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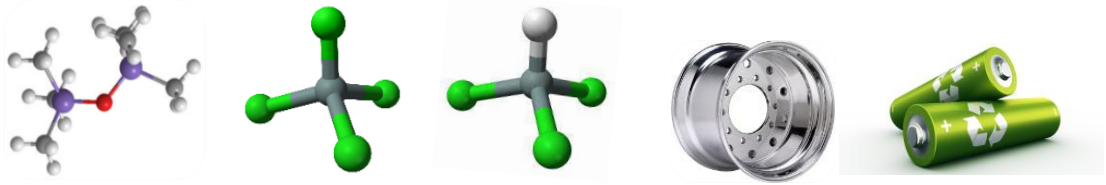
Solar Technology Conference India 2025

How to Lift PV Manufacturing to the Next Level



Route to mgSi and polysilicon production made in India

RCT solutions

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Dr. Wolfgang Herbst, 10.04.2025

Independent Technical, Engineering and Business Advisory Services

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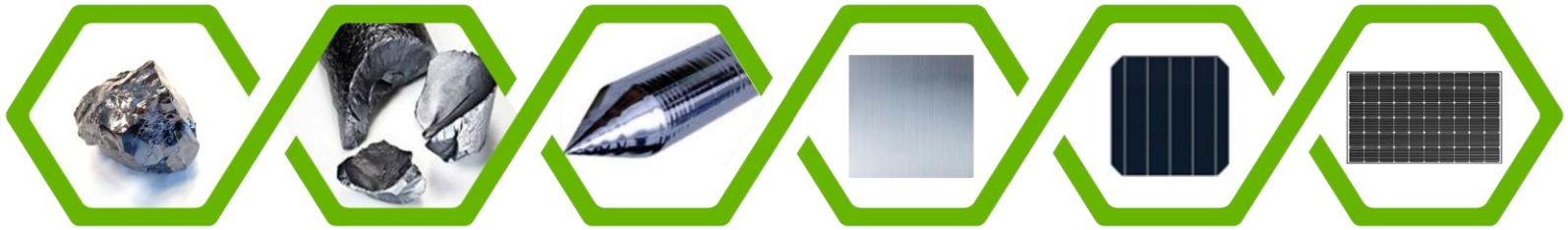
Scope



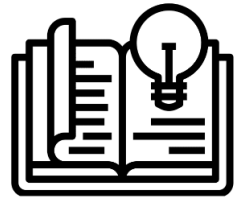
Services

Finance & Economics

Process &Technology

Strategy & Risk

Value & FEED Engineering



Operations & knowhow

Clients

Owners

Managers

Banks

Governments

Investors

Engineers / EPC

Businesses

Producers

Global Footprint in Silicon & PV

2012

Founded

14
Si
Silicon
28.086

25 +

Countries

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Market & Business Environment

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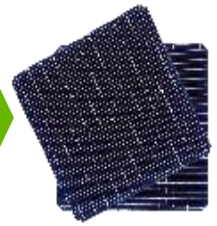
Silicon: Raw materials for various industries

ALUMINUM

SOLAR

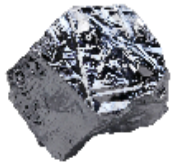
Ingot

Solar wafer



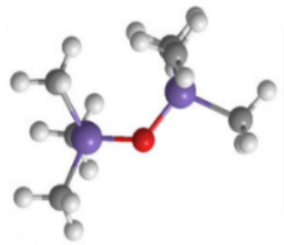
Solar cell

Solar module



mgSi

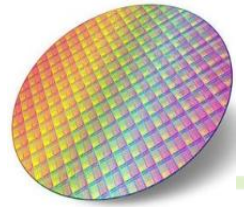
Polysilicon



SILICONES

Ingot

Semiconductor wafer



Semiconductor chips

Electronic device

SEMI

Silicon metal (mgSi) and polysilicon: Two different worlds

Metallurgical grade silicon (mgSi)

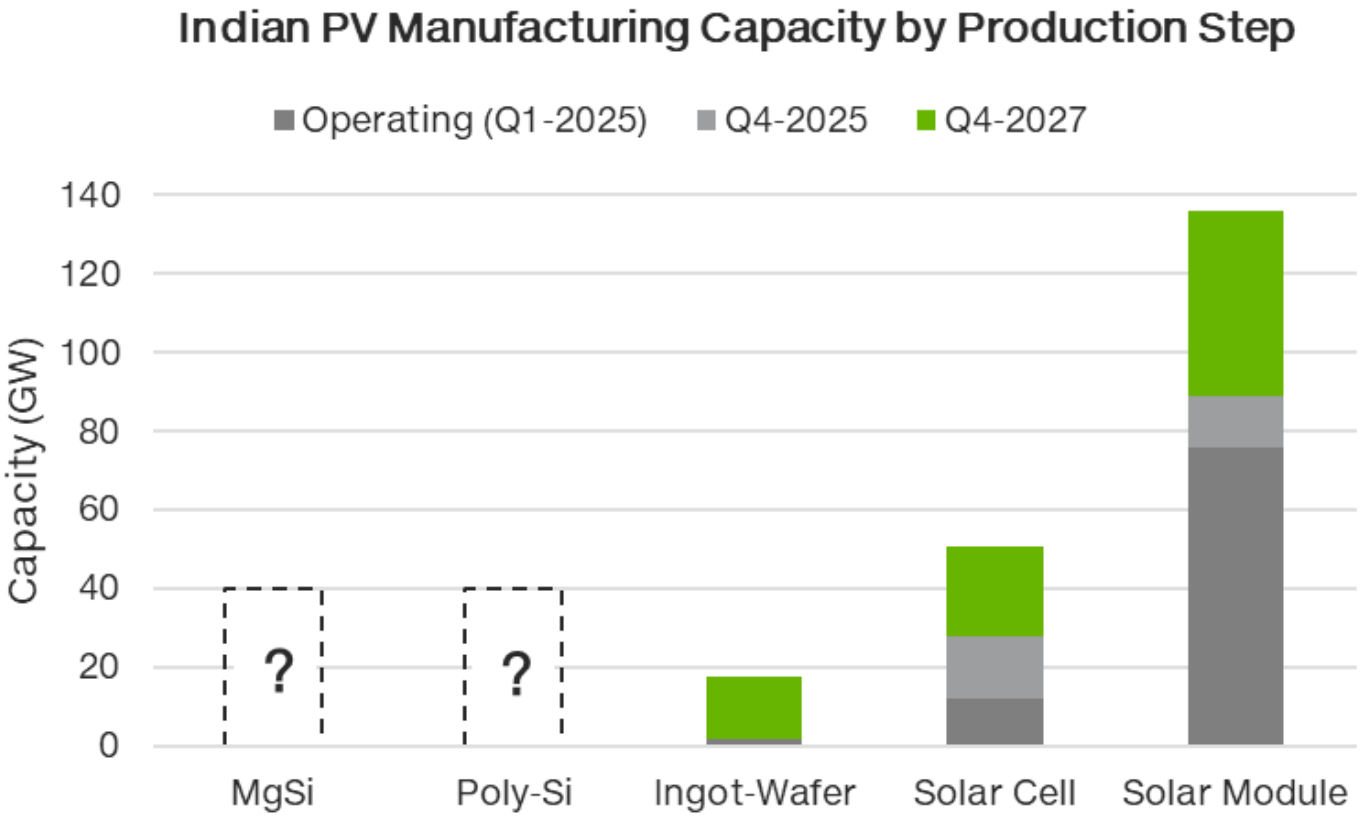
- Field of Metallurgy
- Submerged Arc Furnace Technology
- Hot Process (> 2000° C)!
- Similar to Ferrosilicon production
- **THREE BUSINESS SEGMENTS:**
  Al + Silicones + Solar/Semi

Polysilicon

- Chemical Industry
- TCS synthesis, purification by distillation, CVD deposition
- Chemicals, dangerous gases
- Similar to chemical production plant
- **ONLY FOR SOLAR AND SEMICONDUCTOR**

Integrated mgSi/Poly: Heat transfer and other synergies

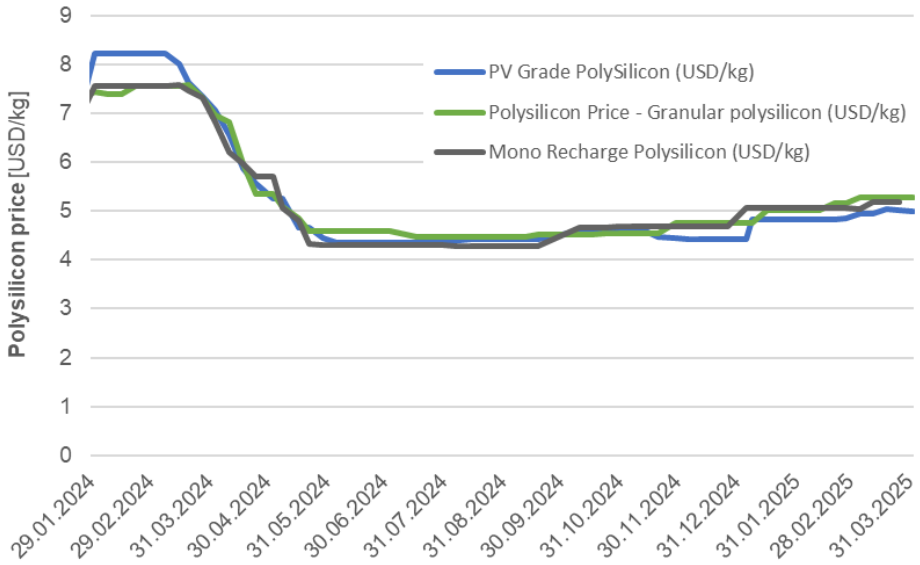
Silicon/Polysilicon: A gap in India's PV industry



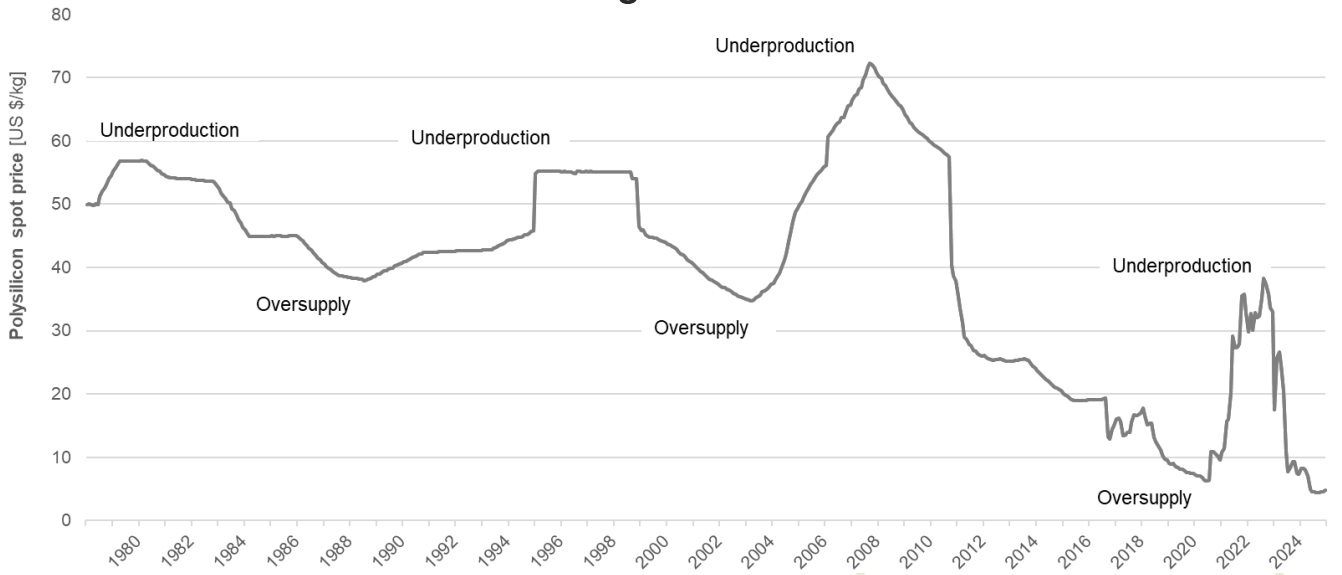
- India: One of the largest PV manufacturing hubs outside China
- Large domestic PV demand
- Push for more independence: PLI, custom duties, DCR and Make in India programs
- **Large gap in upstream, especially silicon**

Challenges: Polysilicon price levels and volatility

short-term view



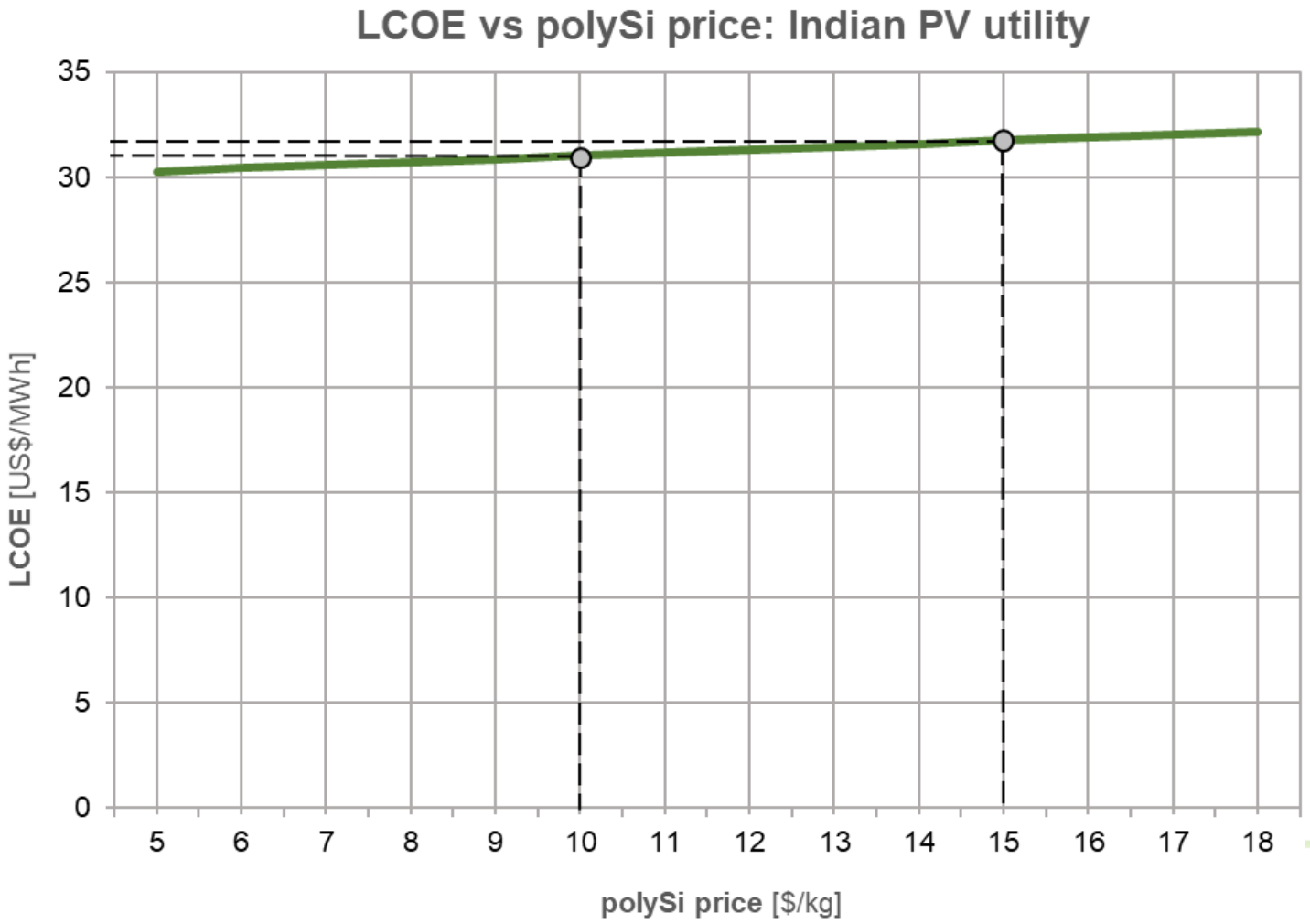
long-term view



- 5 $/kg, how can that be profitable?
- Price recovery?
- Import barriers?

- Cycles of oversupply and overproduction since decades
- Anti-cyclical investments required?

Impact of polysilicon cost on utility LCOE



$/kg

$/kWh

An increase of the polysilicon price reflecting a more sustainable and/or a more ESG compliant polysilicon supply affects LCOE, but less pronounced as expected.

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How to make it happen: Quartz & Electricity

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Indian Quartz Production
Indian Minerals Yearbook 2022 – IBM

30-20 Quartz & Other Silica Minerals

The term 'quartz' is often referred to as a synonym for silica. Silica is one of the ubiquitous materials in the earth's crust. Quartz, quartz crystals, quartzite, silica sand, sand (others) and moulding sand are all coined together in one generic name 'silica minerals'. This is because all these commodities are essentially crystalline silicon dioxide (SiO_2) with variations mostly related to their crystalline structure and presence of minor or trace impurities. Silica occurs in several forms giving rise to different varieties.

Crystalline Varieties

The important varieties of crystalline quartz are vein quartz (massive crystalline quartz); milky quartz (white, translucent to opaque); ferruginous quartz (containing brown limonite and red haematite and almost opaque); aventurine quartz (containing glistening flakes of mica or haematite); cat's eye (opalescent greenish quartz with fibrous structure); rock crystal (clear, colourless, well-crystallised transparent quartz); amethyst (clear-purple or violet- blue), transparent quartz; rose quartz; smoky quartz; etc. Occurrences of massive crystalline quartz in veins or pegmatites have been recorded in almost all the States.

Clastic or Granular Varieties

These varieties include sand consisting largely of unconsolidated quartzose grains (0.06 mm to 2 mm diameter), gravel consisting largely of unconsolidated coarse quartzose grains or pebbles (2 mm to 8 mm in diameter), sandstone and quartzite. Quartzite is a granulose metamorphic rock consisting essentially of quartz and sandstone cemented by silica which has grown in optical continuity around each grain. Occurrences are reported from Andhra Pradesh, Bihar, Delhi, Haryana, Karnataka, Kerala, Madhya Pradesh, Rajasthan,Tamil Nadu, Uttar Pradesh, etc. The silica sand from Naini area in Allahabad district, Uttar Pradesh is of a very high quality.

Cryptocrystalline Varieties

This group includes chalcedony, agate, jasper, onyx, flint and chert. These varieties appear non- crystalline (amorphous) in hand specimens, but under microscope show double refraction which reveals their concealed crystalline nature.

Table-1: Statewise Production of Quartz

(In tonnes)

State	2019-20	2020-21	2021-22
Rajasthan	5744000	3037988	2799048
Andhra Pradesh	878270	547390	-
Telangana	813816	-	-
Gujarat	-	-	-
Maharashtra	245050	-	-
Karnataka	127064	71020	-
Odisha	148	2589	1458

Source: As received from State DGMs and their websites.

Note : " - " NA

Table-3: Statewise Production of Quartzite

(In tonnes)

State	2019-20	2020-21	2021-22
Andhra Pradesh	525726	851897	-
Gujarat	-	-	-
Rajasthan	17000	120079	-
Odisha	72352	86668	173813

Source: As received from State DGMs and their websites.

Note : " - " NA

FUTURE OUTLOOK

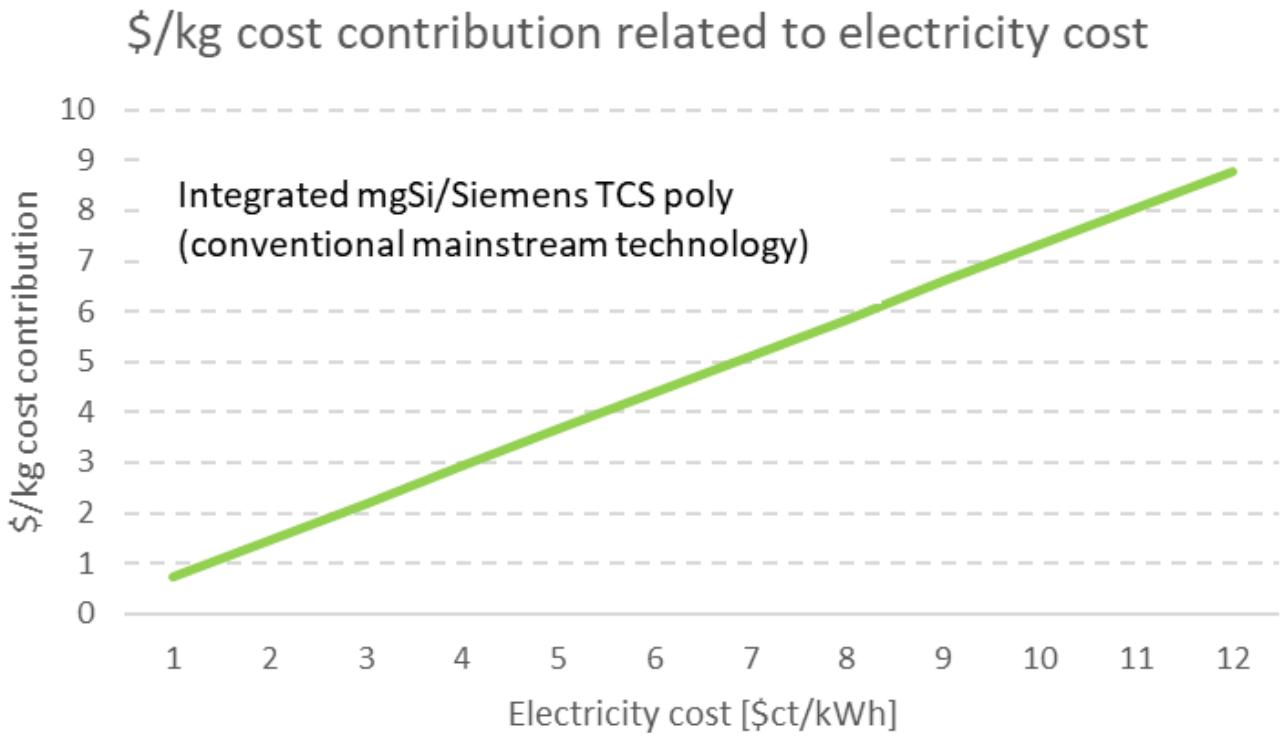
According to its suitability for different purposes, quartz & silica minerals are named as building sand, paving sand, moulding or foundry sand, refractory sand or furnace sand, glass sand, etc. The future market demand of quartz and silica minerals will depend on its application. However, the main use of silica minerals is in the manufacture of different types of glasses, natural silica sand being the preferred material in the Glass Industry. In India, quartz, quartzite and silica sand are used mainly in glass, foundry, ferroalloys, refractory industries and also as building materials. Silica sand is used in the Oil Industry for the hydraulic fracturing process as it helps in the extraction of gases. The market demand of silica minerals may get very high due to increased use in horizontal well drilling by oil companies.

The demand for quartz, silica sand, moulding sand and quartzite is increasing over the years to cater to the requirement of ferrosilicon, silico-manganese, silico-chrome, silica refractories, glass and for moulding & casting purposes. The requirements of these products are linked up directly with Iron & Steel Industry including alloy steel production. Further, setting up foundries and enhancing their capacities are also linked with Metallurgical Industry. There are very good prospects of increasing the production and also the export of quartz and silica minerals to the neighbouring countries.

Source: Indian Minerals Yearbook 2022 – IBM

- Quartz is no longer just a mineral — it's becoming a strategic pillar in the industries shaping the future. With rising demand across glass, metallurgy, foundries, and energy, quartz, quartzite, and silica sand are stepping into the spotlight.
- **Driving this momentum is the increasing need for metallurgical-grade silicon — a key input in the photovoltaic panel supply chain — placing high-purity quartz at the core of the global clean energy transition.**
- But it doesn't stop there. This growing demand also opens doors to boost local industrial development, creating new business opportunities, jobs, and value chains closer to the source.

Electricity supply is key for silicon/poly



Middle East Oil&Gas

Lignite power Xinjiang

Green Hydro power

China East cost

EU Mixed power grid

Stable electricity and large connection power required at low price

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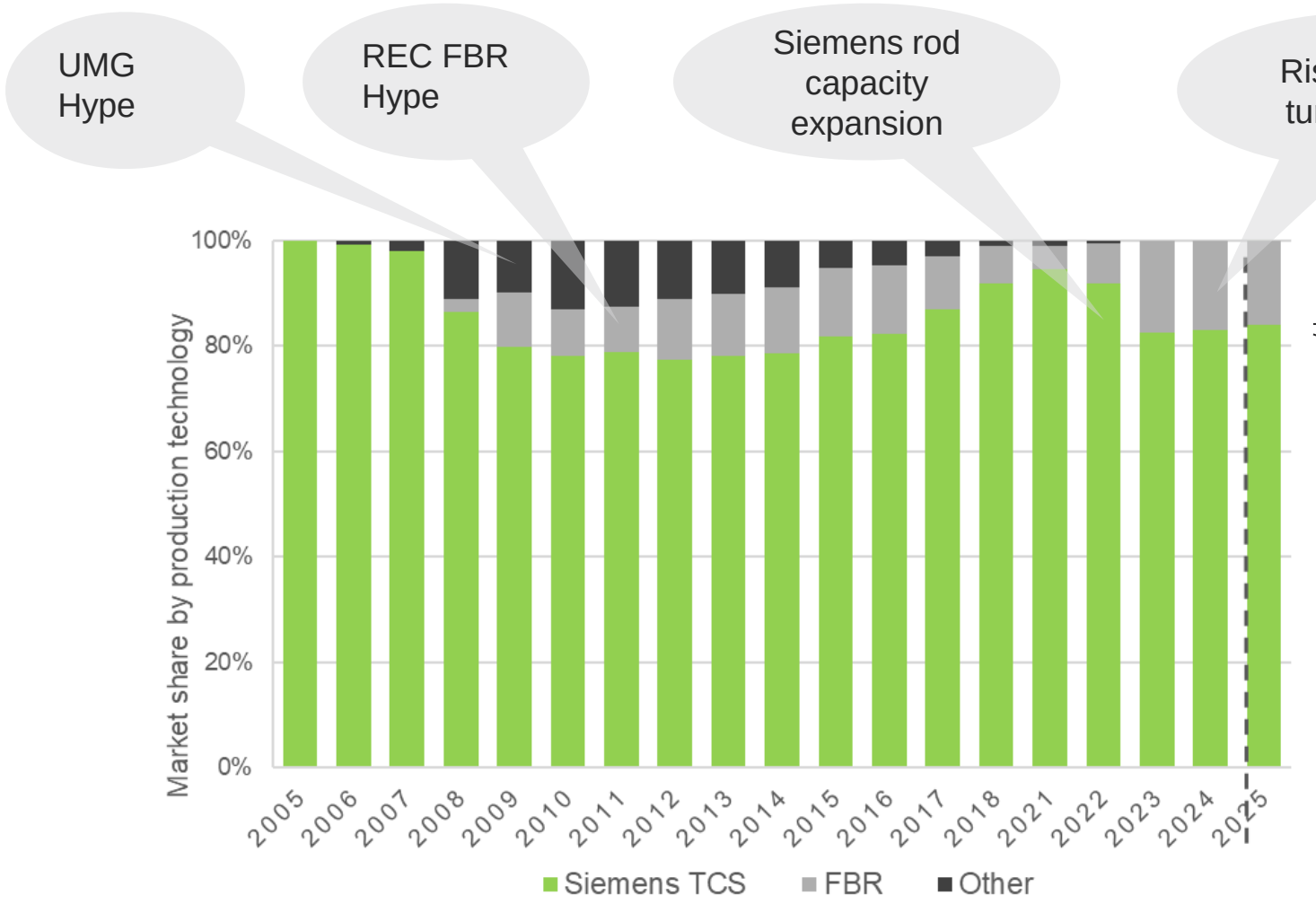
Siemens/FBR market share development

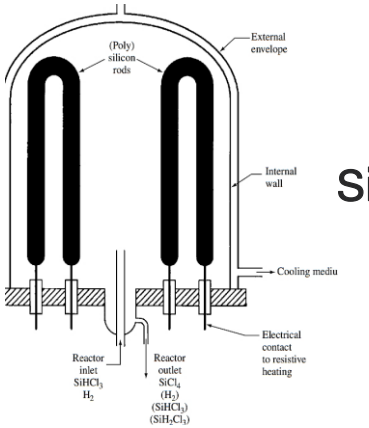


Future of FBR?

- Siemens/TCS dominant over decades
- Race to FBR practically driven by a single company: GCL

Source: CPIA, ITRPV, Viridis.iQ

Production technology alternatives: Standard Siemens route vs. FBR technology



Siemens TCS/CVD

- Mature technology, dominating the market since decades
- Batch process; Product: Silicon rods
- Cold wall reactor, requiring high electricity consumption (~60 kWh/kg)
- Reduced productivity due to low TCS conversion rate (~15%)
- Semiconductor quality capable

FBR Technology

- Technology with higher cost saving potential
- Product: Granular silicon
- Excellent gas-solid contact: 100% conversion
- Hot wall continuous reactor with low electricity consumption rate (<20 kWh/kg)
- Highly differentiated technology with high barrier to entry
- NOT FOR BEGINNERS

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How to Lift PV Manufacturing to the Next Level

How to make it happen: Structured project development

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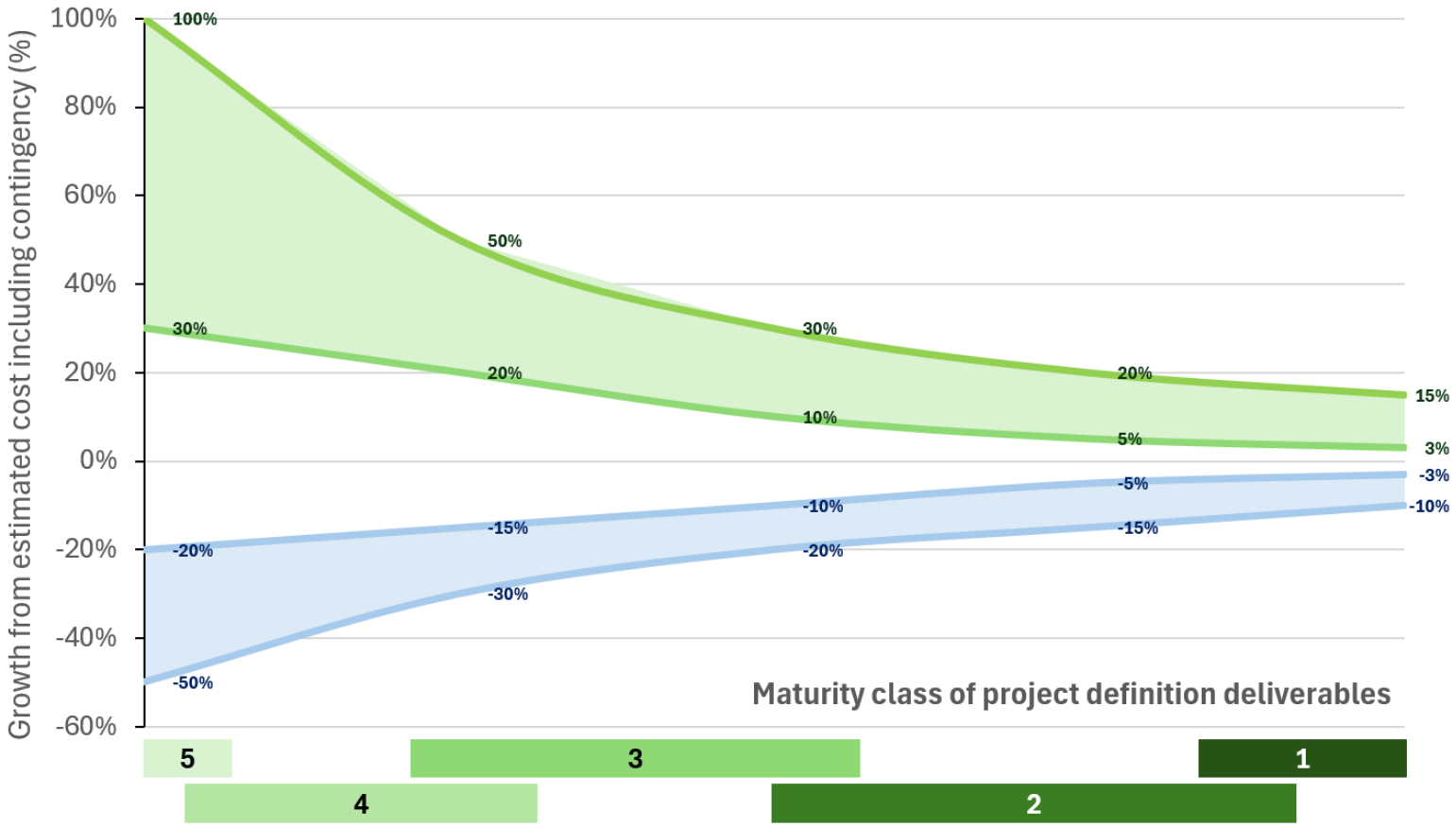
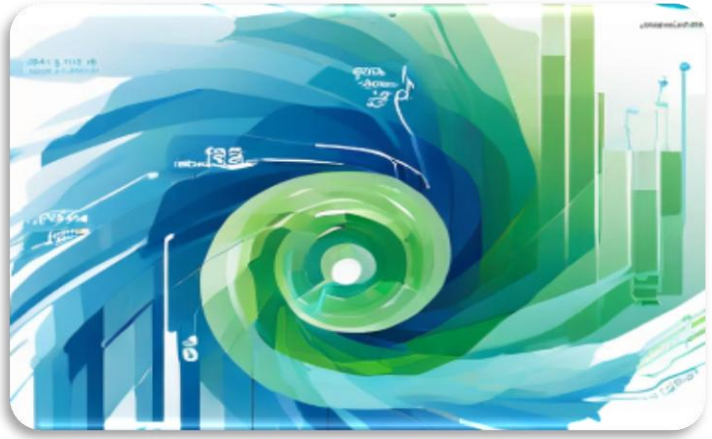
AACE Methodology for Process Industries



- Accuracy bandwidths are reduced during project development
- Engineering, budgeting and planning phases shrink the uncertainty of input variables
- Project variance is project specific = no two projects are the same.

Early-stage finance strategy decisions can also be led of course by focusing on lesser important variables that may not have a large impact at later maturity stages.

Integrated Analysis for Risk Mitigation

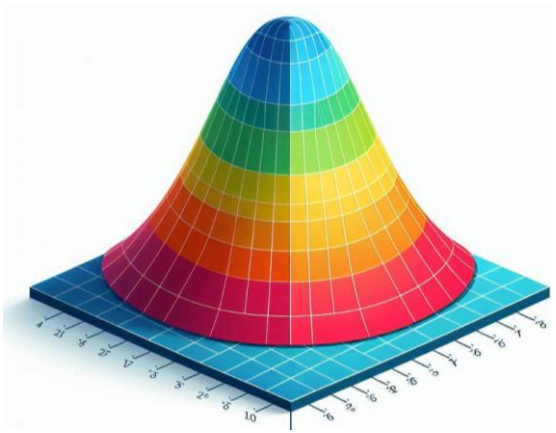


Tornado Analysis

- Identifies key variables and their impact on financial outcomes.
- Visualizes sensitivities and relationships in input variables.

Heat Map Analysis

- Visualizes risk levels for different combinations of variables.
- Identifies critical variable combinations to categorize risks.



Monte Carlo Simulation

- Probabilistic view of potential outcomes and likelihood of achieving specific financial targets.
- Improves contingency requirements and risk mitigation.

- Integrated analysis gives comprehensive understanding of a project's financial risks and opportunities
- Allows for proactive risk mitigation strategies, informed decision-making and more accurate financial planning.

Base Case Assumptions

- Generic “India” location
- ViQ database assumptions used for OPEX, labor, materials and equipment & construction costs
- Class level and maturity is **NOT** just related to engineering phases, but includes many other aspects
- Uncertainties decrease with project maturity, as estimates become more accurate
- Variances are project specific – not a one size fits all analysis
- Pricing assumptions extrapolated from CRU data as all in costs including freight, duties, handling, etc.

Uncertainty of input data	Project development maturity		
	Class 4	Class 3	Class 2
CAPEX	±20%	±15%	±5%
Labor	±15%	±10%	±5%
Materials	±20%	±10%	±5%
Electricity	±25%	±10%	±5%
Sales price	±25%	±15%	±5%

Base Case Assumptions (integrated mgSi/polySi plant)

Base case data sets and ranges of project variance

Input data		Number of trials	30000		CE stage
Parameters	Unit	Base case data set	Range Max	Range Min	Standard deviation
CAPEX	mUS$	929	1103	754	58
Labor	US$/kg	0.23	0.26	0.19	0.01
Materials	US$/kg	1.61	1.94	1.37	0.09
Electricity	US$/kWh	0.040	0.046	0.034	0.00
Sales price	US$/kg	12.00	15.00	9.00	1.00

Input data		Number of trials	30000		BE stage
Parameters	Unit	Base case data set	Range Max	Range Min	Standard deviation
CAPEX	mUS$	929	1043	814	38
Labor	US$/kg	0.23	0.25	0.21	0.01
Materials	US$/kg	1.61	1.77	1.45	0.05
Electricity	US$/kWh	0.040	0.044	0.036	0.00
Sales price	US$/kg	12.00	13.8	10.20	0.60

Input data		Number of trials	30000		DE stage
Parameters	Unit	Base case data set	Range Max	Range Min	Standard deviation
CAPEX	mUS$	929	975	882	15
Labor	US$/kg	0.23	0.24	0.22	0.00
Materials	US$/kg	1.61	1.69	1.53	0.03
Electricity	US$/kWh	0.040	0.042	0.038	0.00
Sales price	US$/kg	12.00	12.6	11.40	0.20

Class 4

- Feasibility assessment
- Strategic planning
- Viability assessment
- Alternate project schemes

Class 3

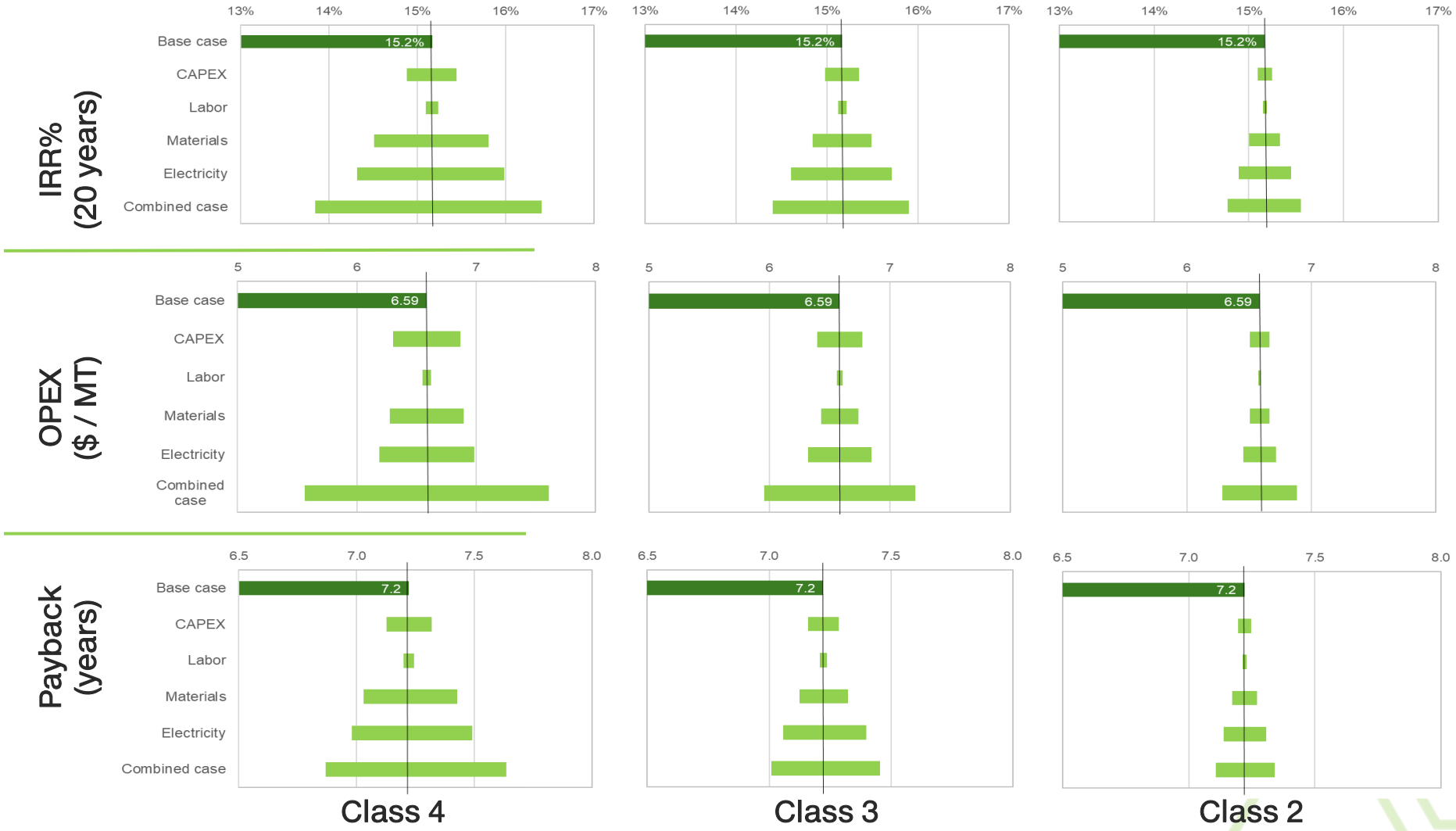
- Project Planning Phase
- Budgetary estimates
- Engineering design (basic)
- Initial project schedule

Class 2

- Baseline project cost
- Bid & tender based estimates
- Refined project timeline,
- Material take-offs

Disclaimer: The values shown are purely hypothetical, and any resemblance to actual projects is entirely coincidental. It is important to recognize that each project is unique, with specific characteristics that distinctly influence both implementation and operational costs. These variations must be carefully considered and integrated into the analysis throughout all stages of the project's lifecycle.

Tornado Chart Analysis: Individual sensitivities



Higher Maturity / Accuracy from Class 4 to Class 3 to Class 2

Individual sensitivities can be quantified and illustrated

Identification of the variables that most influence the project outcome, highlighting the key risks

Heat Map Analysis

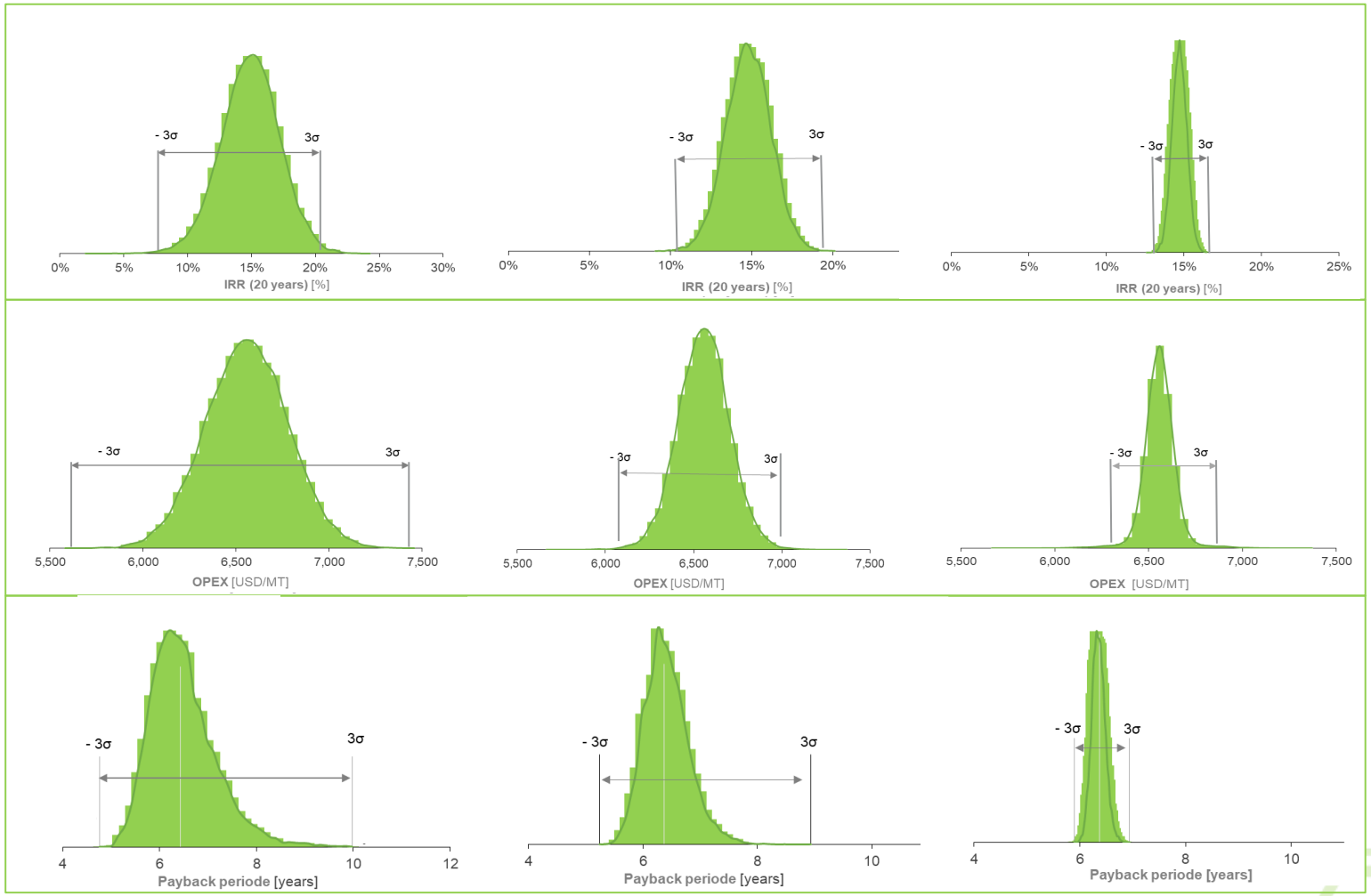
IRR (20 years)		Electricity price [$/kWh]									
		0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
Combined CAPEX [US$/kg]	22.5	17.8%	16.3%	14.6%	12.9%	11.1%	9.1%	6.8%	3.9%	-0.3%	-6.5%
	23.0	17.4%	15.9%	14.3%	12.6%	10.8%	8.8%	6.5%	3.6%	-0.6%	-6.8%
	23.5	17.1%	15.6%	14.0%	12.3%	10.5%	8.5%	6.3%	3.3%	-0.9%	-7.1%
	24.0	16.8%	15.3%	13.7%	12.0%	10.3%	8.3%	6.1%	3.0%	-1.1%	-7.4%
	24.5	16.5%	15.0%	13.4%	11.8%	10.0%	8.1%	5.8%	2.7%	-1.4%	-7.6%
	25.0	16.1%	14.7%	13.1%	11.5%	9.7%	7.8%	5.6%	2.5%	-1.7%	-7.9%
	25.5	15.8%	14.4%	12.9%	11.3%	9.5%	7.6%	5.4%	2.2%	-1.9%	-8.2%
	26.0	15.6%	14.1%	12.6%	11.0%	9.3%	7.4%	5.2%	2.0%	-2.2%	-8.5%
	26.5	15.3%	13.9%	12.4%	10.8%	9.0%	7.1%	4.9%	1.7%	-2.4%	-8.8%
	27.0	15.0%	13.6%	12.1%	10.5%	8.8%	6.9%	4.7%	1.5%	-2.6%	-9.0%
	27.5	14.7%	13.3%	11.9%	10.3%	8.6%	6.7%	4.4%	1.2%	-2.9%	-9.3%
	28.0	14.5%	13.1%	11.6%	10.1%	8.4%	6.5%	4.2%	1.0%	-3.1%	-9.6%
	0.0	14.2%	12.8%	11.4%	9.9%	8.2%	6.3%	3.9%	0.8%	-3.3%	-9.8%

Fixed sales price: 12.00 US$/kg

Visualizes risks in terms of probability and impact, helping to prioritize those that require the most attention such as:

- Electricity price is country / location specific and will vary within a narrower range than CAPEX
- CAPEX reduction strategies can be maximized with local content and hybrid sourcing approach

Monte Carlo Analysis: Quantify project contingencies



- Project contingencies and capital raising bandwidths can be narrowed with each maturity stage
- Refined OPEX ranges provide confidence and reduce uncertainty for investors and lending institutions
- Robust analysis strengthens project owner and investor confidence and allow for resource allocation to competitive advantages versus variance risks

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How to Lift PV Manufacturing to the Next Level

Summary

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What is required to make it happen?

- India: Strategic goal for independence supported by appropriate policies
- Resources
  - Quartz and reductants
  - Low cost, green and stable electricity supply
- Technology selection and solid engineering approach
- Structured project development approach
- Capital, solid financing

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