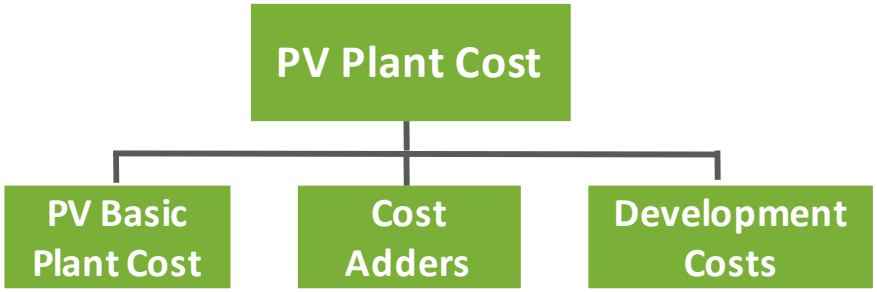


Introducing the PV – LCOE Framework



PV - LCOE

High-Level PV Power Plant Cost Categories



PV Plant Cost

The PV Basic Plant

Iberdrola
Alamosa – 30MW

PV Plant Cost

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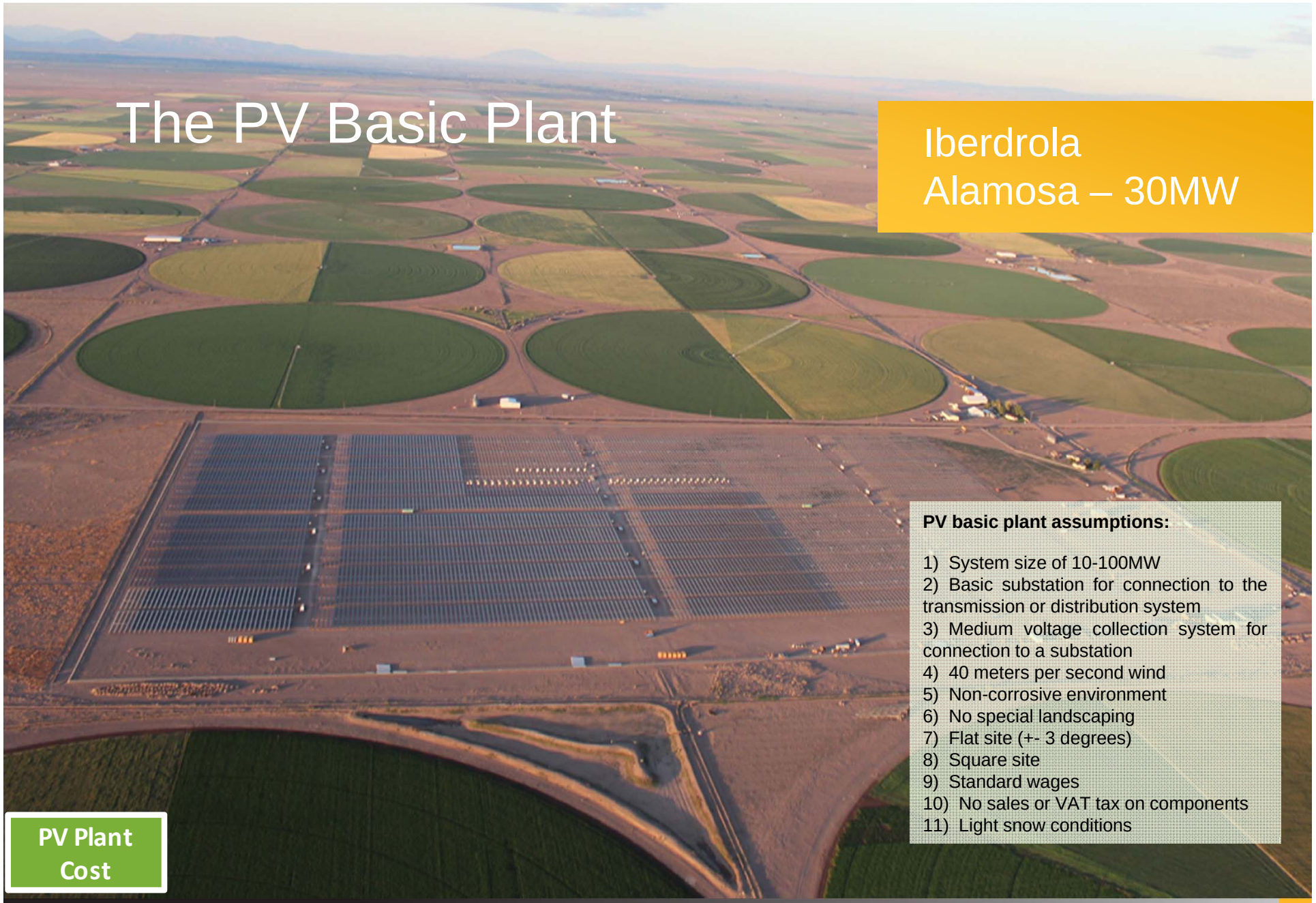
The PV Basic Plant



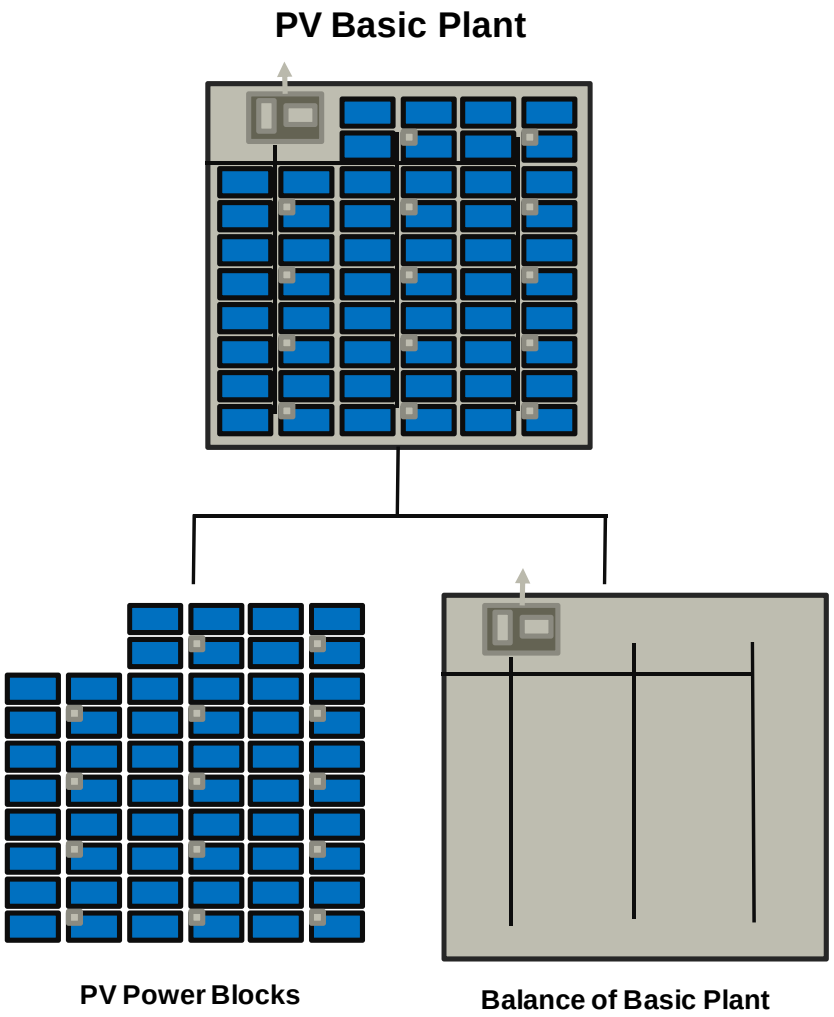
Iberdrola
Alamosa – 30MW

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

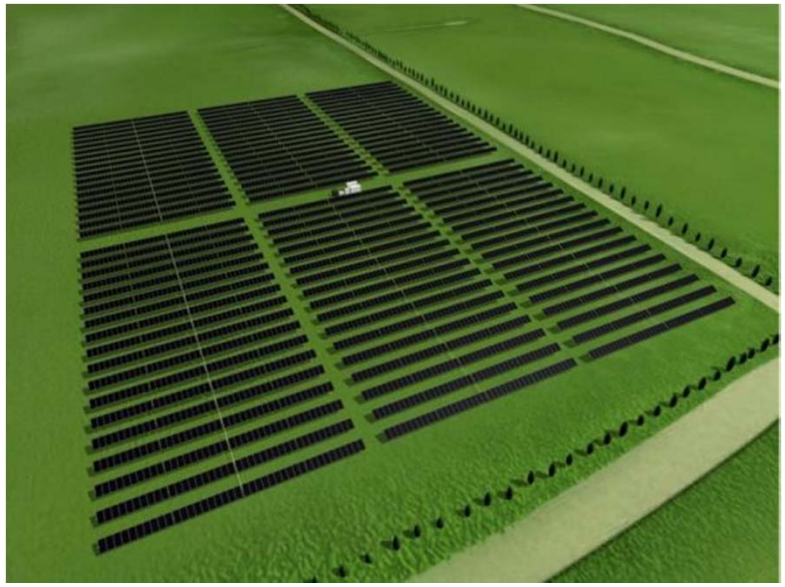
PV Plant Cost

High-Level PV Power Plant Cost Categories



PV Plant Cost

SunPower Oasis 1.5MW PV Power Block

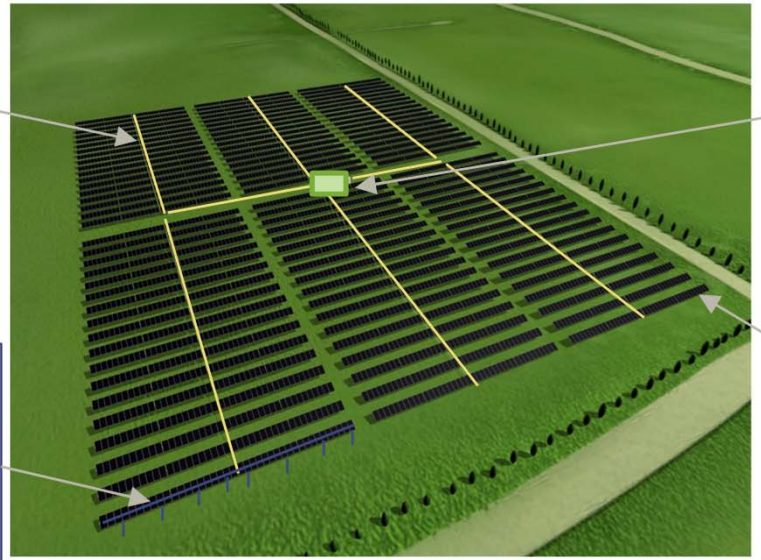


PV Plant Cost

SunPower Oasis 1.5MW PV Power Block

DC Collection
Array wire
DC feeders
Combiner boxes
Conduit
Trenching

AC station
Inverters
SCADA
MV transformer
AC conduit
Equipment pad



Mounting system
Tracker or fixed structure
Mechanical controls
Module attachment
Foundations

PV panel

PV Plant Cost

PV Power Block – AC Station

SunPower Oasis 1.5MW AC Station

PV Plant Cost

PV Power Block – Mounting System

SunPower Oasis - T0 Tracking System

PV Plant Cost

PV Power Block Assembly

SunPower Oasis – Power Block Assembly

PV Plant Cost

Capacity Factor Drivers

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

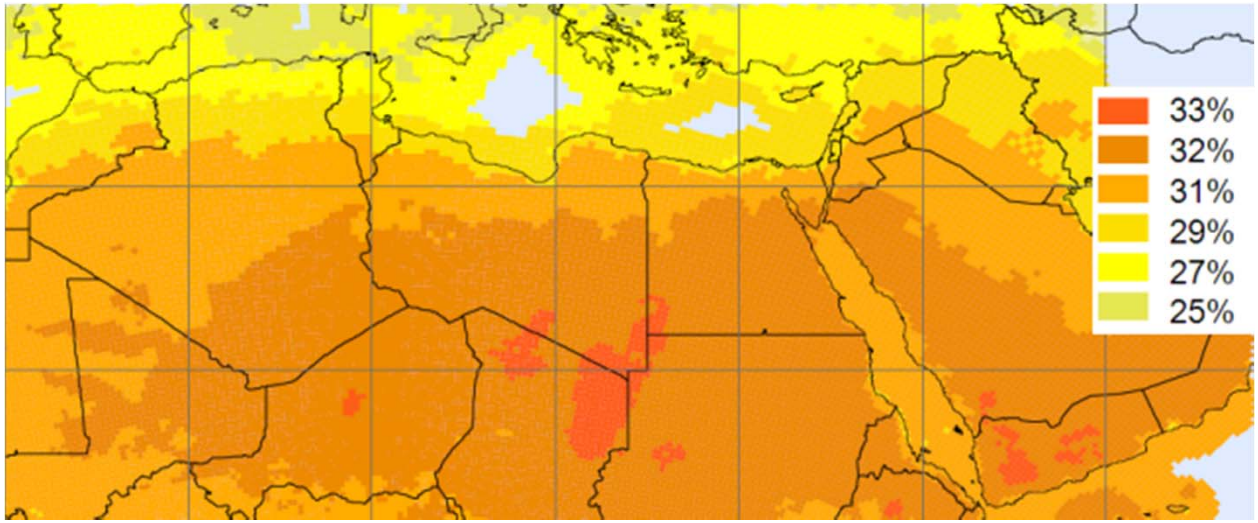
Major capacity factor drivers:

- 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

Capacity Factor

Sample Capacity Factors



Approximate 1-axis horizontal tracker PV power plant capacity factors

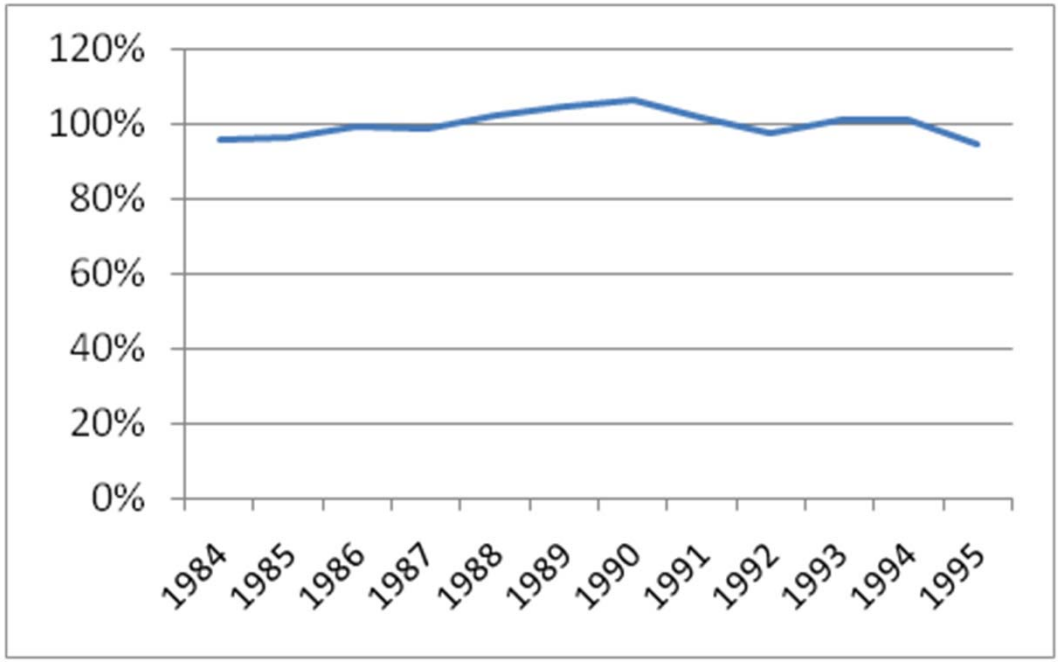
Capacity Factor

Discount Rate / Cost of Capital Drivers

Off-take risk	
Government FIT	Credit rating of the country providing a FIT guarantee
Utility PPA	Credit rating of the utility signing the PPA agreement
Merchant plant	Market price volatility in a wholesale power market
Performance risk	
Weather risk	Weather materially differs from that modeled in the plant's performance predictions
Technology risk	Technology underperforms relative to predictions
O&M risk	Operations and maintenance costs exceed those forecasted in project financial model
Property risk	
Damage	System damaged by severe storm or seismic event
Theft	Theft of system components

Cost of Capital

Solar Resource Risk



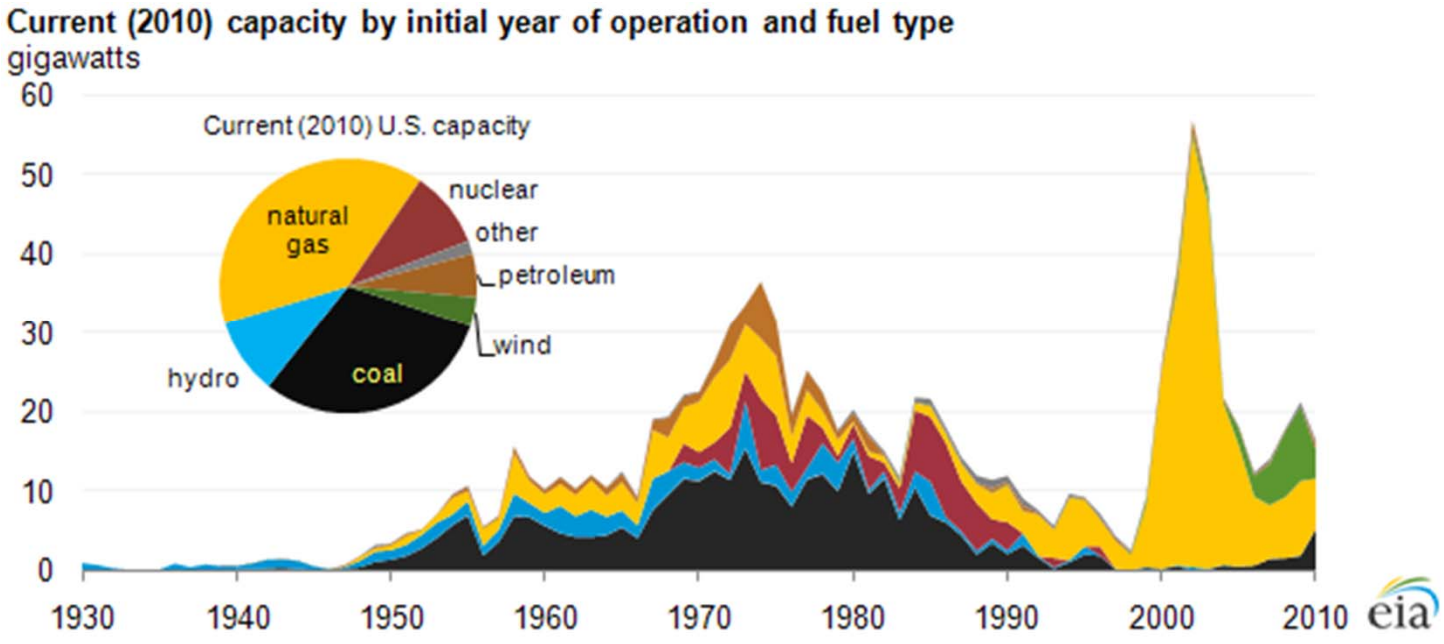
Predicted power plant output based on measured annual weather data for Southern California power plant

PV power plants generate very consistent returns similar to a bond

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

Cost of Capital

Power Plant System Life



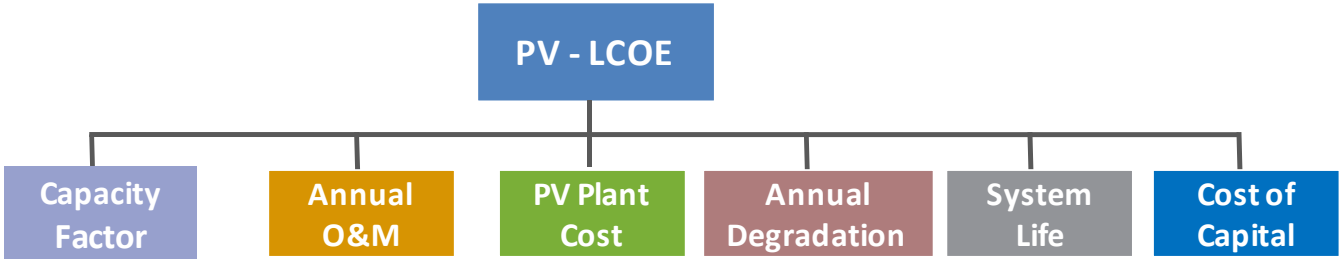
51% of USA generation older than 30 years

System Life

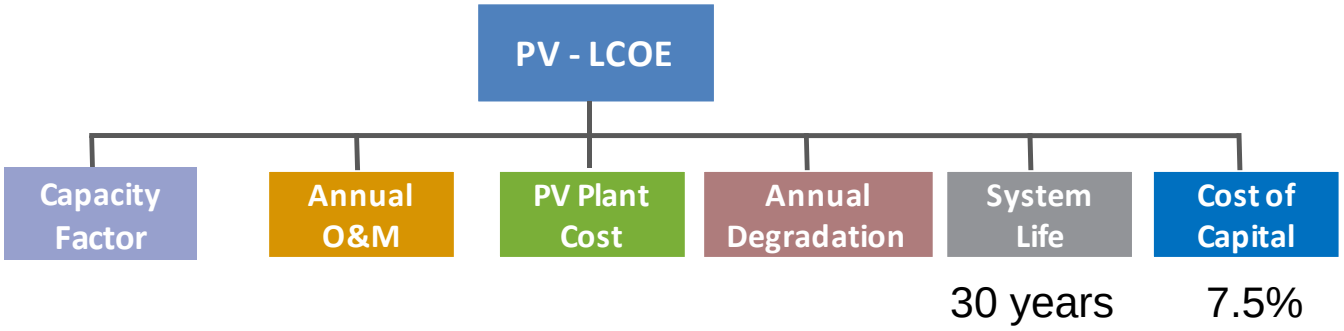
…and 73% of coal power plants are older than 30 years, why can't PV achieve a similar lifetime?

System Life

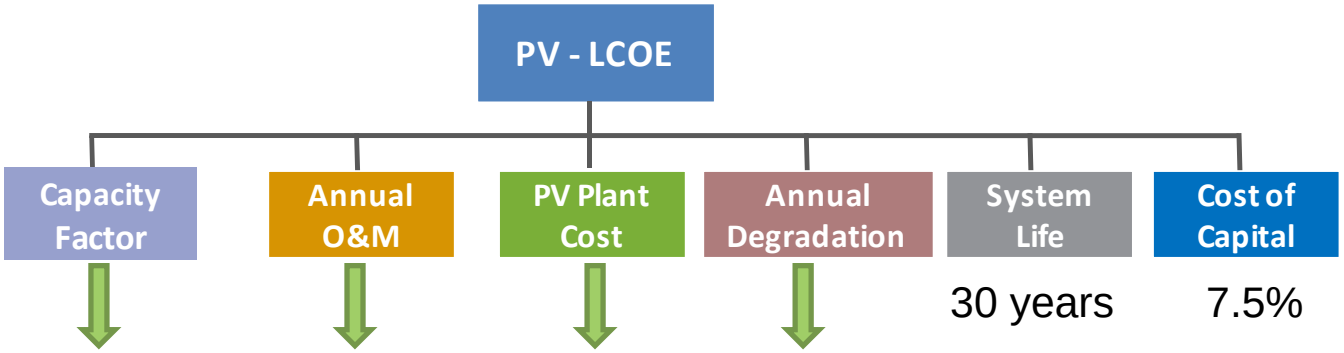
The PV-LCOE Equation



The PV-LCOE Equation



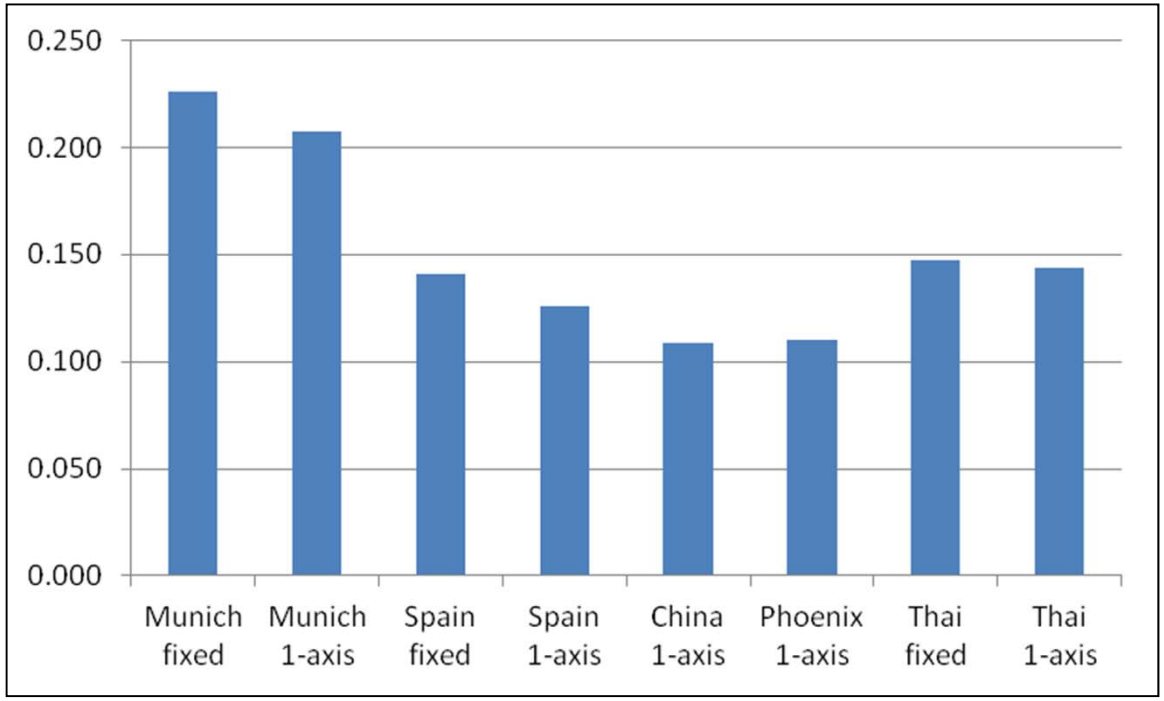
The PV-LCOE Equation



$$\text{PV - LCOE} = \frac{0.085 * \text{Capital Cost}_{W\,AC} + \text{Annual O\&M}_{W\,AC}}{8.76 * \text{Capacity Factor}_{AC} * (1 - \text{Degradation Rate} * 8.4)}$$

PV - LCOE

PV LCOE Sample Results



	DC/AC ratio	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Input Variables	Capital Cost ($/Wdc)	2.60	2.70	2.60	2.70	2.50	2.70	2.15	2.60
	Capital Cost ($/Wac)	*3.25*	*3.38*	*3.25*	*3.38*	*3.12*	*3.38*	*2.69*	*3.25*
	Yr 1 Capacity Factor	15%	17%	24%	28%	30%	31%	19%	24%
	O&M/Wac/yr	0.023	0.025	0.023	0.025	0.023	0.025	0.021	0.023
	Annual Degradation	0.75%	0.75%	0.75%	0.75%	0.75%	0.35%	0.75%	0.75%
	PV-LCOE ($/kWh)	**0.226**	**0.207**	**0.141**	**0.126**	**0.109**	**0.110**	**0.148**	**0.144**

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

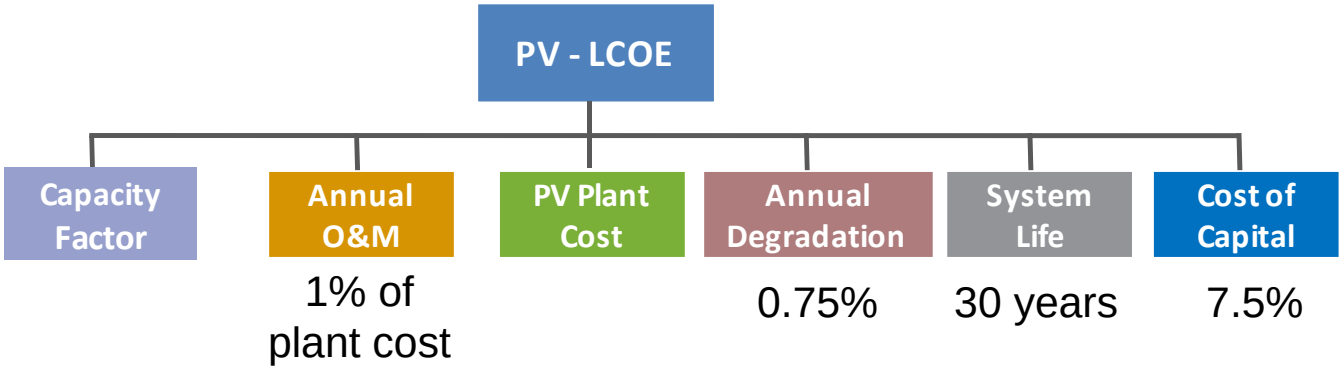
Acknowledgements

- 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

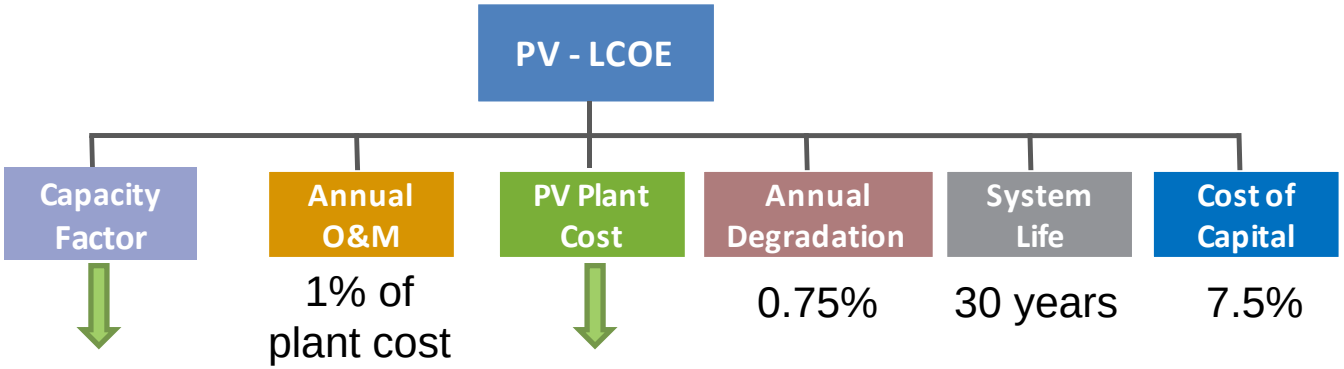
THE WORLD'S STANDARD FOR SOLAR™

Highest Efficiency | Highest Reliability | Guaranteed Performance

PV - sLCOE



PV - sLCOE



$$\text{PV} - \text{sLCOE} = \frac{0.0115 * \text{Capital Cost}_{\text{W AC}}}{\text{Capacity Factor}}$$