WHEN TRUST MATTERS

DNV’s Technical Bankability Level

Framework Applied to Crystalline Solar Technologies.

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Solar Project Lifecycle: DNV Solar Services

Products (Modules, Inverters & Mounting)

- Technology Review
- Manufacturing Evaluation

Equipment Manufacturers & Developers

Project Feasibility

- Utility Grid Integration
- Technology Review & Verification
- Energy Assessment
- Environmental Permitting

Developers & Equipment Manufacturers & Utilities

System Design & Development / Construction & Commissioning

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- Owner's Engineering
- Design Assistance

Developers & Financiers Utilities

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- Resource and Energy Forecasting
- Existing Asset Consulting, Refinancing and Decommissioning

Developers & Owners & Utilities

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Project reference: Product Due diligence Portfolio

DNV provided technical due diligence for below manufacturers globally

Project reference: Product Due diligence Portfolio

DNV provided technical due diligence for below developers in North America

What is "Technical Bankability"

- The demonstration that technical risks are managed to a level that financiers are comfortable with.
- A primary technical objective is the reliable prediction and modelling of long-term performance, which requires:

A. Durability and Safety: Are failure modes understood and mitigated? Have highly accelerated lifetime tests (HALT) been appropriately designed and validated with field data? Is the technology safe in the field and after end-of-life?

B. Manufacturing Quality: Can the technology be produced at scale with consistent quality? Are the process setpoints and margins understood? Are IQC/IPQC systems in place?

C. Can the long-term energy output in real-world conditions be accurately predicted and modeled based on measurable module characteristics?

A. Have highly accelerated lifetime tests (HALT) been appropriately designed and validated with field data?

False positive results: incorrect failure

- Test induces failure mode not observed in the field (need field data) e.g. acceleration factor too high.
- Test probes a failure mode that does not exist in technology

False negative results: incorrect acceptance

- Tests do not probe failure mode.
- See the modes of failure after field deployment
- Examples in silicon: LID, PID, LETID and UVID

Demonstrate failure modes with field data and validate HALT

B. Manufacturing Quality

- Can the technology be produced at scale with consistent quality?
- Are the process setpoints and margins understood?
- Are IQC/IPQC systems in place?
- Are Quality tests mitigating the field failures?

C. Can the long-term energy output be accurately predicted and modeled based on measurable module characteristics

- Current generation modeling tools accurately simulate both crystalline silicon and CdTe technologies, giving financiers strong confidence in long-term performance forecasts.

Technology	Modeling Basis	Typical Accuracy	Notes
Crystalline Silicon (c-Si)	Standard 5-parameter single-diode model	±2–3% annual	Highly reliable and well-validated
CdTe Thin Film	Modified one-diode with spectral & recombination adjustments	±4–7% annual	Accuracy depends on climate and spectral conditions

How to assess

NASA's "Technology Readiness Level" (TRL)

In the 1970's NASA developed the TRL.

TRL has been adopted by various industries, including defense, energy, healthcare, and manufacturing.

TRL not great for renewables as it doesn't include economic competitiveness

Readiness	Level	Characteristics
Low **Technology is in research stage.**	1	Basic principles observed and reports
	2	Technology concept and/or application formulated
	3	Experimental proof of concept
Medium **Technology features some characteristics for successful operation. Technological or conceptual improvements may be required.**	4	Technology validated in lab
	5	Technology validated in relevant environment.
	6	Technology demonstrated in relevant environment.
High **Technology is viable and meets technical requirements.**	7	System prototype demonstration in operational environment
	8	System complete and qualified
	9	Actual system proven in operational environment.

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NLR (Formerly NREL) developed “Technology Performance Level”

But TPL still does not cover “technical bankability”

Performance	Level	Characteristics
Low **Technology is not economically viable.**	1	Majority of key performance characteristics and cost drivers do not satisfy, and present a barrier to, potential economic viability.
	2	Some key performance characteristics and cost drivers do not satisfy potential economic viability.
	3	Minority of key performance characteristics and cost drivers do not satisfy potential economic viability.
Medium **Technology features some characteristics for potential economic viability under distinctive market and operational conditions. Technological or conceptual improvements may be required.**	4	Economic viability under distinctive and favorable market and operational conditions, some key technology implementation and fundamental conceptual improvements are required.
	5	Economic viability under distinctive and favorable market and operational conditions, some key technology implementation improvements are required.
	6	Majority of key performance characteristics and cost drivers satisfy potential economic viability under distinctive and favorable market and operational conditions.
High **Technology is economically viable and competitive as a renewable energy form.**	7	Competitive with other renewable energy sources given favorable support mechanism.
	8	Competitive with other energy sources given sustainable support mechanism.
	9	Competitive with other energy sources without special support mechanism.

DNV'S TBL: SIX PILLARS, ONE COMPREHENSIVE ASSESSMENT

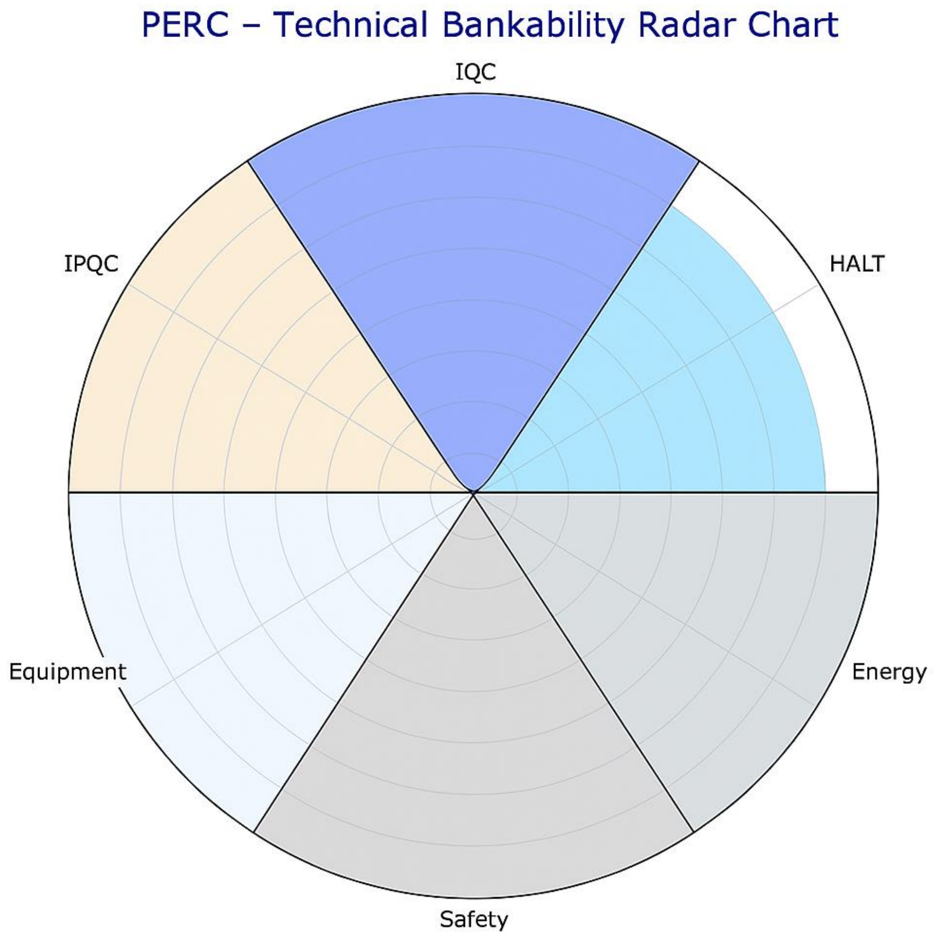
Technical Bankability Level

Six core pillars form the basis of a complete technology evaluation

Reliability & HALT	Incoming Quality Control (IQC)	In-line Process Quality Control (IPQC)	Equipment Management	Safety & Toxicity	Energy prediction & modelling
Is the module design and bill of materials (BOM) durable and safe throughout the expected lifespan?	Are the raw materials used have consistent quality across large – scale production?	Is the manufacturing process quality consistent across large-scale production?	Are the manufacturing equipment capable of producing consistent quality products across large-scale production?	Is the technology safe for human use? What are the environmental impacts?	Can the long-term energy output in real-world conditions be accurately predicted and modeled based on measurable module characteristics?

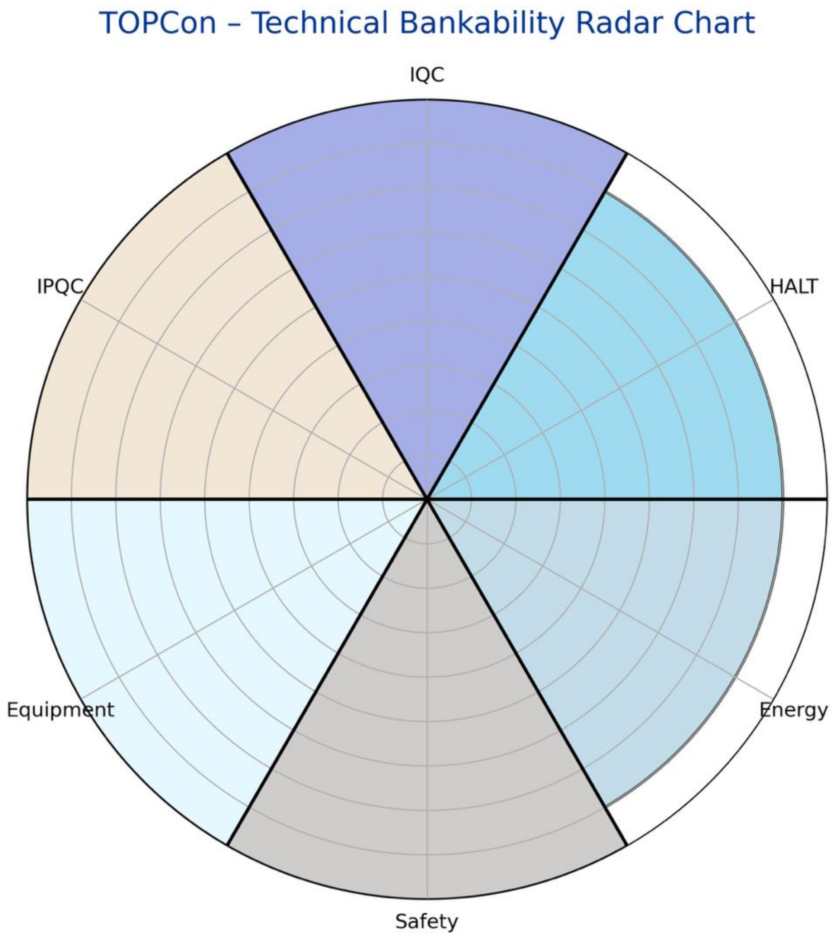
Bankability levels		Failure modes and HALT	Incoming quality controls (IQC)	In-line process quality control (IPQC)	Equipment management	Safety and toxicity	Energy prediction and modeling
Low Technology is not bankable. Failure modes are poorly characterized or controlled. Manufacturing methods are small scale and poorly defined. Energy prediction models are not developed.	1	Failure modes are not identified.	Quality and tolerances of incoming materials not well understood	Manufacturing risks are unknown	Equipment not selected	Toxicity not studied or understood	Energy yield behavior is unknown
	2	Rudimentary understanding of failure modes specific to new technology	Rudimentary knowledge of incoming materials quality requirements	Some manufacturing risks identified; process controls, off-line and in-line testing being developed.	Pilot line equipment selected	Safety failures studied	Ability to determine initial efficiency at STC
	3	Pilot projects with 10's kWp deployed in field.	Pilot production with basic understanding of IQC and impact on performance	In-line & off-line process metrology & tests developing for process consistency	Pilot line established. Equipment SOP and maintenance developing	IEC 61730 failures identified	Field deployment informs metastabilities and behavior
Medium Technology and manufacturing features some characteristics for potential bankability under distinctive market and operational conditions. Extensive field trials are expected to validate: a) field failure modes vs HALT, b) IQC and IPQC test procedures, and c) energy prediction models.	4	Fielded modules elucidate modes of failure beyond existing PV technologies, HALT developing	Pilot production provides early tests on incoming materials variability and tolerances.	In-line process metrology implemented on pilot line; off-line tests implemented starting validation of tests.	Pilot line process windows & equipment variability explored.	Toxicity understood but not managed	Approximate modeling parameters identified; initial measurement methods identified
	5	Field data informs failure modes and test design to probe failure modes. Begin planning large demonstration projects.	Medium understanding of incoming materials quality. Development of a suite of IQC tests and validation with final quality.	In-line process metrology implemented with SPC; destructive and non-destructive off-line tests implemented with SPC.	Equipment maintenance and calibration understood, process windows developing	Toxicity begins to be managed	Understanding of path-dependencies of efficiency/Pmax, parameterization and initial measurement
	6	HALT reproduces failure modes observed in the field. Build large demonstration projects.	Establishment of IQC testing and validation with performance and yield. Scale-up begins	SOP every process step, process monitoring and in-line testing developed, SPC and scale-up.	Equipment preventative maintenance understood, scale-up	Pass IEC 61730, toxicity managed	Algorithm and parameterization of metastabilities, spectral response, and thermal influences.
High Technology is bankable with generally understood and validated: a) field failure modes and HALT, b) IQC and IPQC test procedures, and c) energy prediction models.	7	Complete suite of HALT tests are established with validation data.	Well established understanding of the IQC testing tolerances & impact on performance and yield at scale-up.	SOP every process step, process monitoring and in-line testing validated, SPC at high scale.	At scale equipment maintenance, calibration, & set points implemented	Safety and toxicity managed & demonstrated	Demonstration and initial validation of capability of modeling energy yield.
	8	Further validation of HALT outcomes with field results in large demonstration projects	Operation of IQC testing, record keeping, non-conformity management, MES, at high-volume manufacturing	SOP established at every process step, process monitoring and in-line testing well developed, SPC validated at high volume.	Equipment set points defined, maintenance and calibration understood, MES integration	Safety and toxicity managed & demonstrated	Demonstration and validation of capability of modeling energy yield.
	9	Well understood failure modes & accelerated testing	Well understood, validated, and demonstrable IQC	Well understood, validated, and demonstrable IPQC	Well understood, validated, and demonstrable IPQC	Safe operation demonstrated	Energy yield modeling validated

DNV TBL Application to PERC Modules



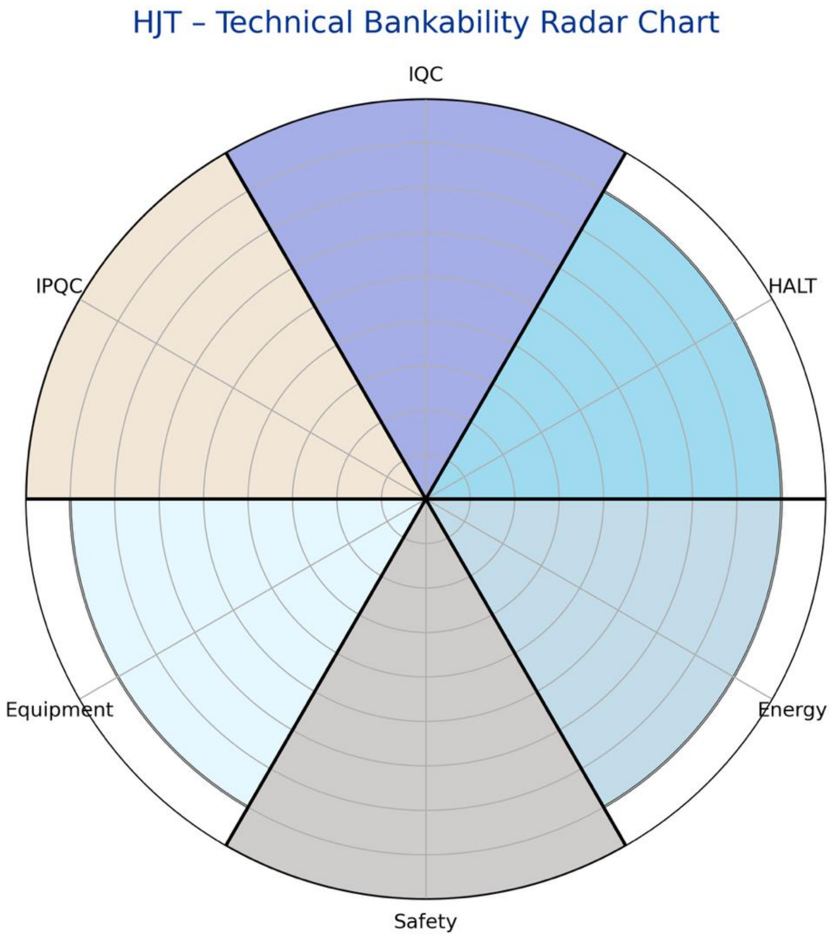
- Overall TBL Level: 8-9 – High bankability with strong field validation.
- HALT: Proven stress performance with PID/LETID verification, but risks related to module mechanical stability on trackers.
- IQC: Rigorous supplier qualification and traceability.
- IPQC: Mature SPC, EL/PL, and process stability controls.
- Equipment: Industrialized, calibrated, GW-scale reliability.
- Safety: IEC 61730 compliant with strong EHS governance.
- Energy Modeling: Predictable, validated long-term yield models.

DNV TBL Application to TOPCon Modules



- Overall TBL Level: 8 – High bankability with growing field validation.
- HALT: Established stress testing with ongoing validation of polysilicon/oxide interface, UVID reliability and risks related to module mechanical stability on trackers.
- IQC: Tight material control and strong supplier qualification for TOPCon-specific components.
- IPQC: Robust SPC, PL/EL metrology, and precise process windows for oxide and poly-Si layers.
- Equipment: Mature TOPCon-capable toolsets with added complexity during PERC-to-TOPCon transitions.
- Safety: Fully IEC 61730 compliant with standardized EHS practices for silane and polysilicon processes.
- Energy Modeling: Strong yield predictability driven by bifacial gains, with refinements continuing for AOI and rear-side effects.

DNV TBL Application to HJT Modules



- Overall TBL Level: 7–8 – High bankability with strong intrinsic stability and expanding field validation.
- HALT: Excellent stress-test performance with ongoing validation of TCO stability UVID reliability and risks related to module mechanical stability on trackers.
- IQC: Tight upstream control of N-type wafers, TCO uniformity, and low-temperature metallization materials with strong supplier qualification.
- IPQC: Highly sensitive process requiring precise SPC, PL/EL metrology, and strict control of a-Si and TCO deposition windows.
- Equipment: Specialized PECVD and TCO sputtering toolsets with higher calibration demands but strong stability once established.
- Safety: Fully IEC 61730 compliant with well-established EHS practices for PECVD and sputtering environments.
- Energy Modeling: Strong yield predictability driven by high bifaciality and low temperature coefficients, with refinement continuing for AOI and spectral effects.

Technical Bankability Level: guides for manufacturers to consider:

- **HALT (Reliability):** BOM-specific IEC 61215/61730 + IEC 63209 (UV/TC/DH/PID) and enhanced mechanical load (static/cyclic, torsion/transport) for large-format/tracker modules.
- **IQC:** Supplier qualification + change control (material/formulation/site/tooling); risk-based incoming sampling for critical BOM items. Lot-to-module traceability to enable rapid containment and stronger links between BOM, HALT results, and field outcomes.
- **IPQC:** Critical-to-quality (CTQ) parameters with SPC + reaction plans (lamination, stringing, layup, cure) and standardized inline EL/PL defect thresholds. MES “genealogy” linking module serial ↔ material lots ↔ recipes ↔ tool IDs ↔ operators for fast root-cause analysis.
- **Equipment Management:** Tool matching/comparability and calibrated metrology across parallel lines; documented PM schedules and drift limits/alarms. Scale-up evidence that yield and defect rates remain stable through ramp (pilot → mass production).
- **Energy Prediction & Modeling:** Stable model inputs (temp coef, bifaciality, AOI/IAM) and degradation assumptions with uncertainty bounds. Roadmap to reduce uncertainty using multi-climate field datasets (3–5+ years) and controlled technology iteration with documented parameter shifts.

Thank you

DNV helps translate test data, field evidence, and manufacturing maturity into bankable outcomes.

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