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Solar Power Development Process Workshop at NBET

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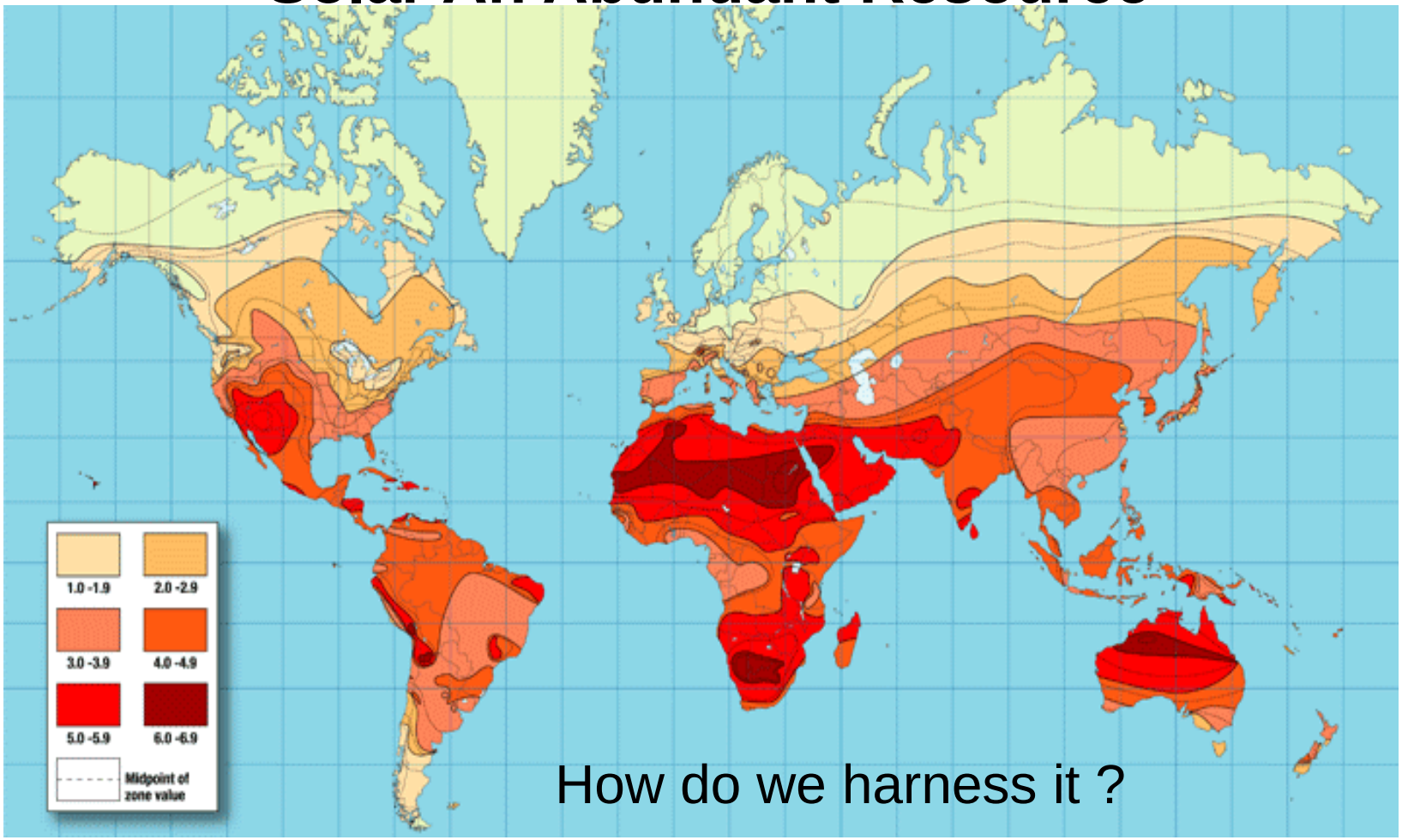
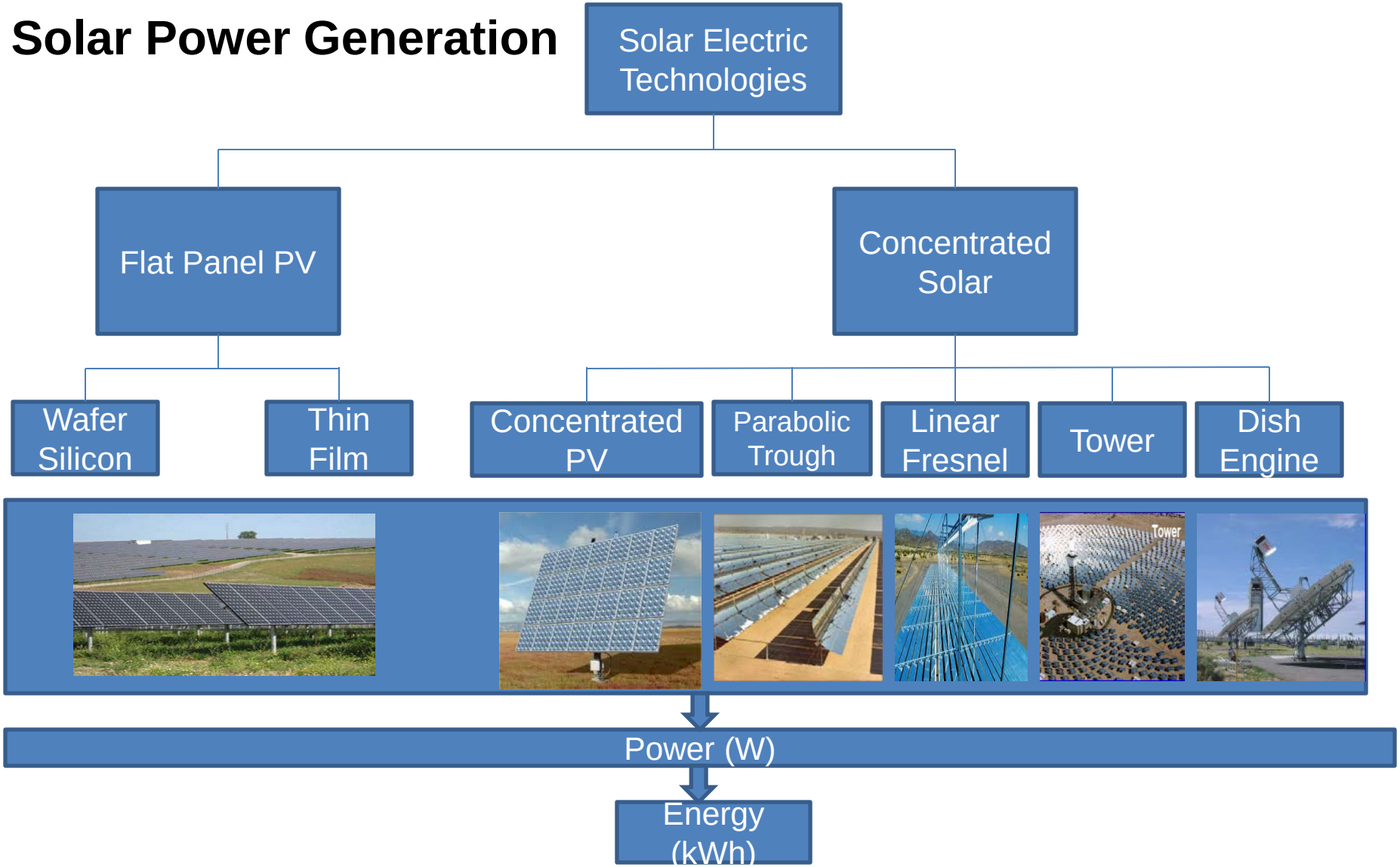
Solar An Abundant Resource



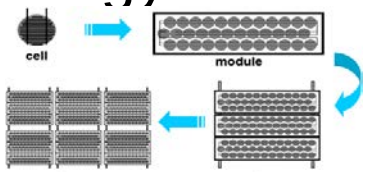
How do we harness it ?

Solar Power Generation



Basic Background

- Solar photovoltaic (PV) cells convert radiant energy to electricity.



  - Cells -> Modules -> Panels ->Arrays
  - Panels are combined together to achieve a desired output capacity
  - Modules are rated at Peak Power under Standard Test Conditions (STC) - 25 ℃, incident solar irradiance of 1000 W/m^2 and Air Mass 1.5 spectral distribution
- PV allows for distributed generation as well as utility scale power generation; off grid and grid-tied
- Panels generate DC and must be converted to AC for traditional applications (connection to grid or appliances load).

Basic Background

Components of a PV Power Plant

- Panels
- Balance Of System (BOS)
  - Mounting Systems
  - Inverters
  - Cable/Wiring
  - Controls
  - Transformers
  - Substation/Grid Integration

BOS - Modules/Panels

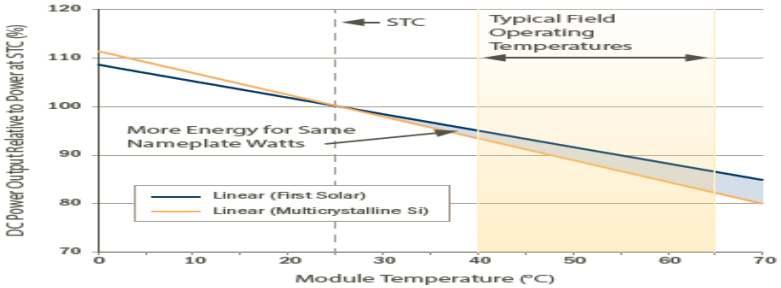
- Data sheet specification very important but is based on STC and must be viewed as such!
- No single PV technology is best (preferred) for all projects
  - Attention must be paid to characteristics (temperature, efficiency, performance, degradation rate etc.)
  - Evaluate project and associated technology on its own merit
- Panels are framed or frameless
- Useful life of good quality panel is 25 - 30 years
- Power output is warranted up to 25yrs, (mostly 20yrs) but panels' performance degrades over time and results in lower annual output.

Sample Data Sheet

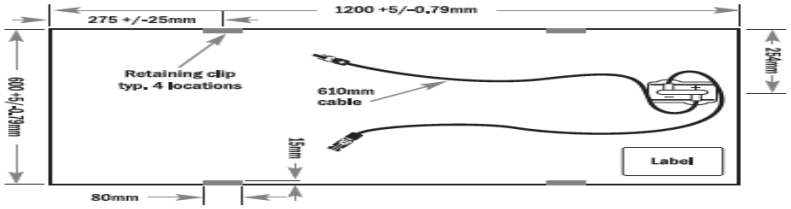
MECHANICAL DESCRIPTION	
Length	1200mm
Width	600mm
Weight	12kg
Thickness	6.8mm
Area	0.72m²
Leadwire	2.5mm², 610mm
Connectors	MC4[8]
Bypass Diode	None
Cell Type	Thin-film CdTe semiconductor, 216 active cells
Frame Material	None
Front Glass	3.2mm heat strengthened Series 4A™ includes anti-reflective coating
Back Glass	3.2mm tempered
Encapsulation	Laminate material with edge seal

MODULE NUMBERS AND RATINGS AT STC[4,5]						
NOMINAL VALUES		FS-4102-2 FS-4102A-2	FS-4105-2 FS-4105A-2	FS-4107-2 FS-4107A-2	FS-4110-2 FS-4110A-2	FS-4112-2 FS-4112A-2
Nominal Power (± 5%)	P_{MPP} (W)	102.5	105.0	107.5	110.0	112.5
Voltage at P_{MAX}	V_{MPP} (V)	67.0	67.8	68.6	69.4	70.2
Current at P_{MAX}	I_{MPP} (A)	1.53	1.55	1.57	1.59	1.60
Open Circuit Voltage	V_{OC} (V)	85.3	86.0	86.6	87.2	87.7
Short Circuit Current	I_{SC} (A)	1.74	1.74	1.75	1.75	1.75
Maximum System Voltage	V_{SYS} (V)	1500[6] / (1000 UL)				
Limiting Reverse Current	I_R (A)	4.0				
Maximum Series Fuse	I_{CF} (A)	4.0				
MODULE NUMBERS AND RATINGS AT 800W/m², NOCT[7] 45°C, AM 1.5[5]						
Nominal Power (± 5%)	P_{MPP} (W)	76.4	78.3	80.1	82.0	83.9
Voltage at P_{MAX}	V_{MPP} (V)	62.1	62.6	63.1	64.1	65.0
Current at P_{MAX}	I_{MPP} (A)	1.23	1.25	1.27	1.28	1.29
Open Circuit Voltage	V_{OC} (V)	80.4	81.0	81.6	82.1	82.6
Short Circuit Current	I_{SC} (A)	1.40	1.40	1.41	1.41	1.41
TEMPERATURE CHARACTERISTICS						
Module Operating Temperature Range	(°C)	-40 to +85				
Temperature Coefficient of P_{MPP}	T_K (P_{MPP})	-0.34%/°C				
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.29%/°C				
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C				

SUPERIOR TEMPERATURE COEFFICIENT



MECHANICAL DRAWING



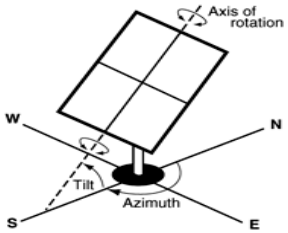
END-OF-LIFE RECYCLING

- Recycling services available through First Solar's industry-leading recycling program or customer-selected third party.

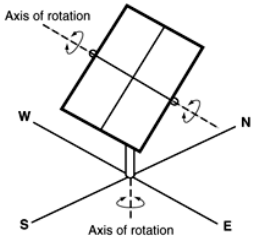
1 Testing Certifications pending.
2 Limited power output and product warranties subject to warranty terms and conditions.
3 Ensures 97% rated power in first year, -0.7%/year through year 25.
4 Standard Test Conditions (STC) 1000W/m², AM 1.5, 25°C
5 All ratings ±10%, unless specified otherwise. Specifications are subject to change.
6 Application Class A for 1000V (class II). Application Class B for 1500V (class 0)
7 Nominal Operating Cell Temperature: Module operation temperature at 800W/m² irradiance, 20°C air temperature, 1m/s wind speed.
8 Multi-Contact MC4 (PV-KST4/PV-KBT4)

BOS – Mounting Systems

- Fixed
- Tracking (Single-axis or dual-axis trackers)



One axis tracking PV array with axis oriented south.



Two-axis tracking PV array

- Material
  - Steel
  - Aluminum
- Location (Orientation & Tilt Angle)
  - Northern Hemisphere – Panel must face South
  - Southern Hemisphere – Panel must face North
  - Rule of thumb for Tilt angle - Latitude +/- 15 degrees

BOS - Inverter

- Role – Converts DC to AC and may include MPPT to maximize output
- Types
  - Central Inverters
    - Connects to parallel strings.
    - Easy to install and highly reliable
  - Micro Inverters -one per panel
    - Single panel optimization can lead to improved efficiency in the range 20% - 30%
- Advance inverters can support grid code
  - Disconnects outside a specified range (Anti-islanding)
  - Provide some ancillary services (match voltage and frequency of grid)

BOS - Interconnection

- Transformer (LV to HV)
- Substation/Switchyard
- Metering

Factors that affect Panel Power output

- Solar Irradiation
- Ambient Temperature
- Shadowing
- Soiling (Dust Conditions)
- Array mis-match

Potential Energy Losses

Design Factors that influence Performance		
Component Derate Factors	Common Factor	Range
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availabilty	0.98	0.00 - 0.995
Shading	1	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC-to-AC derate factor	0.77	

With lifetime Performance Ratio of 77%
20 – 30% potential energy can be lost!

Cost-Effective Technical Solutions

- Standards and guidelines are critical, available and must be adhered
- Technologies selected must fit local conditions
- Validate/Ensure long term technical sustainability with standards, qualified and reputable manufacturers and engineering companies.
- Good system design with standards-based quality equipment is cost-effective in the long run.

IEC Technical Specifications

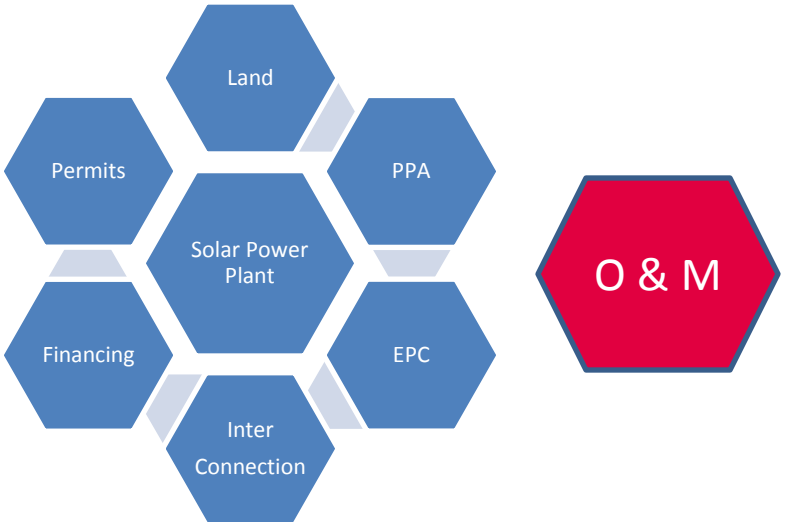
- The International Electrotechnical Commission (IEC) is the leading global organization that prepares/publishes international standards for all electrical, electronic and related technologies.
- Solar projects should follow international best practice guidelines in order to ensure that the best products/systems are installed.
- Consult technical standards specified for the particular technology e.g. IEC 61215 for silicon, IEC 61646 for Thin Film.

Sample Standards

	Test	Description
Panels	IEC 61215	Crystalline silicon terrestrial photovoltaic modules
	IEC 61646	Thin-film terrestrial photovoltaic module
	IEC 61730	PV module safety qualification
	IEC 60364	Protection against electric shock
	IEC 61701	Resistance to salt mist and corrosion
	IEC 60068-2-68	Dust and Sand Resistance
	ISO 9001/14001	Quality and Environmental Management
	UL 1703	Listed Class B Fire Rating
Charge Controllers	IEC 62509	Performance and functioning of photovoltaic battery charge controllers
	IEC 62109	Safety of power converters for use in photovoltaic power systems
	IEC 62093	BOS components - Environmental reliability testing - Design qualification and type approval
Inverters	IEC 61683	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
	IEC 62109	Safety of power converters for use in photovoltaic power systems
	IEC 62093	BOS components - Environmental reliability testing - Design qualification and type approval
	IEC CISPR 11:1990	Limits and methods of measurement of electromagnetic disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment
	PV GAP, PVRS 8A	Inverters for photovoltaic stand-alone systems

Utility Scale Solar Power Plant

- Utility-scale renewable resource power plants and traditional generation facilities are constructed through a very similar process.

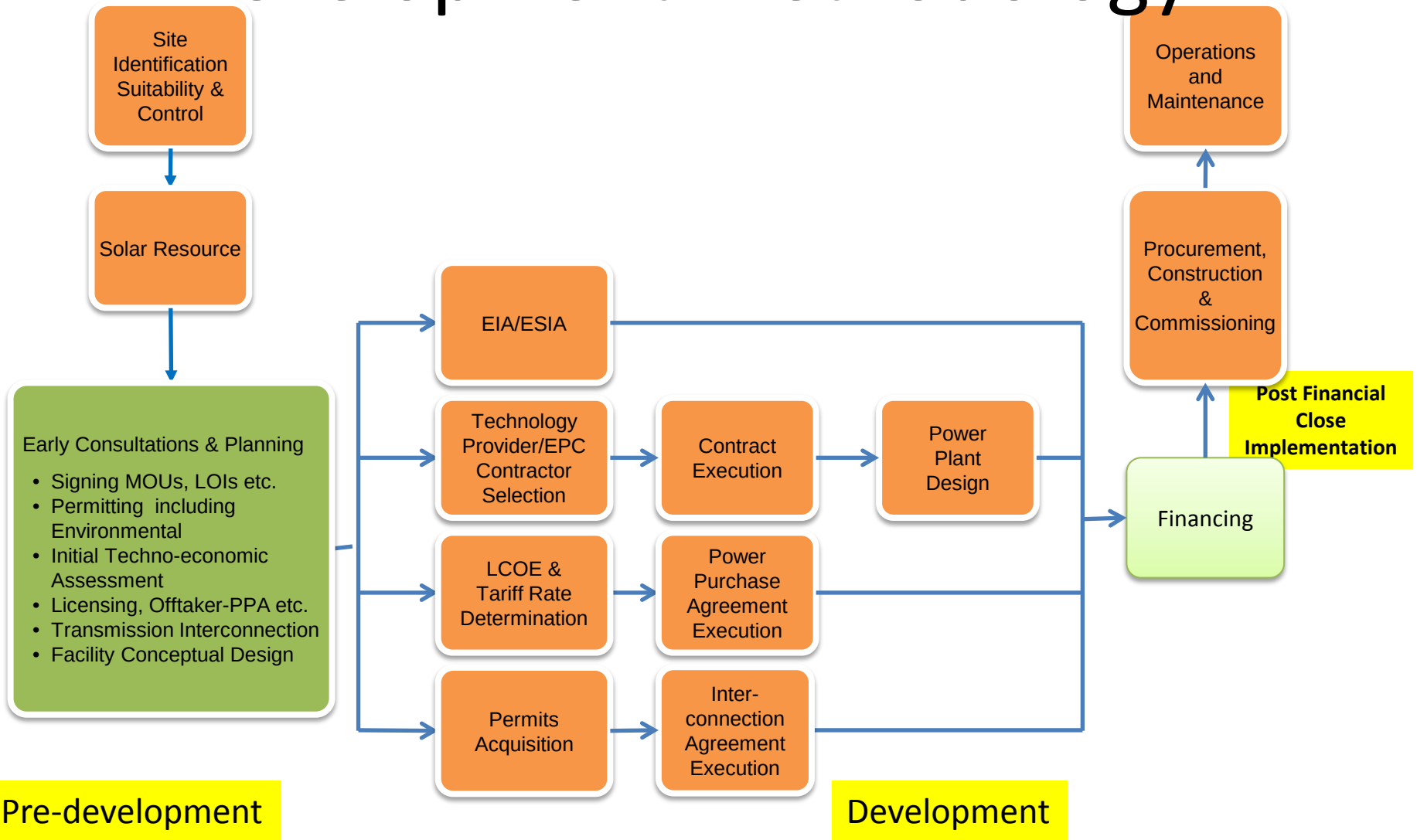


- Developers/Sponsors work with government institutions, financiers, EPC firms, manufacturers, legal counsel, etc. to identify and secure, permits, appropriate sites, transmission infrastructure, contracts, and comply with all government mandated requirements.

Site Selection (case study)

- Goal: Maximize location output at minimum cost subject to what constraints?
  - ❖Climate/weather
  - ❖Solar resource
  - ❖Available area & Accessibility
  - ❖Topography
  - ❖Land use
  - ❖Grid connection
  - ❖Module soiling
  - ❖Water availability
  - ❖ Available Incentives*

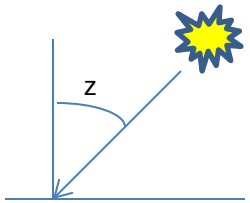
Development Methodology



Pre-development Phase

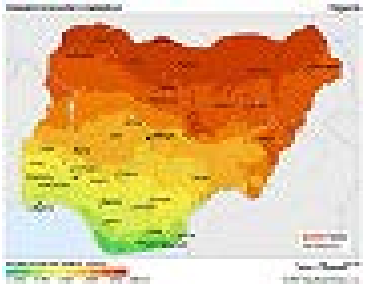
- Solar Resource Assessment
- Permitting and Licensing
- Land Use
- Transmission Assessment
- Environmental Impact Assessment
- Community Engagement

Solar Site Assessment



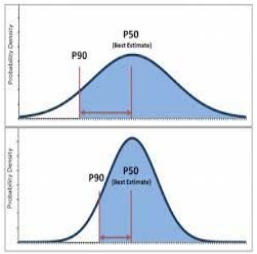
- GHI = DHI + DNI*cos(z), where z is the solar zenith angle

- GHI: Global Horizontal Irradiance measured with Pyranometer
- DNI: Direct Normal Irradiance measured with Pyrheliometer
- DHI: Diffuse Horizontal Irradiance measured with Pyranometer
- Irradiation data can be obtained from ground measurements or satellite data
  - Ground measurement and interpolation between weather stations: Meteonorm.
  - Satellite measurement and interpretation of data: PVGIS, NASA, SODA, etc.
  - Irradiation Unit kW/m^2



Yield Report & Analysis

- It's all about confidence level and risk appetite!
- Confidence to <u>exceed is measured in P50, P75, P90, P95 etc..</u>
- Annual Yield or Energy Production (AEP) validity is mandatory for a bankable PV project.
- P50 preferred by developers and <u>some</u> equity investors interested in long term.
- P90 preferred by debt lenders (i.e. commercial banks) since they are interested only in project's minimum ability to pay back loan)



Grid Integration Issues

- Reliability, Efficiency of Interface & Cost
- Weak, unstable Grids
- Variability – Solar as an Intermittent power source connected to the power grid can impact frequency and voltage stability.
  - Transmission system operator must adopt counter-measures to maintain frequency and voltage stability
  - Stable systems generally can tolerate a 10% RE in generation mix, however for unreliable systems that would not be the case!
- Mitigation measures for ensuring voltage stability are well known (i.e. procuring additional operating reserves, contingency resources and/or requiring voltage control capability etc.)

Interconnection Issues

- Who will conduct studies and who pays?
- Feasibility and System Impact studies
- Substation & location
- Metering
- Interconnection Agreement
- Upgrades to Transmission Network

Environmental Issues

Negative Impact

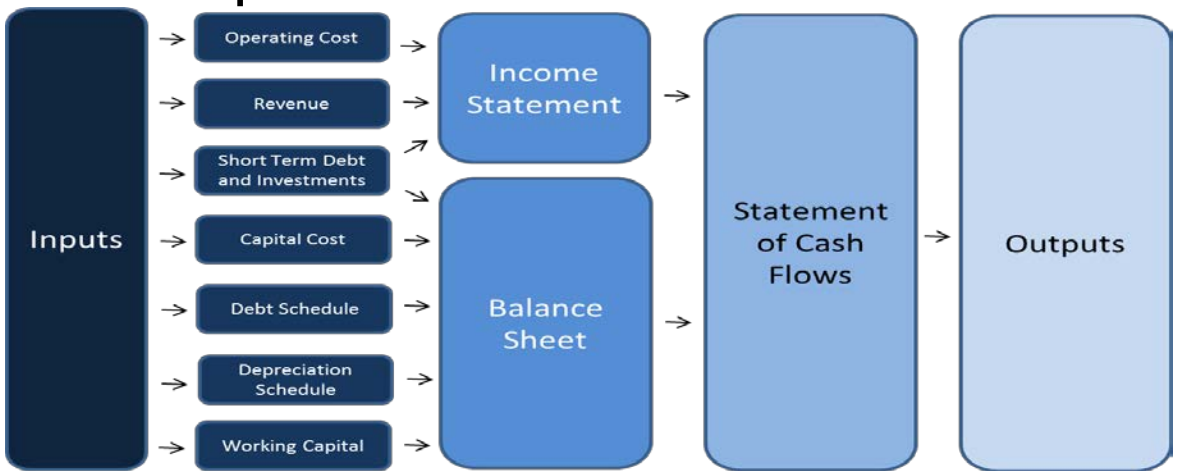
- Danger of toxic chemical pollution from heavy metals used in photovoltaic cells and are hard to recycle.
- Large amounts of land are required for solar farms and may have negative effect on wildlife, eco system etc.
- Water use and drainage
- Panels are dangerous to firefighters (respiratory, electric shocks etc.)

Development Phase Activities include:

- Completion of a full feasibility report
- Submission and acquisition of all applicable permits and licenses
- Completion of interconnection studies & signing of interconnection agreement.
- Detail Environmental & Social Impact Assessment (EIA/ESIA).
- Finalize contracting strategy and sign a turnkey EPC contract or multi- contracts. Prepare EPC tender documentation.
- Detail system design and modelling.
- Finalize Financing.

Development Phase Activities include:

- Contract negotiations and executions.
- Completion of a bankable energy yield.
- Development of Pro Forma - financial model covering the full life cycle of the plant



- Completion of a project risk analysis.
- Securing financing for the project.

Due Diligence (Preliminary & Detailed)

- **Company/Sponsor/Developer**
  - Technical & Managerial prior project experience
- **Resource**
  - Suitability of land/site, site control, resources and forecasting mechanism.
- **Technology, Engineering & Procurement**
  - Key components/systems, standards
  - Plant Design/layout
  - Civil/Structural works
  - Grid interconnection & code compliance
  - Track record, Experience & Project workplan
- **Environmental**
  - Review impact assessments (EIA/ESIA) for Nigeria's Environmental certification and conformance to WB/IFC requirements and the Equator principle.

Due Diligence (Preliminary versus Detailed)

- **Legal Agreements & Documentation**
  - Project structure and obligations of project parties
  - Review Contracts / project agreements (land lease, EPC Contract, component supply contracts, O&M Contract)
  - Review permitting requirements and licenses (status, constraints, etc.)
  - Adequacy of the technical warranties and verification procedures i.e. Guarantees of Contracts / liquidated damages provisions etc.
- **Financial**
  - Project management, risk and mitigation details
  - Financial modelling - verify project ROI/LCOE
    - CAPEX & OPEX / Capital replacement
    - Sensitivity Analysis (Financials, Electricity yield etc.)
- **Sabotage, terrorism and theft risk**
  - Security & Surveillance

Post-Financial Close

Financing

Financial Close

Procurement & Construction

Commissioning

Operations and Maintenance

De-Commissionning & Recycle

Thank You
&
Energy Access For All