Design of Off-grid Solar PV system

13 – 15 Julai 2020

Unit Perunding Kecekapan Tenaga Elektrik
Cawangan Kejuruteraan Elektrik

KURSUS DESIGN OF OFF-GRID SOLAR PV SYSTEMS
(31 JULAI – 2 OGOS 2018)

HARI/MASA	8.00 Pagi - 8.30 Pagi	8.30 Pagi – 10.30 Pagi	10.30- 11.00 Pagi	11.00 Pagi - 12.00 T/hari	1.00 - 2.30 Petang	2.30 Petang - 4.30 Petang	4.30 - 5.00 Petang
RABU 31/07/2019	PENDAFTARAN PESERTA	Sesi 1 Review on Renewable Energy System & Technology & Solar PV Fundamental	MINUM PAGI	Sesi 2 Off-grid Solar PV system design: Part 1 (Step 1 – 5)	MAKAN TENGAHARI	Sesi 3 Off-grid Solar PV system design: Part 1 (Step 6 – 10)	MINUM PETANG
		Penceramah : Dr. Abdul Muhaimin		Penceramah : Dr. Abdul Muhaimin		Penceramah : Dr. Abdul Muhaimin	
KHAMIS 1/8/2019		Sesi 4 Off-grid Solar PV system design: Part 1 (Step 11 – 15)		Sesi 5 Off-grid Solar PV system design: Part 2 (Balance of System)		Sesi 6 Case study assignment	
		Penceramah : Dr. Abdul Muhaimin		Penceramah : Dr. Abdul Muhaimin		Penceramah : Dr. Abdul Muhaimin Fasilitator: Mohd Quyyum	
JUMAAT 2/8/2019		Sesi 7 Hands-on Practical		Sesi 8 Group presentation & conclusion			
		Penceramah : Dr. Abdul Muhaimin Fasilitator:		Penceramah : Dr. Abdul Muhaimin Fasilitator:			

Objektif Latihan

- Kesedaran (awareness)
- Mengenali asas Tenaga Boleh Baharu (TBB) – Renewable Energy
- Memahami asas teknologi Solar PV – teori, operasi & pengujian
- Merekabentuk sistem solar PV off-grid

KANDUNGAN KURSUS

1. Pengenalan Tenaga Boleh Baharu (TBB)

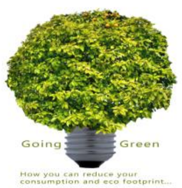
- Senario tenaga global
- Sumber & teknologi TBB;

2. Teknologi Sistem Solar PV

- Asas Kejuruteraan Sistem Solar PV
- Off-Grid solar PV

3. Latih amal

- Latihan pengiraan & rekabentuk
- Latihan (Individu & berkumpulan
- Hands-on
- Case study

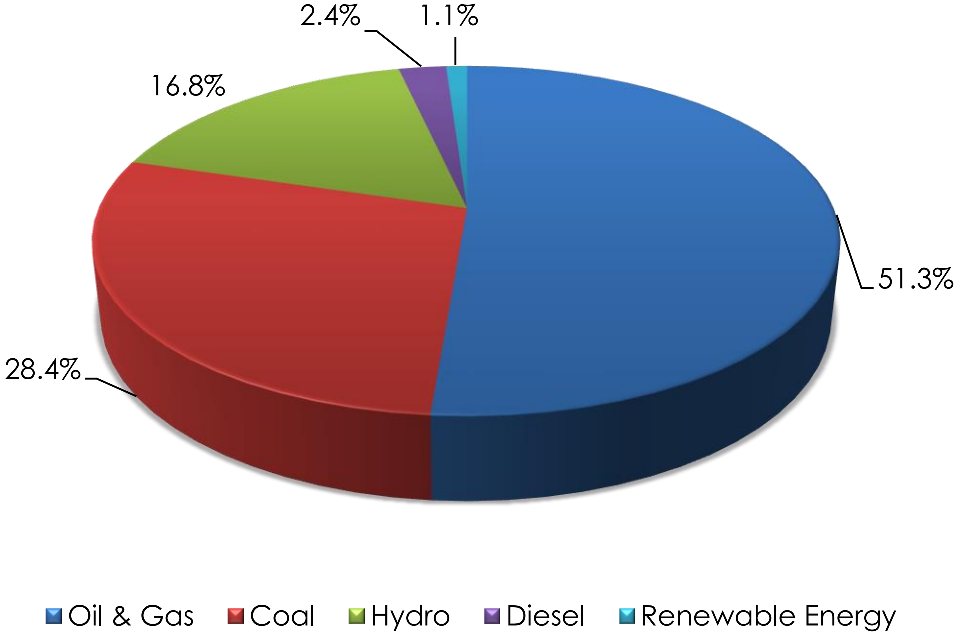


CHAPTER 1

- Review on Renewable Energy System Technology

Energy Resources

- The world energy demand is still dependent on fossil fuel base energy generation
  - Gas & oil
  - Coal
  - Diesel



Resources	Capacity (MW)			
	Peninsular	Sabah	Sarawak	Total
Oil and gas	11,988.4	1,034.2	608	13,630.6
Coal	7,056.0	-	480	7,536.0
Hydro	1,899.1	76.9	2,496	4,472.0
Diesel	-	487.3	163	650.3
Other renewable energy	234.2	52.0	-	286.2
Total installed capacity	21,177.7	1,650.4	3,747	26,575.1

Source : Energy Commission of Malaysia, KeTTHA, SEDA

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Pengenalan Tenaga Boleh Baharu / Renewable Energy

Energy Emission Overview

- Every day we damage our climate by using fossil fuels for energy & transport

- Malaysia emitted 208 mill. tonnes of CO_2 or 7.1 tonnes per capita in 2009

- Projected total emissions – 285.73 mill tonnes CO_2 (2020). Largest emitting sector – electricity generation (43.4%)

Source : Energy Revolution, Greenpeace

Global Issues

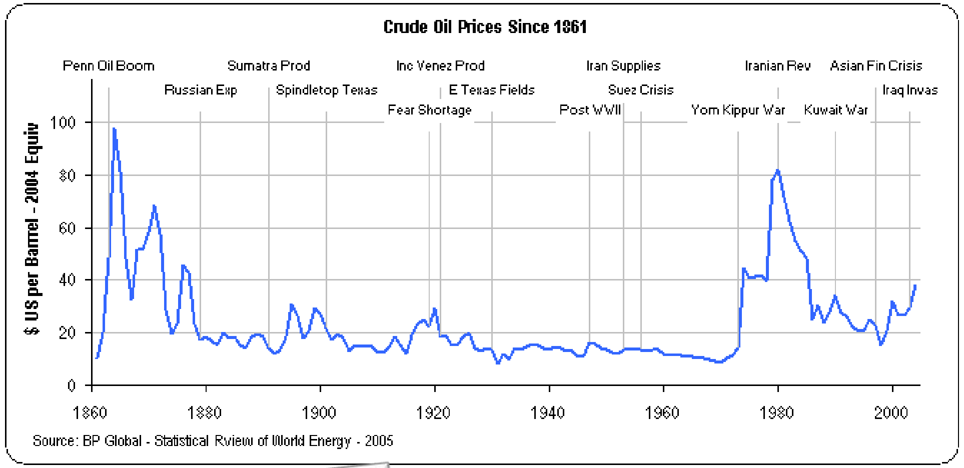
- Fossil fuel based energy will be depleted by time

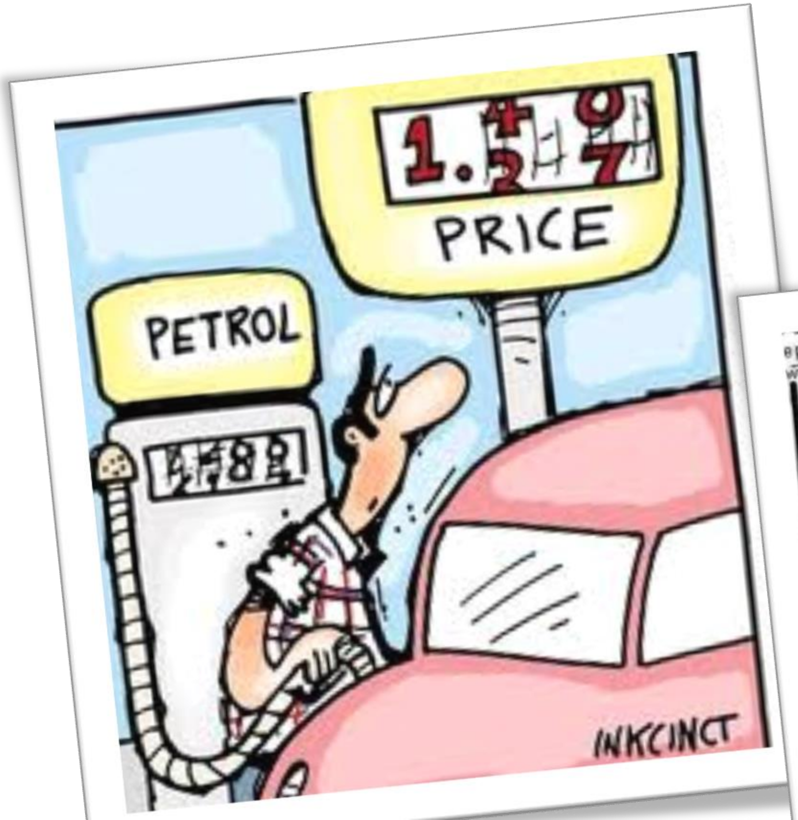
  – **Malaysia's energy reserve**

  - Oil reserve of three billion barrels. Crude oil production 750,000 barrel/day
  - Natural gas produced 80,000 barrels/day, with 2.12 trillion cubic meter reserves
  - The current reserve amount for oil may last for 19 years & natural gas for 33 years

Global Issues

- Fluctuation of global oil price





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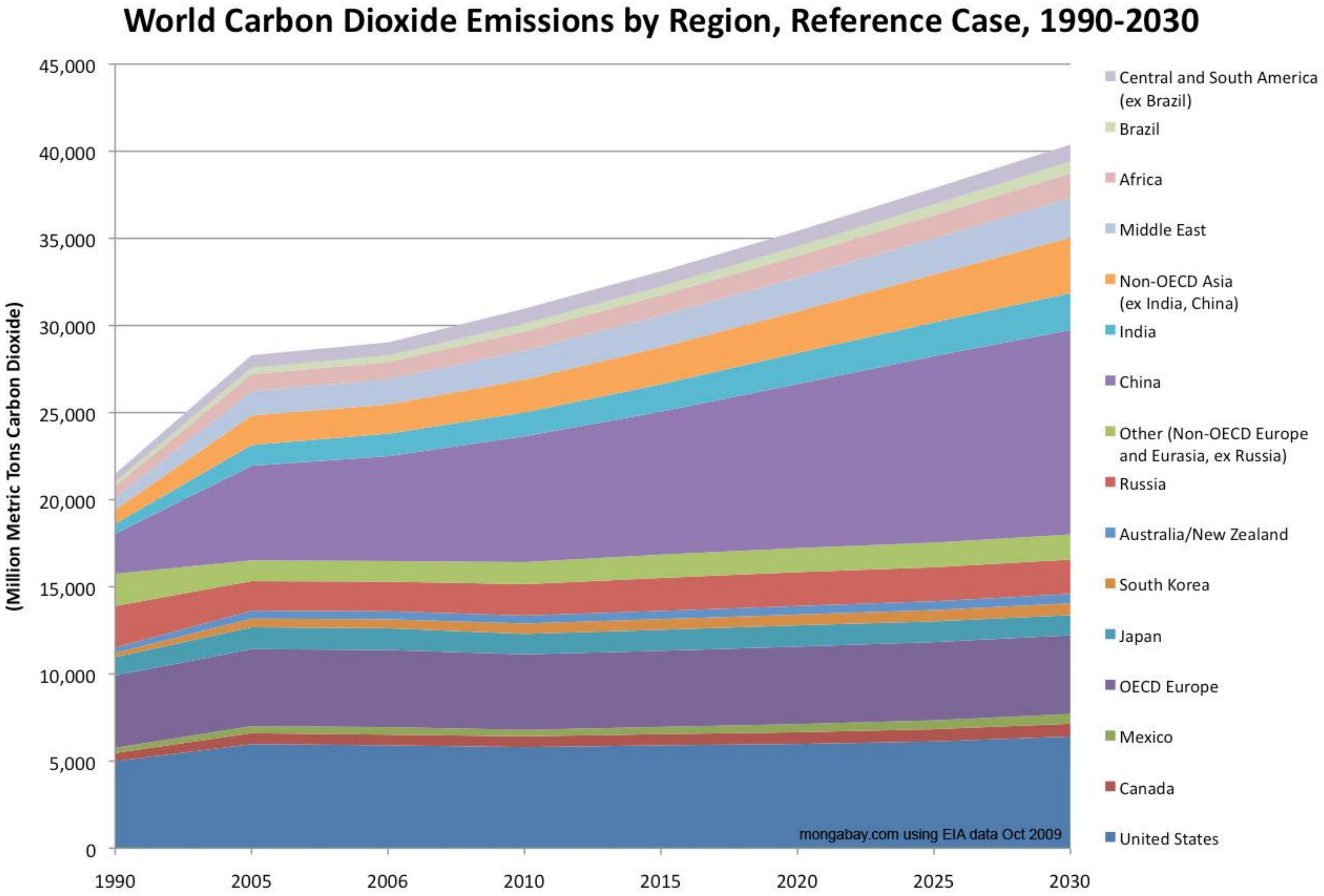
Global Issues

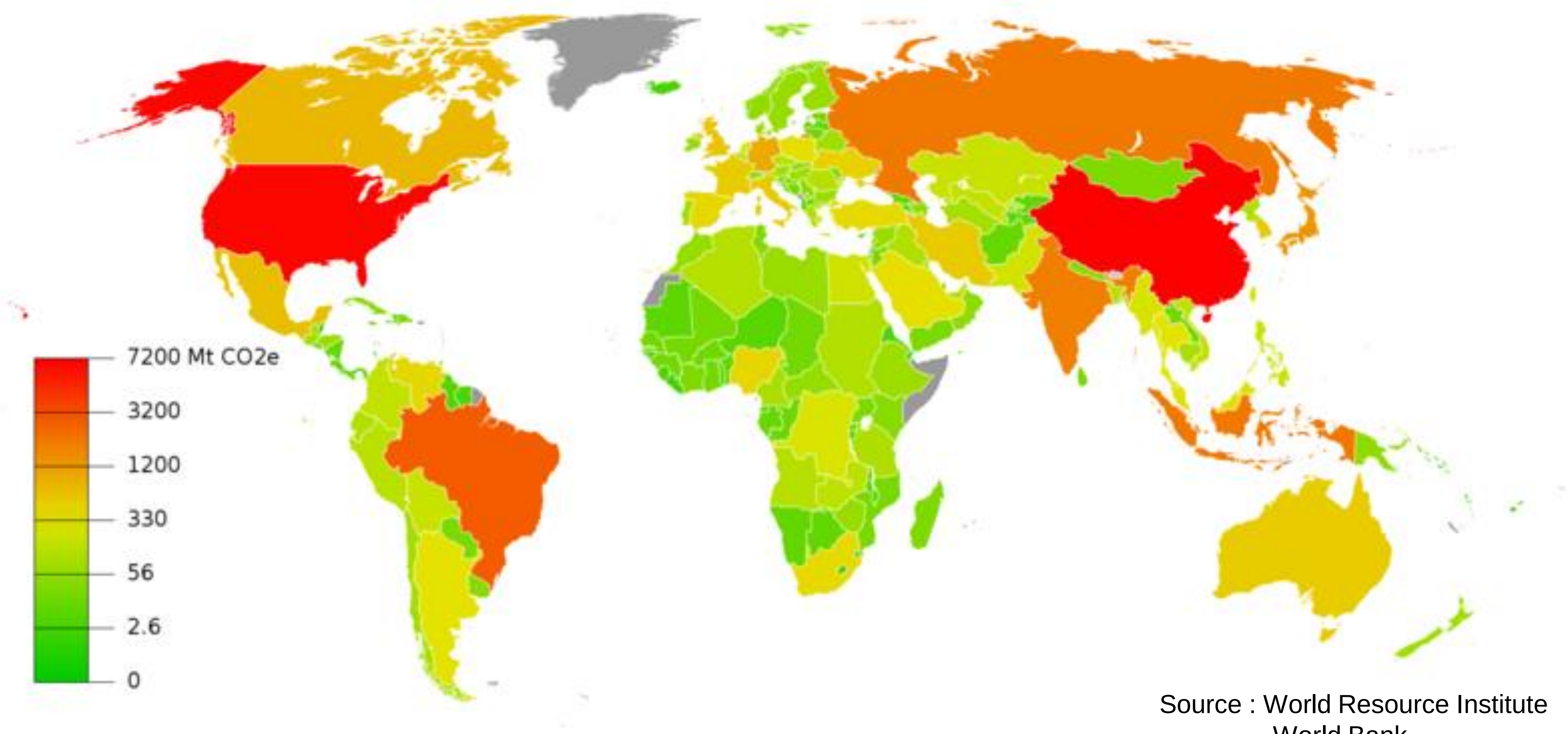
- World population growth requires more energy
- Environmental pollution

Environmental Effect

- Green House Gasses
  - Global warming & climate change



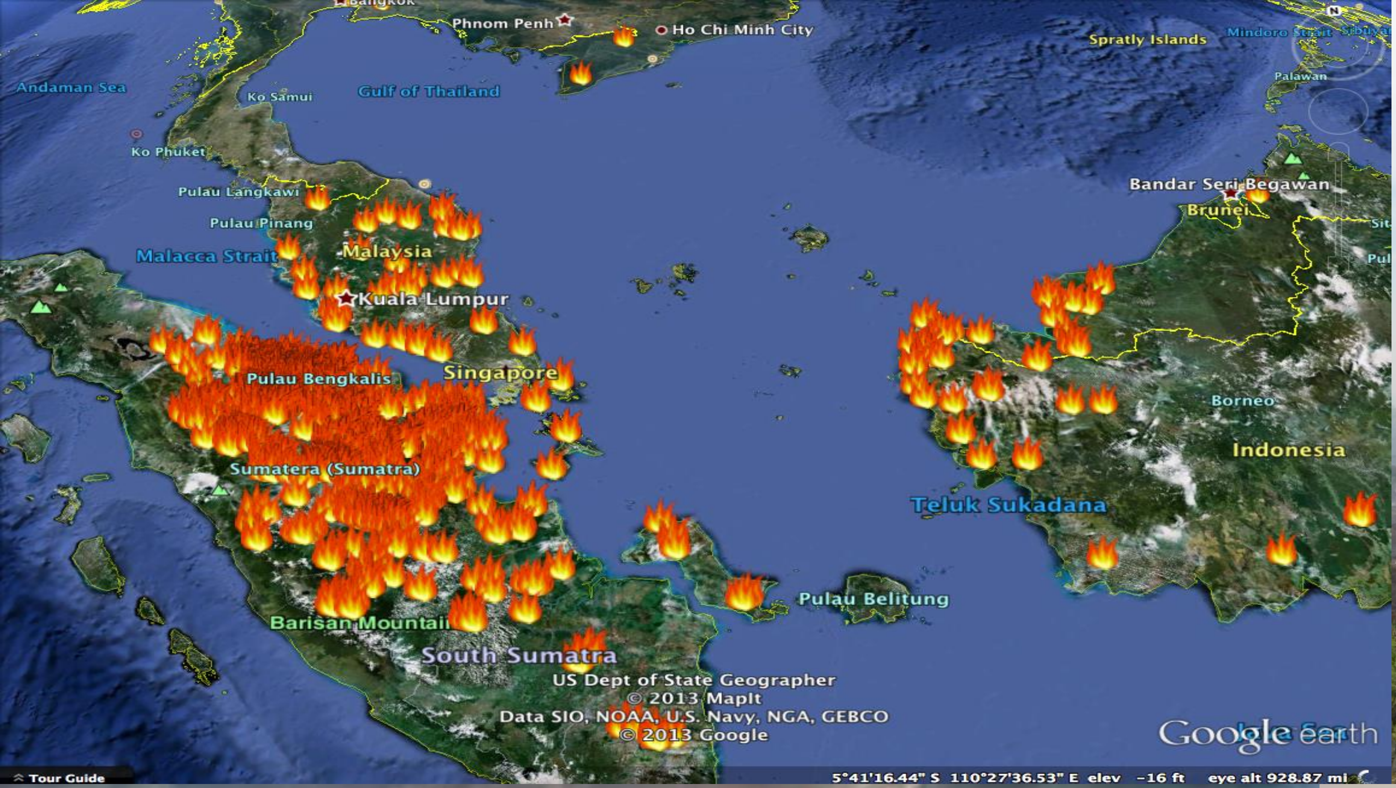
Annual CO_2 emission (2005) including land use



Source : World Resource Institute
World Bank

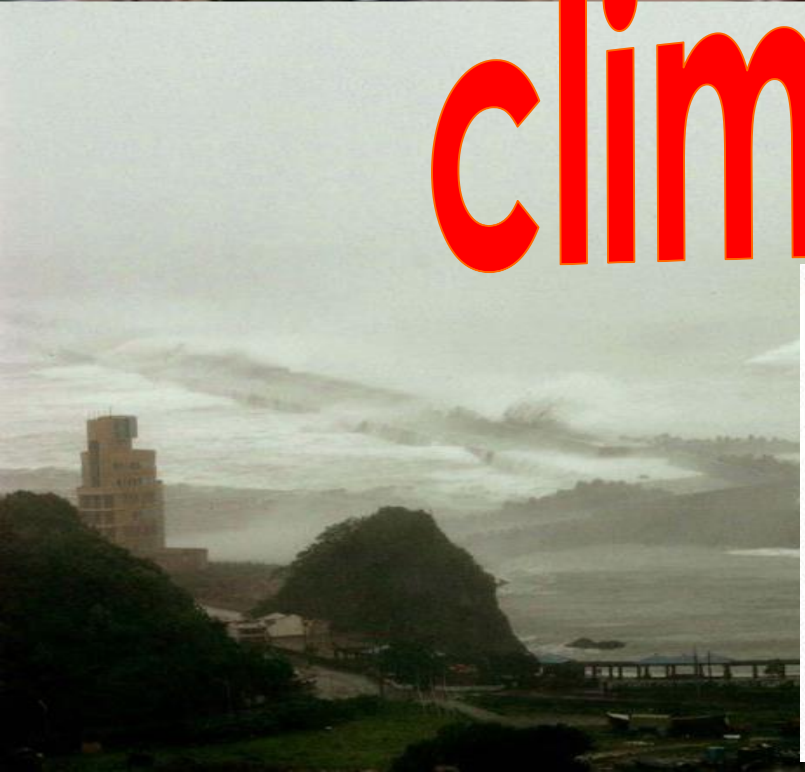
Malaysia

- Annual CO2 emission (2008) = 208,267,000 metric tons (0.7% of world emission)
- Annual CO2 emission per capita (2009) = 7.1 metric tons per capita (not including land use)


Phnom Penh
Ho Chi Minh City
Spratly Islands
Andaman Sea
Ko Samui
Gulf of Thailand
Palawan
Ko Phuket
Pulau Langkawi
Bandar Seri Begawan
Brunei
Pulau Pinang
Malacca Strait
Malaysia
Kuala Lumpur
Pulau Bengkalis
Singapore
Borneo
Indonesia
Sumatera (Sumatra)
Teluk Sukadana
Pulau Belitung
Barisan Mountai
South Sumatra
US Dept of State Geographer
© 2013 MapIt
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2013 Google
Google earth
Tour Guide
5°41'16.44" S 110°27'36.53" E elev -16 ft eye alt 928.87 mi


DIMANAKAH INSAN
DIKALA BUMI DINODAI


climate change !!!



The earth needs to be healed….

- Sustainable energy is the answer…

RENEWABLE ENERGY

ENERGY EFFICIENCY

Definition of Renewable Energy

Renewable Energy (RE) is any form of primary energy from recurring and non-depleting indigenous resources such as agricultural produce, hydro-power, solar, wind, solid-waste, etc.

Biomass

Wind Energy

Hydro

Biogas

Geothermal

Solar PV

Renewable energy technology

- Solar Energy

Solar Photovoltaic

Major applications :

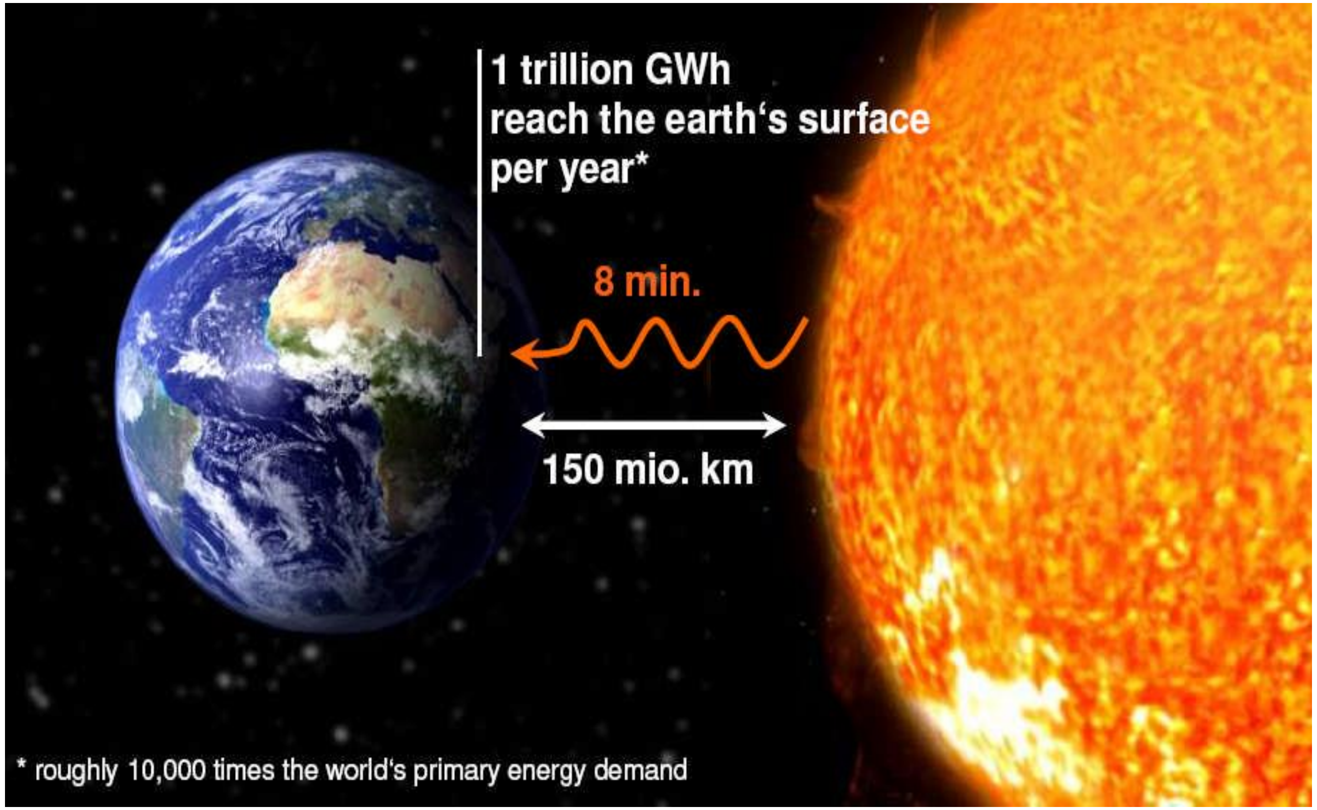
1) Electricity

2) Heat

Solar Thermal

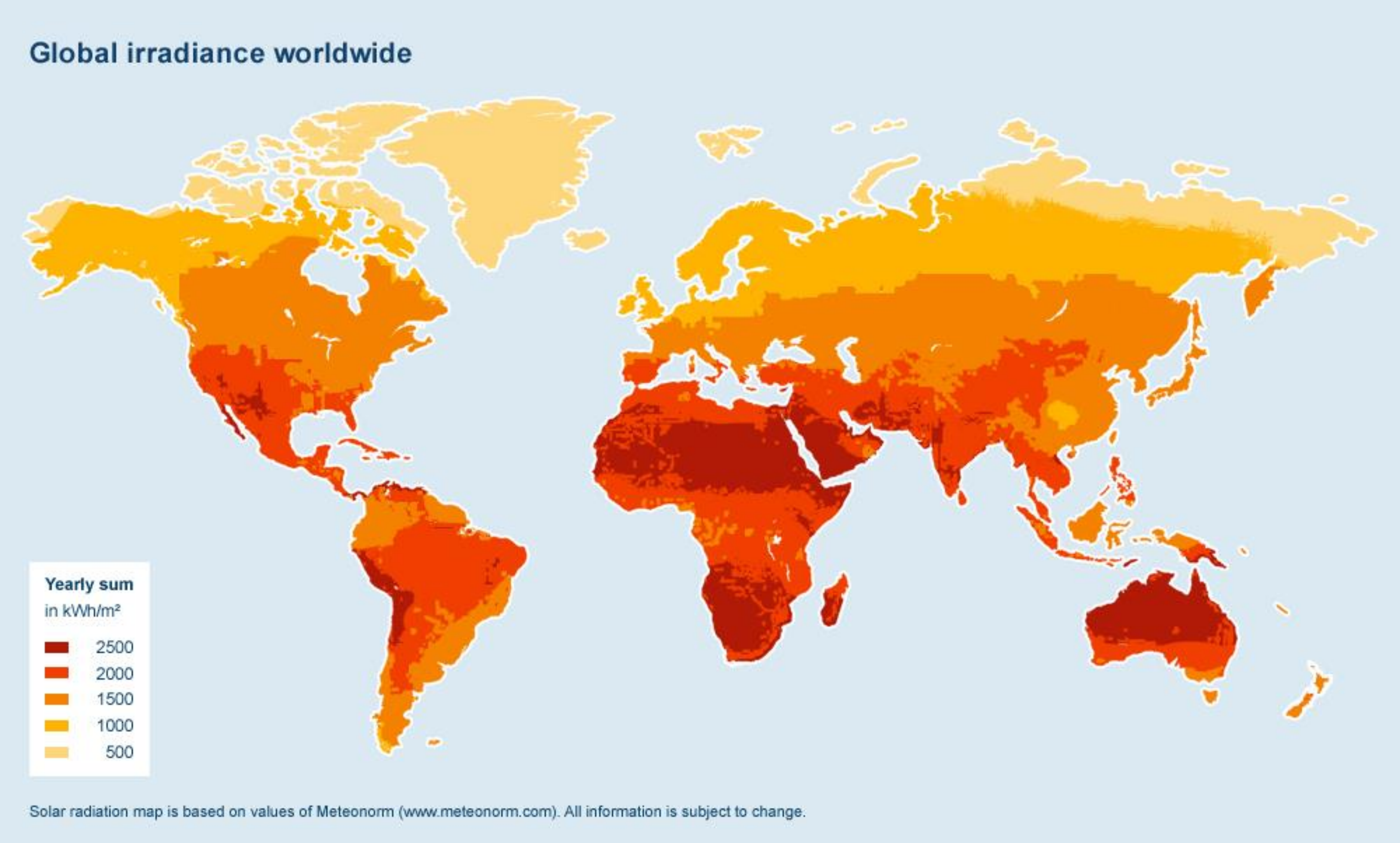
Solar Photovoltaic (PV)

- Convert solar radiation into electric power

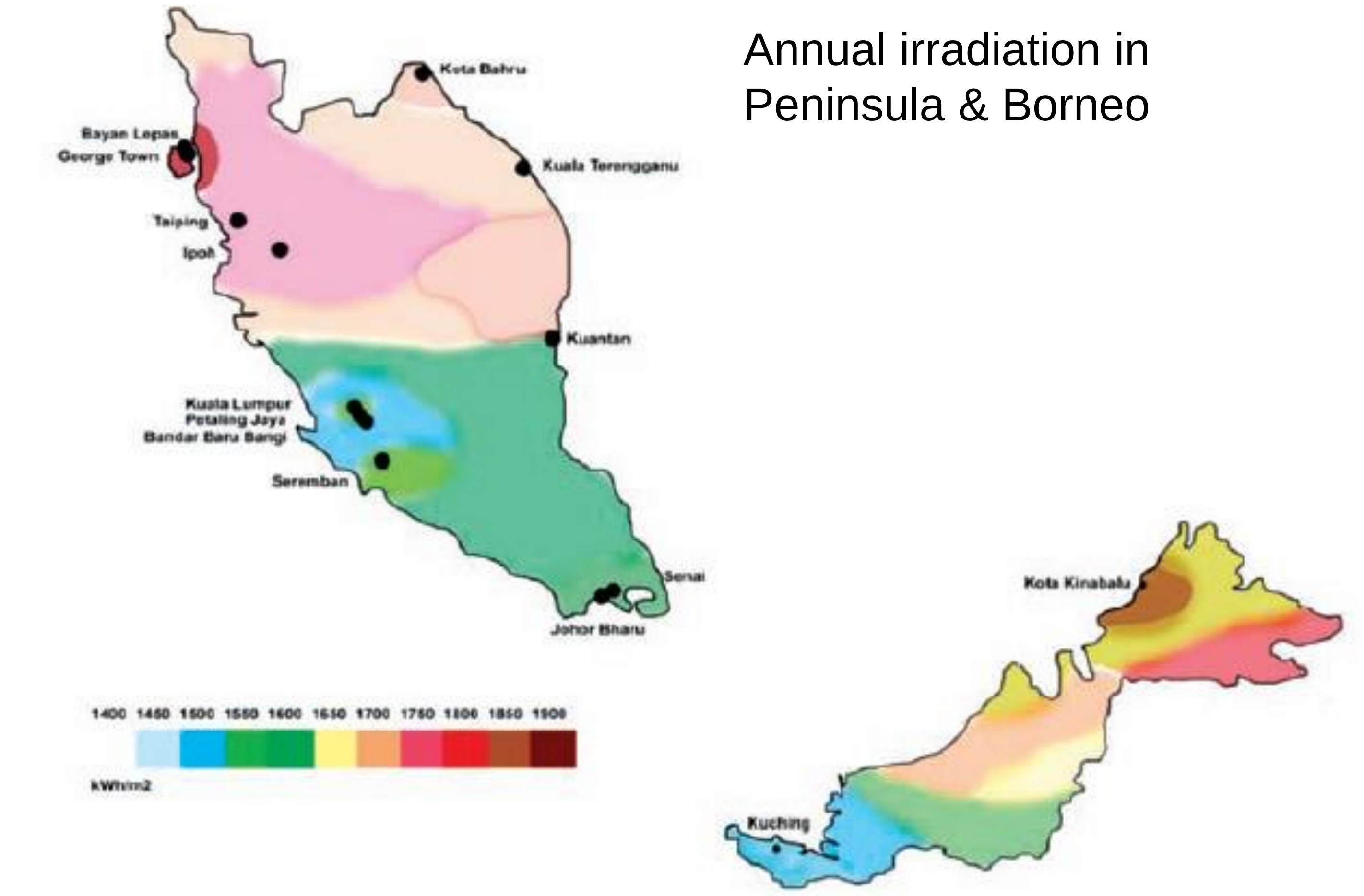


Maximum irradiance that can reach earth surface is ~1,000 W/m2

Global irradiation



Irradiance in Malaysia

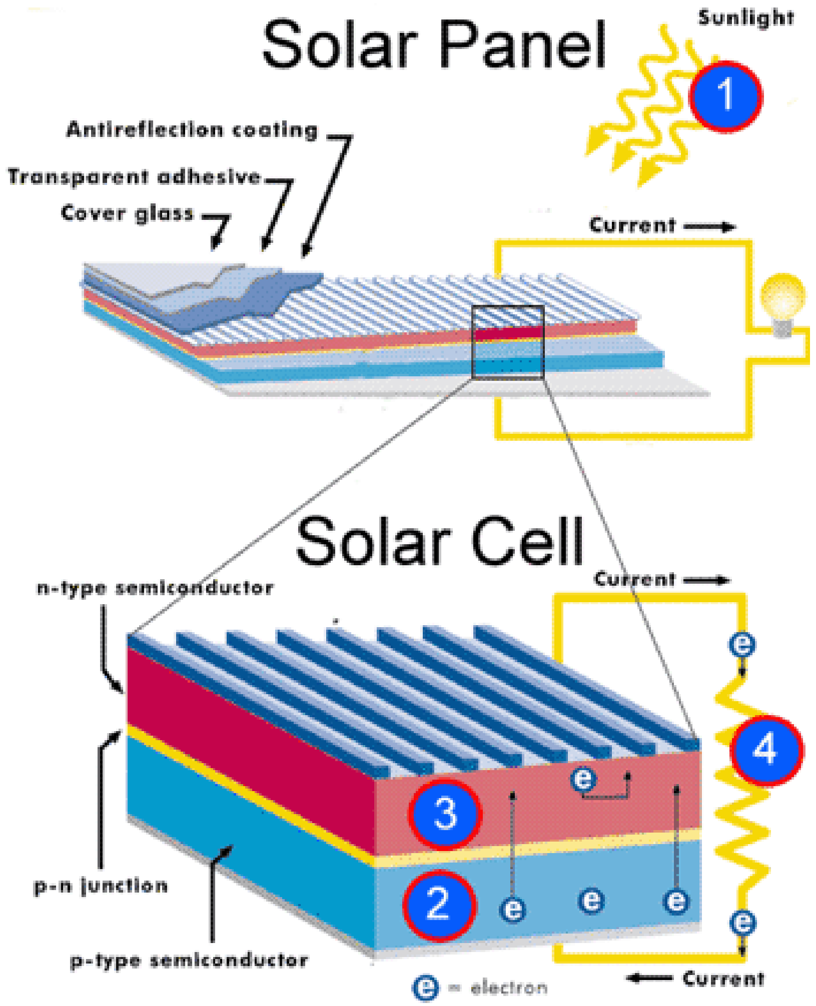


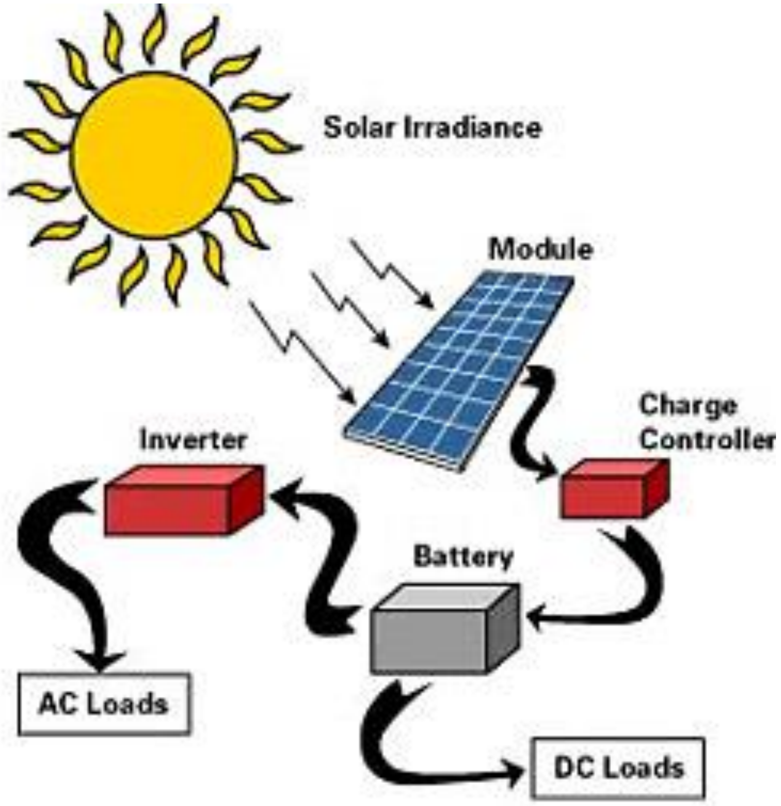
Annual irradiation in Peninsula & Borneo

Average daily irradiation at 4 – 5 kWh/m^2

Source : NREPAP 2009

Solar Photovoltaic fundamental





Example…

20 MWp, Pilgrove Township, New Jersey

40 MWp, Waldpolenz, German

80 MWp, Revigo, Italy

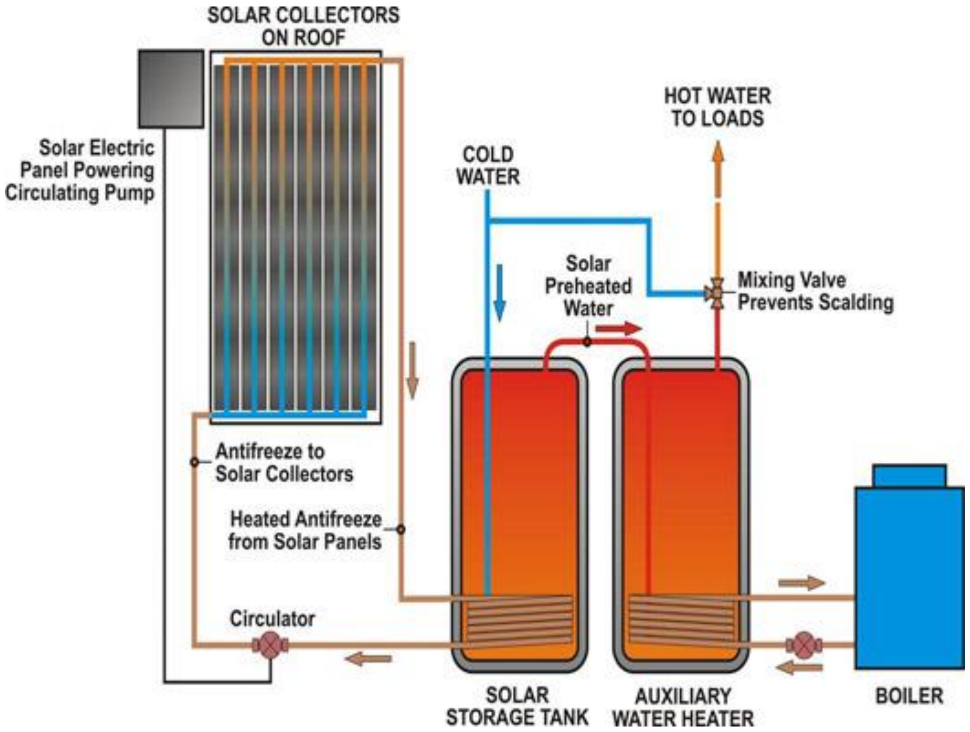
999 kWp, Stadium Verona, Italy

8 MWp at Cypark, Pajam

Solar Home System in Laos
(Source: www.unep.org)

Solar Thermal

Convert solar radiation into thermal power (heat)



Solar thermal power plant

Wind Energy

technological development

Persian wind mill

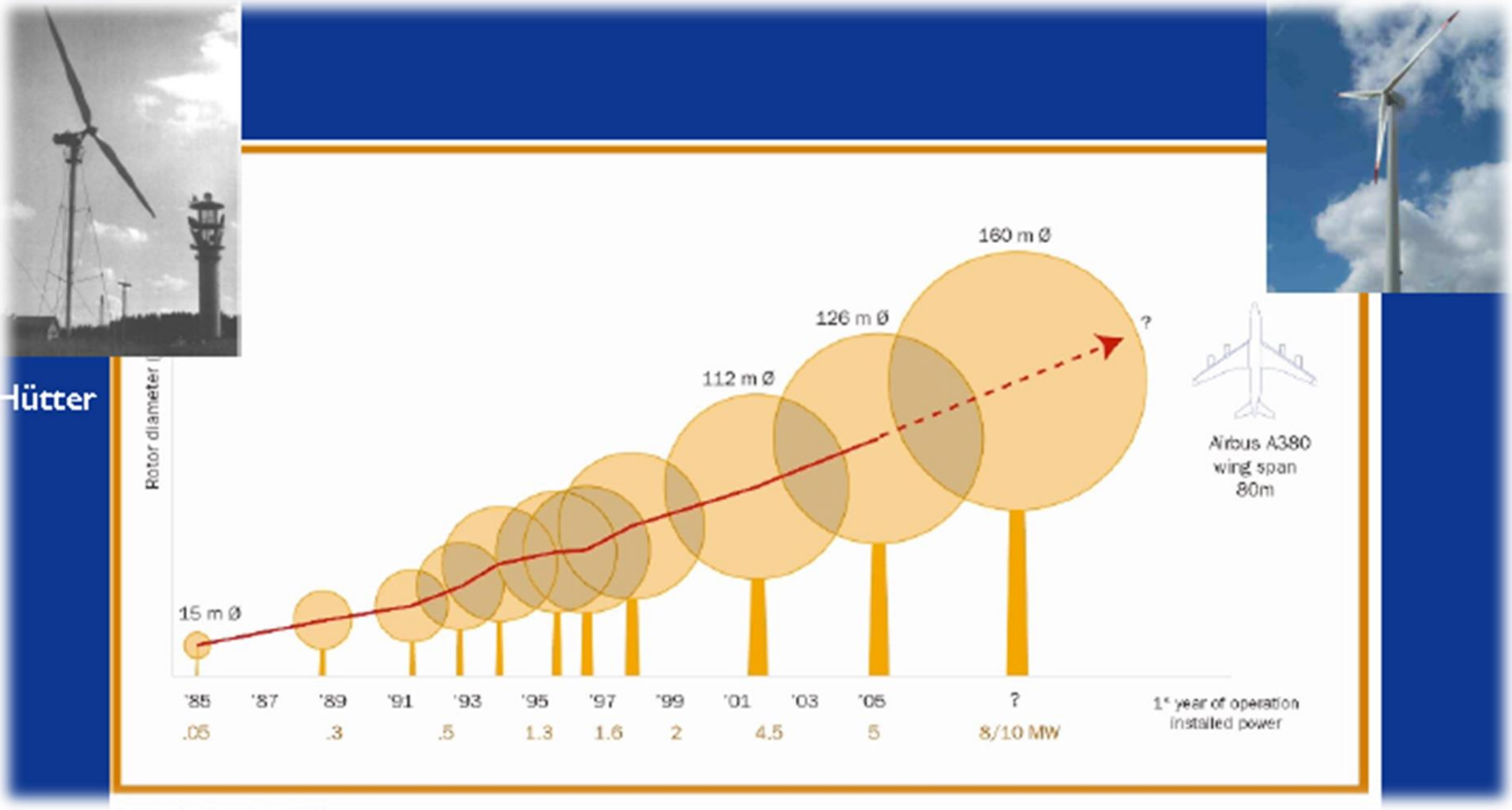
15th century wind mill

french wind mill
Ardenne

new dutch wind mill

modern wind mill

Wind turbine evolution



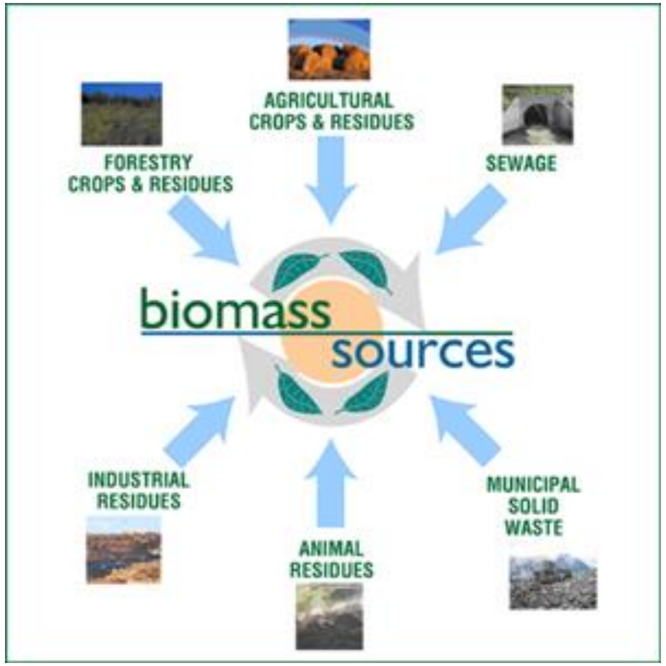
7.5 MW Wind Turbine

Off shore Wind Farm

Vertical wind turbine

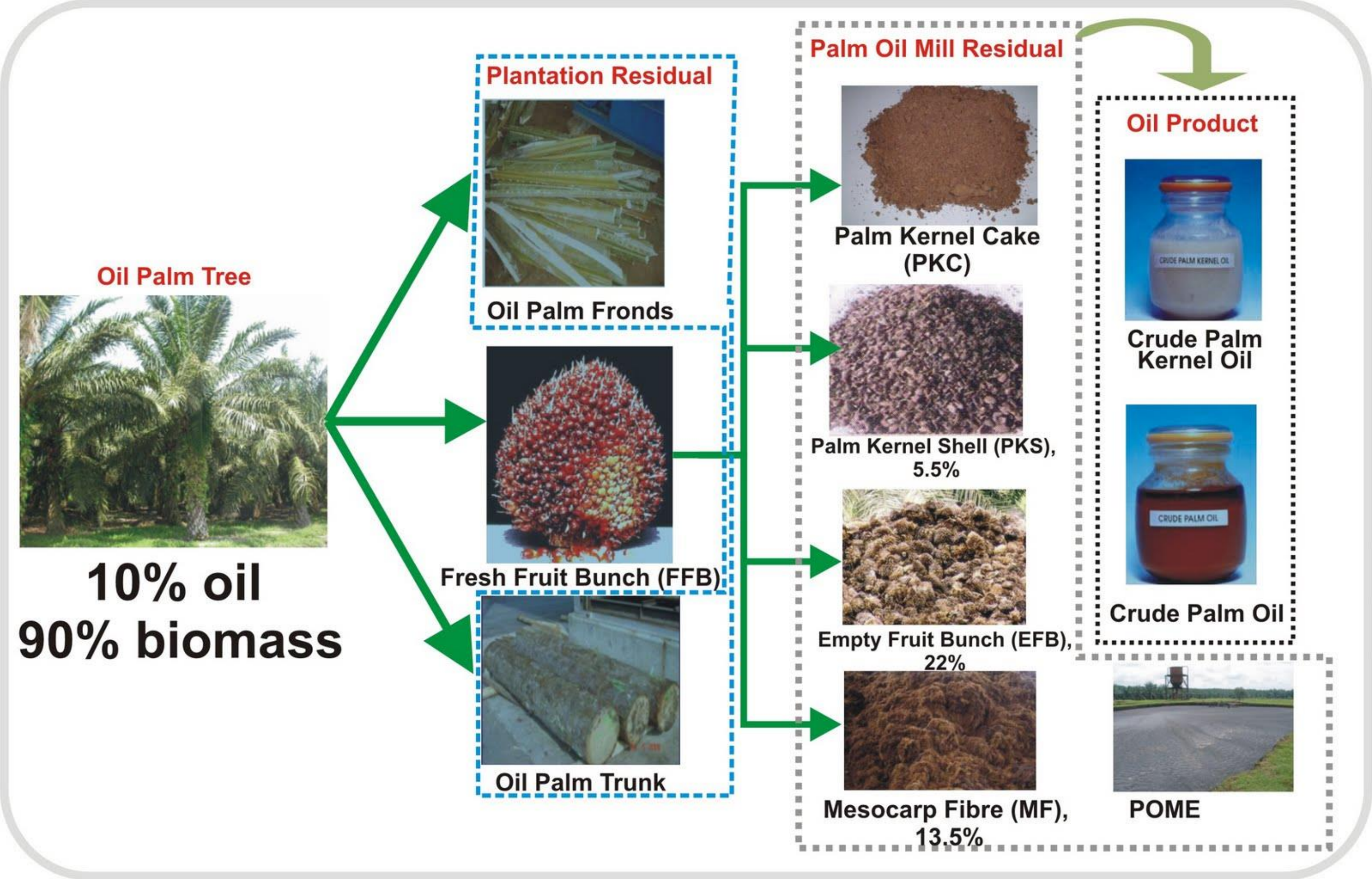
Biomass

- Any organic matter (excluding fossil fuels), that was or is a living organism available on renewable basis and can potentially be used as fuels
- A product of photosynthesis and is a carbon, hydrogen & oxygen based



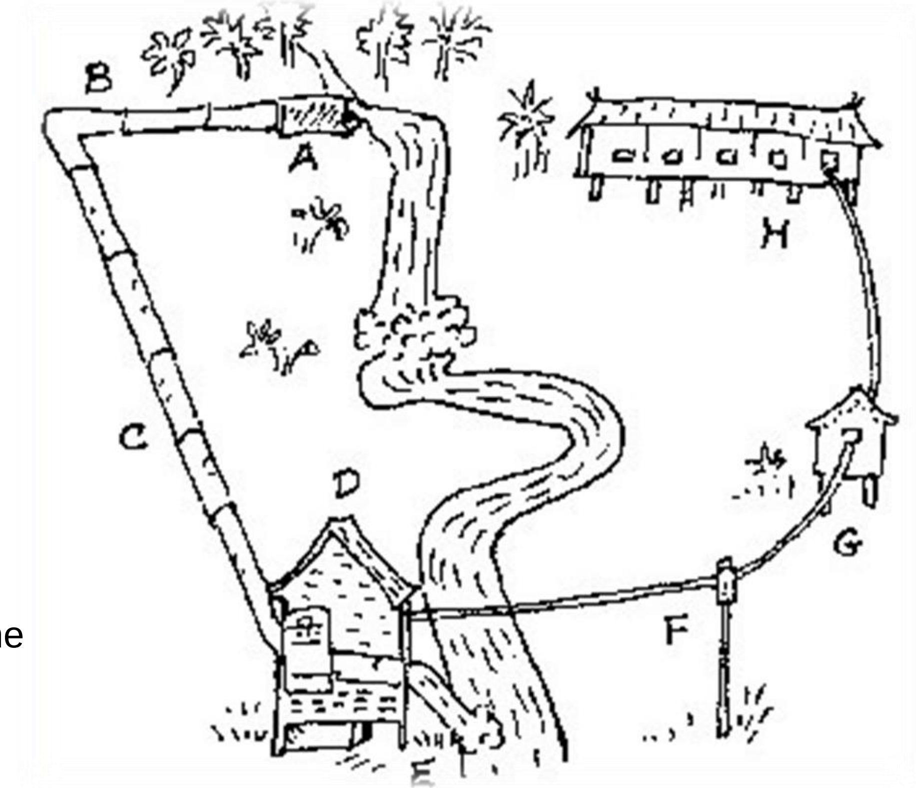
Major Biomass resources in Malaysia

Oil palm, Wood, Paddy, Sugarcane, Municipal waste



Hydro

- Micro / Mini hydro
  - Environmental benign
  - Low cost
  - Best for isolated communities

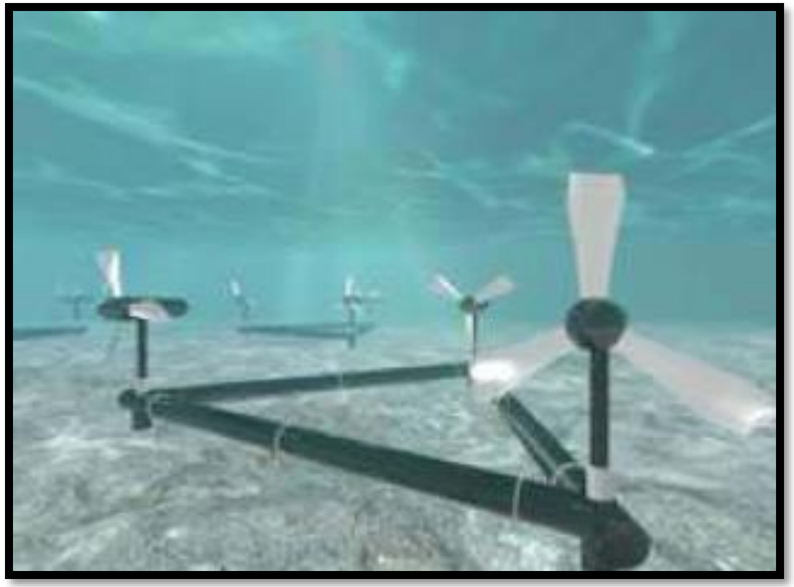


A. Intake
B. Power canal/conduit
C. Penstock
D. Powerhouse
E. Tailrace
F. Electrical Transmission Line
G. Transformer House
H. Village/Longhouse

Other RE resources

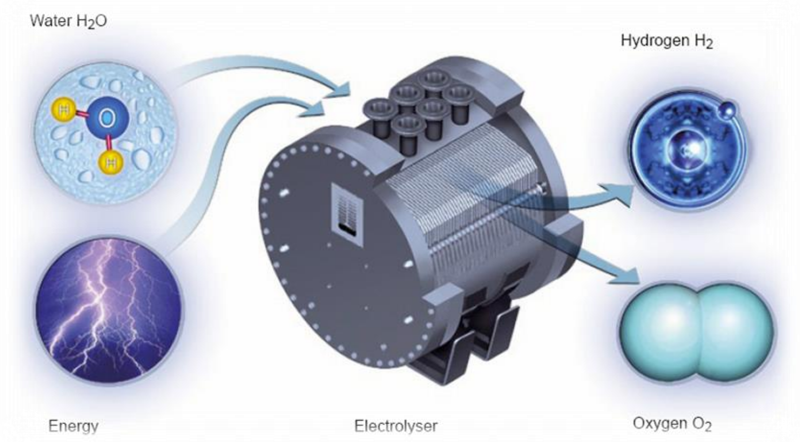
- Geothermal

- Wave



Other RE resources

- Hydrogen
  - Main source:
    - Water
    - Crude oil
    - Biomass
  - Expected to be the main primary energy in the future



Renewable Energy in Malaysia

Development of Energy Policies in Malaysia

- National Petroleum Policy (1975)
- National Energy Policy (1979)
- National Depletion Policy (1980)
- 4-Fuel Diversification Policy (1981)
- 5-Fuel Policy (2001)

RE Policy and Action Plan (2010)

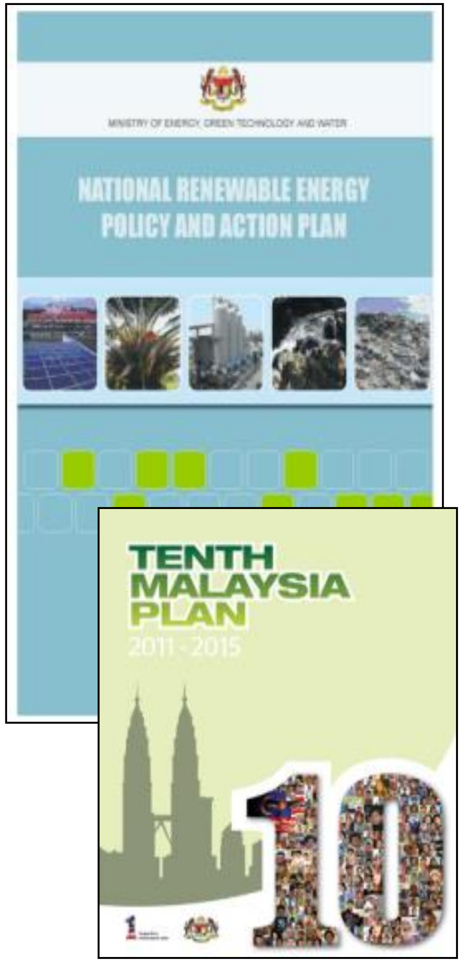
Renewable Energy: Government Policies

2nd April 2010: National Renewable Energy Policy & Action Plan approved

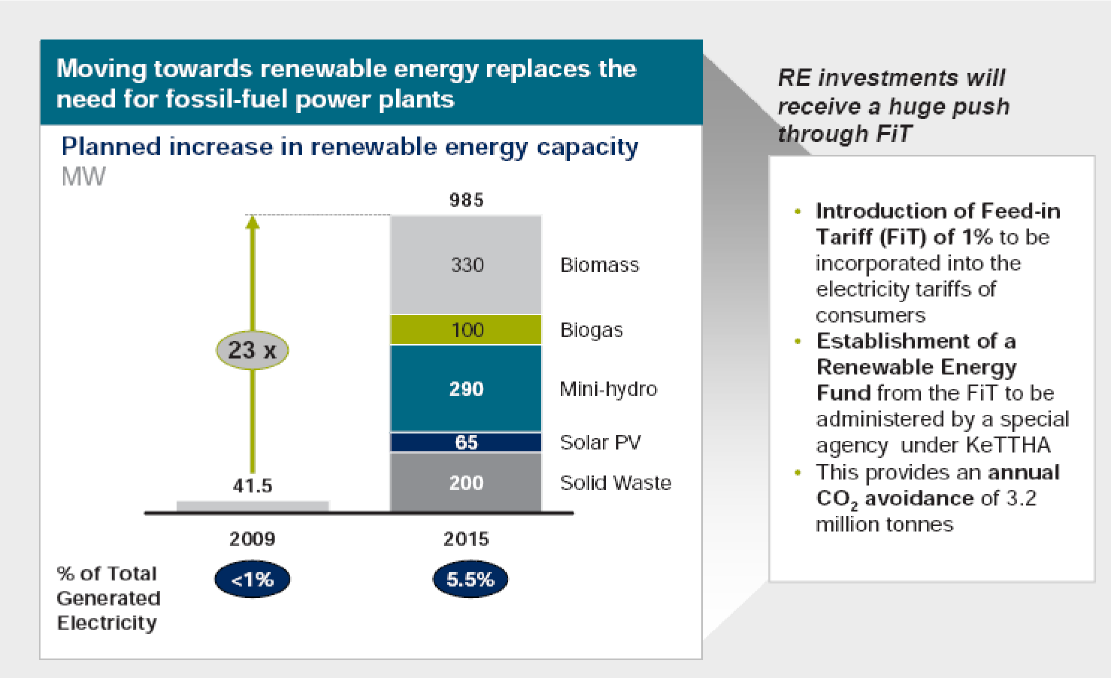
10th Jun 2010: 10th Malaysia Plan (chapter 6)

15th Oct 2010: National Budget 2011 (paragraph 34)

25th Oct 2010: Economic Transformation Programme (chapter 6)



Renewable energy will increase from <1% in 2009 to 5.5% of Malaysia's total electricity generated by 2015



SOURCE: Ministry of Energy, Green Technology and Water

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Malaysian National RE Policy

Policy Statement:

- Enhancing the utilisation of indigenous renewable energy resources to contribute towards national electricity supply security and sustainable socio-economic development

Objectives:

- To increase RE contribution in the national power generation mix;
- To facilitate the growth of the RE industry;
- To ensure reasonable RE generation costs;
- To conserve the environment for future generation; and
- To enhance awareness on the role and importance of RE.

Renewable Energy in Malaysia…cont'd

National RE Targets

Year	Cumulative RE Capacity	RE Power Mix	Cumulative CO_2 avoided
2015	985 MW	5.5%	11.1 mt
2020	2,080 MW	11%	42.2 mt
2030	4,000 MW	17%	145.1 mt

Note: RE capacity achievements are dependent on the size of RE fund

- Assumptions:
  - Feed-in Tariff (FiT) implemented

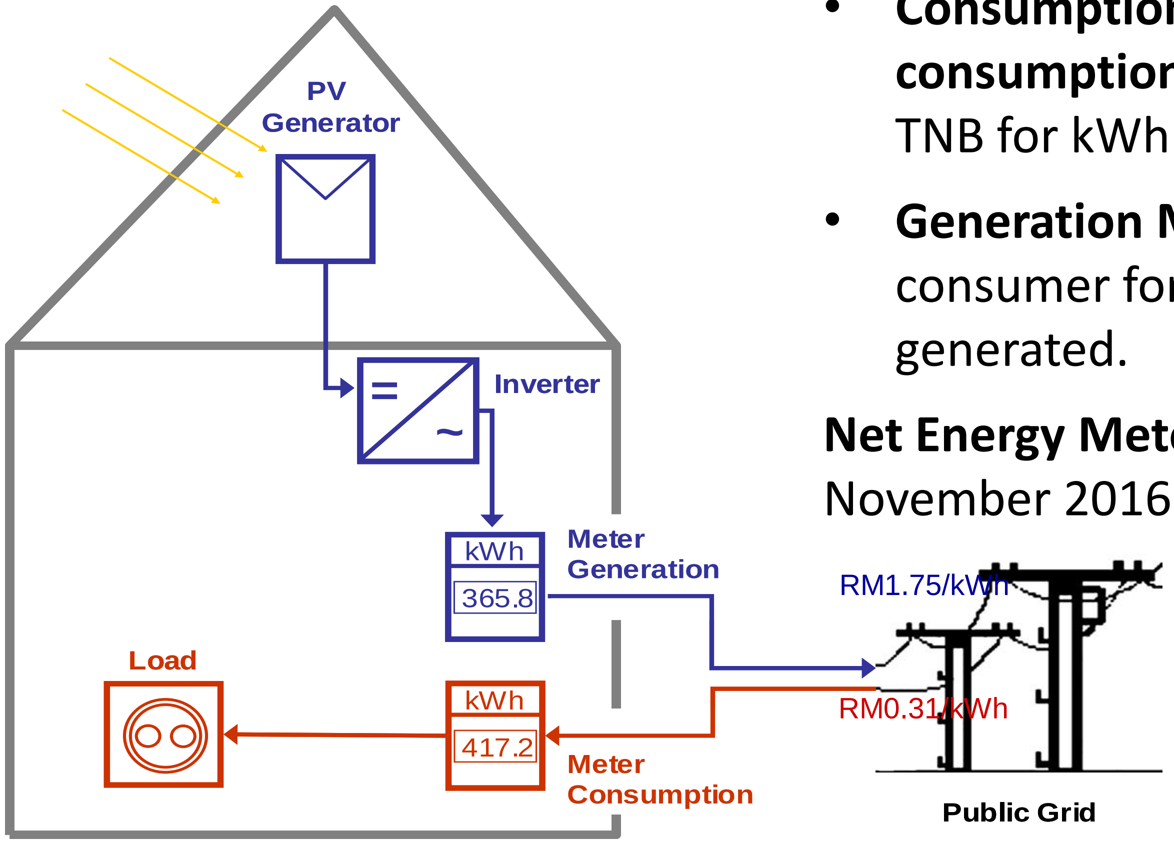
FEED-IN TARIFF

Sources:
www.seda.gov.my

Concept of the Feed-in Tariff (FiT)

- A mechanism that allows electricity produced from indigenous RE resources to be sold to power utilities at **a fixed premium price and for specific duration**.
  - ✓ Provides a conducive and secured investment environment
    - Enable to make financial institutions be comfortable in providing loan with longer period (>15 years)
  - ✓ Provides incentives to RE producers as it only pays for electricity produced
    - promotes system owner to install good quality & maintain the system
    - Provides fixed revenue stream for installed system
- *degression* – annual reduction of tariffs for FiT rates for each technology/ RE source
  - ✓ Promotes reduction of RE costs
  - ✓ Higher portfolio in energy mix

FiT Implementation: Accounts & Payments



2 separate accounts with TNB &

2 separate contracts :

- **Consumption Meter - Electricity consumption bill** : consumer pays to TNB for kWh electricity consumed.
- **Generation Meter -FiT bill**: TNB pays to consumer for gross kWh electricity generated.

Net Energy Meter (NEM) launched on 1st November 2016

Feed-in Tariff Rates

Technology / Source	FiT Duration	Range of FiT Rates (RM/kWh)	Annual Degression
Biomass (palm oil waste, agro based)	16	0.27 – 0.35	0.5%
Biogas (palm oil waste, agro based, farming)	16	0.28 – 0.35	0.5%
Mini Hydro	21	0.23 – 0.24	0%
Solar PV	21	0.85 – 1.78	8%
Solid waste & Sewage	16	0.37 – 0.45	1.8%

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JKR involvement in RE

Bajet 2014

TERAS KELIMA:
MENSEJAHTERA KEHIDUPAN RAKYAT

Indeks Kesejahteraan Malaysia
Meningkatkan Keselamatan dan Ketenteraman Awam
Pemuliharaan Alam Sekitar dan Pengurusan Sumber

158. Bagi terus meningkatkan kecekapan dan penjimatan penggunaan tenaga elektrik, Kerajaan akan melaksanakan audit tenaga dan memasang retrofit di bangunan-bangunan kementerian. Bagi tahun 2014, Kementerian Kesihatan, Sumber Manusia, Belia dan Sukan, Pertanian dan KPDNKK telah dikenalpasti untuk pelaksanaan inisiatif ini. Selain itu, Kerajaan akan memasang solar panel di bumbung bangunan Kementerian-kementerian serta menggantikan lampu sedia ada kepada lampu LED secara berperingkat.

Polisi Pembangunan Lestari JKR Malaysia

- ✓ 3.1.2 Pengurusan Kecekapan Tenaga & Tenaga Diperbaharui
  - 3.1.2.5 Tenaga Diperbaharui:
    - Menggalakkan penggunaan sistem tenaga boleh baharu sebagai sumber tenaga sampingan kepada bangunan Kerajaan dengan sekurang-kurangnya **1%** keseluruhan penggunaan tenaga tahunan dihasilkan daripada sistem RE

J/K Penggunaan Solar Panel JKR

- ✓ J/K Penggunaan Solar Panel JKR telah ditubuhkan;
- ✓ Penyelaras : Caw. Alam Sekitar & Tenaga (CAST);
- ✓ Melibat semua disiplin kejuruteraan & arkitek;
- ✓ Pelaksanaan projek perintis

JKR involvement in RE…cont'd

➢ **Technical advisor & project management**

- Involved in several rural area electrification programs using Solar PV system
  - ✓ Rural Electrification Program using Solar Hybrid System for rural schools in Sabah, Malaysia
  - ✓ Total of 142 schools that were isolated from the electricity grid network in Sabah, were installed with Solar Photovoltaic Hybrid System
  - ✓ The system consists of Solar Photovoltaic (PV) as the primary energy source, diesel generator as the backup energy generation and batteries as the energy storage system
  - ✓ The project started in 2007 with:
    - ❖ 78 schools for Phase 1 ;
    - ❖ 84 schools for Phase 2 (2009)







JKR involvement in RE…cont'd

- **Solar Hybrid System info**

No.	Description	Project phase 1	Project Phase 2
1	Total Project Cost	RM300mil.	RM365mil.
2	Total install capacity (solar PV)	1,585.65kW	1,910kW
3	Total No. of School	78 schools	84 school

JKR Involvement

JKR involvement in RE…cont'd

- **Challenges & Risks**

CHAPTER 2
: Fundamental of solar PV system

Renewable energy technology

- Solar Energy

Solar Photovoltaic

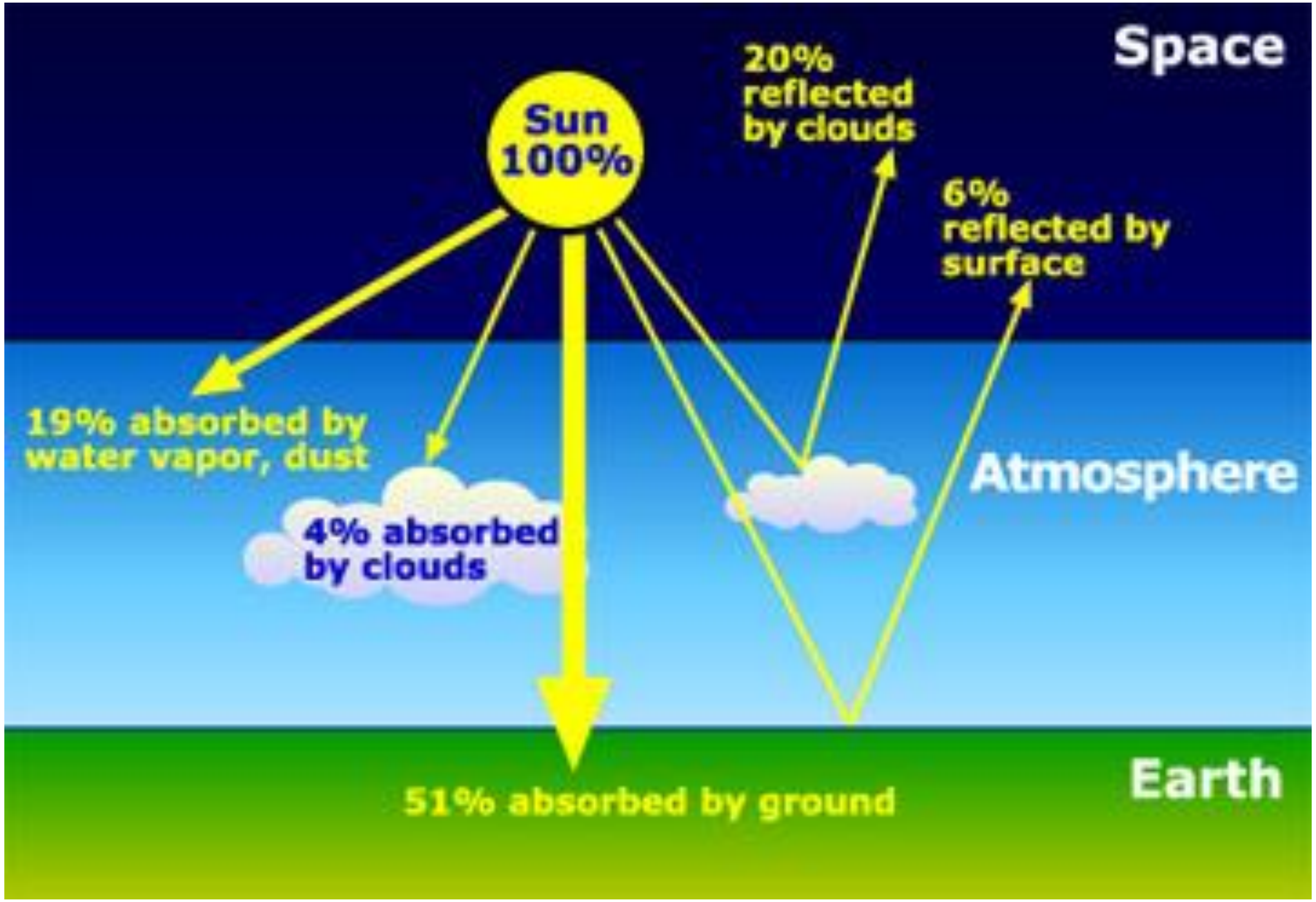
Major applications :

1) Electricity

2) Heat

Solar Thermal

Availability of Solar Energy

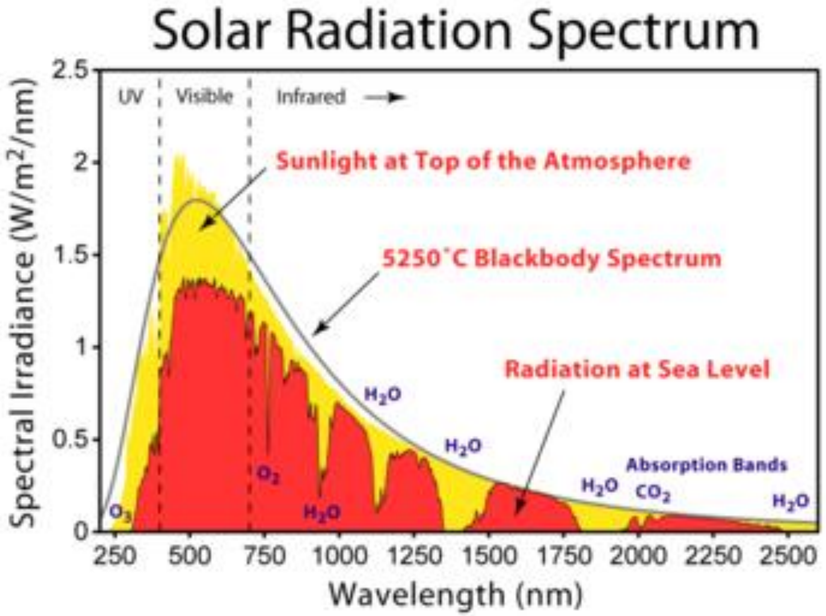


Irradiance & irradiation

Irradiance

The **power** per **unit area** received from the Sun in the form of electromagnetic **radiation** in the wavelength range of the measuring instrument.

Unit of irradiance in W/m^2



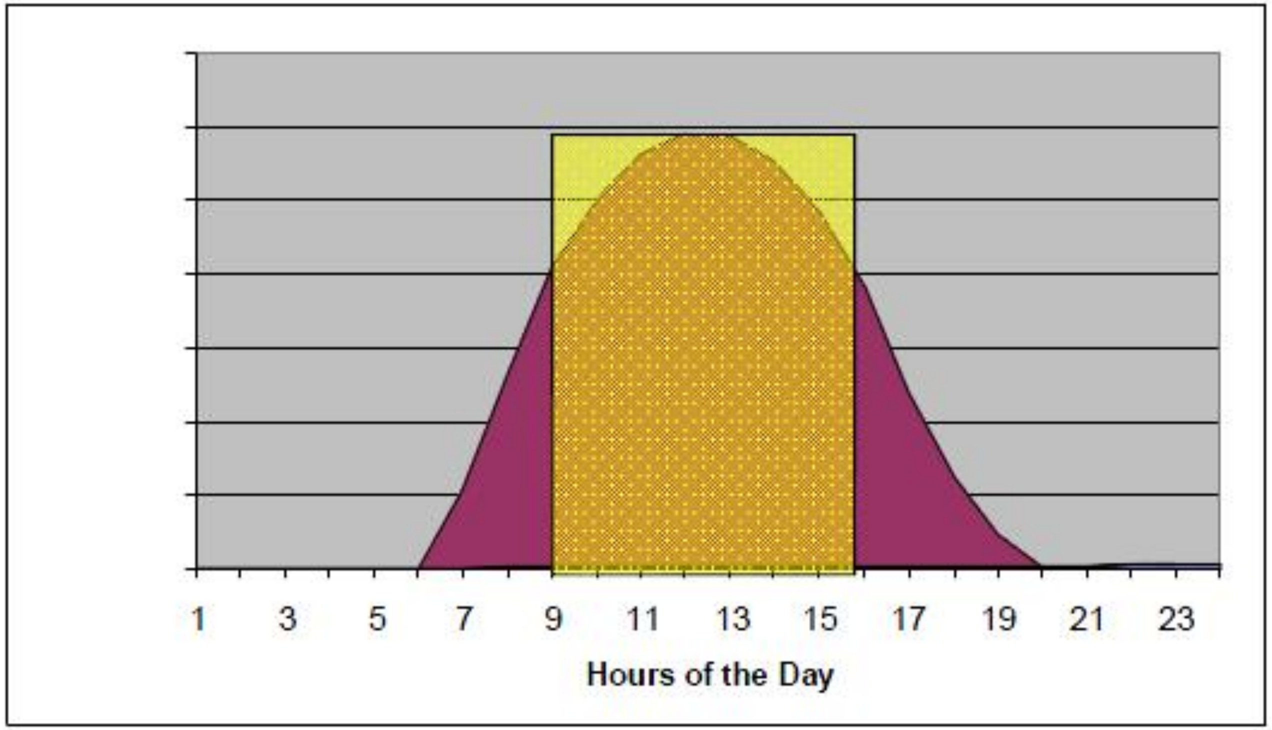
Irradiation

The **energy** per **unit area** received from the Sun in the period of daylight time

Unit of irradiation in Wh/m^2

Peak Sun Hour (PSH)

- The number of hour solar irradiance at 1,000Wm^{-2} gives the equivalent amount of solar irradiation (H) for the day



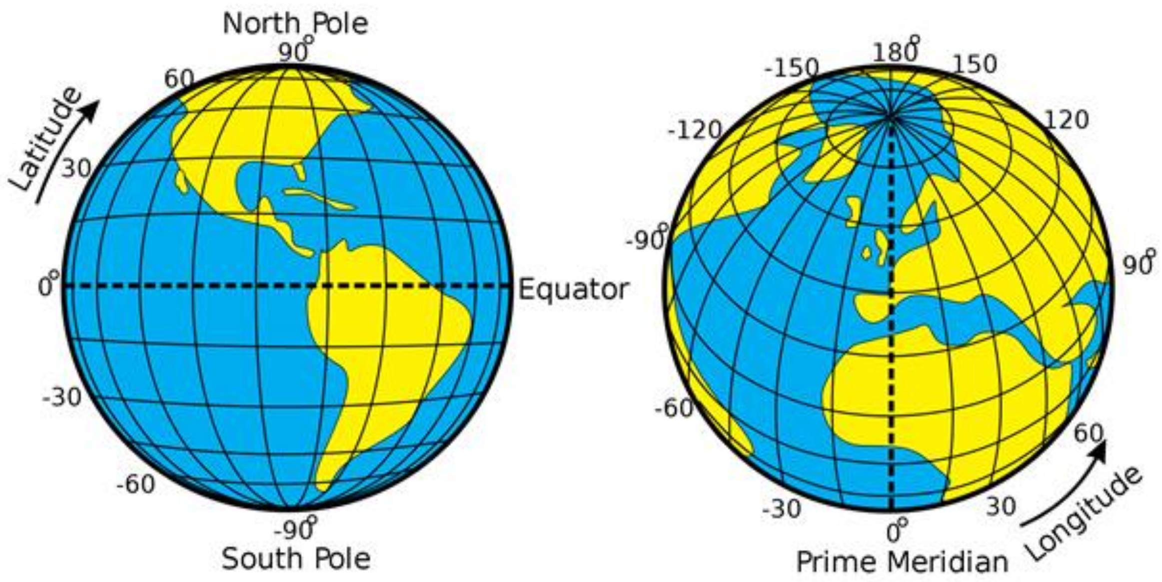
Exercise 1: (10 minutes & 5 minutes discussion)

Location	Irradiation (Wh/m²/day)
A	2,580
B	4,660
C	4,090
D	4,150
E	5,380

1) Calculate the PSH at each location
2) Calculate the annual (365 days) energy generation of 10 kWp solar PV system at each location, assuming irradiation is constant everyday and consider no losses

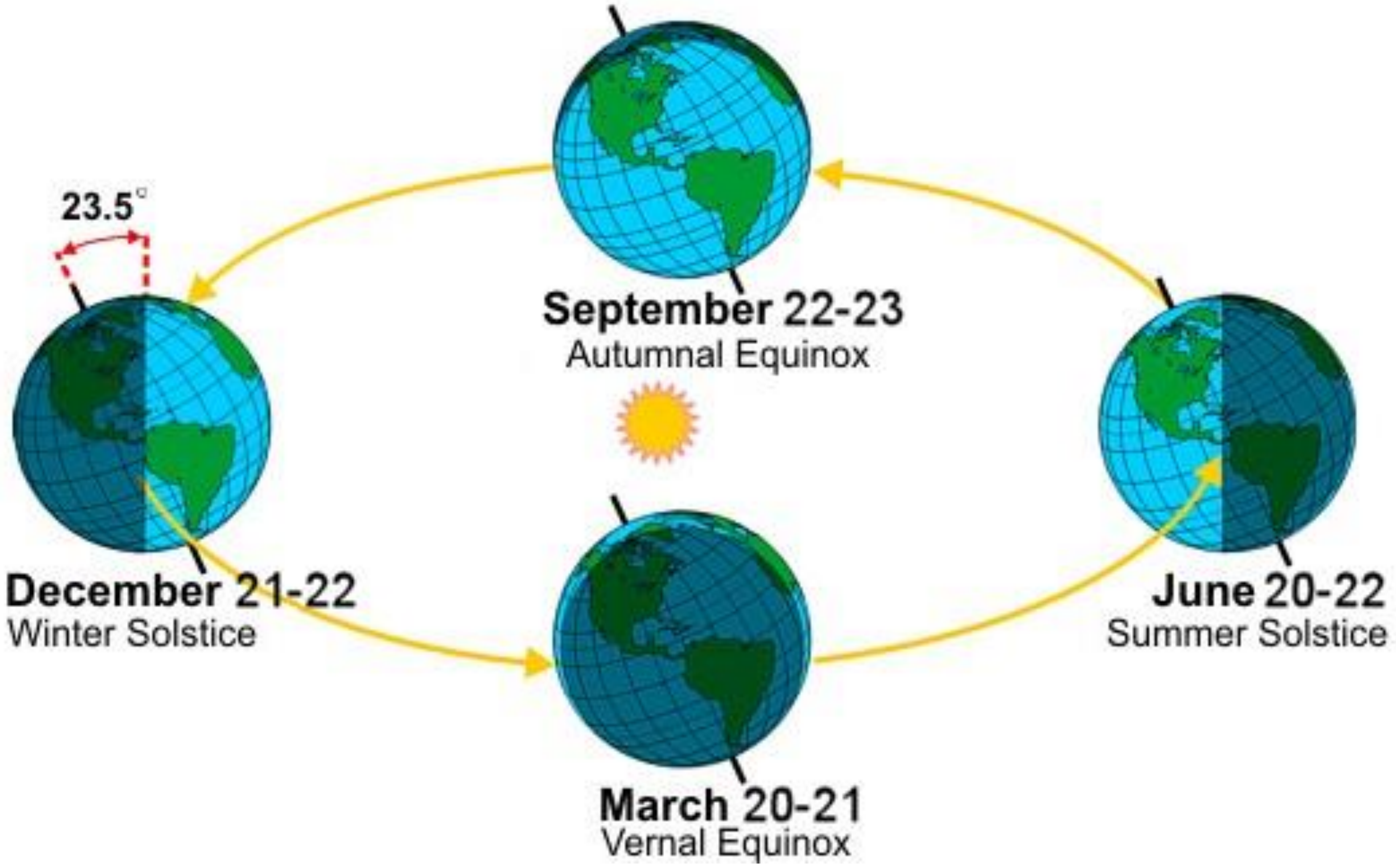
$$E_{PV_{annual}} = P_{PV} \text{ X } \frac{H}{G_{stc}} \text{ X } 365 \text{ days}$$

Geographic Coordinate System



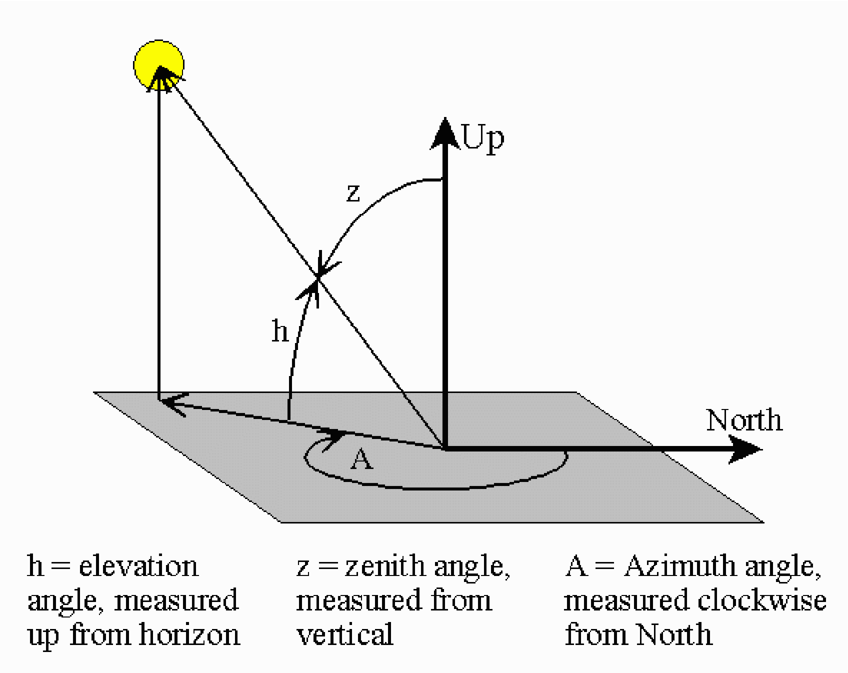
- Main lines/latitude of reference:
- Malaysia:
  - Latitude: 1^0 to 7^0 N
  - Longitude : 99^0 to 120^0 E

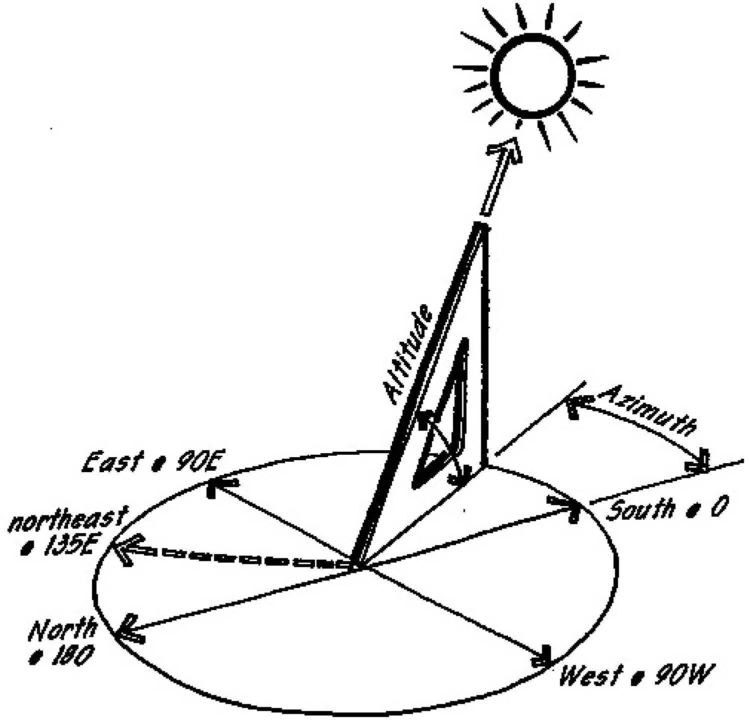
Tilt angle and revolution around the Sun



Describing Location of the Sun

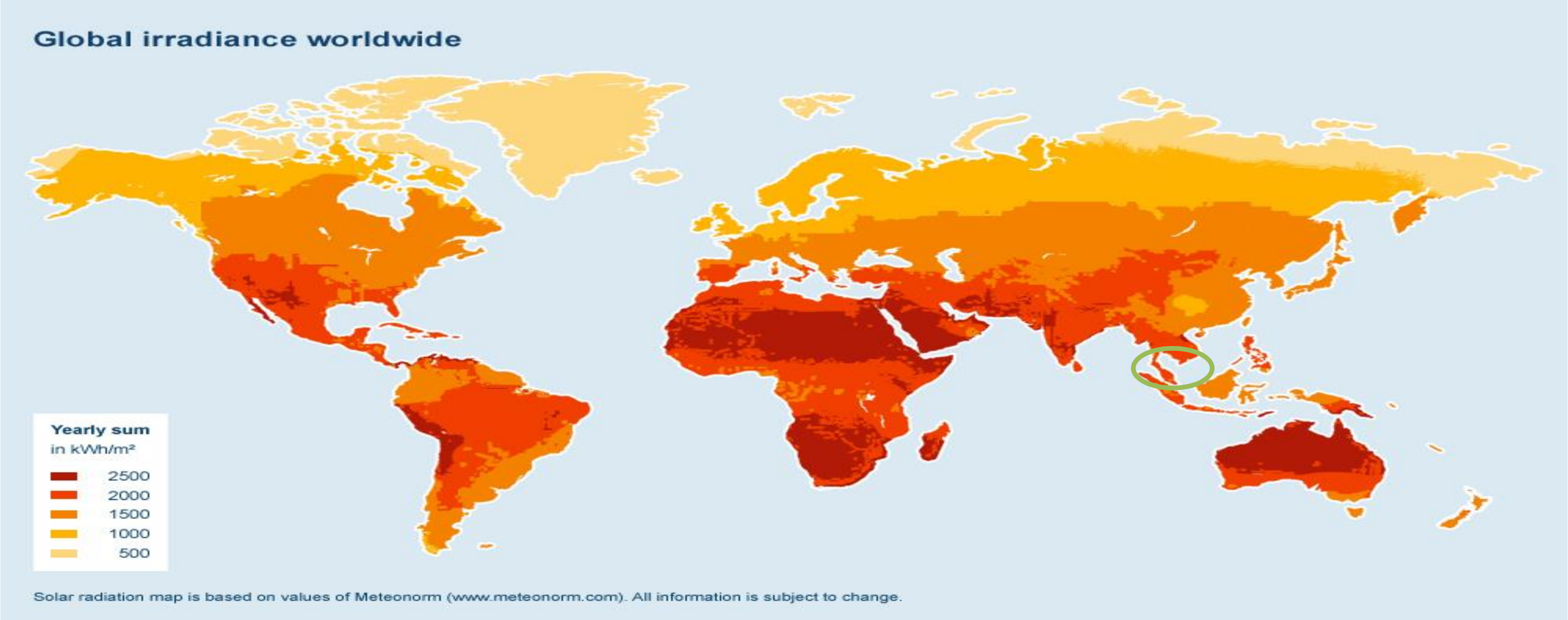
- Azimuth – horizontal angle of sun east or west of due south
- Elevation / altitude - angle of sun above the horizon
- Zenith angle – angle of the sun measured from vertical
- Azimuth and altitude describe the location of the sun in the sky at a given time.





Availability of Solar Energy…cont'd

Global irradiation

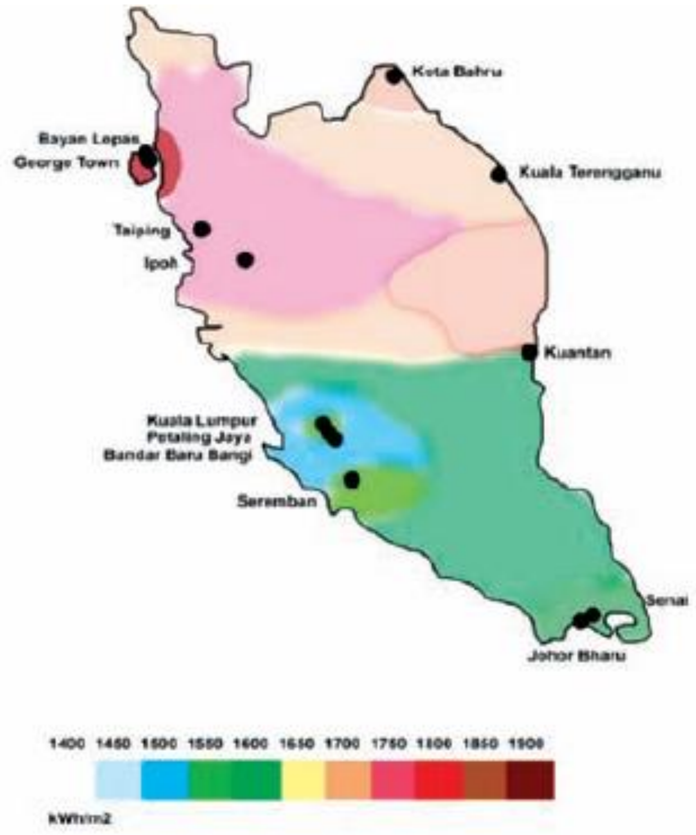


Average daily irradiation at 4 – 5 kWh/m²

- Malaysia is entirely equatorial
- Average solar radiation ~ 4.5 kWh per square meter per day. Highest solar radiation in Sabah region
- Average sunshine at 12 hours daily the whole year

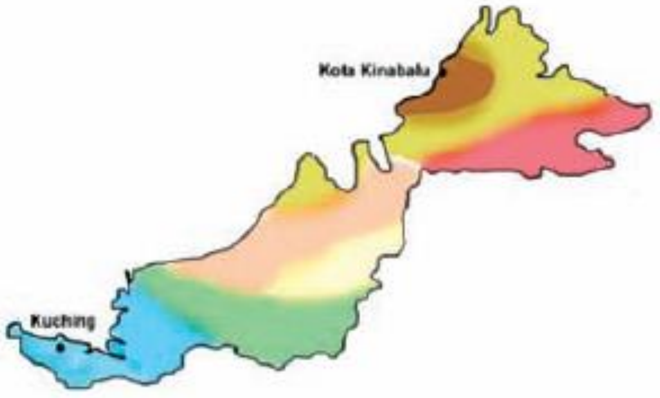
Availability of Solar Energy…cont'd

Annual irradiation in Peninsular & Borneo



Irradiance (Yearly average value - globa

Kuching	1470 kWh/m2
Bandar Baru Bangi	1487 kWh/m2
Kuala Lumpur	1571 kWh/m2
Petaling Jaya	1571 kWh/m2
Seremban	1572 kWh/m2
Kuantan	1601 kWh/m2
Johor Bharu	1625 kWh/m2
Senai	1629 kWh/m2
Kota Bahru	1705 kWh/m2
Kuala Terengganu	1714 kWh/m2
Ipoh	1739 kWh/m2
Taiping	1768 kWh/m2
Georg Town	1785 kWh/m2
Bayan Lebas	1809 kWh/m2
Kota Kinabalu	1900kWh/m2



PV Energy Yield: KL (1,200 kWh/kWp/Yr) = 1.3 x Germany

- How to quantify solar radiation?

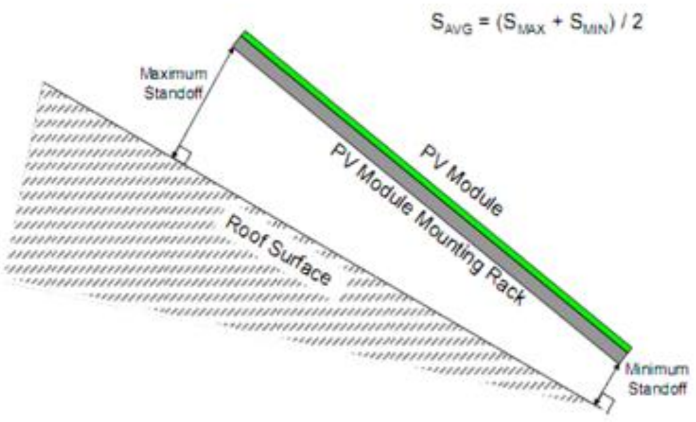
Solar cell sensor

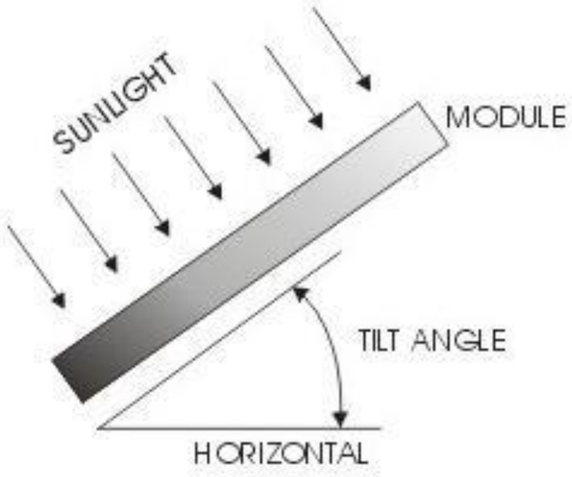
pyranometer

Sun Earth Collector Geometry

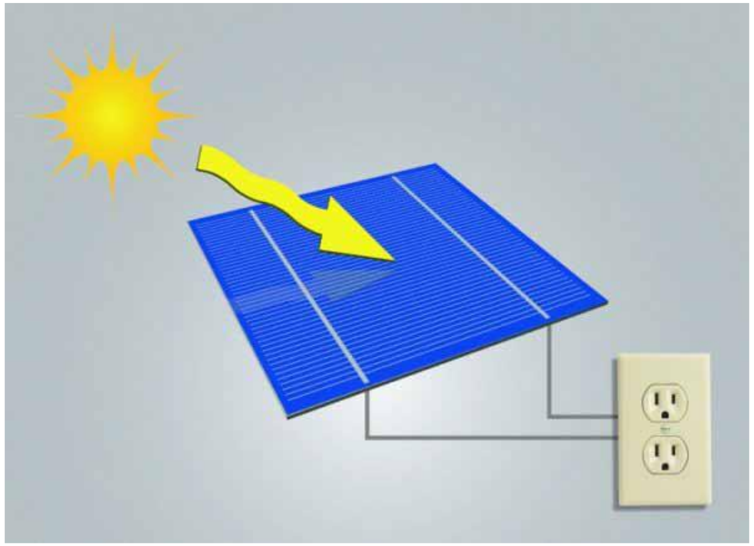
Tilt angle of solar collector

- Tilt angle is the angle between a collector plane and the ground plane

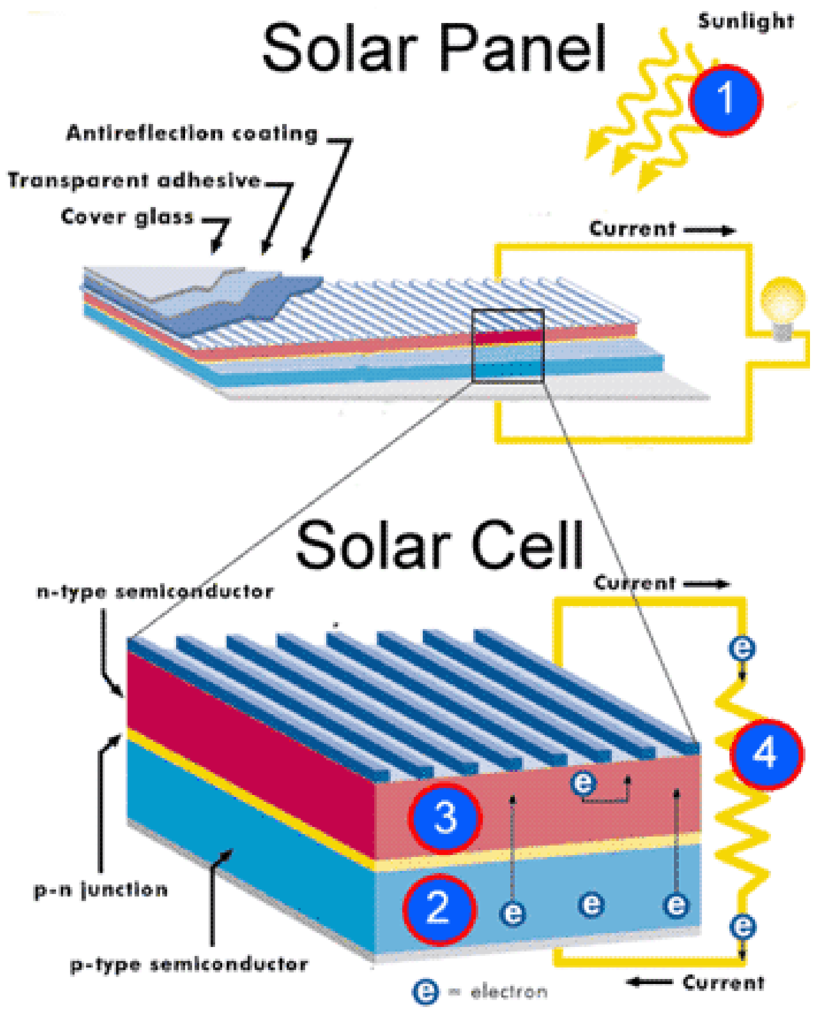




- **Photovoltaic Effect**
  - photo = light; voltaic = produces voltage
  - Photovoltaic (PV) systems convert light directly into electricity (using semiconductors)



Solar Photovoltaic fundamental



- Usually produced with semiconductor grade Silicon
- Dopants create positive and negative regions
- P/N junction results in 0.5 volts per cell
- Wire grid provides path for current

PV Terminology

Cell

Module

Array

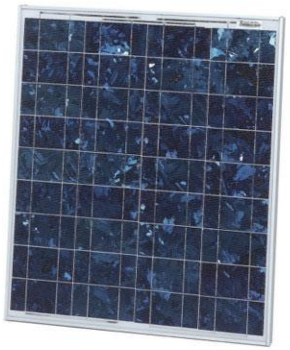
PV System Sizing:

4 kWp PV system: means that 4,000 watts (4 kW) is the MAXIMUM it will produce in full sunlight, ie at 1,000 W/m^2, 25°C & 1.5 Air Mass

Types of Solar PV cell

- **Crystalline Silicon PV**

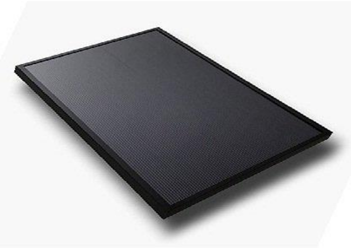
Mono crystalline

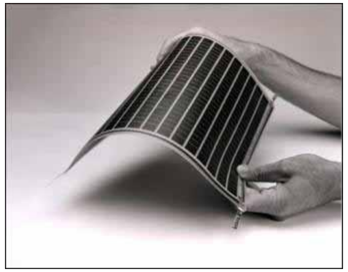


Polycrystalline

- Firm, like crystals
- Longest track record, over 50 years
- Most common, over 85% of the market
- Highest efficiencies: avg. 15%, up to 22%

- **Thin-Film PV**





- Can be applied on many different materials
- Longevity still to be proven
- Production growing at high rate
- Lower efficiencies: avg. 7%, up to 15%
- Has potential for big cost reduction
- Requires about 200 sf. per kilowatt

- Others like Hetero-junction intrinsic thin layer (HIT), Organic etc….mostly still in early research & manufacturing stage

Types of Solar PV cell…cont'd

Cell Technology	Crystalline Silicon	Thin Film
Types of Technology	• Mono-crystalline silicon (c-Si) • Poly-crystalline silicon (pc-Si/ mc-Si)	• Amorphous silicon (a-Si) • Cadmium Telluride (CdTe) • Copper Indium Gallium Selenide (CIG/ CIGS) • Organic photovoltaic (OPV/ DSC/ DYSC)
Temperature Coefficients	Higher	Lower (Lower is beneficial at high ambient temperatures)
Module construction	With Anodized Aluminum	Frameless, sandwiched between glass; lower cost, lower weight
Module efficiency	14% - 22%	4% - 12%
Required Area	Industry standard	May require up to %50 more space for a given project size
Example Brands	Kyocera, Evergreen, Sanyo, Schuco, Canadian Solar, Sharp, Yingli, ET Solar, Solon, Schott, Conergy, REC, Solarworld	First Solar, Solyndra, UniSolar, Konarka, Dye Solar, Bosch Solar, Sharp, Abound Solar

Thin-film needs about twice as much space for the same-size system.

Photovoltaic Modules…cont'd

Datasheets

- The electrical ratings of a PV module are normally rated at a Standard Test Conditions (STC), i.e. the PV module has been tested under this condition

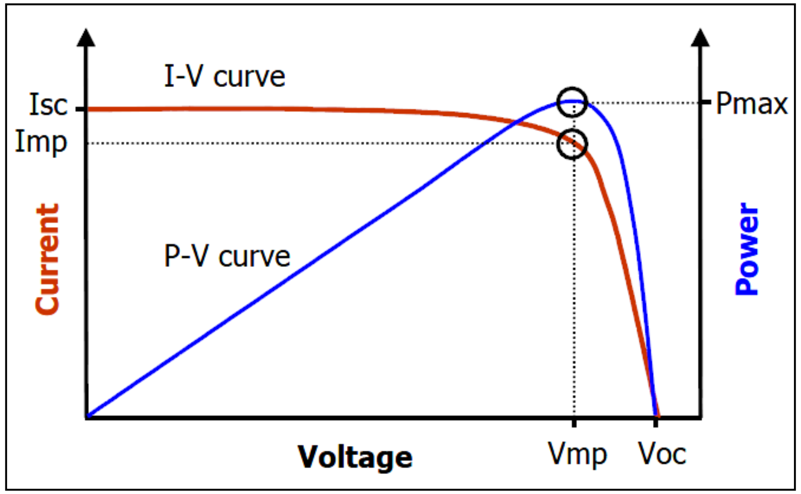
- The STC refers to
  - Irradiance of 1,000 Wm^{-2}
  - Cell temperature of 25 deg C
  - Solar spectrum of Air Mass (AM) 1.5 (48.2^{o})

- The electrical ratings of a PV module are also sometimes rated at Nominal Operating Cell Temperature (NOCT) conditions, i.e. the PV module has been tested under several conditions.

- The NOCT conditions refer to:
  - Irradiance of 800 Wm-2
  - Ambient temperature of 20 deg C
  - Solar spectrum of Air Mass (AM) 1.5
  - Wind speed of 1.0 ms^{-1}

Characterization of PV modules

- A PV module is characterized based on current-voltage performance of the string (s) of solar cells on the PV module
- The current-voltage performance is characterized using an I-V curve and power curve
- The I-V curve and power curve are valid at a particular irradiance and cell temperature only



Characteristics of a PV modules

Legend :

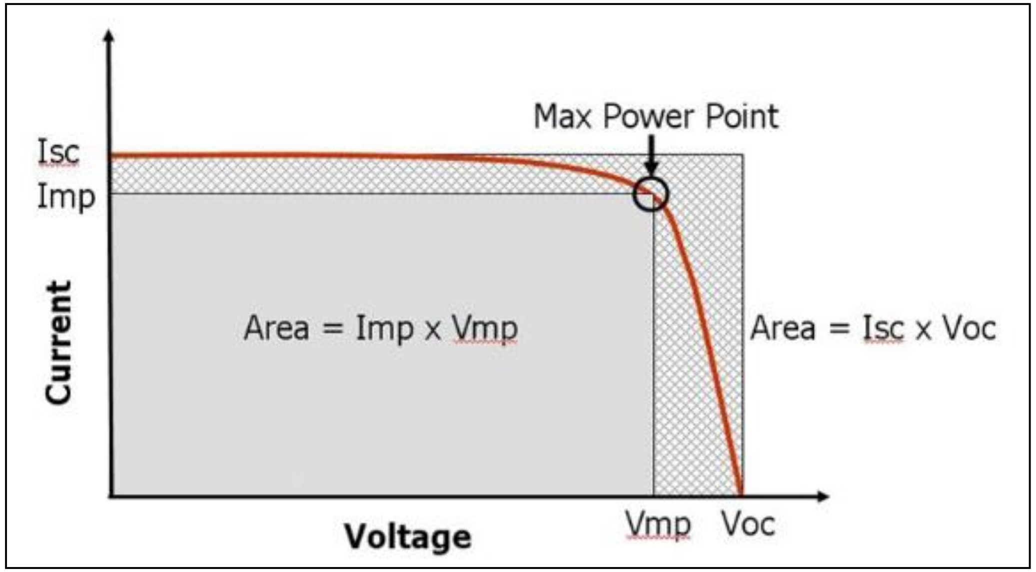
P_{mp} = Maximum power in W
V_{oc} = Open circuit voltage in V
V_{mp} = Voltage at maximum power in V
I_{sc} = Short circuit current in A
I_{mp} = Current at maximum power in A

Photovoltaic Modules...cont'd

Characterization of PV modules

- Fill Factor (FF) represents the degree of squareness of the IV curve
- The FF of a PV module or string is an important performance indicator

$$FF = \frac{I_{mp} \times V_{mp}}{I_{sc} \times V_{sc}}$$



Where :

V_{oc} = Open circuit voltage in V
V_{mp} = Voltage at maximum power in V
I_{sc} = Short circuit current in A
I_{mp} = Current at maximum power in A

Photovoltaic Modules…cont'd

Characterization of PV modules

- Efficiency, η represents the efficiency

$$\eta = \frac{I_{mp} \times V_{mp}}{G \times A} = \frac{P_{mp}}{G \times A}$$

Where :

P_{mp} = Maximum power in W
V_{mp} = Voltage at maximum power in V
I_{mp} = Current at maximum power in A
G = Irradiance in Wm^{-2} at STC (1,000 W/m^2)
A = Area of solar PV module in m^2

Efficiency of a solar PV modules only describes the ability of the module to produce maximum power at its surface area at STC level (G = 1,000 W/m^2).
It should not be used as the only parameter in determining the quality of the module.

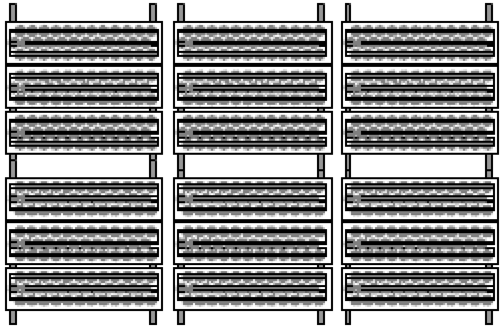
Exercise 2: (10 minutes & 5 minutes discussion)

- Refer to datasheet solar PV module:
  - Determine FF of the module
  - Determine efficiency of the module
  - Base on the efficiency of the modules, what can you summarize?

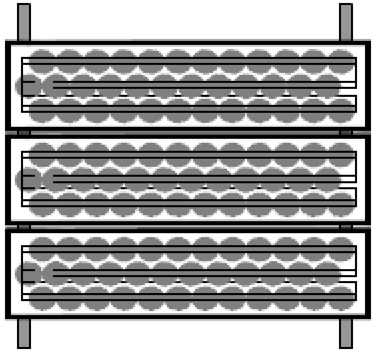
Photovoltaic Modules…cont'd

Array Configuration

- PV modules can be electrically inter-connected to form a string or array:
  - String: consists of several PV modules being electrically connected in series
  - Array: consists of one or more than one PV string(s)



Array



String

Array Configuration

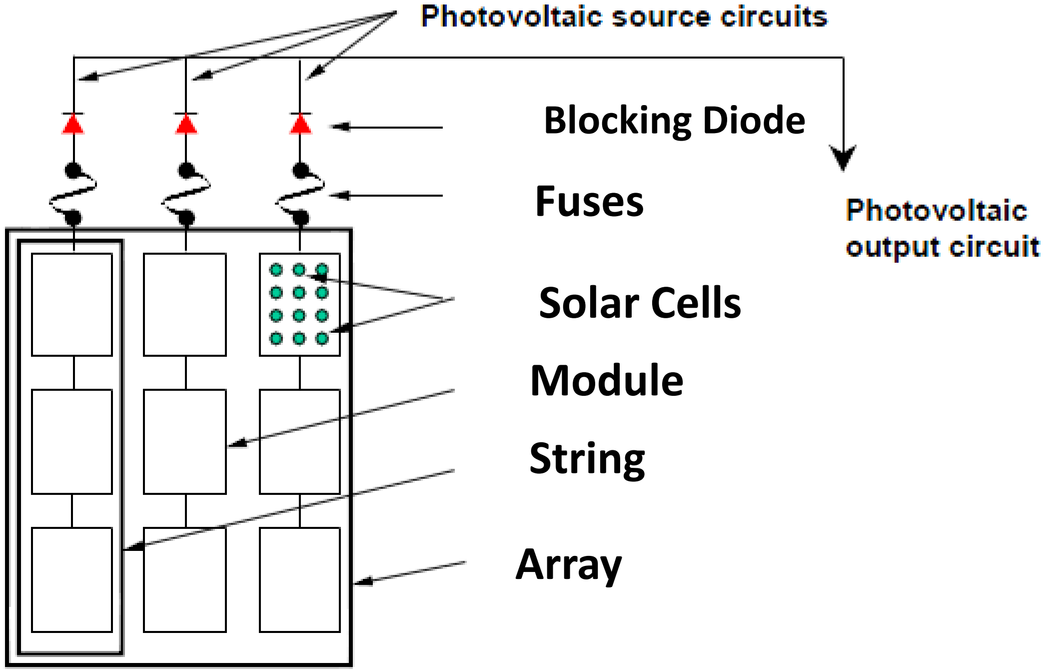


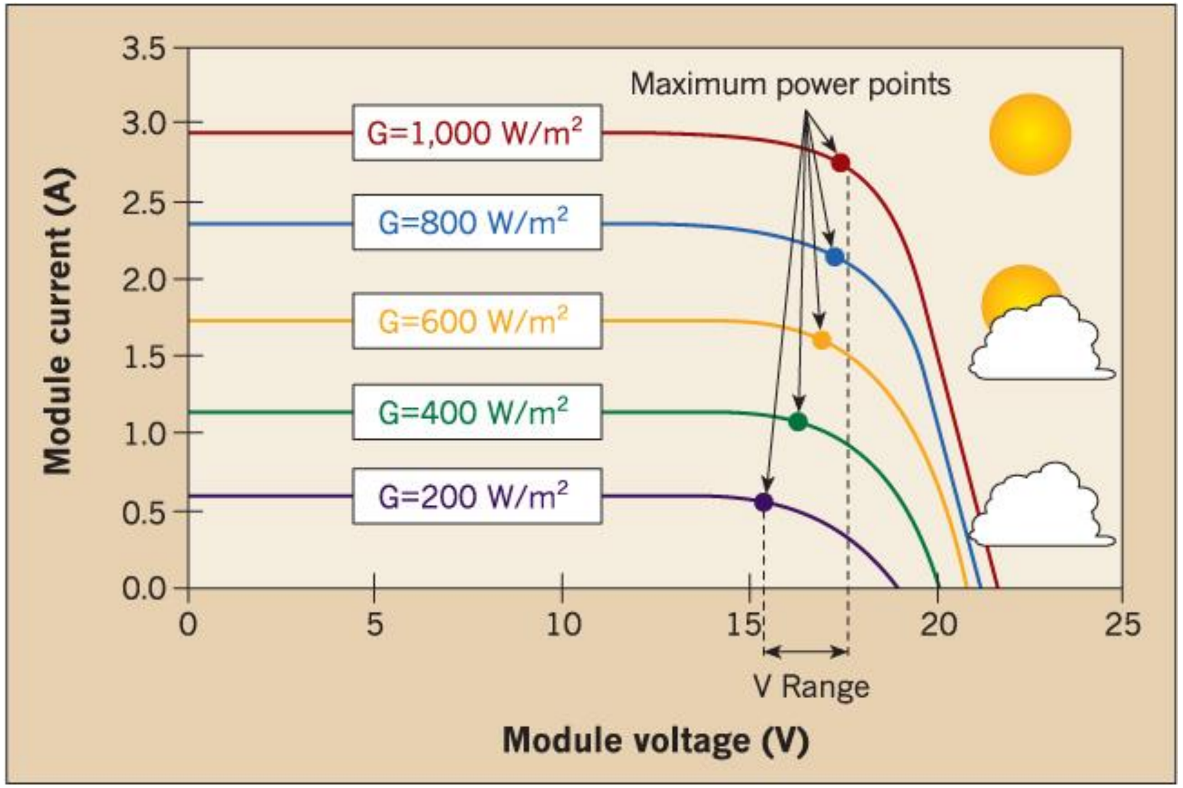
Illustration of string and array

Photovoltaic Modules…cont'd

Operational Issues

- The output performance of a PV module depends on several factors such as:
  - Irradiance falling on the solar cells
  - Temperature of solar cells

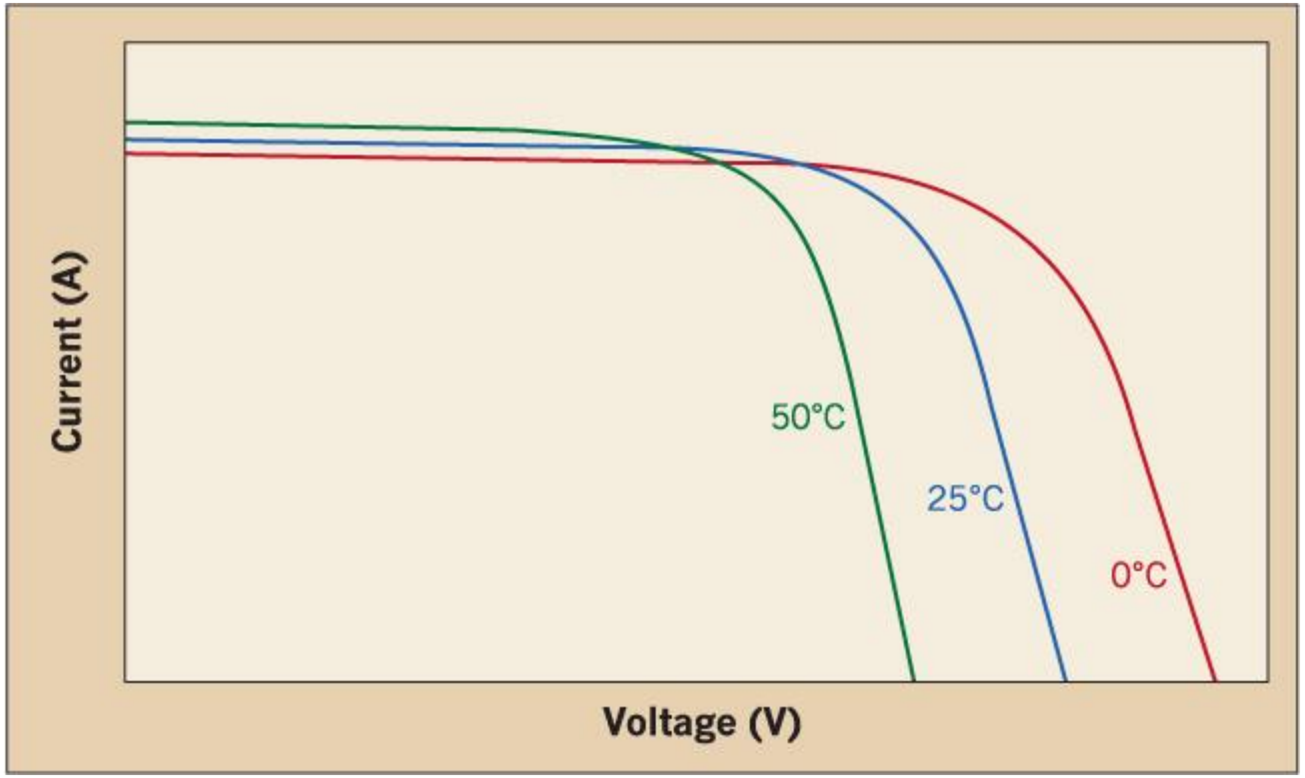
Operational Issues



I-V curve of a PV module at different levels of irradiance

Photovoltaic Modules…cont'd

Operational Issues



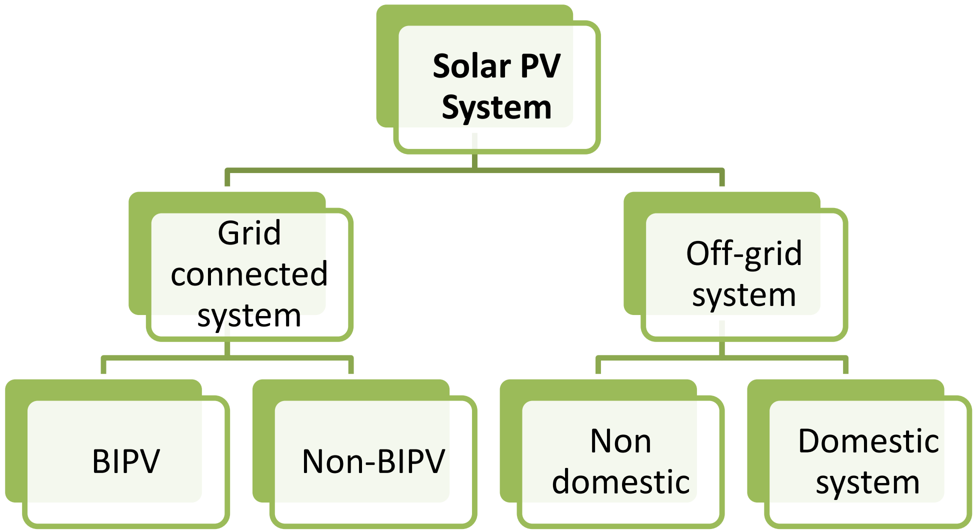
I-V curve of a PV module at different cell temperatures

Photovoltaic (PV) System

Type of PV Systems

- Classified according to:
  - Functional & operational requirements
  - Component configurations
  - Connection to other power sources & electrical loads

- 2 Main categories:
  - Grid Connected (GCPV)
    - ✓ Operate interconnected (in parallel) with the utility grid
  - Stand-alone (SAPV)
    - ✓ Operate interconnected of the utility grid, includes hybrid system



Off-grid PV (OGPV)

OGPV System

➢ Features of off-grid solar PV (OGPV) Systems:

- Not connected to the electric utility grid
- Designed to operate independent of the electric utility grid
- Commonly installed in remote locations with no utility grid
- Supply DC and/or AC electrical load
- Inverter is used for AC load
- Can be configured in several ways, such as direct coupled system or hybrid system

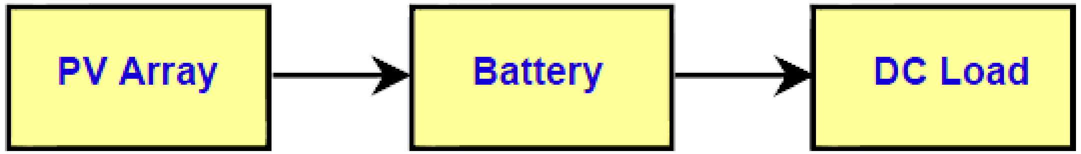
Configuration of a direct-coupled OGPV System

- Simplest type of SAPV system, common application include water pump and fans
- DC load is directly connected to a PV array, no energy storage
- No overcurrent device typically required

System Configuration

OGPV System with battery storage

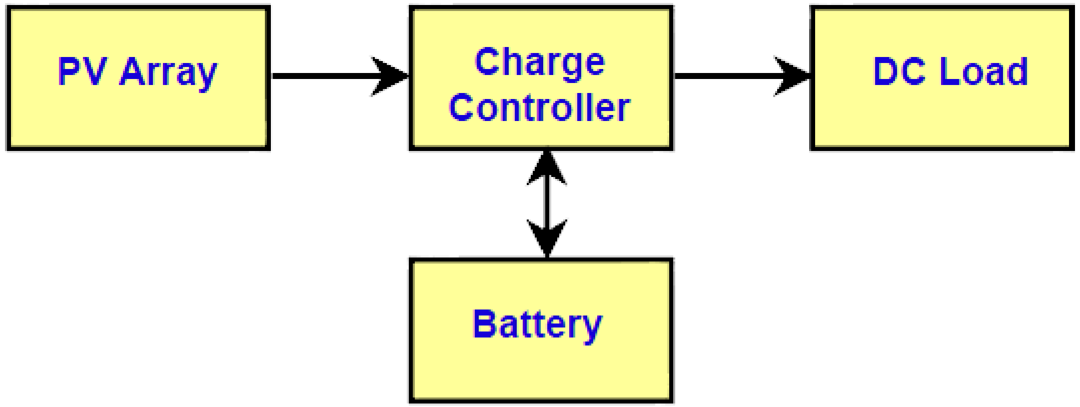
- PV array charges battery which supplies power to DC electrical loads as needed
- Without charge control, battery is susceptible to overcharge and over discharge.
- Charge control may only be eliminated under special circumstances the load is well defined and the battery is oversized.



System Configuration…cont’d

OGPV System with battery storage & Charge Control

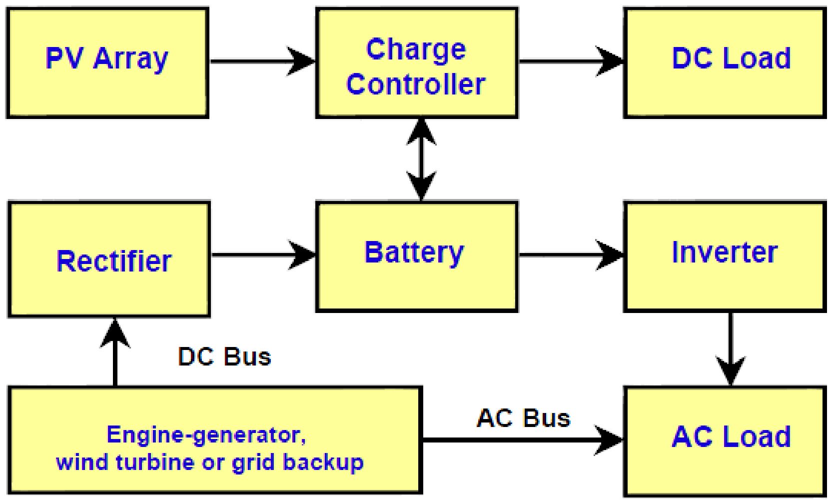
- Charge Control Charge control is required whenever the load is variable and the battery is not oversized.
- Protects the battery from overcharge and over discharge, and may provide load control functions.
- Charge controllers manage interactions and energy flows between a PV array, battery bank, and electrical load.



System Configuration…cont'd

OGPV Hybrid System

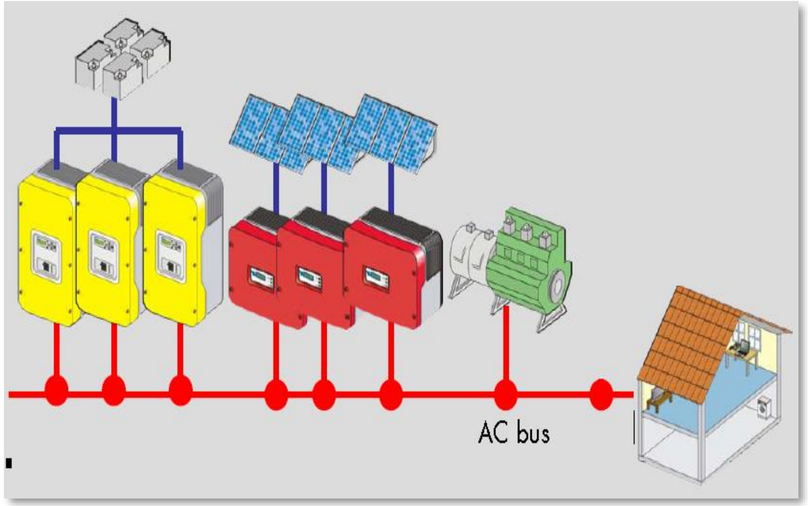
- One or more energy sources are used in addition to the PV generator
- Common hybrid sources used in off-grid PV systems include engine generators, wind turbines, small hydro and fuel cells
- Reliance on any single generating source is reduced, battery storage capacity and size of PV array can be minimized
- Hybrid PV systems are often the least costly for remote power applications.



System Configuration…cont'd

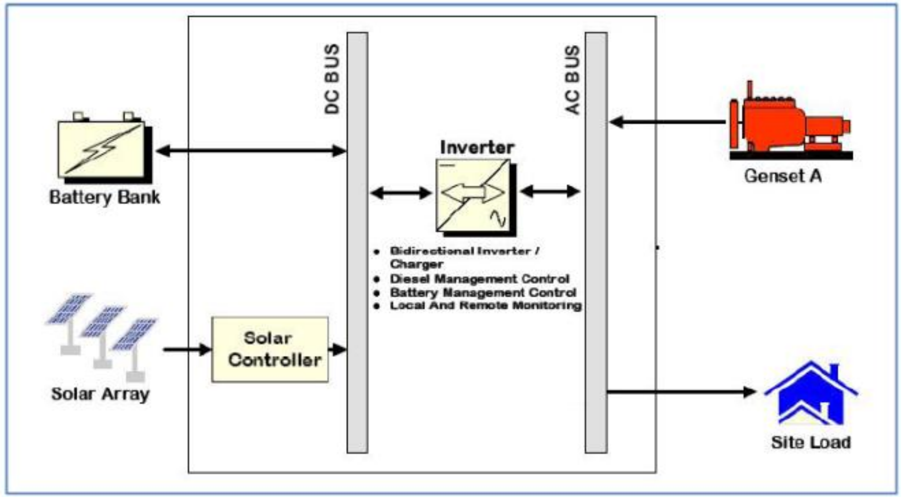
➢ AC Couple vs DC Couple

AC Couple System Diagram



- Two types of inverter – Bidirectional (yellow) & grid inverter (Red)
- All components directly connected to the AC bus
- Capability for future expansion and additional of other power source

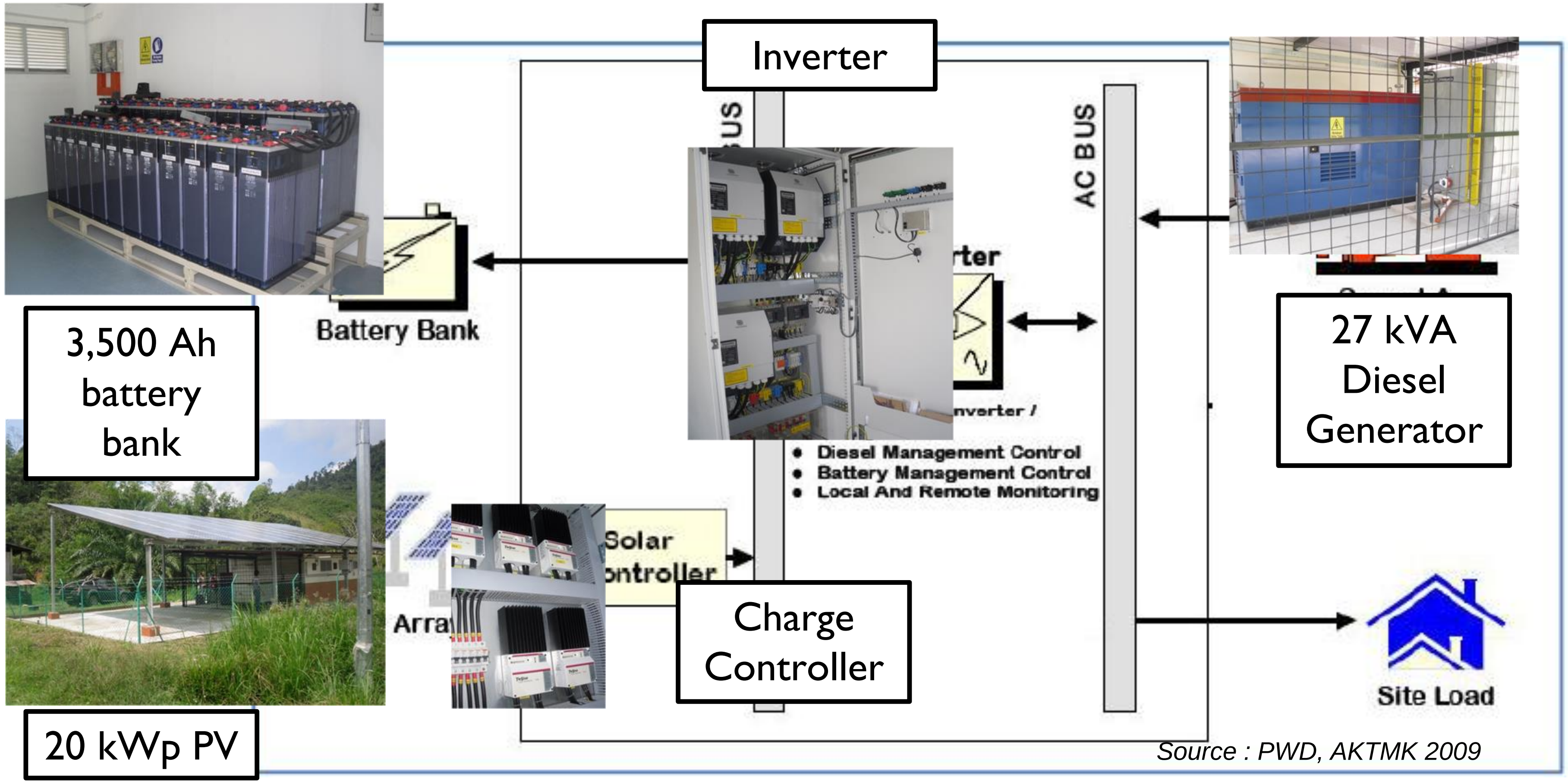
DC Couple System Diagram



- Only one inverter – bidirectional inverter
- DC bus connected to the battery bank and solar panel
- AC bus connected with Load and other AC power source

SAPV Hybrid System

OGPV Hybrid System



Configuration of SAPV Hybrid System for SK Penontomon, Keningau , Sabah

OGPV Hybrid System

- Solar batteries are key components of OGPV system as they act as energy storage and backup
- Solar batteries are designed to have deep cycle and can last longer compare to automotive batteries that only design for cranking purposes.
- Normally for OGPV system used Lead acid batteries
- Types of lead acid batteries:
  - Flooded lead acid batteries
  - Valve Regulated Lead Acid
    - Absorbed Glass Mat (AGM)
    - Gelled electrolyte
- Other energy storage type is Lithium Ion, Lithium Polymer, Sodium, Redox battery, Fly wheel, Fuel cell

Training & Certification

- Training for certification is provided by SEDA
- Training is held at UiTM and SHRDC
- Refer to SEDA website at www.seda.gov.my

LANGKAH BERJAGA-JAGA DAN KESELAMATAN

- **Sistem solar PV adalah selamat** jika dioperasikan dengan **cara dan kaedah yang betul**, tetapi **berpotensi untuk mendatangkan bahaya** jika cuai
- Sila patuhi **langkah-langkah keselamatan** dan **prosedur operasi dan senggara** yang ditetapkan
- Hanya **orang kompeten sahaja dibenarkan** untuk menjalankan kerja-kerja operasi dan senggaraan

- **AC Voltage**
  - **240V AC power** adalah merbahaya dan boleh mengakibatkan maut jika ‘live wires/terminal’ terdedah dan boleh juga mengakibatkan kebakaran

LANGKAH BERJAGA-JAGA DAN KESELAMATAN

- **Solar PV array**
  - Electric shock (V_{oc} = 696.9 V_{dc})
  - Kemalangan disebabkan kedudukan pemasangan di tempat tinggi

DANGER

NOTE
maintenance can only be undertaken by a suitably licensed electrical worker or contractor.

- **PERINGATAN!!**
  - Sentiasa pastikan **bekalan kuasa suis utama** dan **suis-suis di solar PV array** dan **bilik inverter dimatikan** sebelum sebarang kerja-kerja penyenggaraan dan pembaikan dan seumpamanya dijalankan

Exercise 3: (20 minutes & 5 minutes discussion)

- Based on the given solar PV module datasheet, works in group:
  - Determine the total output power at STC of 10 modules
  - Determine the total system V_{oc} and I_{sc} of the following configuration;
    a) 5 modules in series per string
    b) 2 modules in series per string
  - How many strings for (a) and (b)?

*Hints: Try to sketch the configuration

CHAPTER 3
: Off-grid solar PV system design
(Part 1)

1.0 Effect of temperature on output

- The output of PV module is effected by temperature:
  - Current marginally increases with module temperature increases
  - Voltage significantly decreases with increase in module temperature
  - Power significantly decreases with increase in module temperature
- Question:
  - What is the best condition for a PV module operating condition?

Determining cell operating temperature

- Formula to calculate cell or module temperature:

$$T_{cell} = T_{amb} + [\frac{NOCT - 20}{800\ W/m^2}\ X\ G]$$

T_{cell}	= temperature of cell during operation (^oC)
NOCT	= given by manufacturer (^oC)
T_{amb}	= ambient average temperature during operation (^oC)
G	= irradiance at ambient temperature (W/m^2)

If NOCT is not available;

$$T_{cell} = T_{amb} + 25^oC$$

Temperature coefficient

- Temperature coefficients are used to determine the correct output values in different climate conditions
- Temperature coefficient can be in 2 forms:
  - Percentage values; eg, (%/^{o}C)
  - Absolute values; eg, (mV/^{o}C)
- y_{Pmp} (Temperature coefficient for Maximum Power)
- y_{Isc} (Temperature coefficient for short circuit current)
- y_{Voc} (Temperature coefficient for open circuit voltage)
- y_{Vmp} (Temperature coefficient for voltage at maximum power)
- y_{Imp} (Temperature coefficient for current at maximum power)

Temperature correction factor

- Percentage values

$$f_{temp\_x} = 1 + [\frac{y_x}{100} \text{ x } (T_{cell} - T_{stc})$$

- Absolute values

$$f_{temp\_x} = y_x \text{ x } (T_{cell} - T_{stc})$$

x can be $I_{sc}, V_{oc}, V_{mp}, I_{mp}$ or P_{mp}

Peak Sun Factor (PSF) & corrected output

- PSF is used to determine the expected output of solar PV module under Real Operating Operation (ROC)

$$PSF = \frac{G_{array\_plane}}{1{,}000\ W/m^2}$$

- Thus the expected output power is;

$$P_{mp\_corrected\_PSF} = P_{mp\_STC}\ x\ f_{temp}\ x\ PSF$$

- Can you determine the formula if using absolute value?
- PV system designer must appreciate the module when designing a system for different location
- For a hot & dry regions, as a PV designer, would you a module with;
  a) Low temperature coefficient, or
  b) High temperature coefficient

Exercise 4: 5 - 10 minutes

- Refer to the datasheet given, G is given at 900 W/m^2;
  - Calculate the T_{cell} given the T_{amb} is 30°C
  - Calculate the f_{temp} of $I_{sc}, V_{oc}, V_{mp}, I_{mp}$ or P_{mp}
  - The corrected Power output
  - If you have to consider dirt factor of 2%, determine the corrected Power output

2.0 Batteries system and characteristics

- Battery capacity
  - The amount of charge that can be stored
  - $Capacity(Ah) = Current\ (A)\ X\ Time(h)$
- Battery energy content
  - $Energy = System\ Voltage\ (V)\ X\ Capacity\ (Ah)$
- A battery is also rated based the ability to supply certain amount of charge within a specified period (rate)
  - The Ah rating of battery is quoted at a discharge rate; eg C_5, C_{10}, C_{20}

Exercise 5: 5 - 10 minutes

- Calculate the time needed to completely discharge a 1,000 Ah battery, if the discharging current is 100A
- What is the discharge rate C_x?
- Determine the discharge current at the discharge rate of C_{20}?

State of Charge (SOC) & Depth of Discharge (DOD)

- DOD + SOC = 100%

Maximum Depth of Discharge

- The maximum allowable DOD (%)
- The common value is 80%
- Frequent discharge to DOD_{max} per day will reduce the cycle life dramatically

3.0 Off grid solar PV system components

- Solar PV (module > string > array)
- Inverters (Grid inverter & Bidirectional inverter)
- Charge controller – for DC couple system
- Battery system
- Diesel generator
- Cables (DC & AC)
- Protection (switches, fuse, lightning protection)
- Junction BOX (DC & AC)

4.0 System sizing – Step 1

- Determine the system configuration as required by the client:
  - PV with battery
  - PV with battery & genset
  - PV with batery, wind, hydro etc.
- Determine the Total Energy Required Daily (E_{daily})
  - Several methods can be used:
    - Most common by constructing 24 hours Load Profile for each appliances
    - If the site has existing genset, load profile can be logged
- Determine the Maximum Demand
  - Using Diversity Factor method
  - From the Load Profile

4.0 System sizing – Step 2

- Determine the solar energy resources of the particular site for each month for a year
  - NASA meteorological data
  - Global Solar Atlas http://globalsolaratlas.info/
  - Local meteorological station
- Select the lowest Irradiation (kWh/m^2) in a year

4.0 System sizing – Step 3

- Determine which System Voltage (SV) to use
  - Either 12 Vdc, 24 Vdc, or 48 Vdc
  - Sometimes system with 120 Vdc and 240 Vdc can also be considered
  - The selection of which SV to use may result in quantity of battery to use
- Rule of thumb:
  - $E_{required\_daily} \leq 1$ kWh = 12 Vdc
  - $E_{required\_daily} \leq 4$ kWh= 24 Vdc
  - $E_{required\_daily} > 4$ kWh= 48 Vdc

4.0 System sizing – Step 4

- Convert the $E_{required\_daily}$ to Total Capacity Required (Ah)
  - $C_{required_{daily}} = \frac{E_{required\_daily}}{SV}$
  - Eg; given $E_{required\_daily}$ = 2,400 Wh with SV = 24Vdc;
    - $C_{required_{daily}} = \frac{2{,}400\,Wh}{24\,Vdc}$ = 100 Ah

4.0 System sizing – Step 5

- Battery Bank Capacity Required ($C_{bank_{required}}$)
  - The ability of battery to meet energy demand for a day or a few days (autonomy)
  - The ability of battery to supply peak power demand
  - $E_{required\_daily}$
  - Maximum DOD
  - Maximum Power & surge demand
  - Maximum charging current
- $C_{bank\_required} = C_{required\_daily} \times \frac{T_{autonomy}}{DOD_{max}}$

4.0 System sizing – Step 5 (exercise: 10 minutes)

- If $C_{required\_daily}$ = 100 Ah, $T_{autonomy}$ = 2 days with backup genset, DOD_{max}= 80%. Calculate the capacity of the battery bank required.

- Note:
  - For this training, several steps are not considered and it is assumed that the effect/factors do not influence the sizing method of battery capacity
    - Temperature correction methods
    - Battery bank discharge rate
    - Revised battery capacity
    - Maximum Continuous Discharge Rate (MCDR)
    - Surge Demand

4.0 System sizing – Step 6

- Number of batteries in series string
- $N_{series\_bank} = \frac{SV}{Nominal\ battery\ voltage}$
- Eg; A battery capacity = 875 Ah. If the nominal battery voltage is 2 V and the selected SV is 12 V. The number of batteries required per string is 6 unit

4.0 System sizing – Step 7

- Number of battery strings
- It is important to minimize the number of parallel strings:
  - All strings are required to be fused. Fuses are costly
  - Possibility of uneven charging in parallel strings. The batteries closest to the charging source may charge at marginally higher charging rate than those further away
  - Most manufactures recommend up to 3 to 4 strings
- $N_{parallel\_bank} = \frac{C_{bank\_required}}{C_{per\_battery}}$ (round up the numbers)
- Selected battery bank capacity
  - $C_{bank\_selected} = N_{parallel\_bank}$ X C_{per_bank}

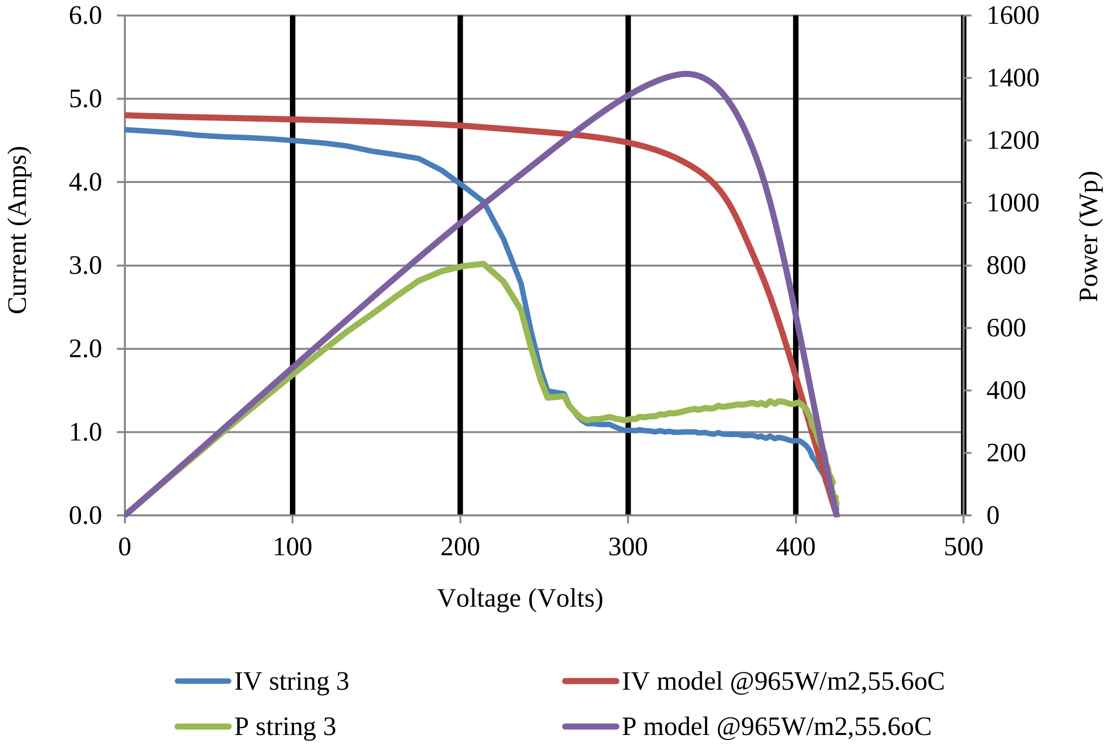
4.0 System sizing – Step 8

- Checking mechanism to determine the estimate Daily DOD < DOD_{max}
  - $DOD_d = \frac{C_{required\_daily}}{C_{bank\_selected}}$
- Exercise:
  - $E_{required\_daily}$ = 2,400 Wh; system voltage is 24 V; autonomy is 3 days; $DOD_{max} = 0.8$; battery 12 V each.
    - Select a battery capacity.
    - Find DOD

Exercise

- Describe the expected IV curve as shown above

Answer



- Shading effect
- Maximum power does not match
- PV produce lower Power

Exercise

- Given the Daily Irradiation of a location is 3,400 Wh/m2,
  - Determine the PSH
  - What is the daily potential energy generation for 1 kWp solar PV modules
- Base on the data sheet of the thin film and monocrystalline solar PV,
  - How much area is required to construct a 30 kWp solar PV, regardless spacing and mounting.
  - determine the estimated (corrected) power that can be produced for a 30 kWp, if:
  - Ambient temperature is 33 ^{o}C
  - Average Irradiance is 750 W/m^2

Exercise

- Total daily energy requirement of a clinics and its quarters in a rural area is 98,450 kWh
  - Design the battery system
  - What is not considered in your calculation and design?
  - Can you suggest other battery technology to be considered.

4.0 System sizing – Step 9

- The items that should be considered in designing solar PV array:
  - Energy form PV shall meet a specified amount of energy required
  - System voltage
  - Solar resources
  - Tilt angle
  - Orientation of PV
  - Derating of PV
  - Efficiency of battery
  - Solar fraction
- Normally a charge controller is equipped with MPPT. Current Grid inverter do have the same features

4.0 System sizing – Step 9

- Determine f_{temp_Pmp}
- Determine the corrected output power of PV modules that includes derating factor of manufacturing tolerance (f_{mm}), and derating factor for dirt (f_{dirt})
- Determine the sub-system efficiency
  - $\eta_{PV\_ss} = \eta_{PV\_batt} \times \eta_{controller} \times \eta_{Wh\_batt}$

  - Where η_{PV_ss} is efficiency of PV sub-system
  - η_{PV_batt} is efficiency of cable from PV array to battery (5%)
  - $\eta_{controller}$ is efficiency of MPPT charge controller/grid inverter (refer manufacturer datasheet)

4.0 System sizing – Step 10

- After considering the Solar Fraction (SF) that the solar PV array shall produce, determine the total number of modules
  - $N_T = \dfrac{E_{required\_daily}\ X\ f_o}{P_{mp_{corrected}}\ X\ PSH\ X\ \eta_{pv\_ss}}$
  - f_o is the over-supply coefficient (1.0 - 1.2)
- Determine the numbers of module connected in series based on Vmp
  - $N_{series} = \dfrac{0.95\ X\ V_{\max\_window\_cc}}{V_{mp}}$

4.0 System sizing – Step 10

- Now we know the total numbers of PV module required and the total numbers of modules in series.
  - Next is to determine the numbers of strings required
    - $N_P = \frac{N_T}{N_S}$
- Total power at STC that can be generated from the PV modules is;

$P \quad = P \quad \times N$

4.0 System sizing – Step 11

- Average daily energy output of PV array is;
  - $E_{PV\_out} = P_{array}$ X PSH
- To confirm whether the design solar PV modules meet the energy required;
  - $E_{check} \geq E_{required\_daily}$
  - $E_{check} = \frac{E_{PV\_out}\ X\ \eta_{PV\_ss}}{f_o}$

Exercise

- Total daily energy requirement of a clinics and its quarters in a rural area is 98,450 Wh
- A solar PV system that can supply 100% electricity to the premise is required
  - Consider the 250Wp Monocrystalline Sunworld
  - Ambient temperature is 25oC
  - Irradiance is 1,000 W/m2
  - Irradiation 3,400 Wh/m2
- Design the capacity of the solar PV module

4.0 System sizing – Step 12

- To size a charge controller, a designer need to consider the amount current the charge controller need to handle
- ie; Short circuit current of the PV array
  - $I_{controller\_rating}$ = 1.3 X I_{sc_stc} X Np

4.0 System sizing – Step 13

- Inverter is costly. Therefore, several factors need to be considered to optimize its operation:
  - Total load at the same time and continuously > MD
  - Energy demand management
  - Avoid load with high surge to start at same time
  - Future load growth 10%-20%
  - Inverter running at low load would reduce the efficiency
- Apparent power of inverter for 30 minutes MD
  - $S_{inv\_30min} = S_{max\_AC} \text{ X } sf_{inv}$; sf_{inv} is safety factor (1.1)
  - $S_{max\_AC} = \frac{P_{real} \, X \, S_f}{PF}$
  - Preal is real power consumption
  - PF is power factor
  - Sf is surge factor (1 for resistive load, 3 for universal motor, 5-7 for induction motor)

4.0 System sizing – Step 13

- S_{max_AC} is obtain from load assessment
- Other factors:
  - Quality of waveform
  - Standby power consumption
  - Installation (outdoor or indoor)
  - Input voltage range
  - Output voltage
  - Frequency
- Important that S_{inv_30min} not greater than C_5 rating of battery

4.0 System sizing – Step 14

- It is important to select a generator (as backup power supply) that can:
  - Meet the power requirements (MD)
  - Not to be oversized for cost effective especially during O&M
- There are three system arrangements:
  - Series mode – power use to charge battery and provide power to DC loads
  - Switch mode – power use to charge the battery and provide AC power
  - Parallel mode (Bidirectional) – power use to charge battery and at the same time to directly supply to AC load
    - $S_{gen\_parallel} = \frac{(S_{bc}+MD)\ X\ 1.1}{f_{gen\_derate}}$

4.0 System sizing – Step 14

- Genset run time
  - Depends on:
    - Battery charging regime
    - Load energy demand
    - Output of energy from PV
    - How the genset is controlled

Case Study

- You are the solar PV specialist consultant for off-grid installation. As a consultant you are required to design a system for rural electrification program. The system to be installed at the following locations:
  - Group A – Lat: N 4.49^o Long: E 115.79^o T_{amb} = 26 ^oC
  - Group B – Lat: N 6.71^o Long: E 116.36^o T_{amb} = 32 ^oC
- Both sites have the same load requirement:
  - School
    - $E_{required\_daily}$ = 49,502 Wh
    - MD = 8,120 W
  - Houses
    - Numbers = 30 houses
    - $E_{required\_daily}$ = 8 kWh
    - MD = 3.2 kW
  - Clinics
    - $E_{required\_daily}$ = 15,420 kWh
    - MD = 3,300 W

- LED Street light
  - Numbers = 10 units
  - Power = 100 W per unit

Design an off-grid solar PV system base on the following criteria:

- Solar Fraction = 70%
- Irradiance = 1,000 W/m2
- Includes all the assumptions