APET

Association of Pioneers of Engineering and Technology

SOLAR ENERGY

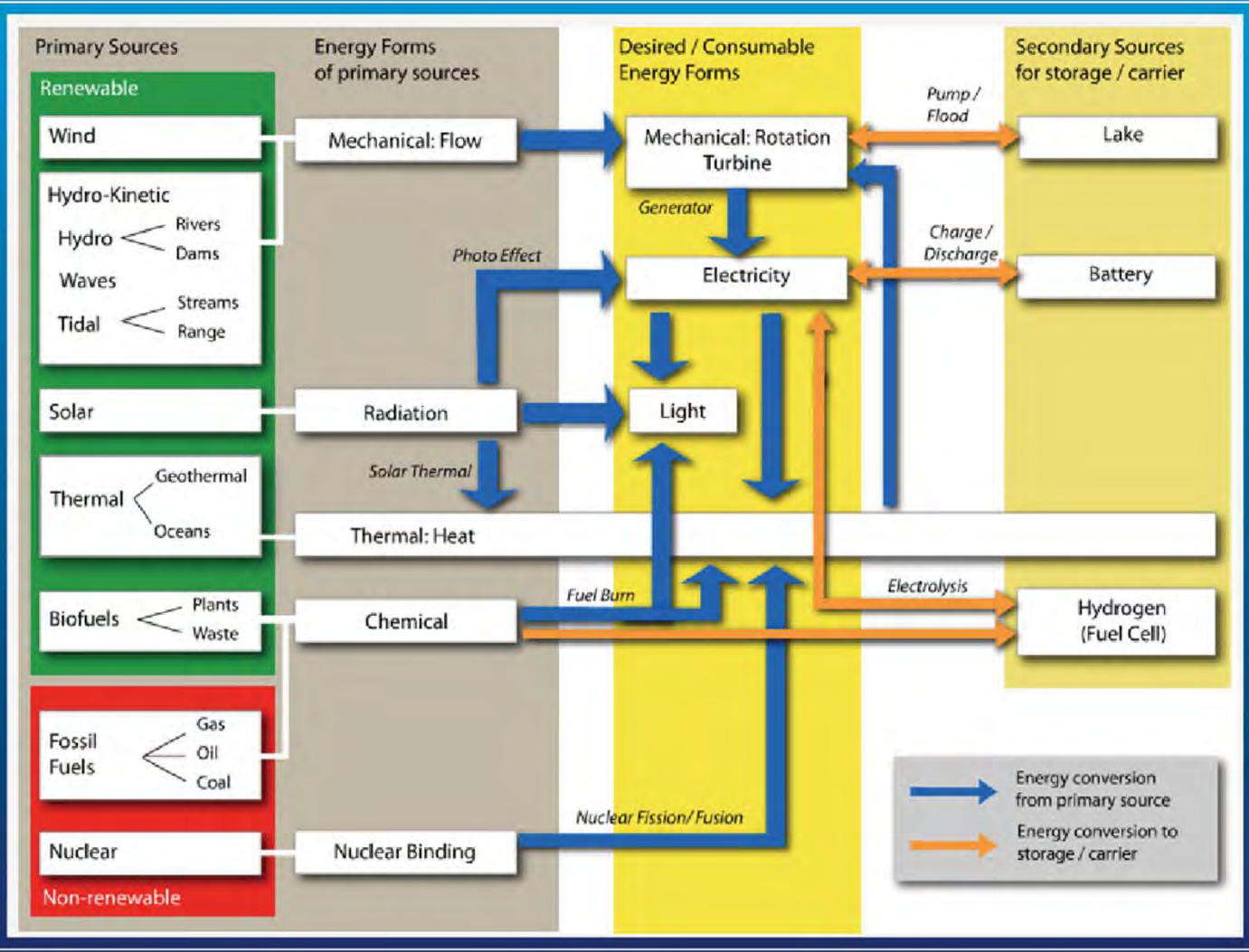
ENG. SHERIF EL SERAFY

APET

ENERGY SOURCES, FORMS & USES

APET

ENERGY VALUE CHAIN



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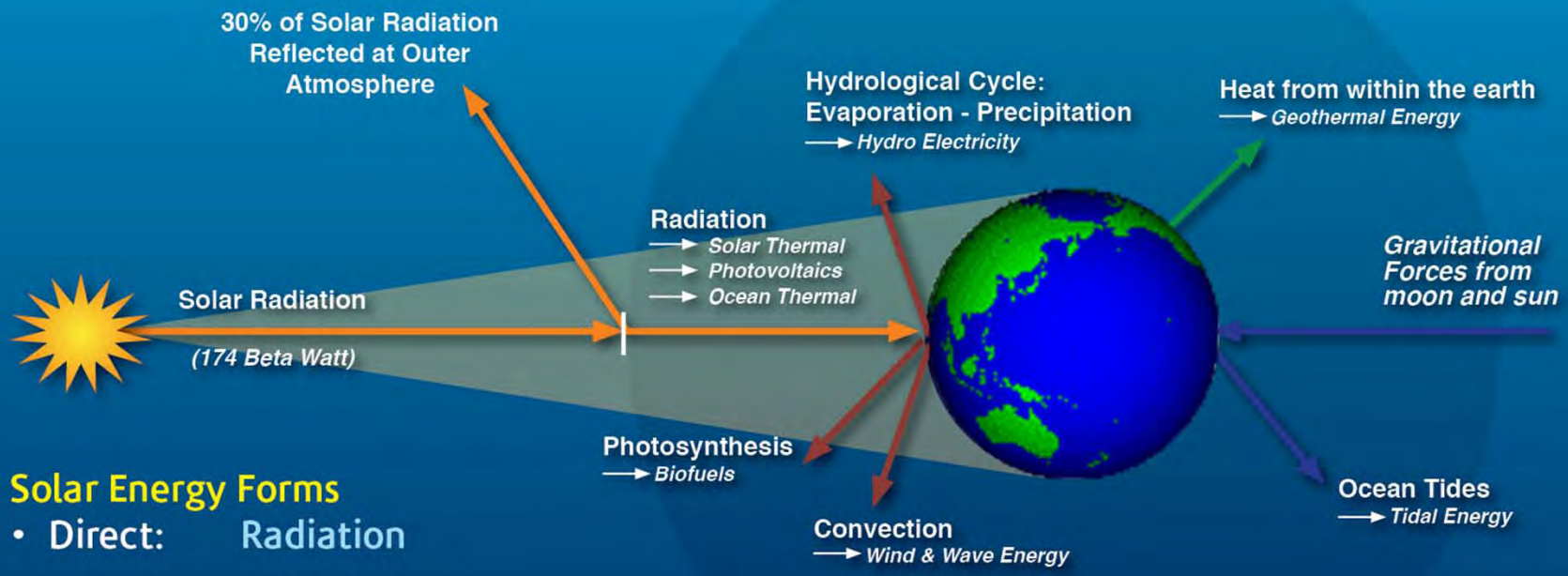
RENEWABLE ENERGY FORMS

Annual Solar Energy to Earth Surface = 2 x All Earth Non-Renewable Resources

(Coal, Oil, Gas & Miniral Uranium)



Solar Energy Forms

- Direct: Radiation
- Indirect: Hydro-Power
  Wind & Wave Energy
  Bio-Energy

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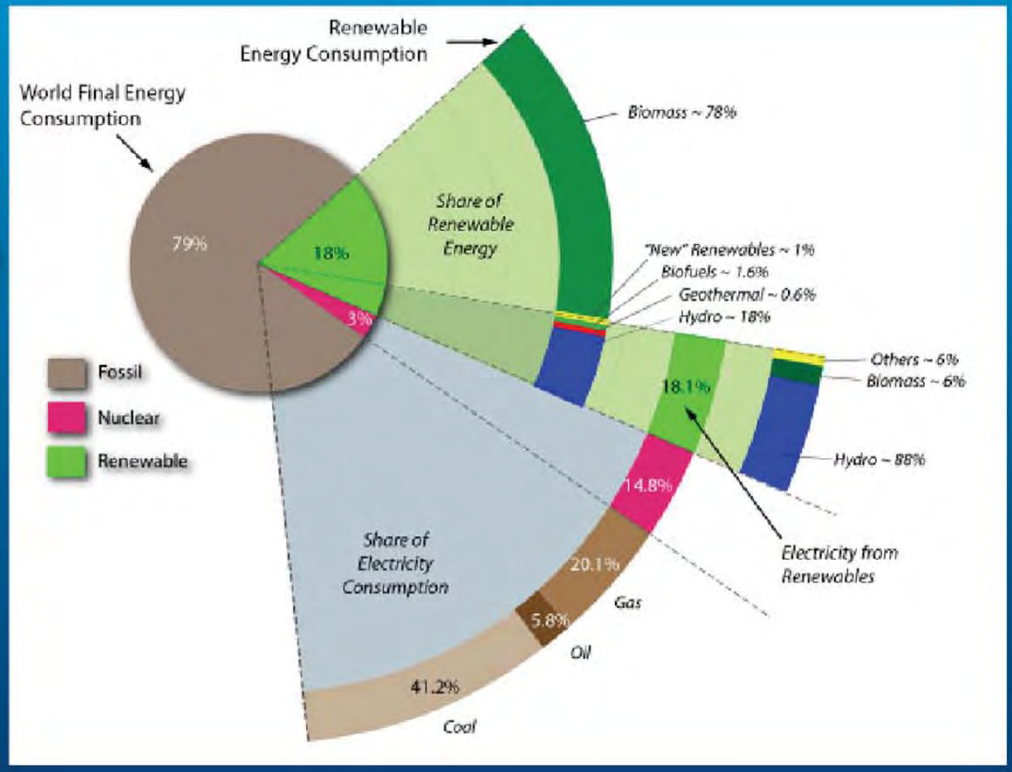
USES & SOURCES OF WORLD ENERGY

- **World's Energy Consumption:**
  - 79% fossil
  - 18% renewable
  - 3% Nuclear
- **Renewable Energy**
  - 78% Biomass (mostly for heating)
  - 18.1% Hydroenergy
  - 1.6% Biofuels
  - 1.0% New renewable (Wind & Solar)
  - 0.6% geothermal
- **18% of Electricity Generation from Renewables :**
  - 88% hydro
  - 6% Biomass
  - 6% Wind, solar& Geothermal



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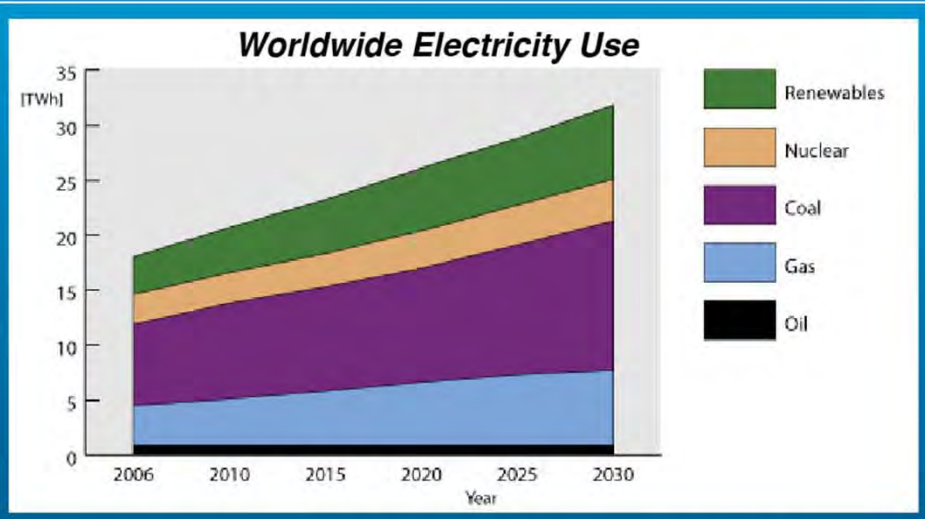
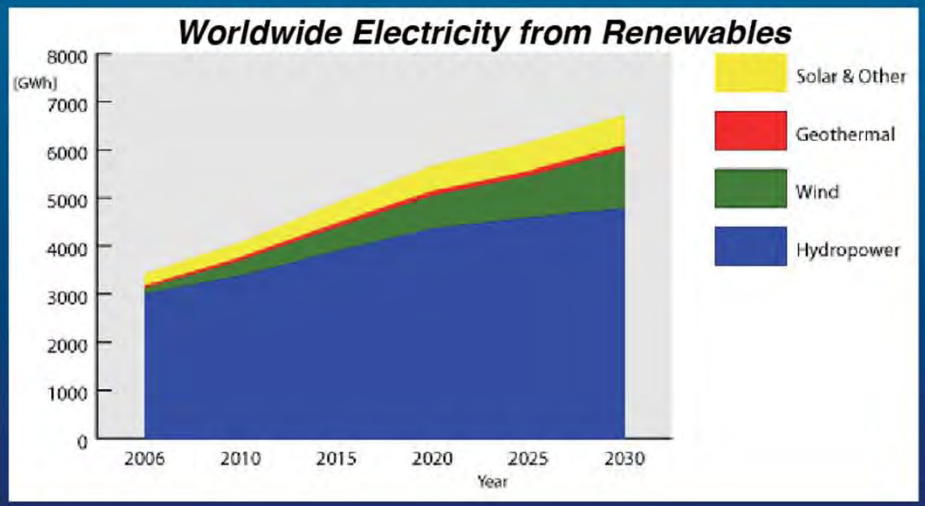
WORLDWIDE ELECTRICITY FROM DIFFERENT FUELS & RENEWABLES





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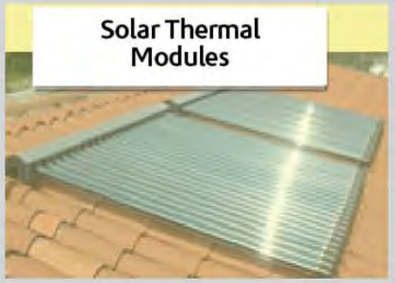
SOLAR RADIATION TECHNOLOGIES

SOLAR RADIATION

Direct Conversion to Elecric Current

Heat Up A fluid



Solar Electricity for Own Use or Power Grid

Solar Thermal for Hot Water & Heating

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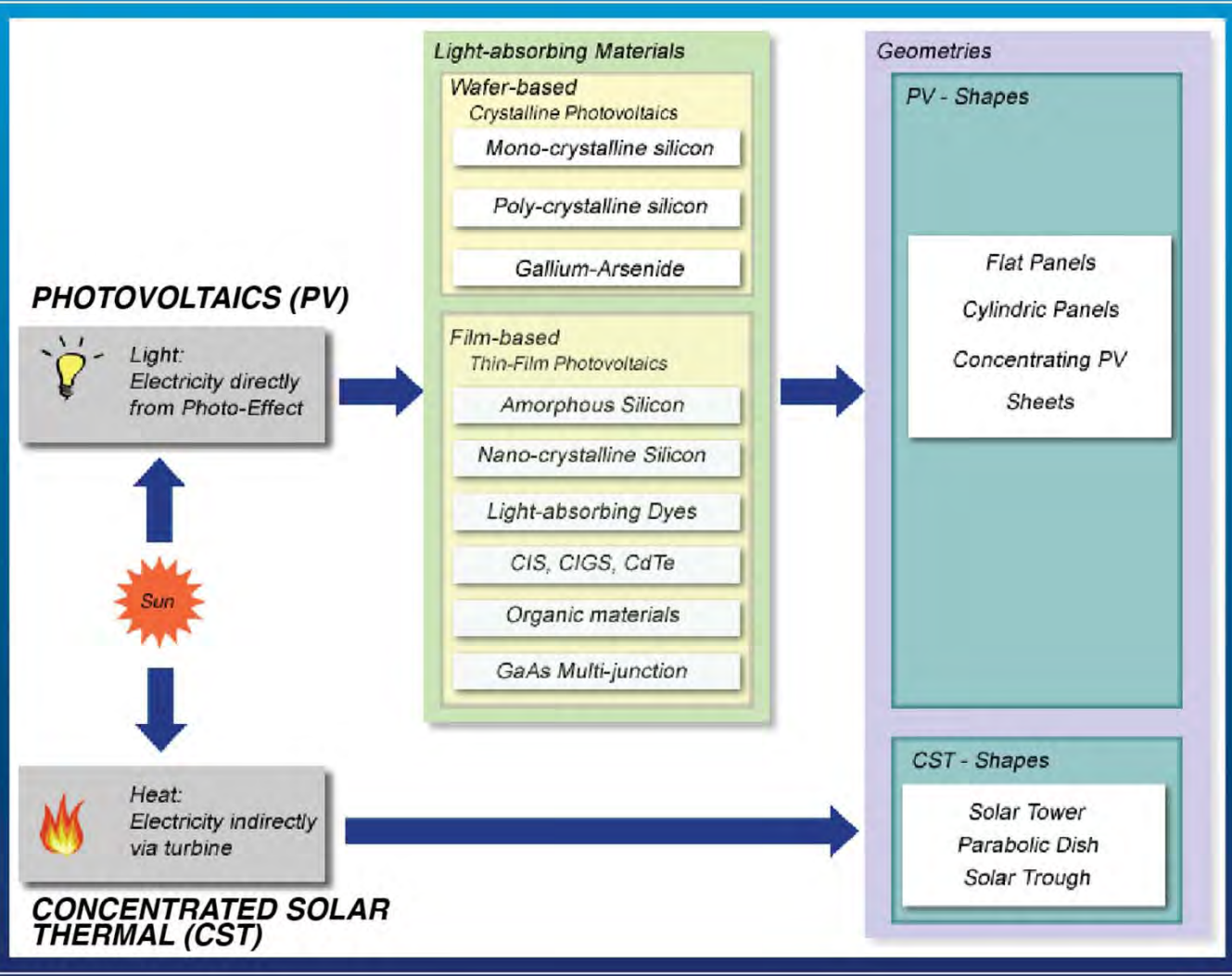
SOLAR POWER TECHNOLOGIES



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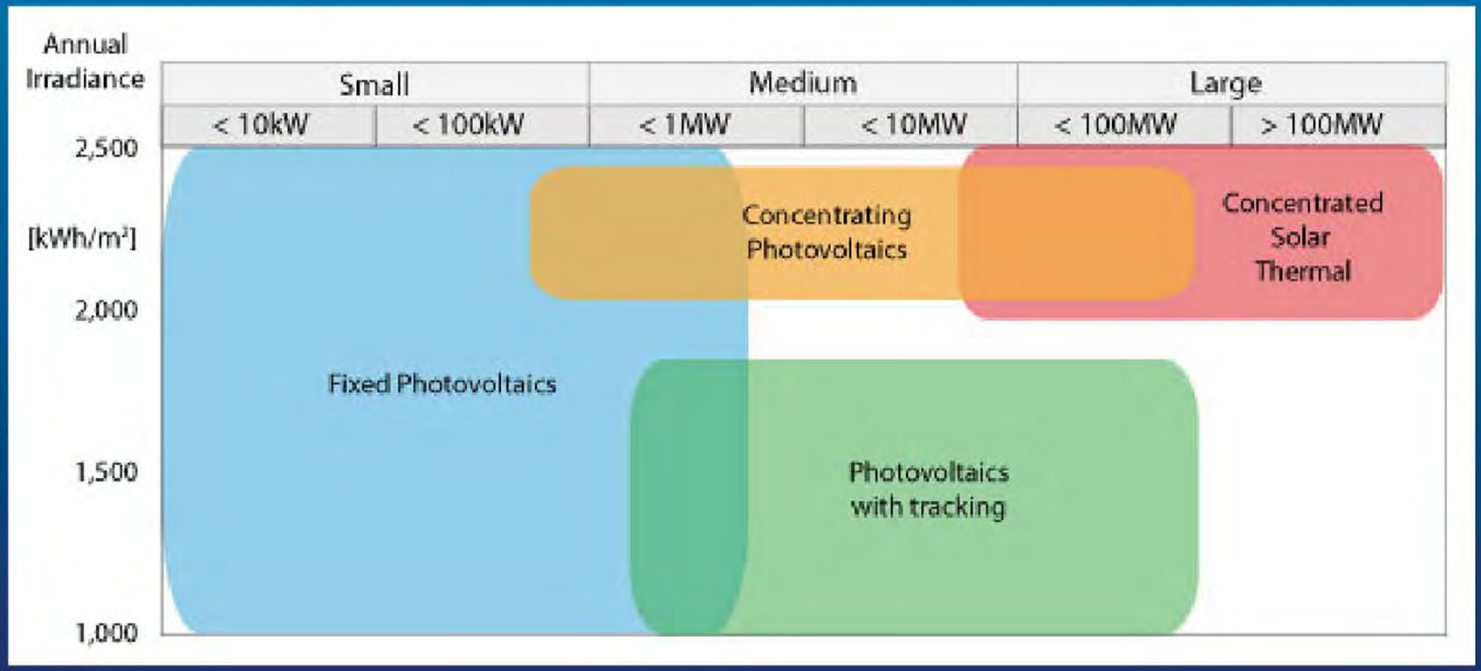
SOLAR POWER TECHNOLOGIES

- The technology depends on:
  - Size and efficiency of installation
  - Annual Solar irradiance at site
- Concentrated energy target Locations where Annual yield >2000 kwh/m^2



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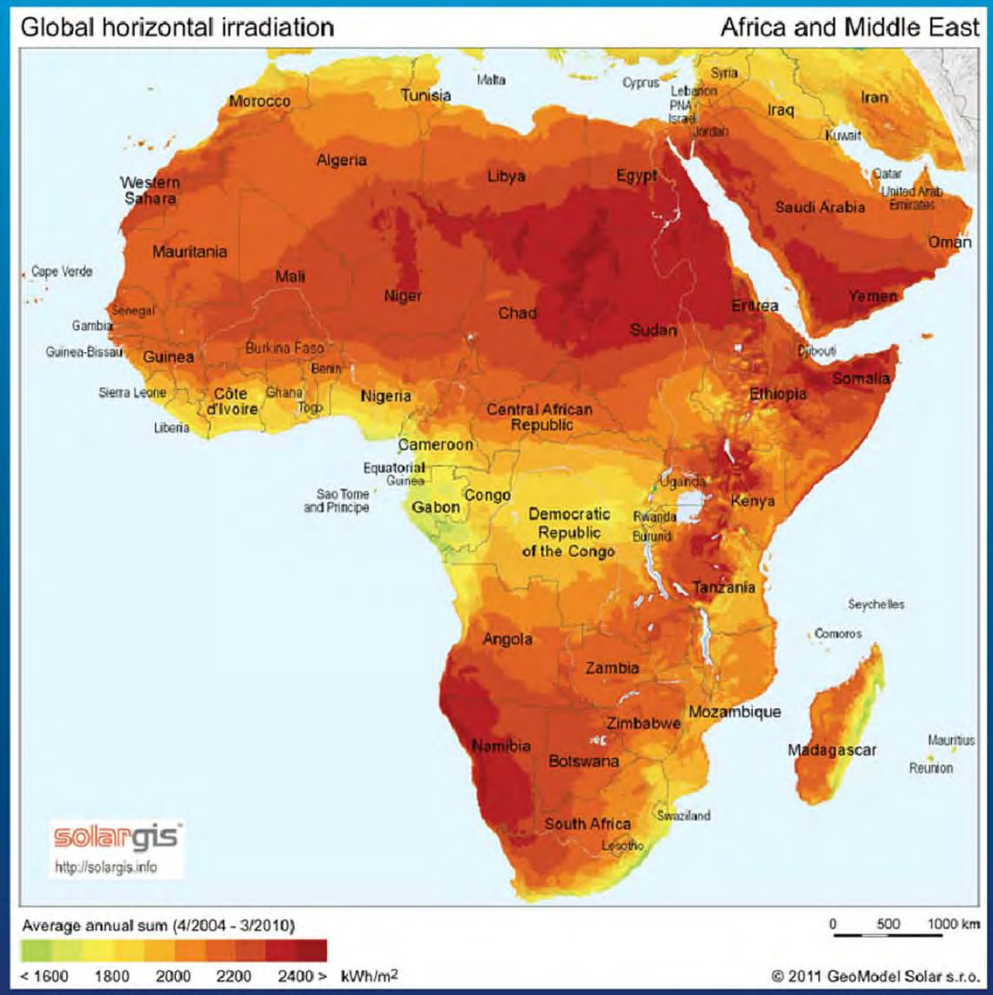
EGYPT IS ONE OF THE SUN BELT COUNTRIES



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CONCENTRATED SOLAR POWER (CSP)

(Concepts & Applications)

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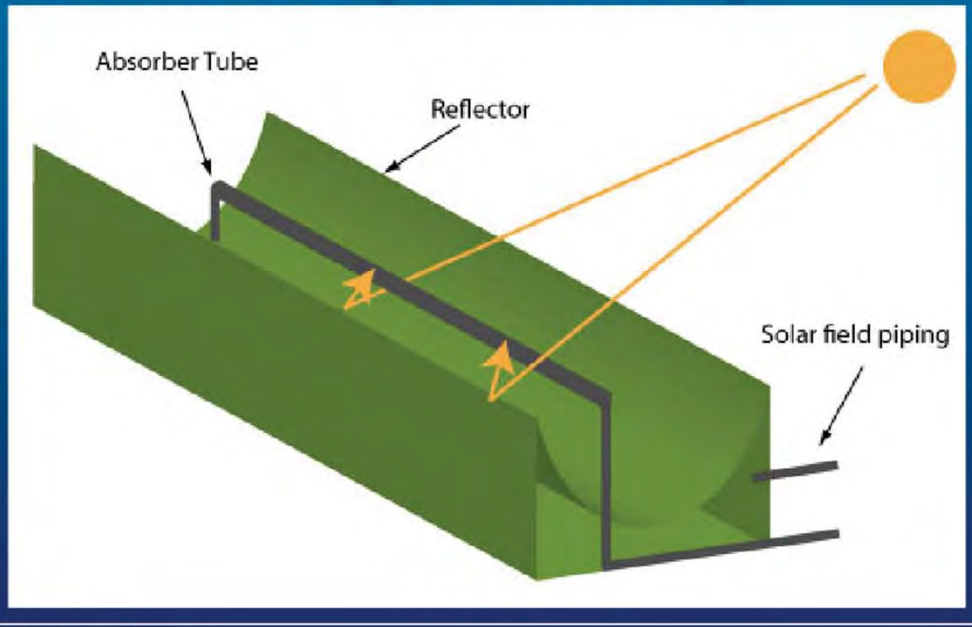
CONCEPTUAL CONFIGURATIONS OF CSP

a) Linear parabolic trough reflectors:

- Parallel collectors each 20-400 meter long
- Absorber tube transfer heated fluid to central heat exchange system
- Troughs track the sun over the day course
- Concentration ratio 100-500x
- Net Effeciency 14% annually

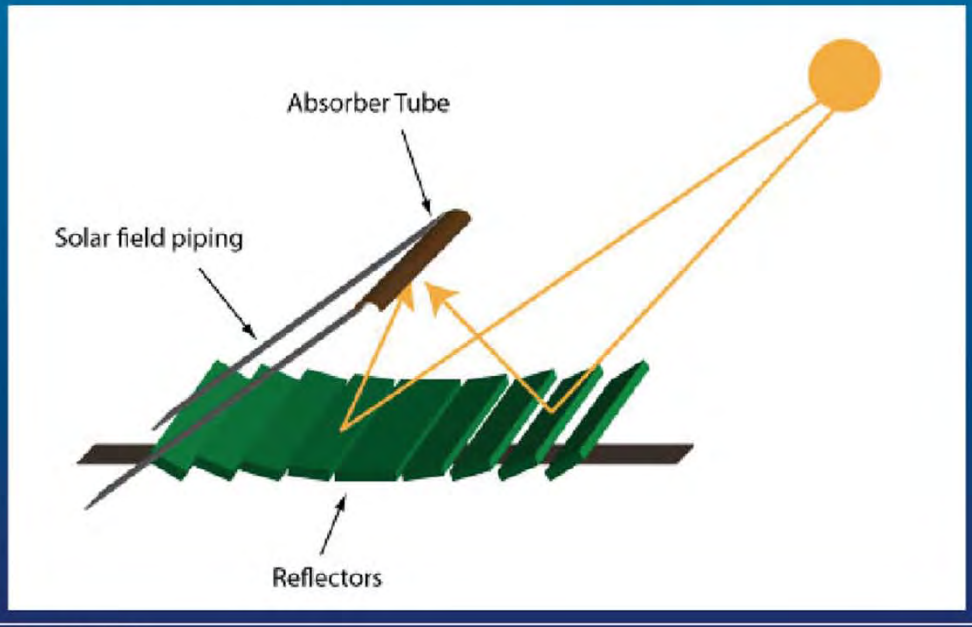


APET

CONCEPTUAL CONFIGURATIONS OF CSP (cont'd.)

b) Linear Fresnel Reflector (new technology):

- Similar to parabolic trough concept except that it uses several reflector strips that automatically track the sun.
- Much less expensive than parabolic trough.
- Concentration ratio 500x at 400°C

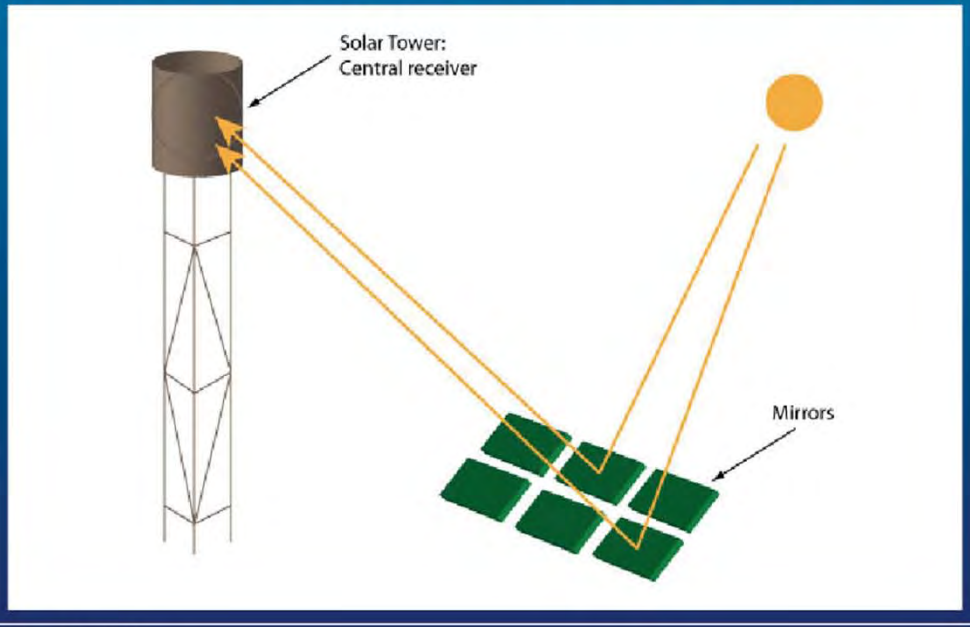


APET

CONCEPTUAL CONFIGURATIONS OF CSP (cont'd.)

c) Solar Power Tower:

- Hundreds of ground reflectors to concente solar radiation into a heat absorbing receiver using automatic dual axis tracking system.
- Temperature up to 1300°C with concentration ratio 1000x.
- Annual solar electric effeciency about 25%.



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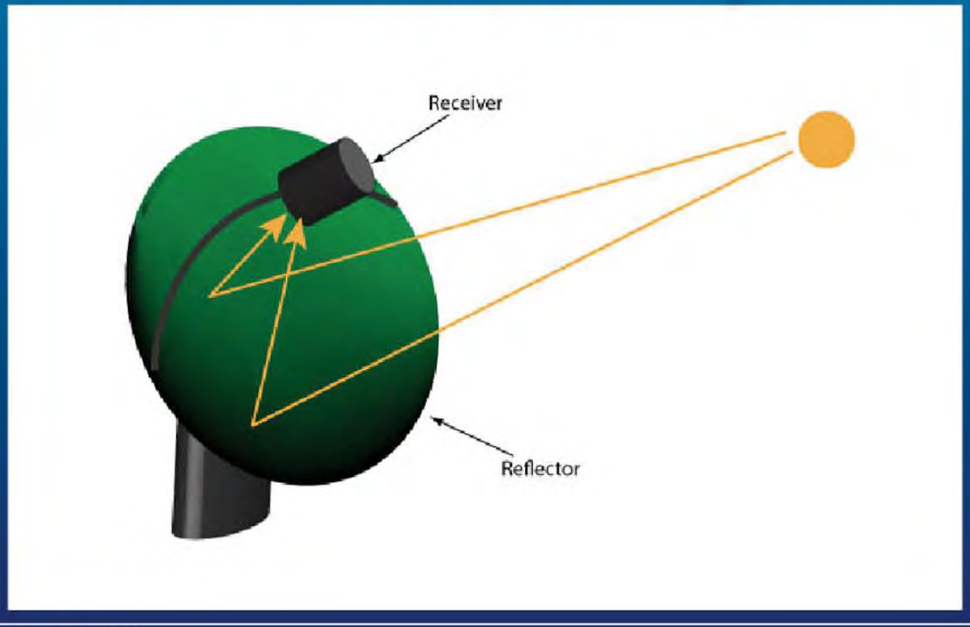
CONCEPTUAL CONFIGURATIONS OF CSP (cont'd.)

d) Solar Parabolic Dish:

- Parabolic mirror reflector turns on two axis to track the sun.
- Direct light is reflected to a thermal receiver at mirror focal point.
- Temperature rise up to 1000°C with concentration ratio 1000X.
- Individual reflector output ranges from 10-15 KW.
- Peak Solar Electric efficiency about 31%.



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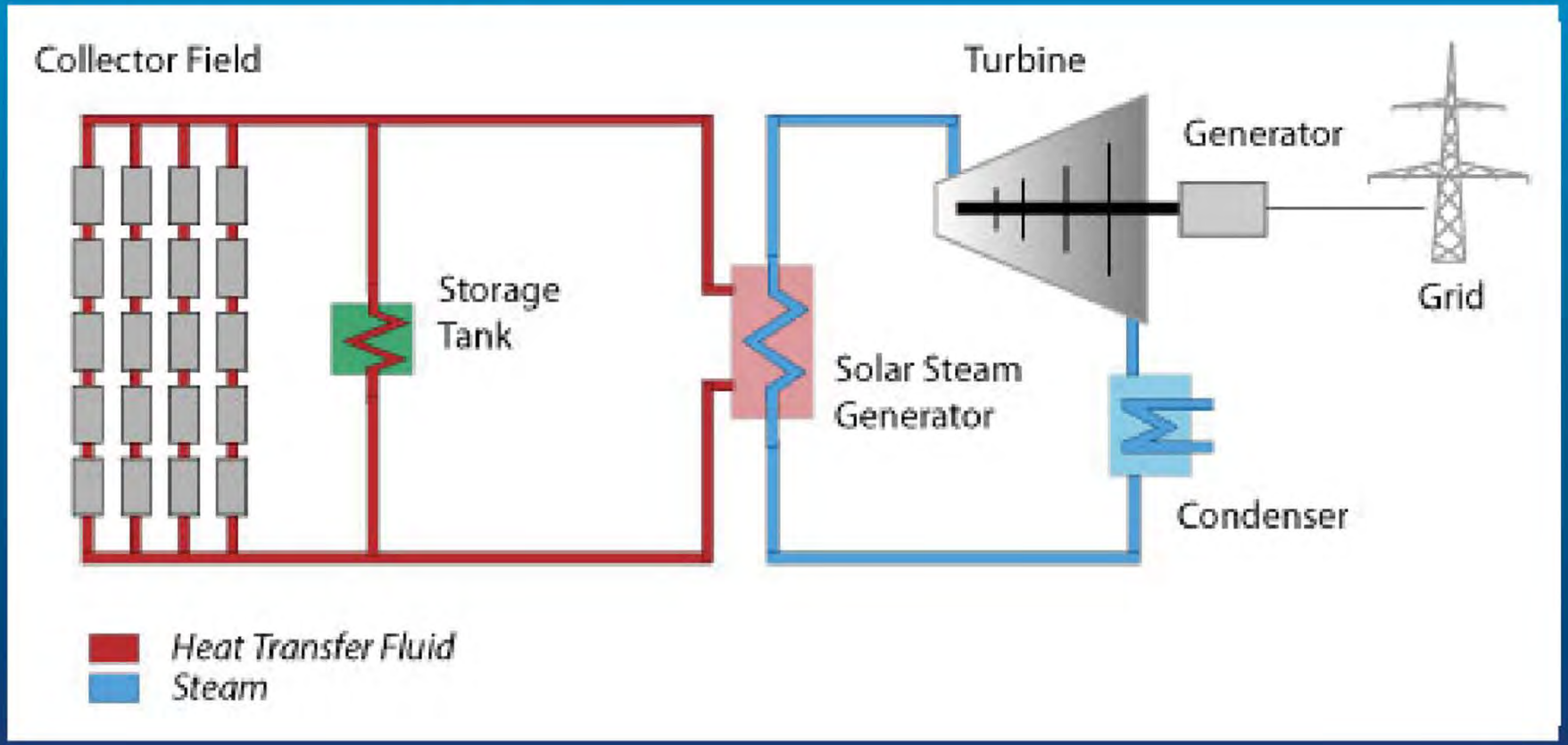
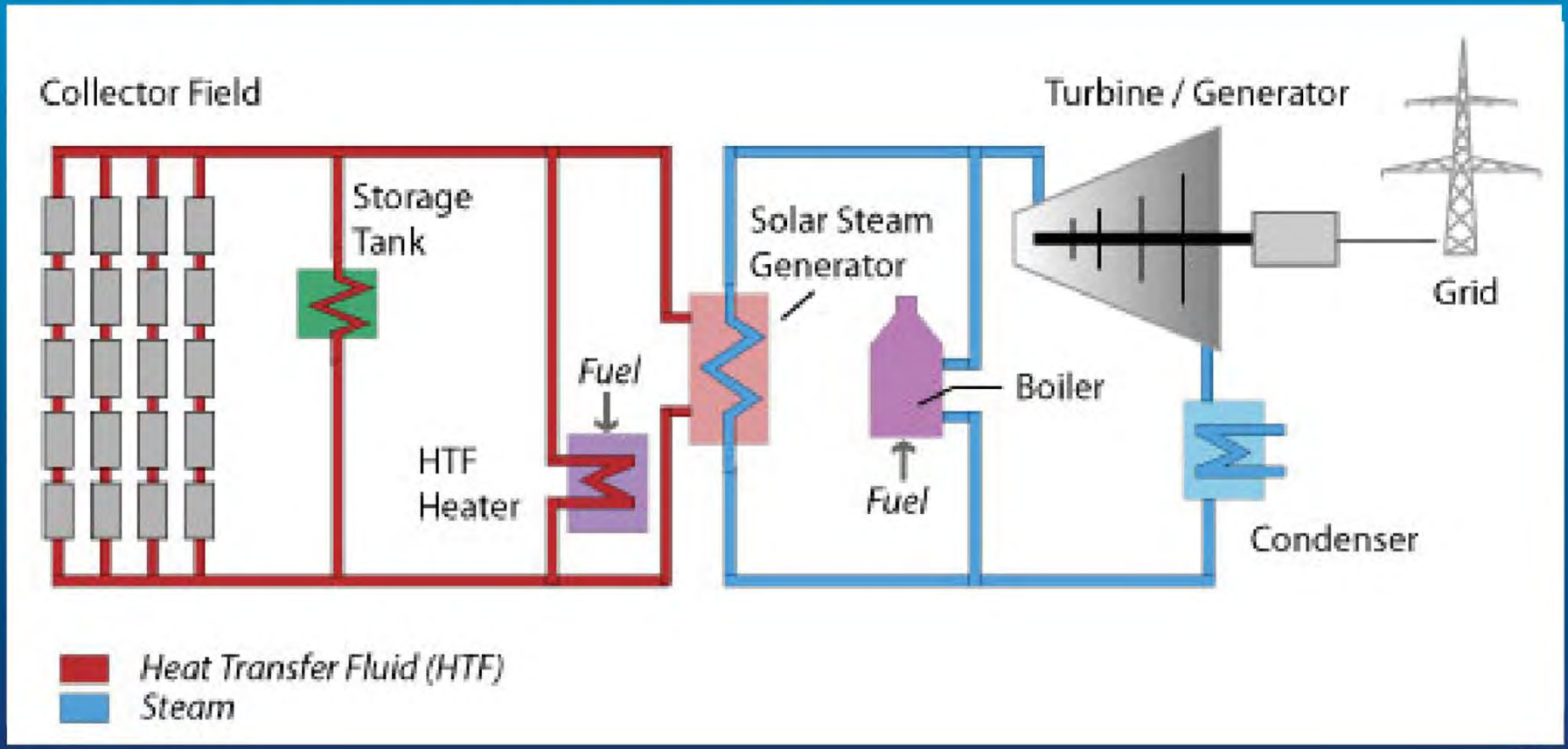
TYPICAL APPLICATIONS OF THERMAL CSP

a) Standalone Solar System



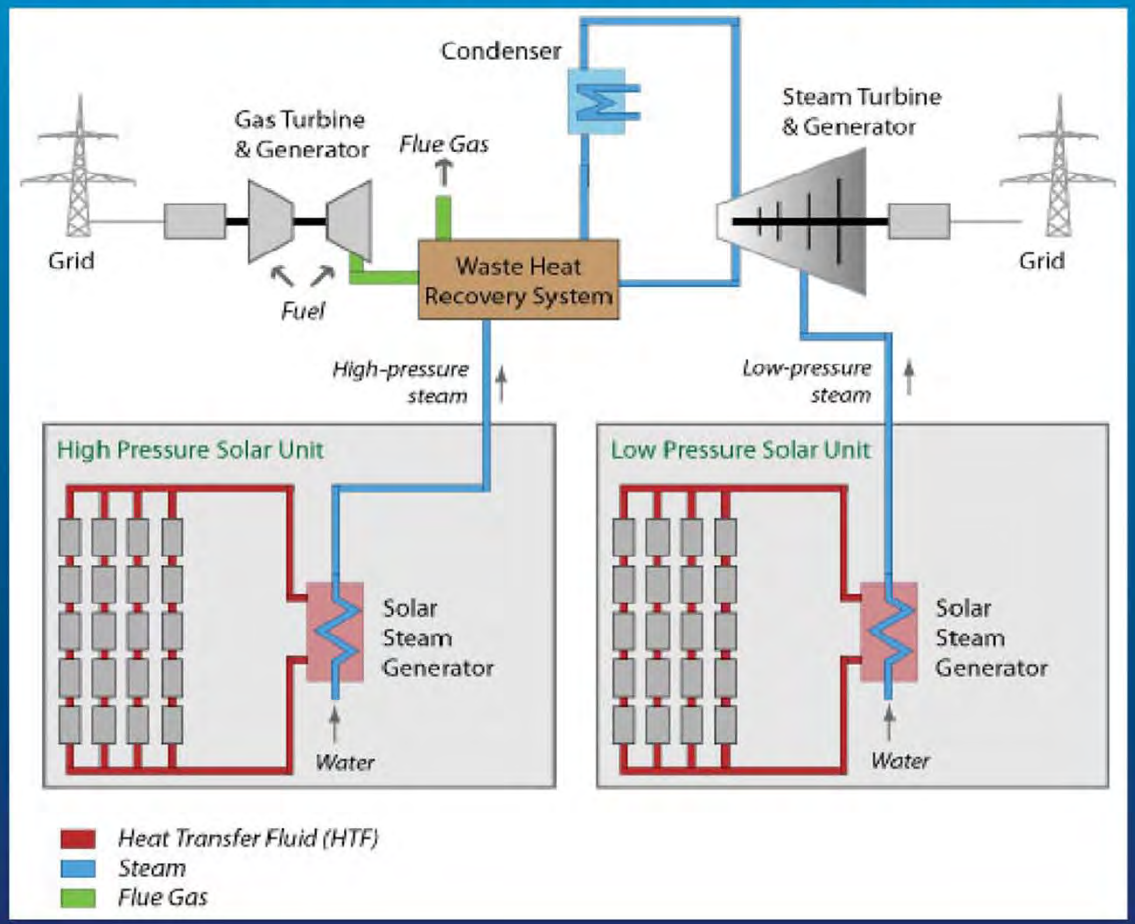
TYPICAL APPLICATIONS OF THERMAL CSP (cont'd.)

b) Hybrid System - Fossil Fuel Backup



TYPICAL APPLICATIONS OF THERMAL CSP (cont'd.)

c) Hybrid System - Integrated Solar Combined Cycle System (ISCC)



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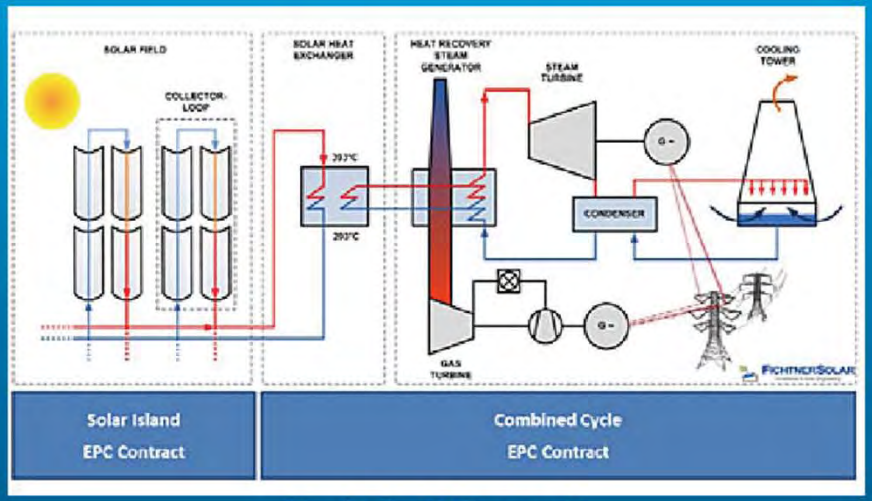
TYPICAL APPLICATIONS OF THERMAL CSP (cont'd.)

Integratd Solar Combined Cycle of Kuraymat - EGYPT

- Parabolic Trough Technology Integrated in a Combined Cycle Power Plant using Natural Gas.
- Total Plant Capacity 140 MW.
- Solar Island to Increase Steam Cycle Output & Save Gas during Daytime:
  - Capacity 61 MWth or 20 MWel.
  - 1920 Collector Modules of 131,000 M^2 Surface Area with Automatic Sun Tracking System.
  - Annual Solar Radiation Intencity ≥ 2400KWHr/ M^2.



Technical Concept

Solar Island

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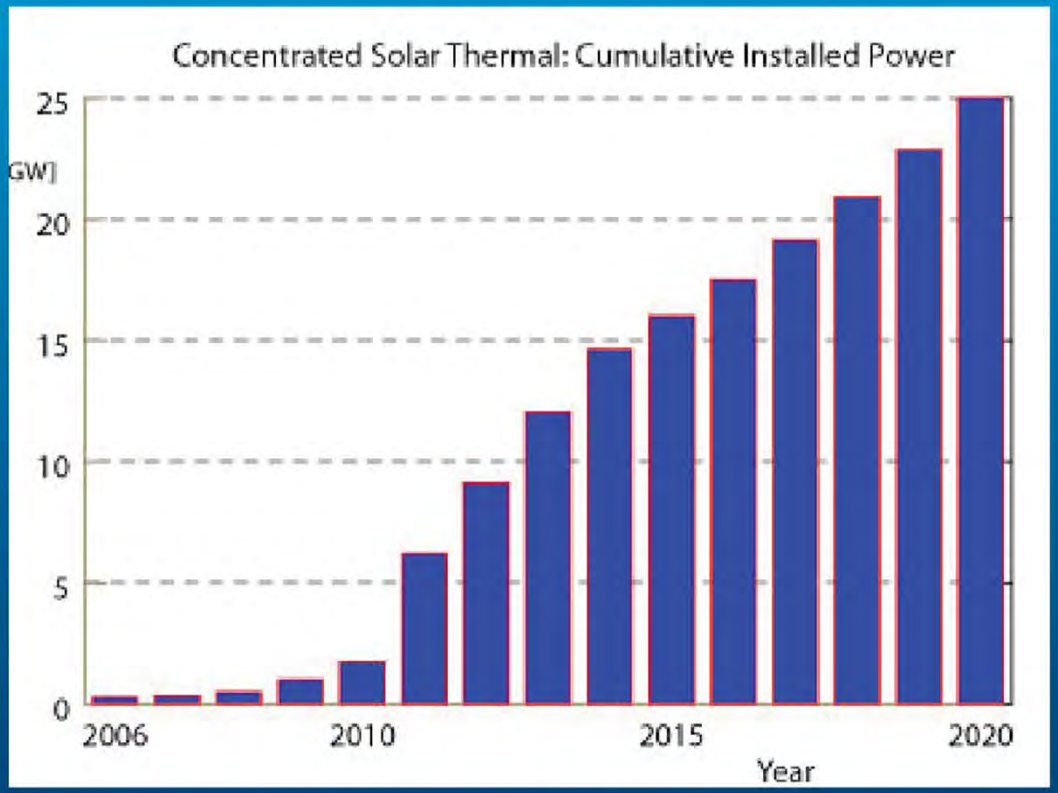
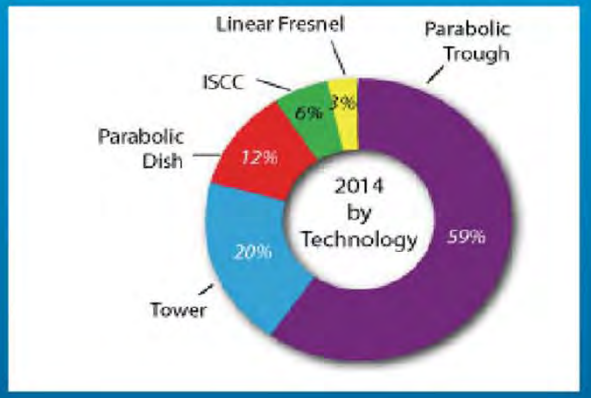
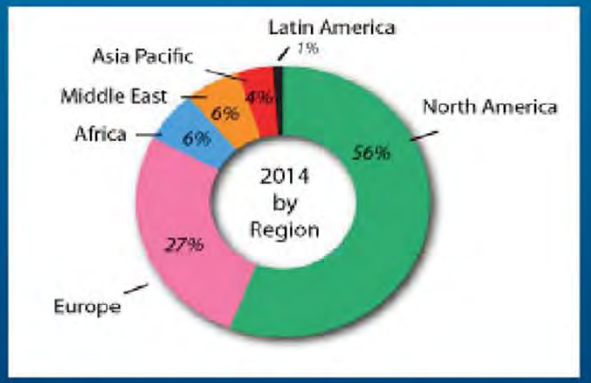
CONCENTRATED SOLAR THERMAL POWER INSTALLATIONS



Concentrated Solar Thermal
Cumuletive Installed Power





Which Technology & Where
it will be deployed

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PHOTOVOLTAIC SOLAR POWER

CONCEPTS & CLASSIFICATION

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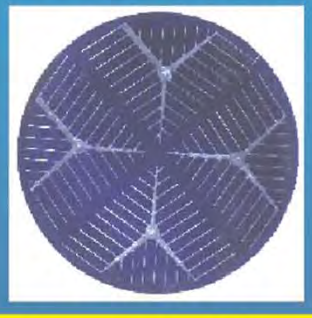
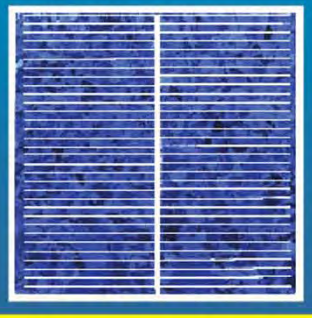
TYPES OF PV SILICON CELLS

PV SILICON CELLS

- Crystaline Silicon
  - Monocrystaline Silicon
  - Poly Crystalline Silicon
- Thin Film
  - Amorphous Silicon





	Monocrystaline Silicon	Poly Crystalline Silicon	Amorphous Silicon
Composed of	Pure mono Crystalline Silicon Circular wafers 125-150 MM	Numerous grains of mono Crystalline Silicon rectangular wafers 100-150 MM	Amorphous Silicon Atoms on Thin Homogenous Layer
Cell effic.	15% -20%	13% -16%	7% -8%
Manufact. cost	****	***	**

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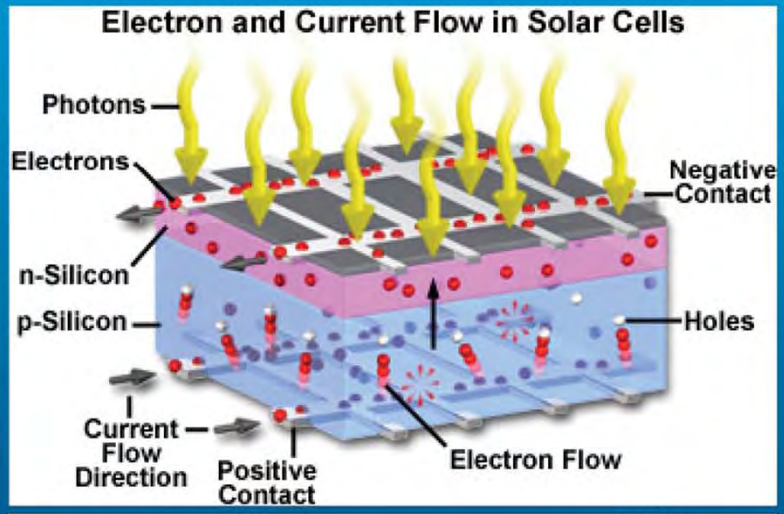
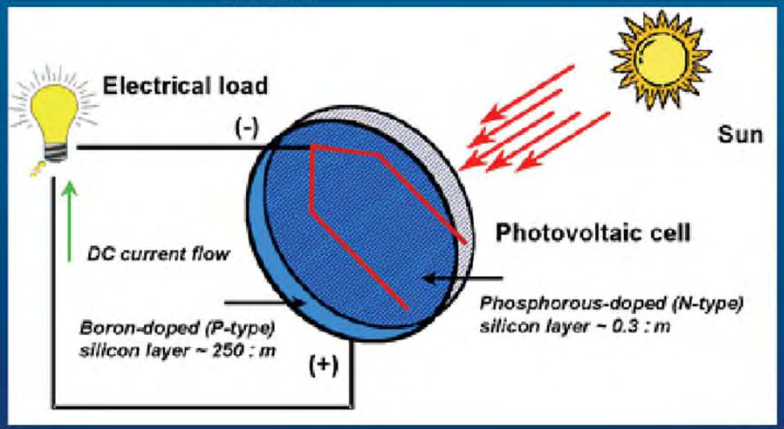
HOW PV CELL WORK

1. Photovoltaic cell is a solid semiconductor (e.g doped silicon chip) that releases electrons from the outer orbits of silicon atoms and creating holes upon subjection to light (PHOTONS).

2. Electrons are attracted to negative silicon doped surface (N) and holes to positive silicon doped surface (P) creating (VOLTAGE) difference between the surfaces of the silicon semiconductor (P-N junction)

3. Upon connecting the two sides of the semiconductor (P-N junction), a DC current flows.





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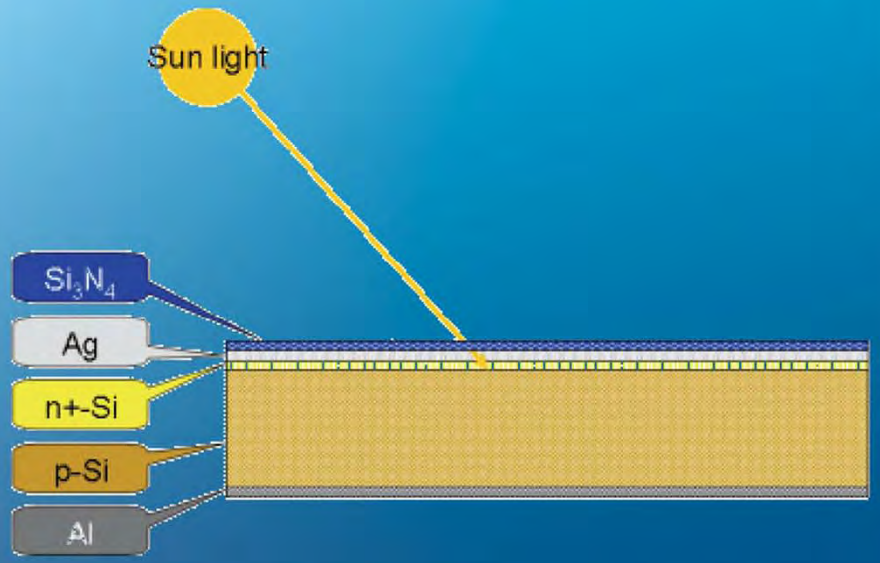
SILICON PV SINGLE JUNCTION CELL

OUTPUT

- The current (power) output of a single silicon PV cell is dependent on:
  - Intensity of light
  - Cell efficiency
  - Surface area
- Typical silicon PV cell produce 0.5 – 0.6 VDC under open circuit condition
- Typical silicon PV cell with 16 cm^2 area produces:
  - 2 watts power → Peak sunlight intensity
  - 0.8 watts power → 40% sunlight intensity

COMPOSITION



Typical Solar Cell Composition (Single Junction)

Si_3N_4 = Silicon Nitrate Antireflector.

Ag = Printed Coating Silver Contact Finger

N-Si = Thin Phosphorous Doped (N-Type) Silicon Layer (0.3 Micron)

P-Si = Boron Doped (P-Type) Silicon Layer (250 Micron)

Al = Holohedral Alumenium Layer

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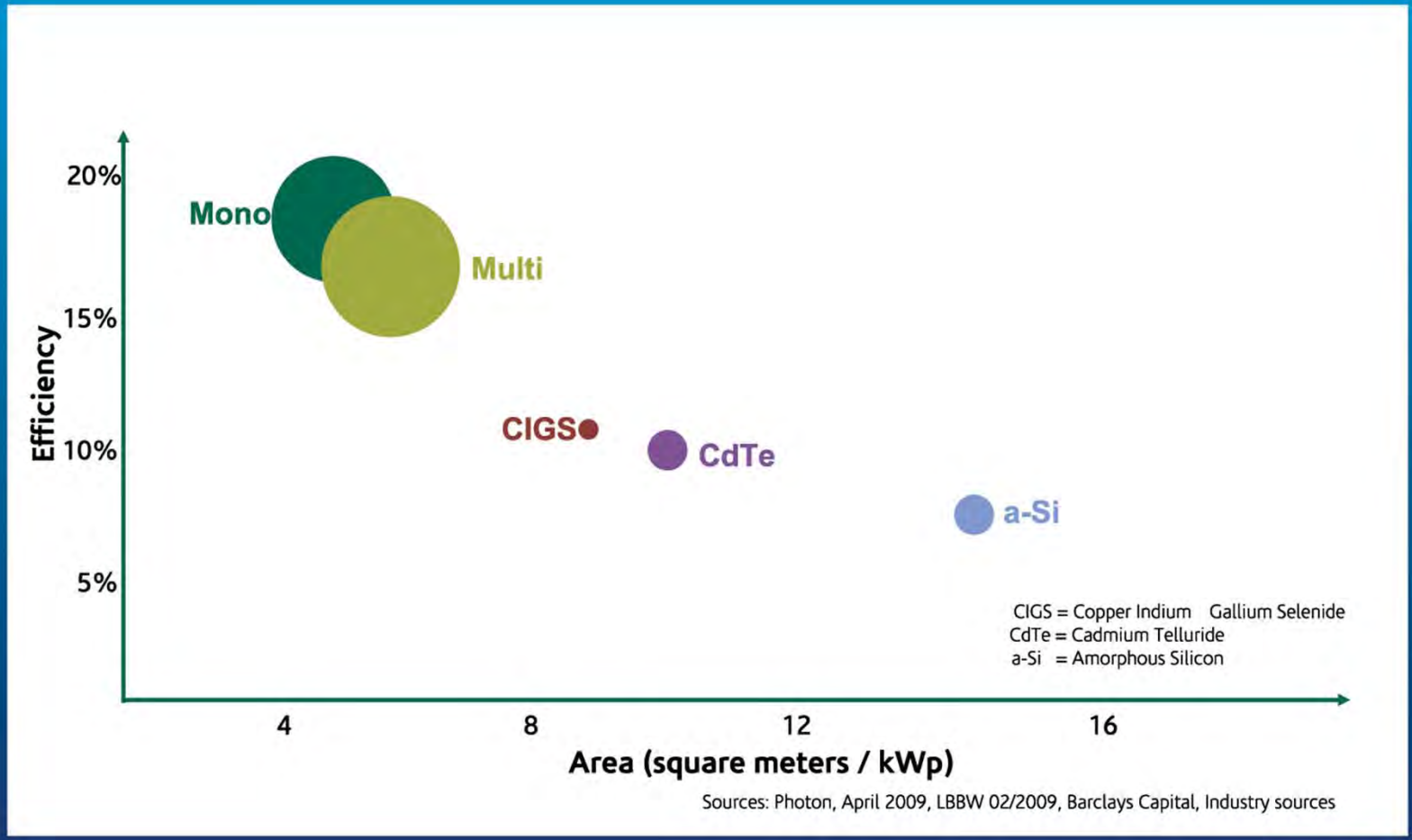
PV CELL vs. REQUIRED SQUARE METERS/KWp



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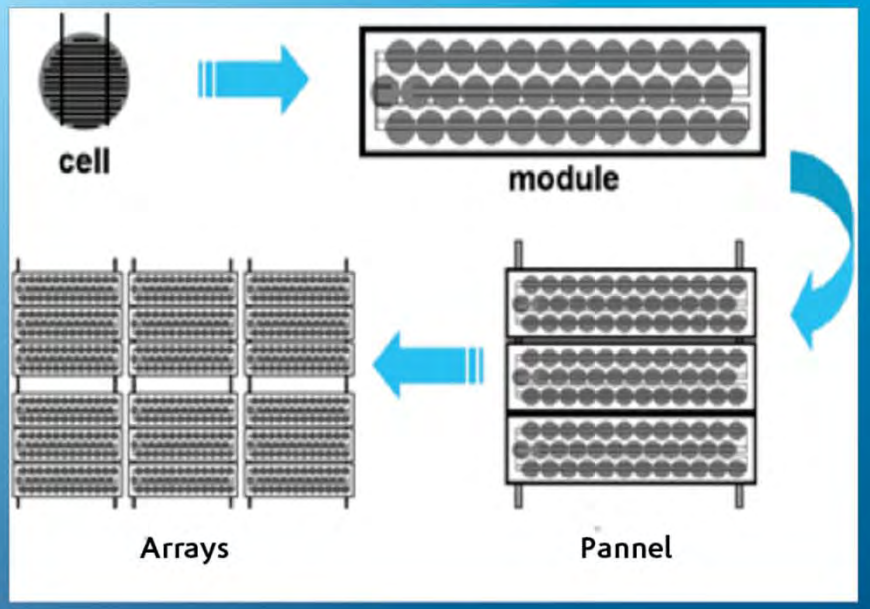
PV ENERGY CONVERSION COMPONENTS

1. **PV cells** are connected in series and /or parallel to produce higher voltage, currants & power levels

2. **PV module:** PV cell circuits sealed in an environmentally protected lamina.

3. **PV panel:** includes one or more PV module assembled and wired field installable unit

4. **PV array:** a power Generation unit consisting of a number of PV panels



PERFORMANCE OF PV MODULE:

- Within 85% to 90% of the STC Rating.
- STC Rating: Max DC power output (watts) under Standard Test Conditions (STC).
- STC: - Operating Temp 25 °C .
  - Irradiating level 1000 w/m ^{2}.
  - Air mass 1.5 spectra / distribution

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CONCENTRATING PHOTOVOLTAICS (CPV)

CPV = Large area of sun light is focused on small area solar cell using optical devices (lenses or mirrors)

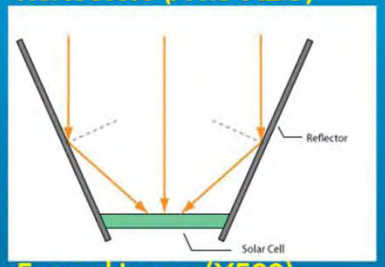
Advantages

- Less PV material to capture the sunlight of non-concentrated PV.
- Makes use of the high efficiency of the expensive multi-junction cell to be more economically viable due to smaller space requirements
- Less expensive PV Cells used with optics manufactured in proven process

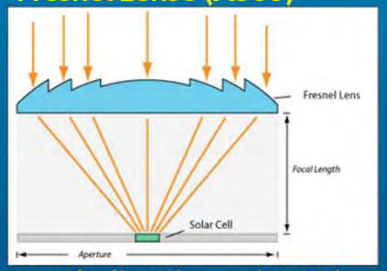
CPV Classification by Concentration

Concentration	Low x2 – x10	Medium X10 – X100	High>X100
Tracking	Not needed	1-axis tracking	Dual Axis Tracking
Cooling	Not needed	Passive cooling	Active Cooling (Cooling Fluide)
PV material	High quality silicon	High quality silicon	Multi-Junction Cells

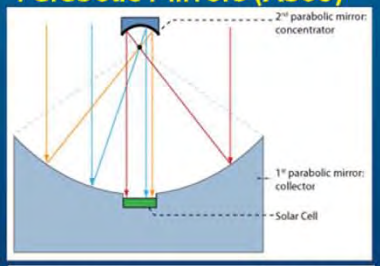
Reflectors (X1.5-X2.5)

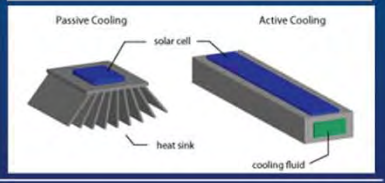


Fresnel Lense (X500)



Parabolic Mirrors (X500)





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WHY SOLAR PV SYSTEMS:

- The widest available clean renewable energy in the world (no waste).
- Fuel is free.
- Contributes in reducing Global Warming (minimal harmful emissions)
- Highly reliable (long life span 20-30 years & stable efficiency)
- Low maintenance (no moving parts)
- Brings electricity anywhere particularly to remote rural areas.
- PV Systems can be aesthetically integrated in buildings (BIPV) (integration in facade & Sun shade of a building)
- Light weight, easy to install and transport.
- Pay back of PV module is constantly decreasing (1.5 -3 years)
- Energy produced from a PV module = 6 to 8 times the energy needed for its manufacturing.

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HOW PV SYSTEM WORKS

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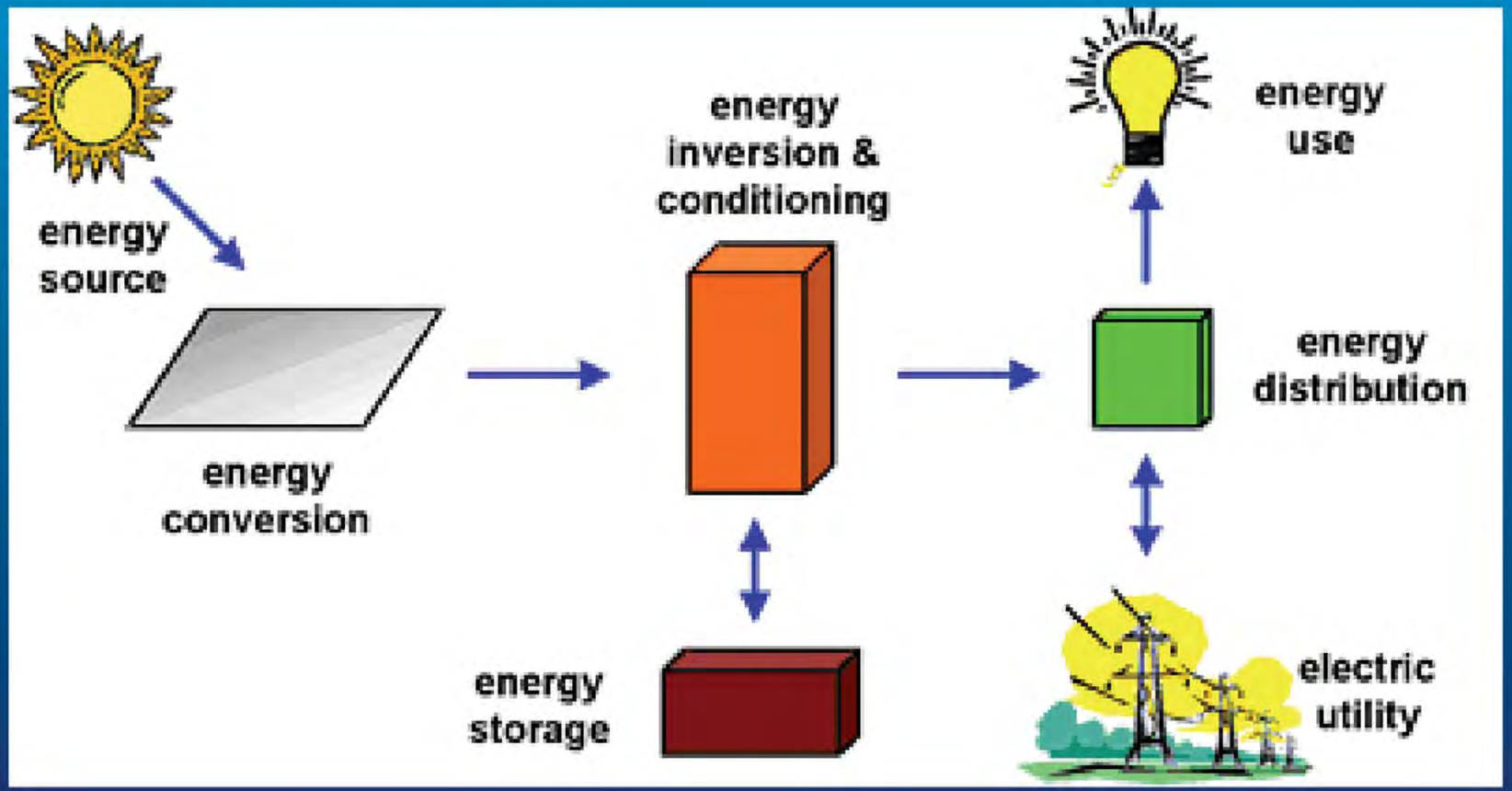
HOW PV SYSTEM WORKS

Major PV System Components



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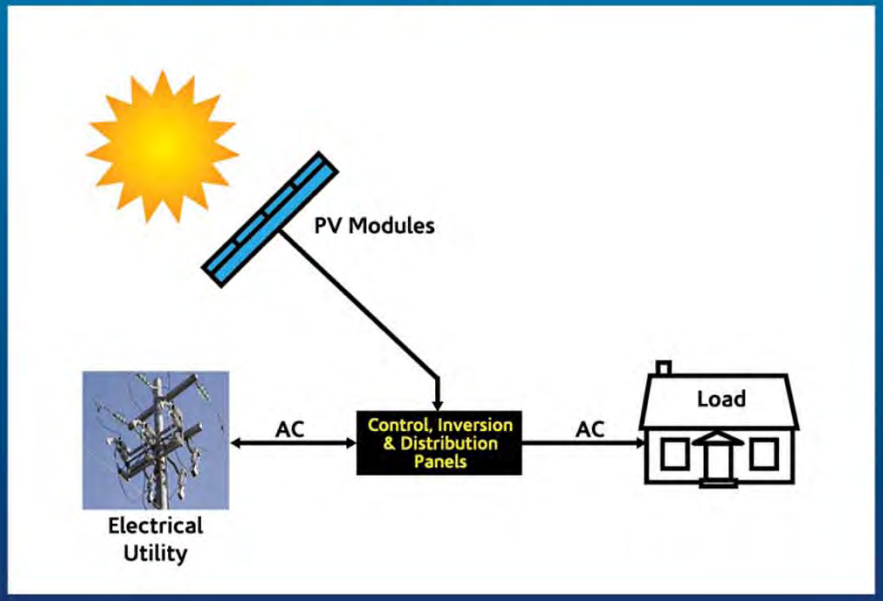
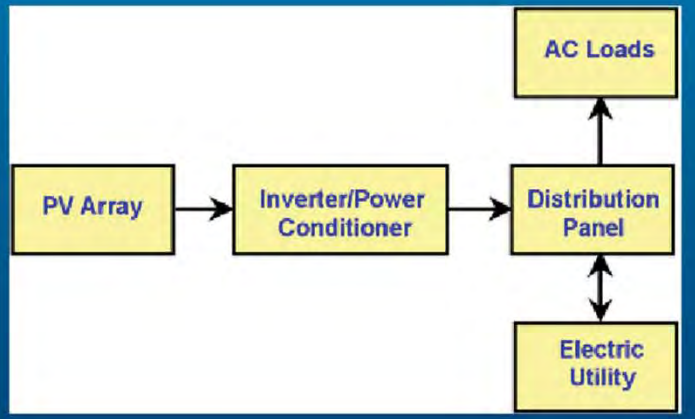
HOW PV SYSTEM WORKS

- Direct Coupled PV System

- Grid Connected PV System





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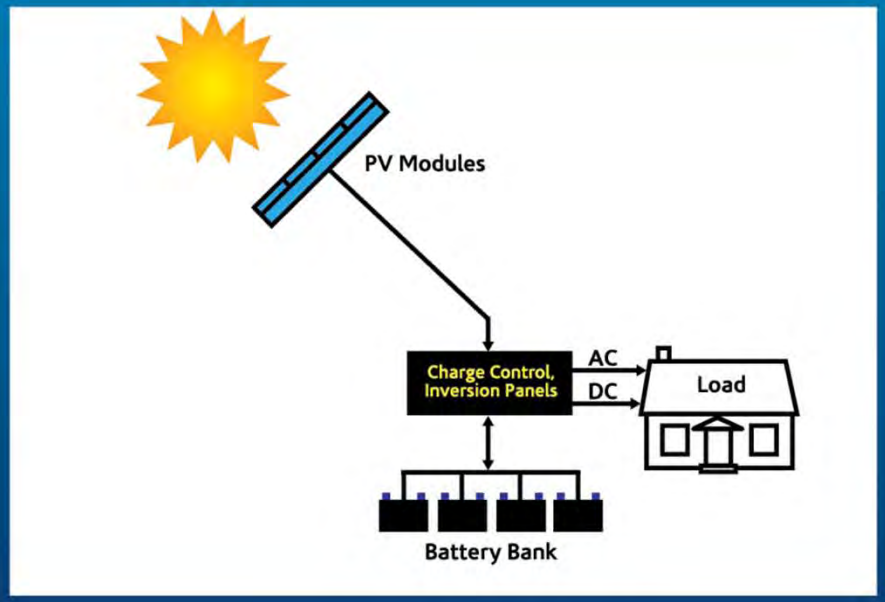
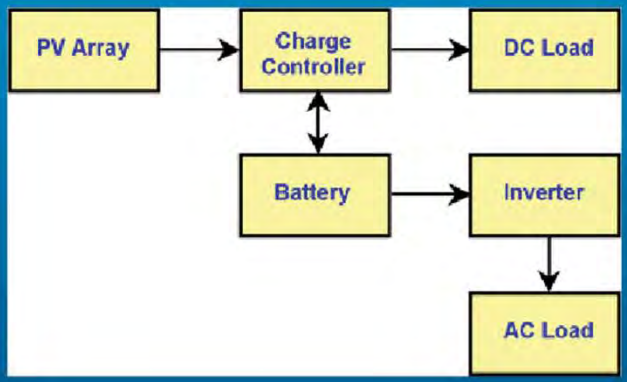
HOW PV SYSTEM WORKS

Standalone PV System with Battery Storage Powering DC & AC Loads





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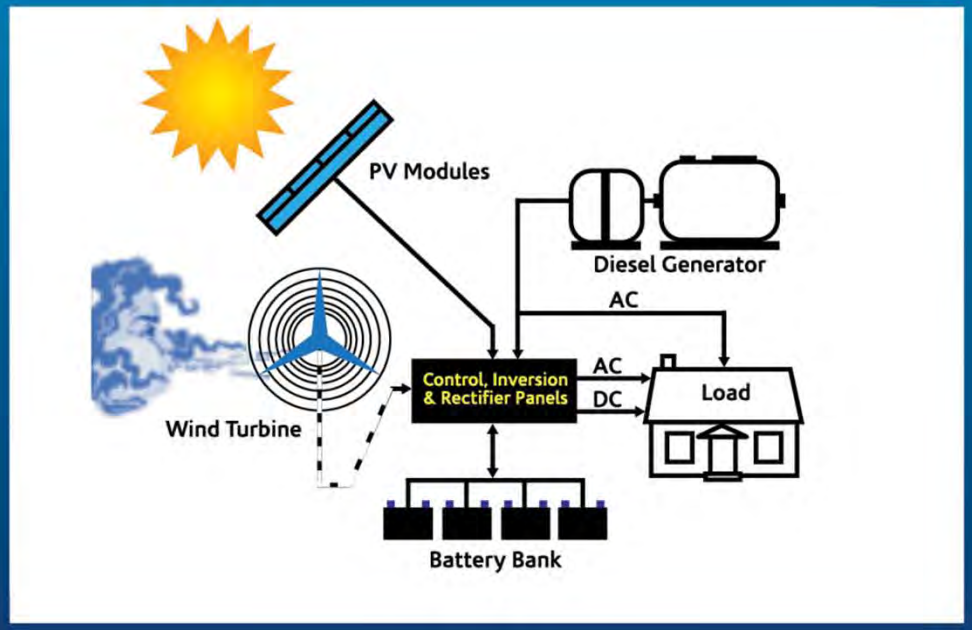
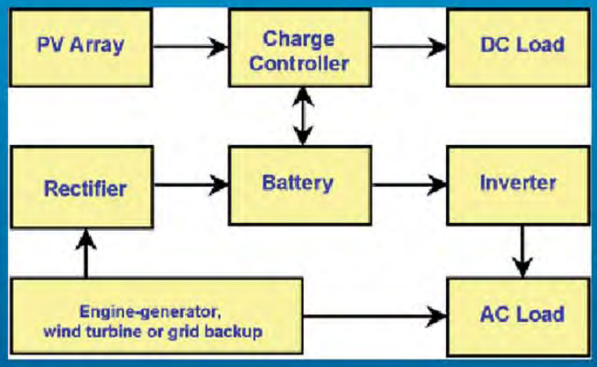
HYPRID POWER SYSTEM





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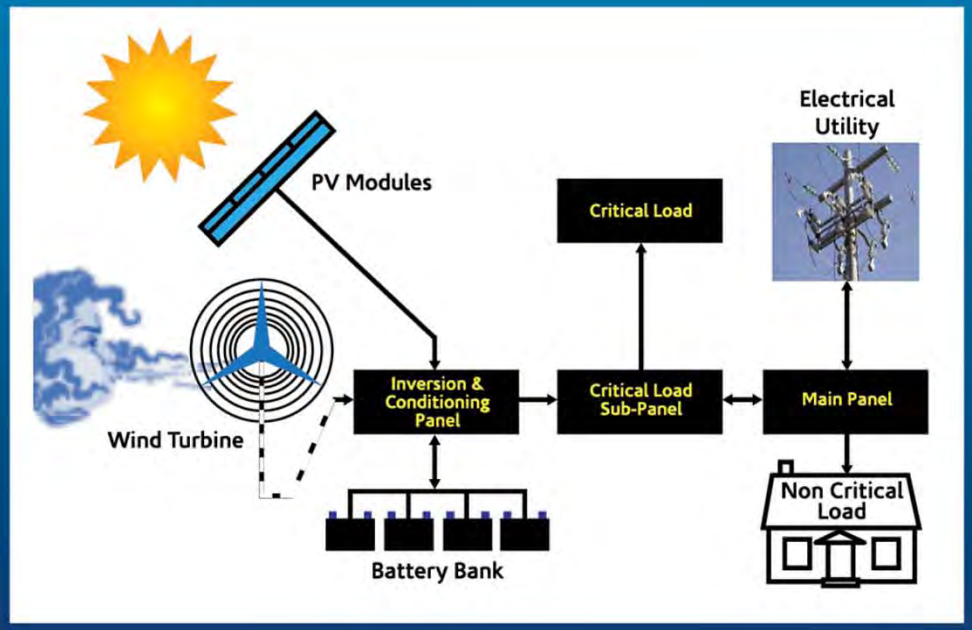
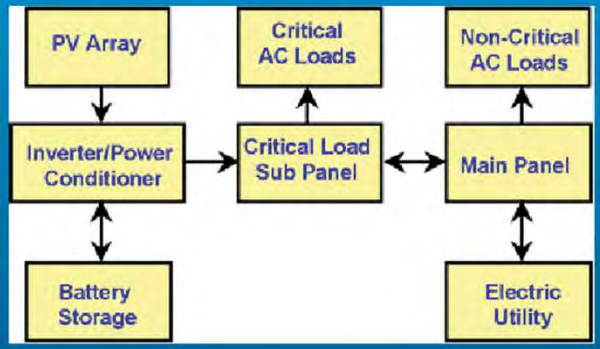
HYPRID CRITICAL LOAD SYSTEM





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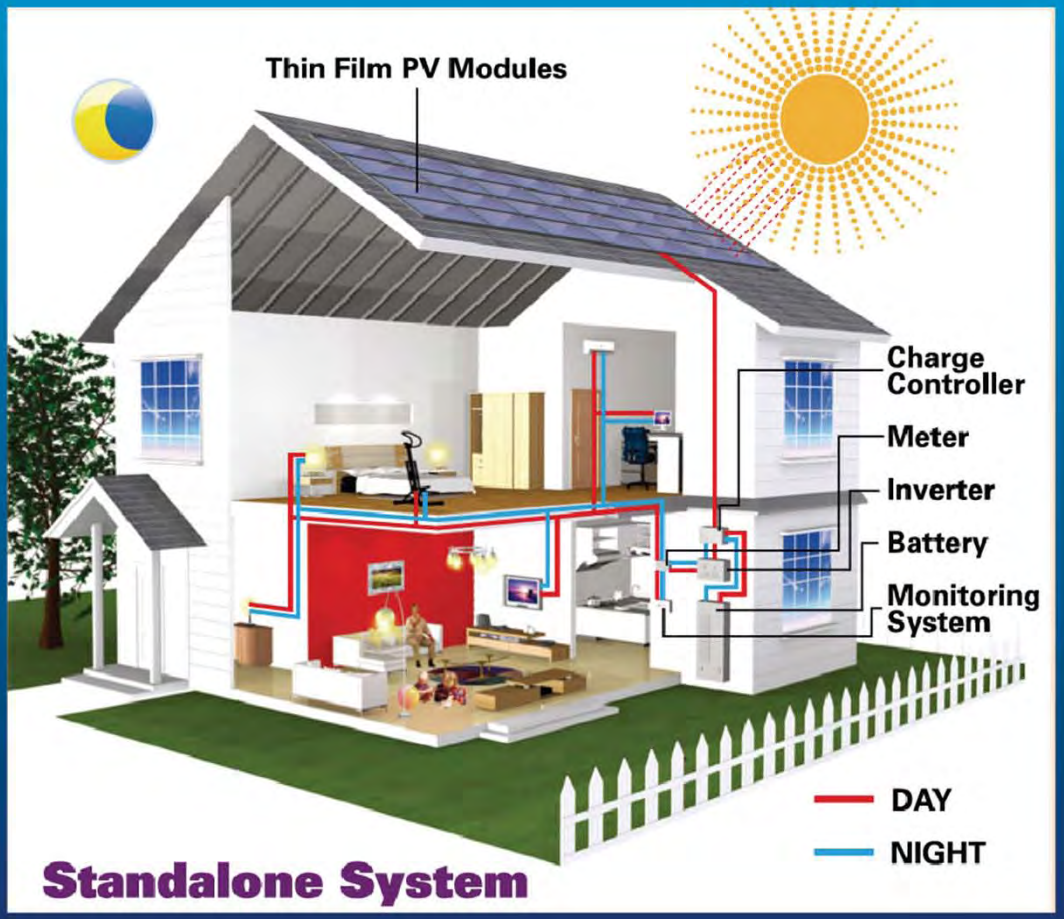
THIN FILM MODULES



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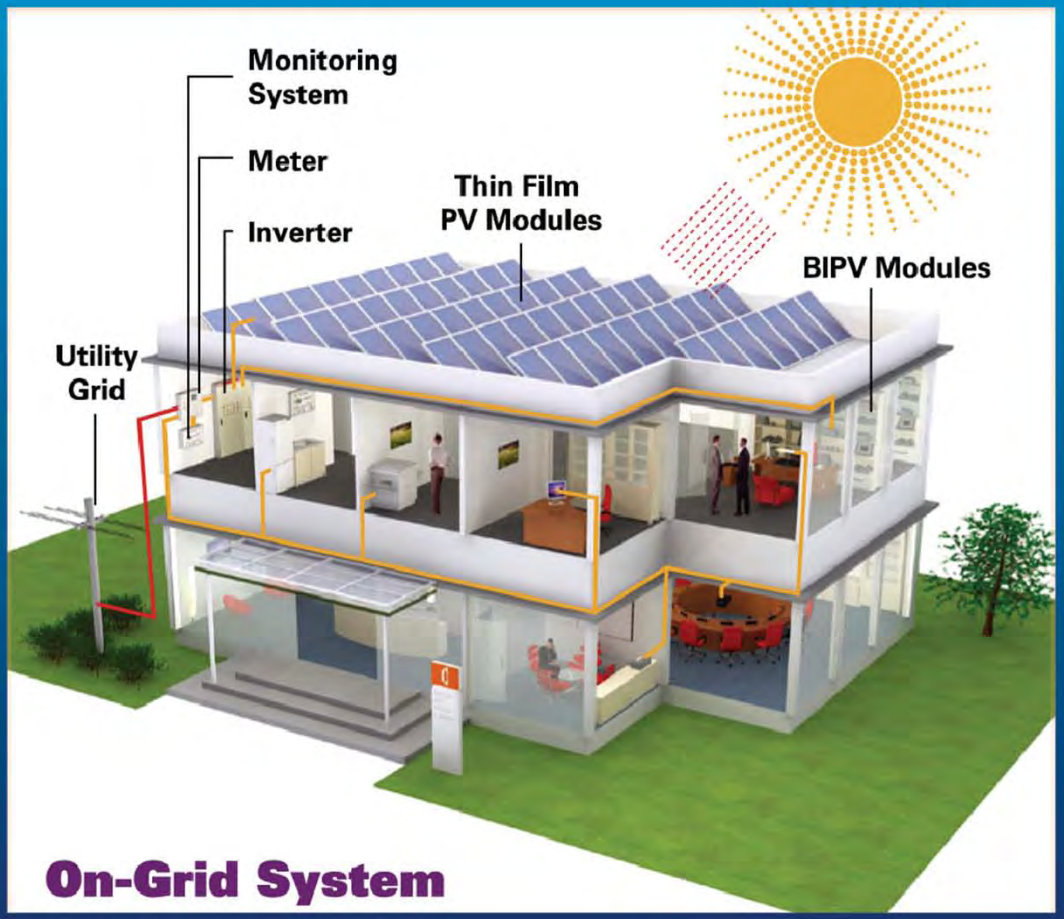
THIN FILM PV & BIPV MODULES



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PV SILICON CELLS & MODULES PRODUCTION TECHNOLOGIES

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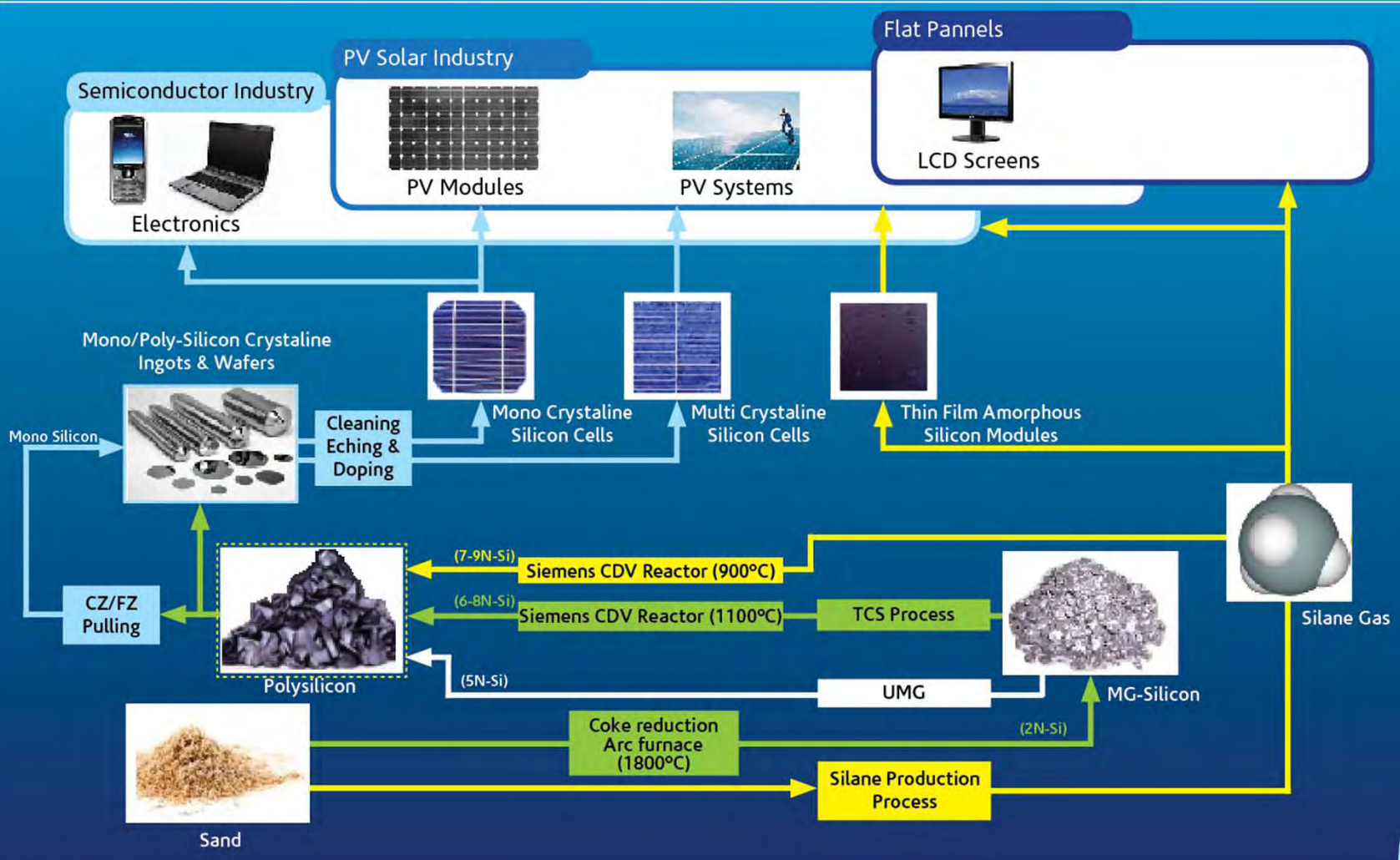
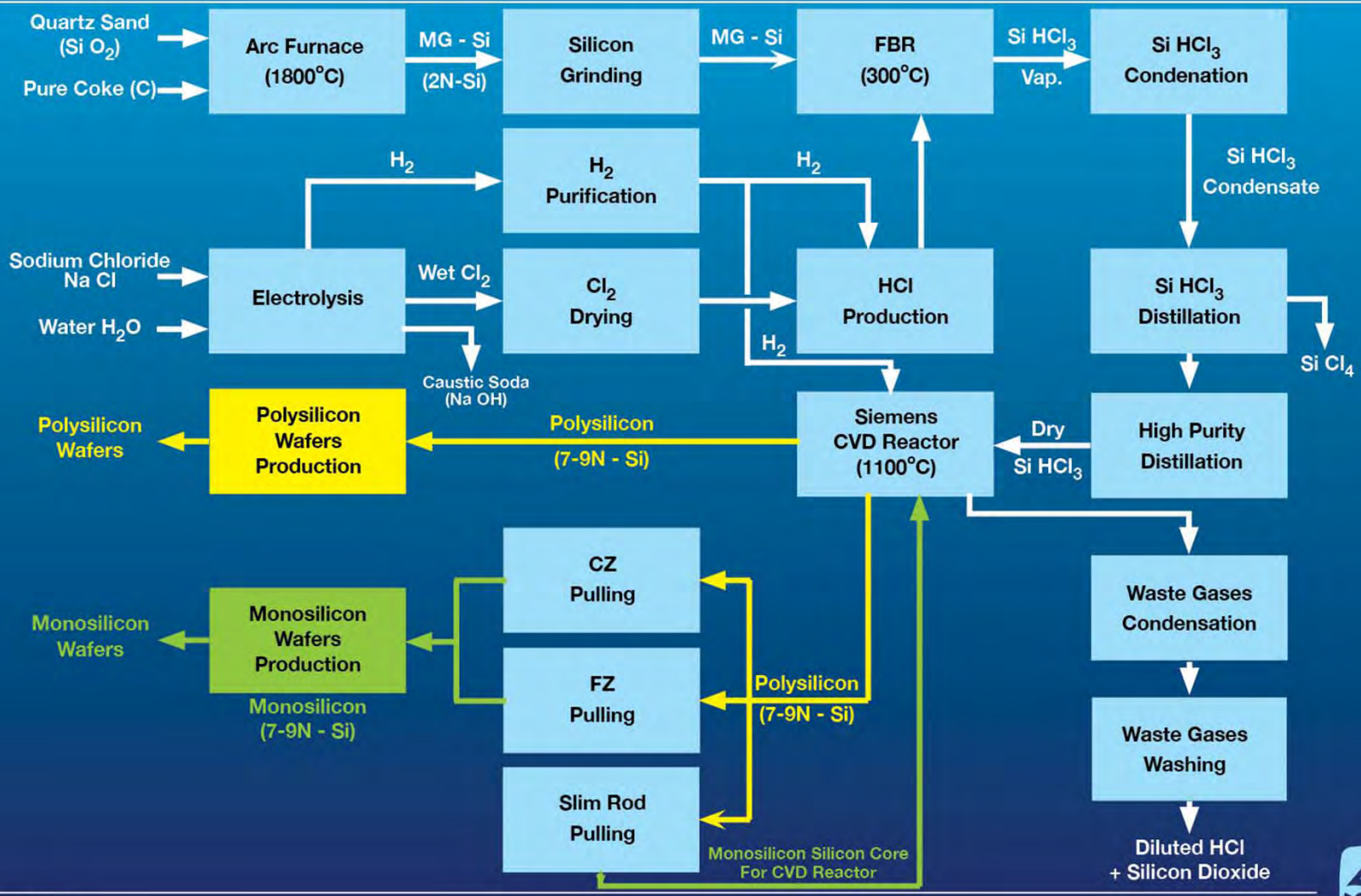
CRYSTALINE SILICON/SILANE VALUE CHAIN



APET

TCS PROCESS FOR POLYSILICON PRODUCTION



SOLAR ENERGY

APET

PRODUCTION OF METALLURGICAL GRADE SILICON (MG-Si)

Equipment:

Arc Furnace

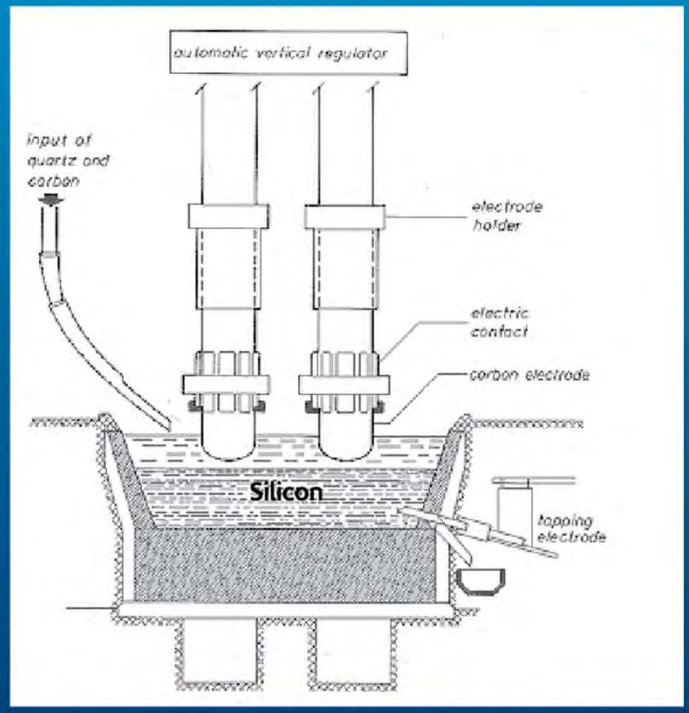
Main Reaction:

$SiO_2 + 2C \xrightarrow{1800^\circ C} Si + 2CO$

Quartz Sand + Very Clean Coke $\xrightarrow{1800^\circ C}$ MG-Silicon (2N-Silicon) + Carbon Mono-Oxide

Side Reaction:

$Si + C \xrightarrow{1800^\circ C} SiC$ (Hard Silicon Carbide)



ARC FURNACE FOR SILICA COKE REDUCTION

APET

PRODUCTION OF TRICHLOROSILANE (TCS)

Equipment:

Fluidised Bed Reactor

Main Reaction:

$$Si + 3HCL \xrightarrow[\text{Catalyst}]{300^{\circ}C} SiHCL_3 + H_2$$

MG-Silicon + Hydrochloric Acid $\xrightarrow[\text{Catalyst}]{300^{\circ}C}$ Trichlorosilane (TCS) + Hydrogen ↑

↓

Condensation & Distillation → Pure (TCS) Gas

Side Reaction:

$$Si + 4HCL \xrightarrow[\text{Catalyst}]{300^{\circ}C} SiCl_4 + 2H_2$$

MG-Silicon + Hydrochloric Acid $\xrightarrow[\text{Catalyst}]{300^{\circ}C}$ Silicon Tetachloride + Hydrogen ↑

(by product)

PRODUCTION OF POLYSILICON (SIEMENS PROCESS)

Equipment:

Chemical Vapor Deposition Reactor (CVD Reactor)

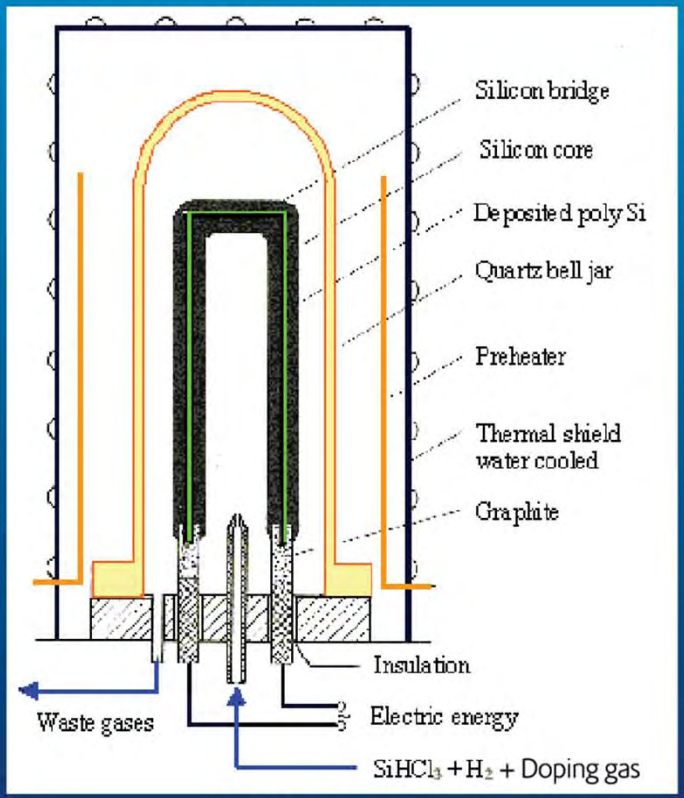
Reaction:

$SiHCL_3 + H_2 \xrightarrow{1100^{\circ}C} Si + 3HCL$

Trichloro Silane + Hydrogen (100L/min) + Doping Gases (1ml/min) ⟶ Polysilicon layer (1kg/hr) + Hydrochloric Acid

N.B

- Doping gases AsH_3 & PH_3 are very poisonous.
- H_2 & $SiHCL_3$ are Combustible/Explosive.
- HCL Gas is very Corrosive & Harmful.
- Reaction Should be Thorougly Optimised & Controlled.



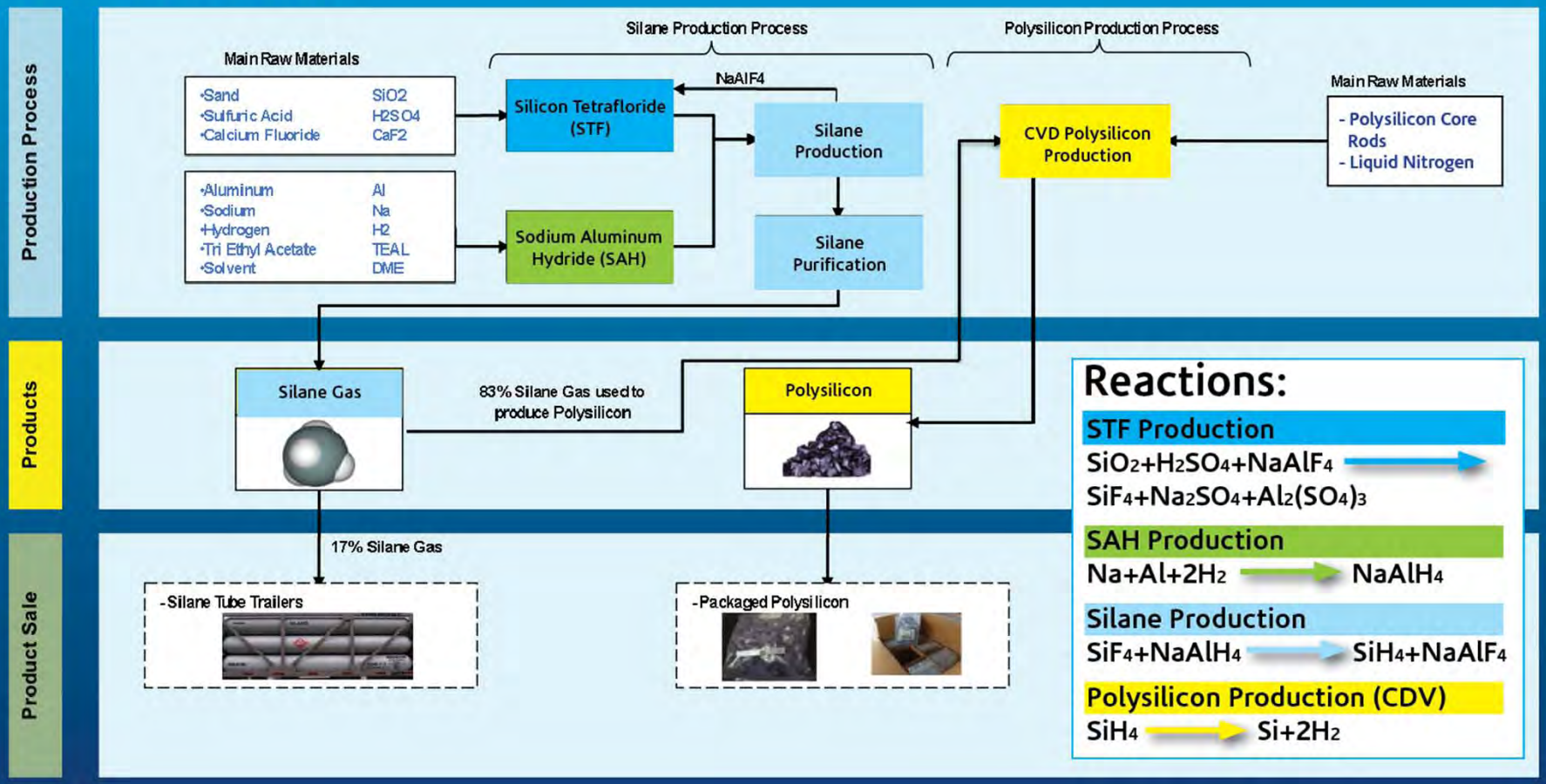
(CVD Reactor)

APET

DEPOSITED POLYSILICON BRIDGE

APET

SILANE SIEMENS PROCESS FOR PRODUCTION OF SILANE & POLYSILICON



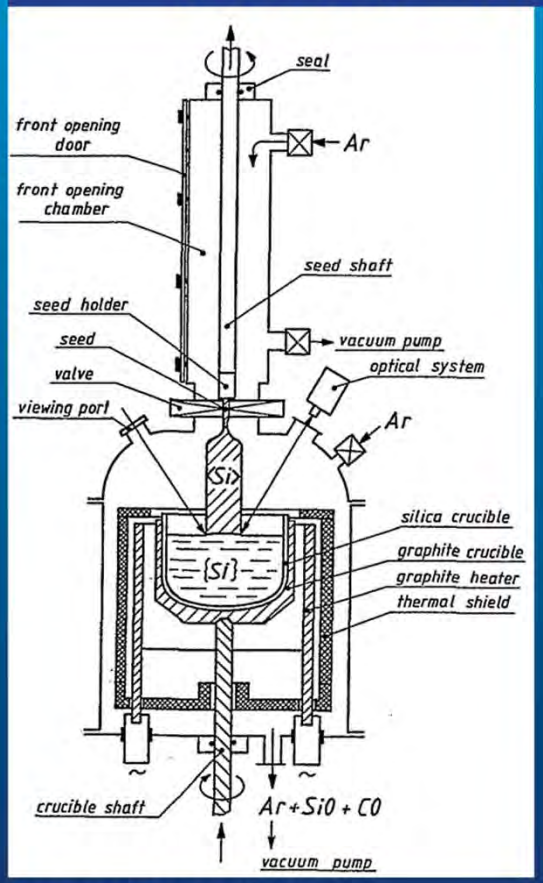
APET

POLYSILICON PEODUCTION TECHNOLOGIES BENCHMARKING

Benchmarking Criteria		Available to Buy Technologies		Other Competing but unavailable technologies	
	Criteria	TCS Siemens	Upgraded Silane Siemens	Silane Siemens	Silane FBR
CAPEX	Average Expected CAPEX - EPC Cost (USD/KG)	120-150	129	129	131
Operational Analysis	Energy Usage (KWH/Kg)	150-250	**50-60**	75-150	30-40
	Raw Material Requirement (Relative to TCS)	100	75	75	75
	Man Power (Relative to TCS)	100	91	91	68
	Plant maintenance & Consumable per Kg (Relative to TCS)	100	63	63	63
	Total Cash Cost per KG (Relative to TCS)	100	**65**	75	51
Strategic Key Points	Used by (% of Total Global Polysilicon Production)	c.80%	Yingli, KCC and Ningbo Solar	REC	MEMC & REC
	Availability of Technology (Existing licensors)	Several	Only Virasa	None	None
	Product mix flexibility	Only Polysilicon	**100% flexibility to produce Silane and Polysilicon**	Only Polysilicon	100% flexibility to produce Silane and Polysilicon

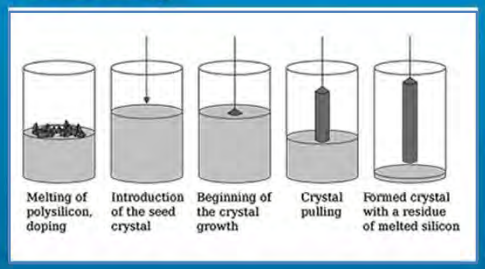
MONOSILICON PRODUCTION TECHNOLOGIES

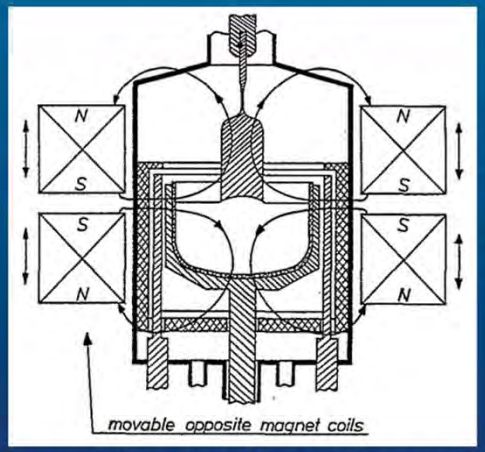
Czochralski Process (CZ Process)



Furnace with Graphite Heater

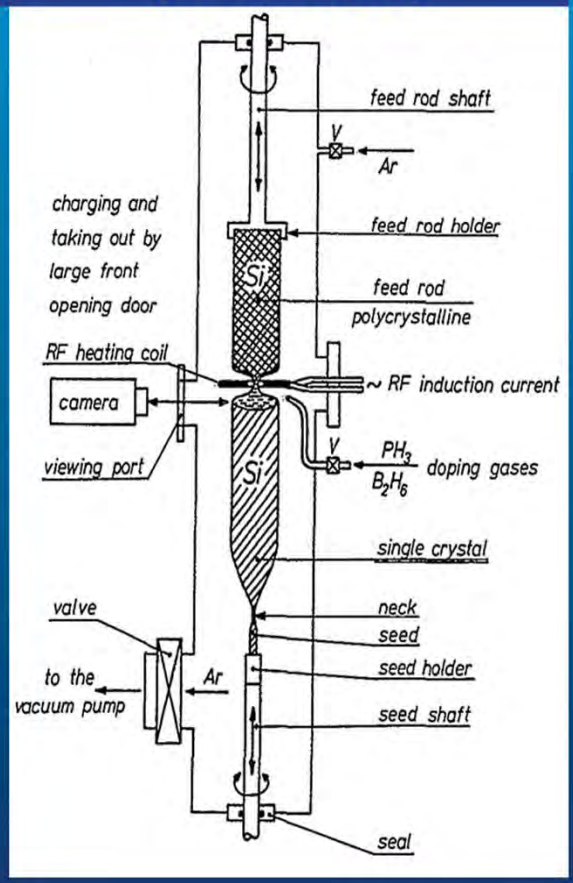
Process Concept





Furnace with 2 moveable opposite magnet coils for damping thermal convection of the melt

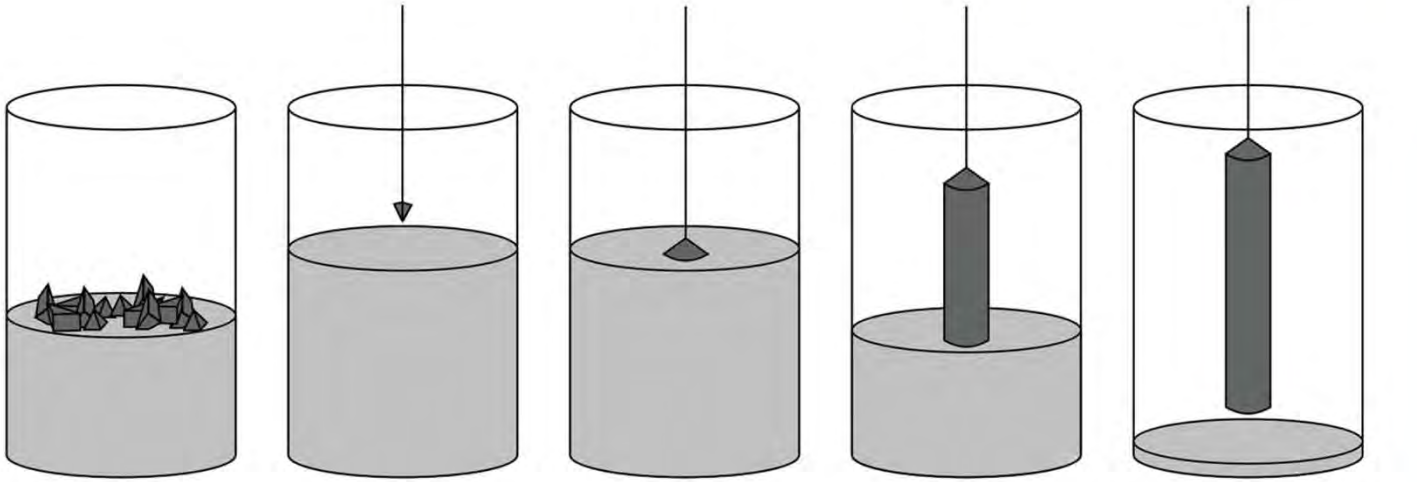
(FZ Process)



APET

CZ Process Concept

CZ Process Concept



APET

MONOSILICON INGOT

APET

WAFERS TECHNOLOGY

1 - Polycrystaline Silicon

2 - Crystaline Growth, Boron Doping, Ingot Drawing

3 - Single Crystaline Silicon Ingot

4 - Shaping

5 - Finished Single Crystaline Silicon Ingot

6 - Slicing

7 - Edge Rounding

8 - Lapping

9 - Etching

10 - Polishing

11 - Cleaning

12 - Inspection

16 - Final Inspection

15 - Antireflector Coating

14 - Alumenium Layer Deposite on P-side

13 - Phosph. Diff. (N-Layer) & Elec. Contact Printing

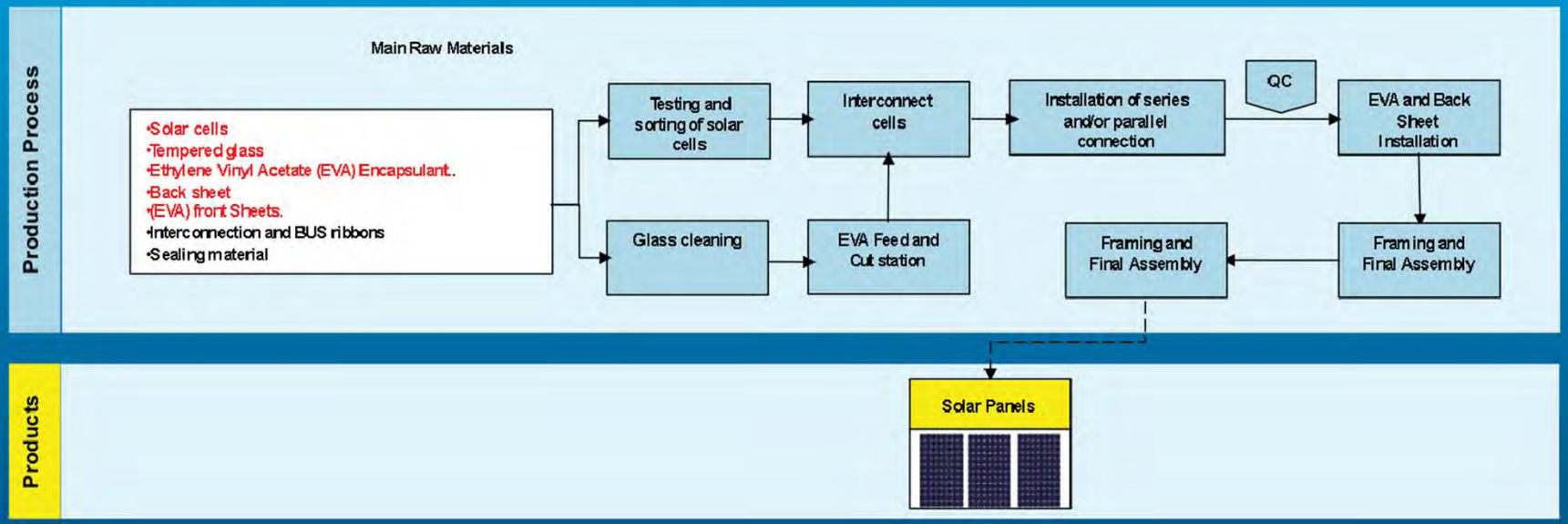
17 - Packing

18 - Shipping

Wafers Lapping Process
(Flatness Tollerence < 1micron for 1000 Cm^2 Surface Area of 300 mm Diameter Wafers).

APET

SOLAR MODULES PRODUCTION



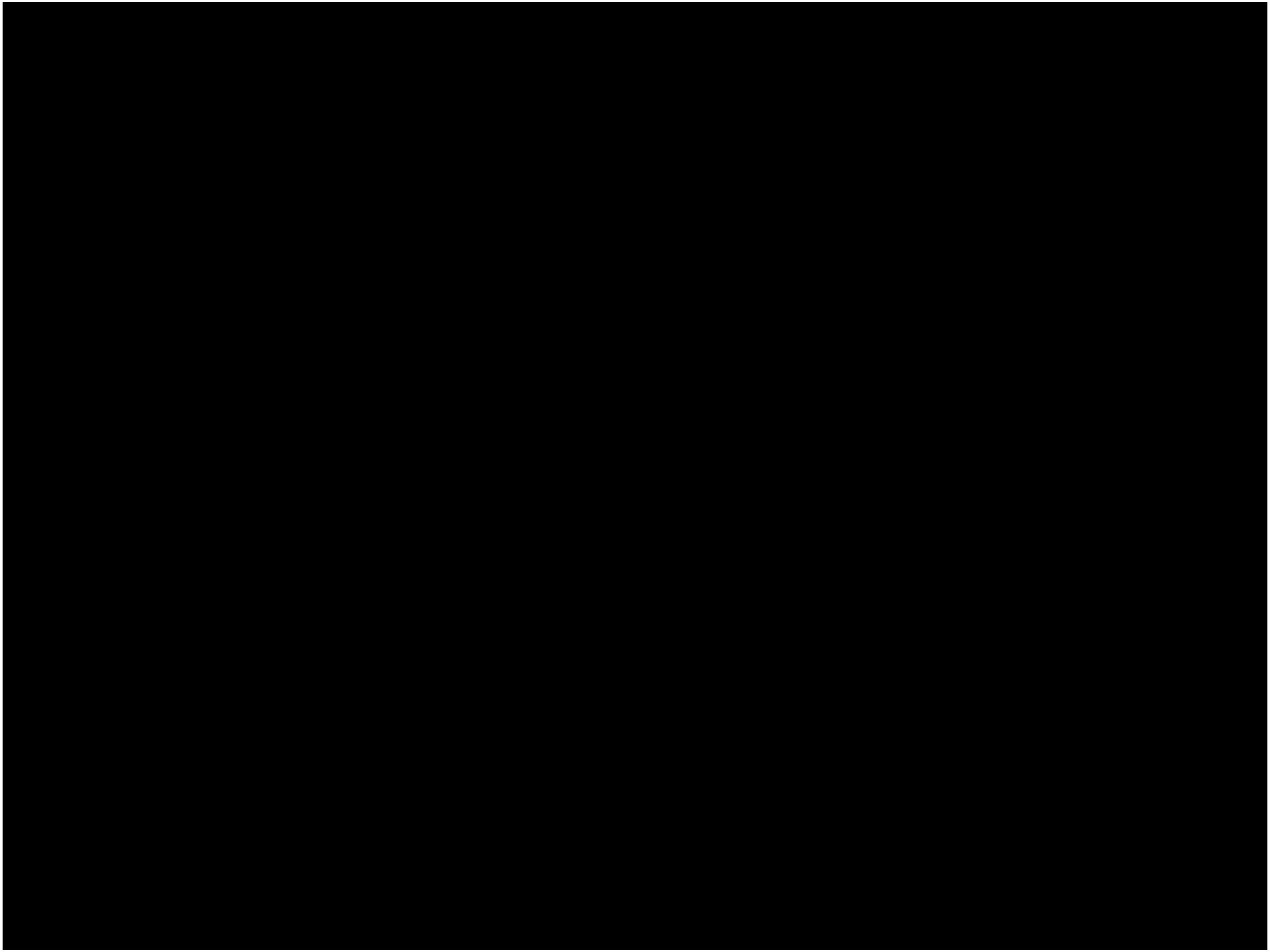
APET

POLYSILICON PROCESS TECHNOLOGY

TCS SIEMENS TECHNOLOGY FOR POLYSILICON PRODUCTUION (SHORT VIDEO)

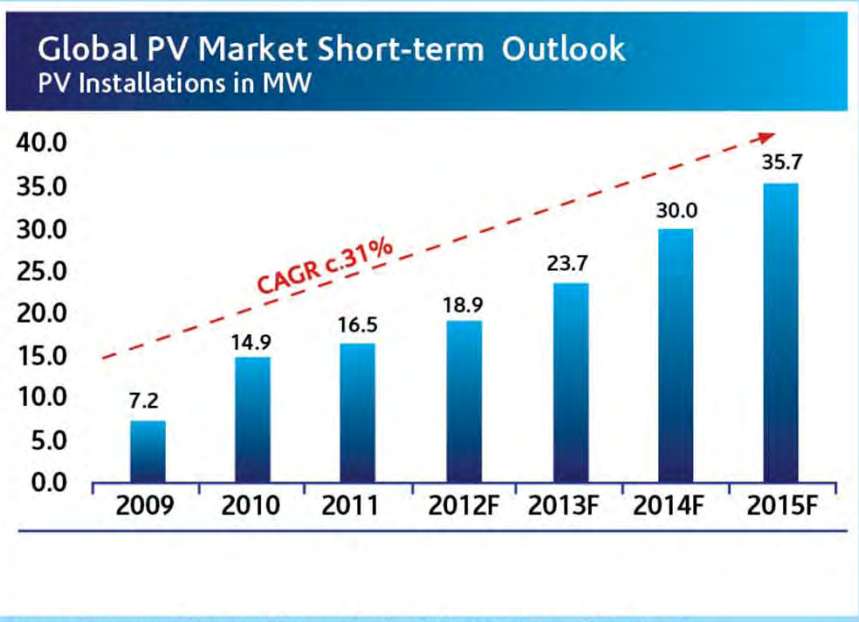
VIDEO SKIP

APET

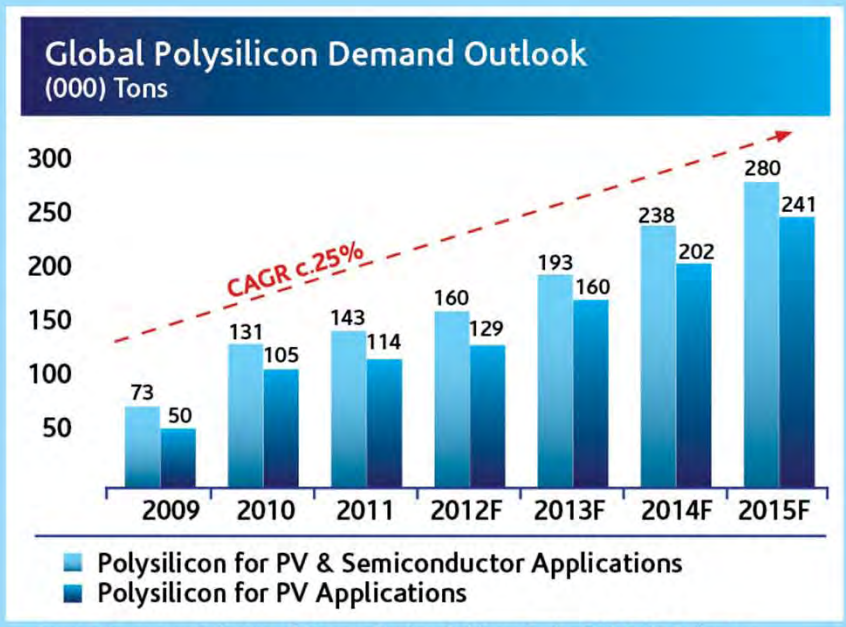


PV MARKET OUTLOOK

POLYSILICON DEMAND OUTLOOK



Source: Consensus Estimates of Morgan Stanley, EPIA, HC Estimates (2015 figure)

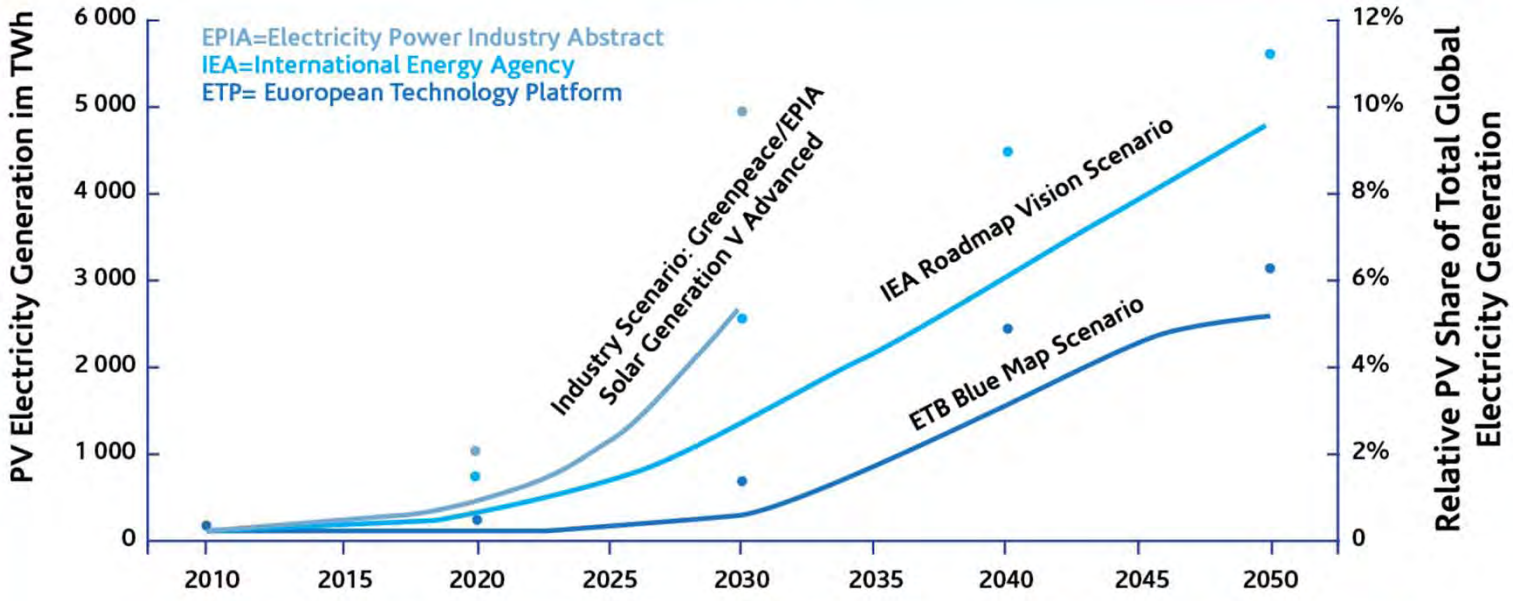


Source: Consensus Estimates of Morgan Stanley, Goldman Sachs, EPIA & HC Estimates

APET

GLOBAL PV MARKET LONG-TERM OUTLOOK

Global PV Market Long-term Outlook

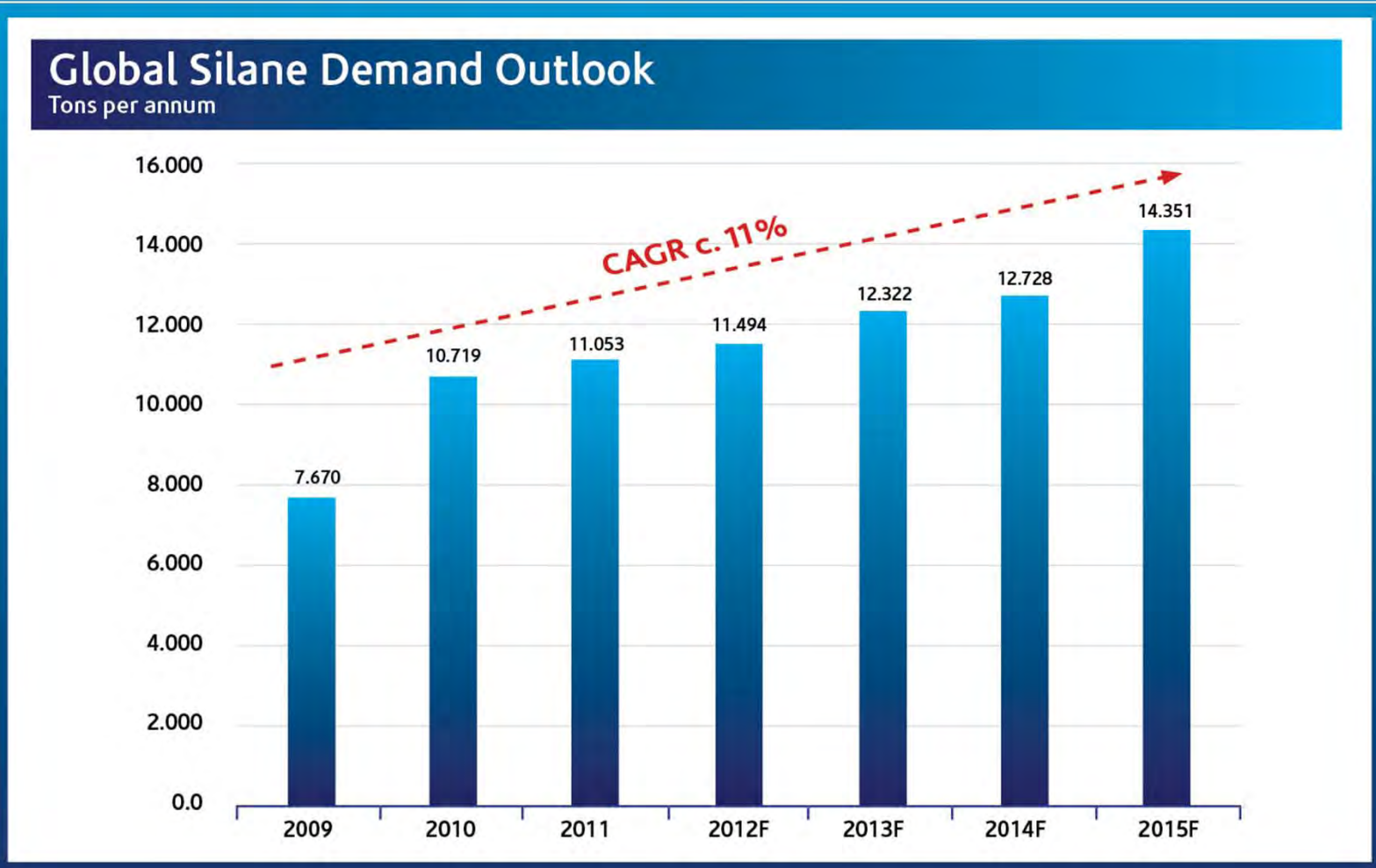


IEA Roadmap envisions PV Providing 11% of Global Electricity Generation by 2050 compared to the current 0.1%

Source: EA Energy Technology Perspective 2008, EPIA/Greenpeace Solar Generation V generation of the ETB Blue map Scenario

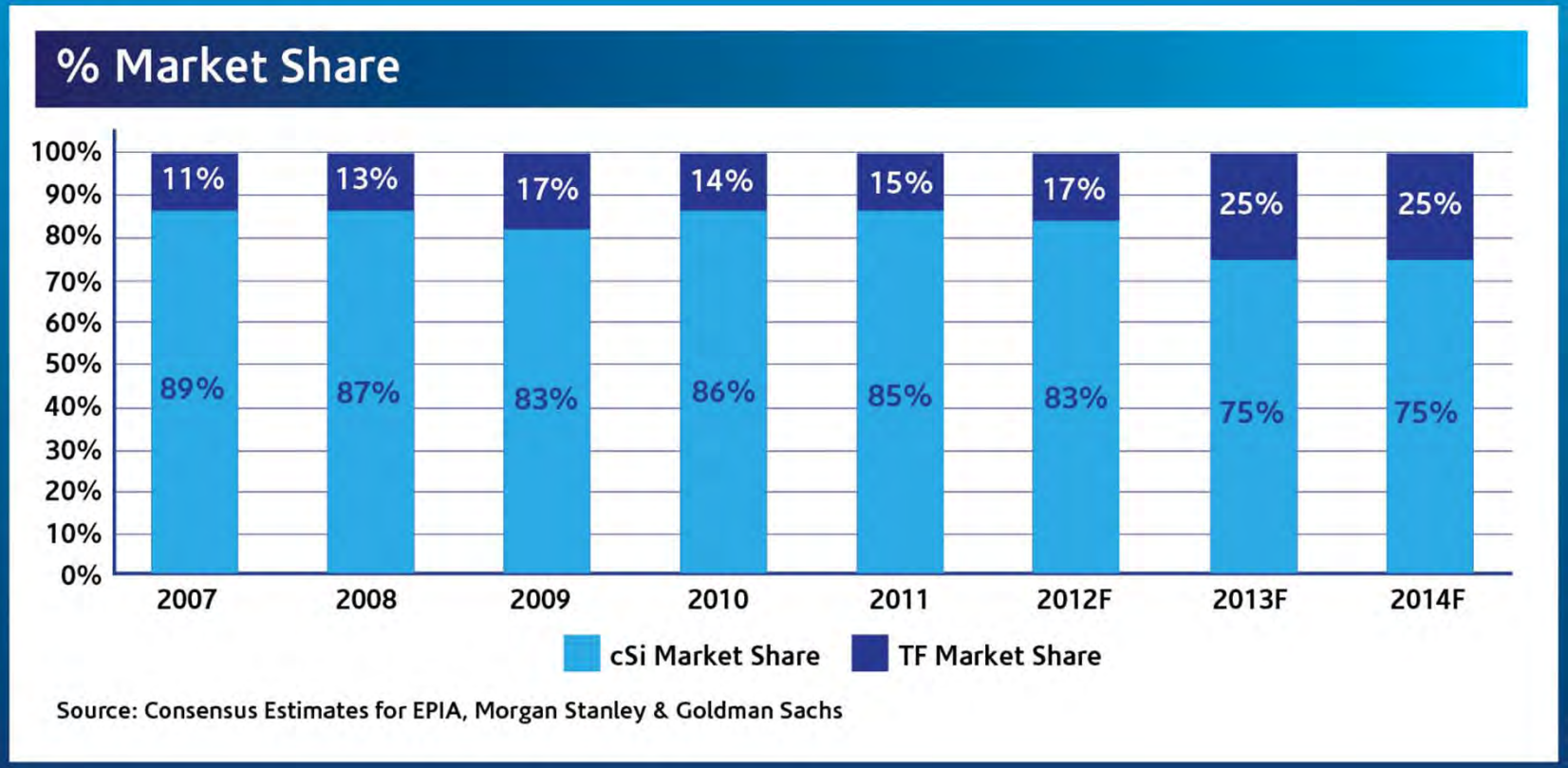
APET

SILANE GAS DEMAND OUTLOOK



APET

PV MARKET COMPOSITION



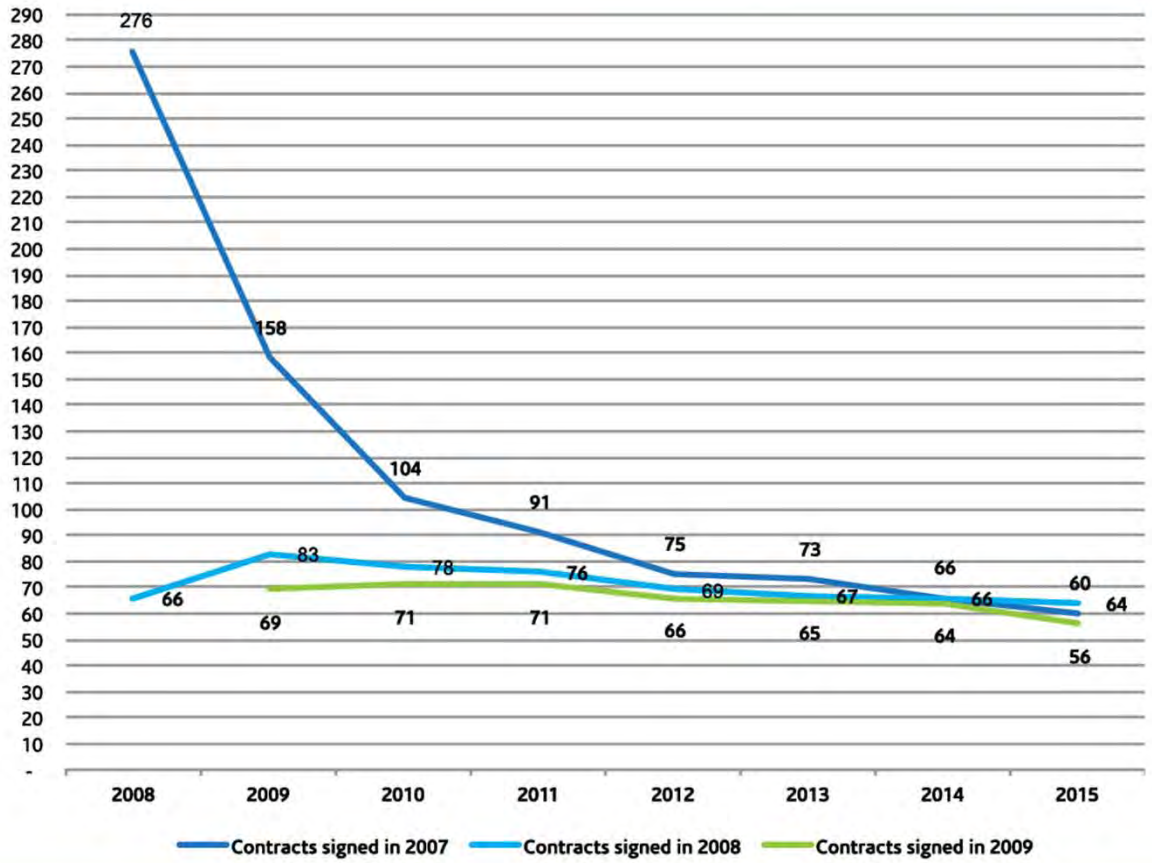
Source: Consensus Estimates for EPIA, Morgan Stanley & Goldman Sachs

APET

POLYSILICON, SILANE & PV MODULE PRICES

POLYSILICON PRICE

Polysilicon Contract Prices
USD per Kg



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SILANE GAS PRICE

Bulk Deliveries:

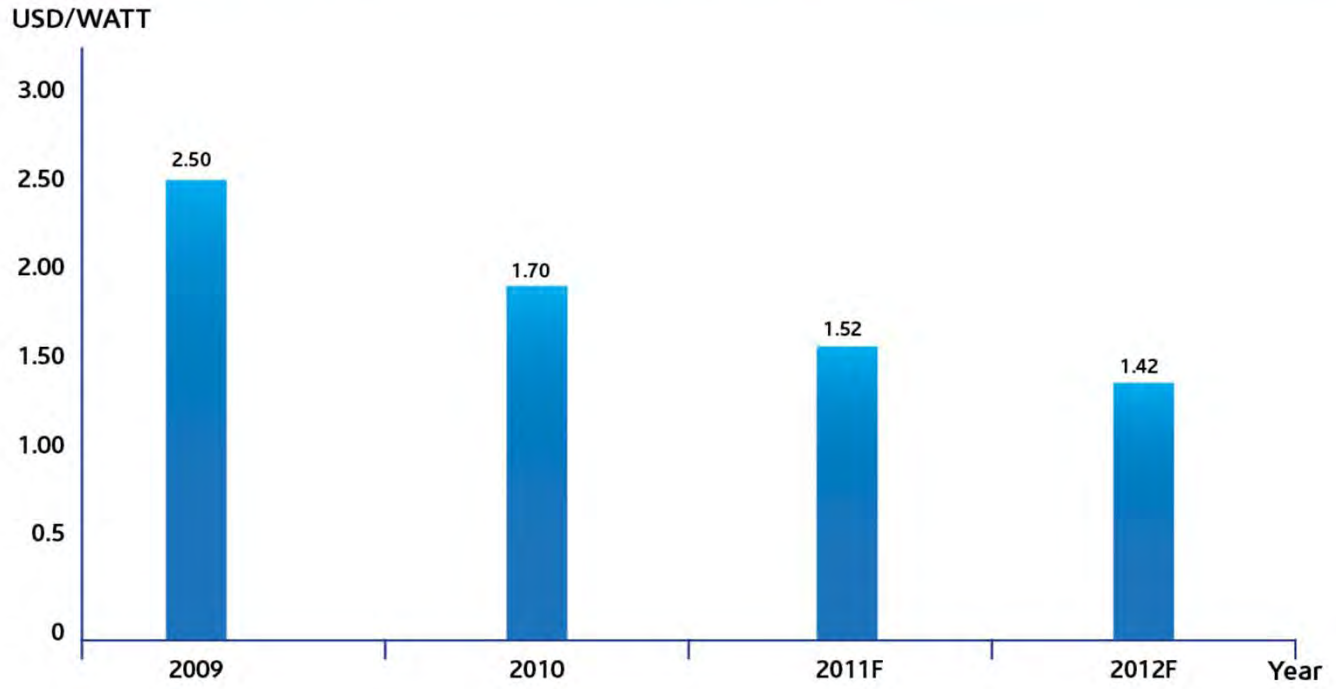
Currently	55-70 USD/Kg
Forecasted Near Future	About 60 USD/Kg

In Cylinders:

Currently	77-98 USD/Kg
Forecasted Near Future	About 80 USD/Kg

PV MODULE AVERAGE SELLING PRICE

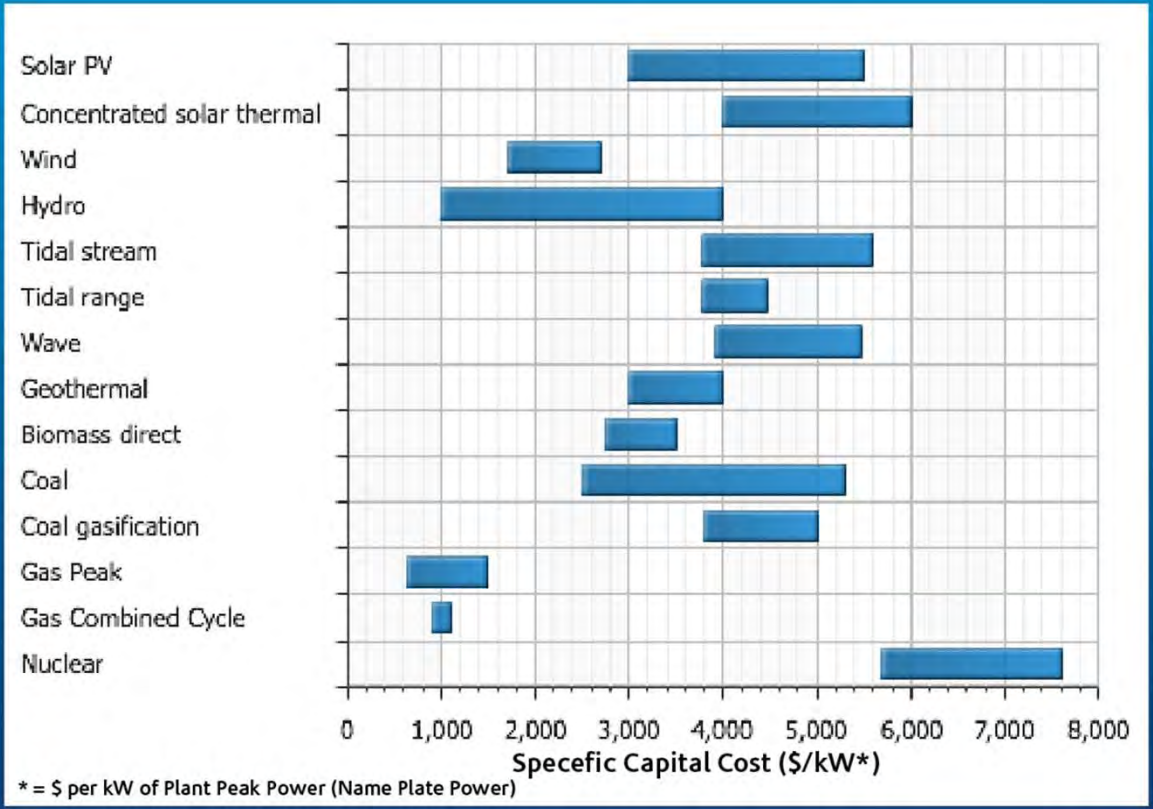
PV MODULES AVERAGE SELLING PRICE



Source: USB 2010

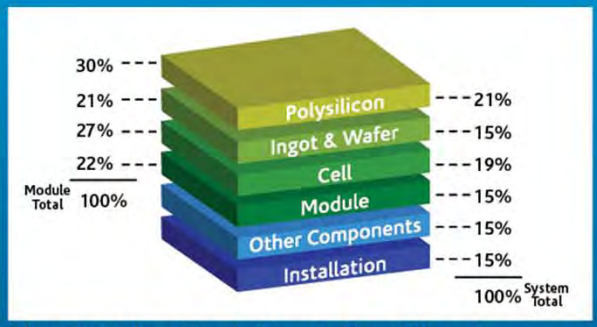
APET

PV ENERGY SYSTEM COST

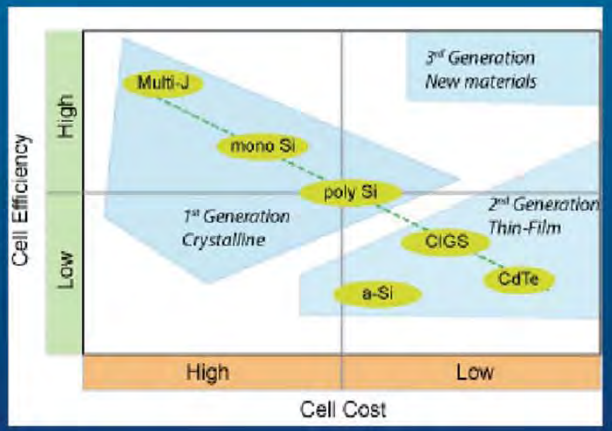


* = $ per kW of Plant Peak Power (Name Plate Power)

Solar PV & Thermal CSP Plants are the most Capital intensive among renewable Energy Plants



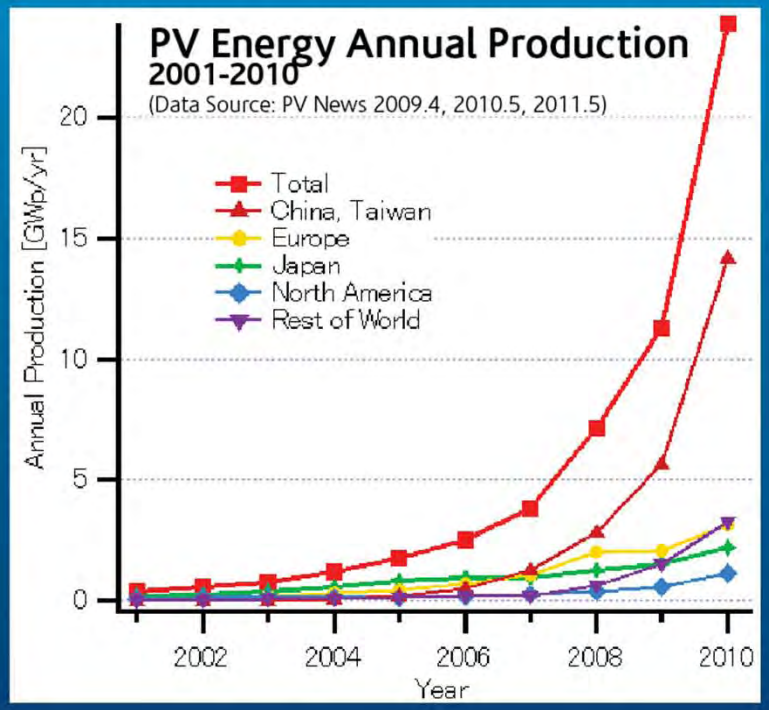
The PV Value Stack (Crystaline Silicon)

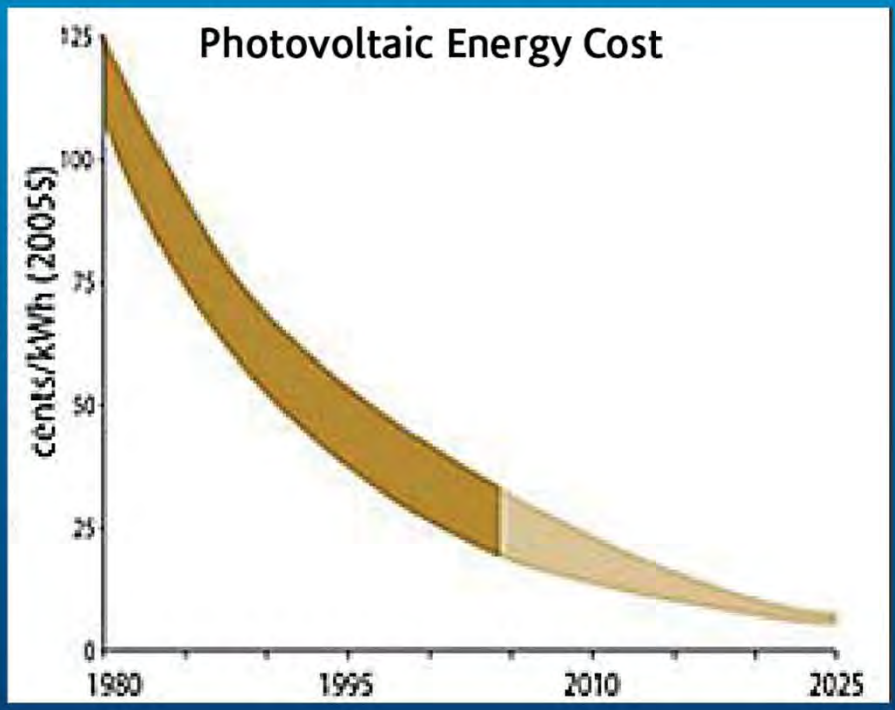


Cell Material Cost Versus Efficiency

APET

PV GENERATED ENERGY & RELEVENT COSTS





APET

SOLAR ENERGY CONTRIBUTION IN EGYPT'S FUTUR DEVELOPEMENT

APET

EGYPT IS AN IDEAL LAUNCHING PAD FOR PV INDUSTRY

- Availability of clean quartz sand as a cheap feed stock for polysilicon industry.
- Centralized ideal location to serve global wafer manufacturers (49% in China & Taiwan, 18% in Japan, 24% in Europe& 3% in USA).
- Competitive electrical power tariffs.
- Competitive taxation system (20% corporate tax vs. 43% in France, 30% in Spain and 25% in China).
- Large Pool of skilled labor.
- Governmental policies for favoring renewable energy (20% of electrical energy from renewables by 2020).
- One of the foreseen world's attractive growing and diversified economics in MENA region.

APET

SOLAR ENERGY IS A FAVORABLE RENEWABLE ENERGY SOURCE FOR EGYPT

- Egypt is within the sun belt countries enjoying:
  1. Highest intensity of direct solar radiation (1900-2800 Kw/m2/year).
  2. Long sun shine duration (9-11 hr/day).
  3. Mostly clear skies
- Solar energy can positively contribute in developing new industrial and urban communities in remote uninhabited locations(e.g. Sinai, Eastern & Western dessert):
  1. Standalone and hybrid electrical power generation.
  2. Water desalination.
  3. Lighting & HVAC of buildings.
- Clean energy production and use.

APET

THANK YOU

APET