Grid Connected Solar: Technical and Policy Issues

Dr. Md. Zahurul Haq

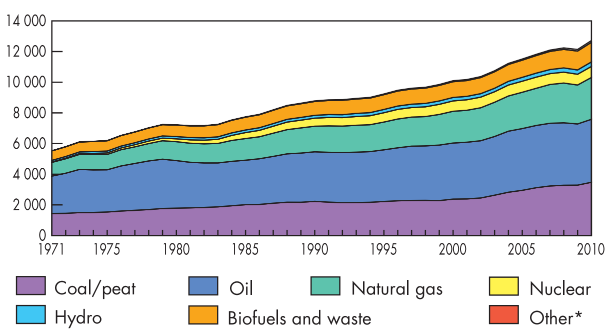
Director, Centre for Energy Studies
Professor, Department of Mechanical Engineering
Bangladesh University of Engineering & Technology (BUET)
Dhaka-1000, Bangladesh

zahurul@me.buet.ac.bd
http://teacher.buet.ac.bd/zahurul/

Renewable Energy Policy, Regulations and Grid Connectivity Issues
SAARC Workshop
21-22 November, 2012 in Thimpu, Bhutan

Outline

World Total Primary Energy Supply (TPES)

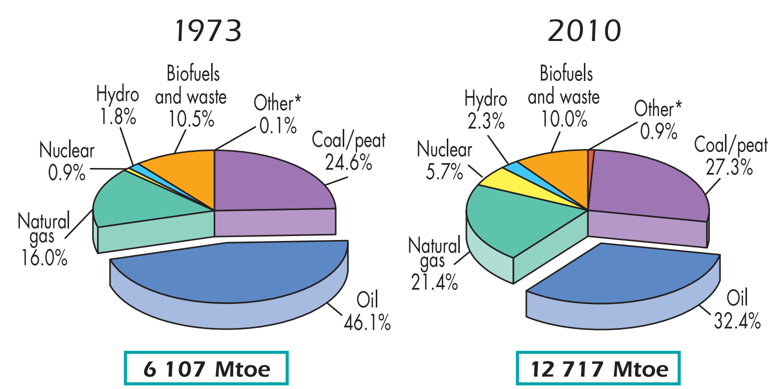


World total primary energy supply from 1971 to 2010 by fuel[1].

* Other includes geothermal, solar, wind, etc.

- 1 Mtoe ≡ = 1 million tonnes of oil equivalent = 41.9×10^{15} J.

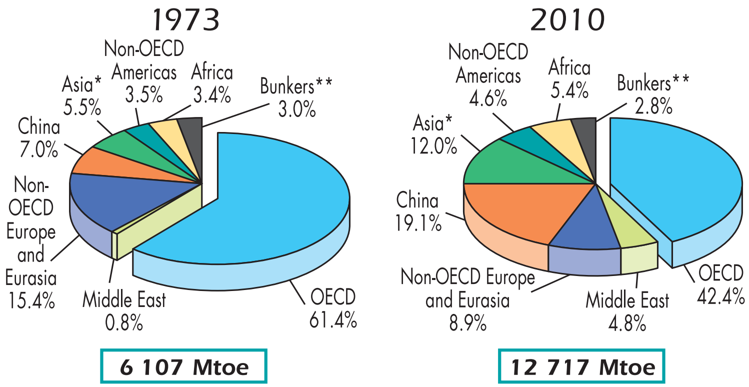
[1] *Key World Energy Statistics 2012* (2012). International Energy Agency.



Fuel Shares of TPES[2].

* Other includes geothermal, solar, wind, etc.

[2] *Key World Energy Statistics 2012* (2012). International Energy Agency.



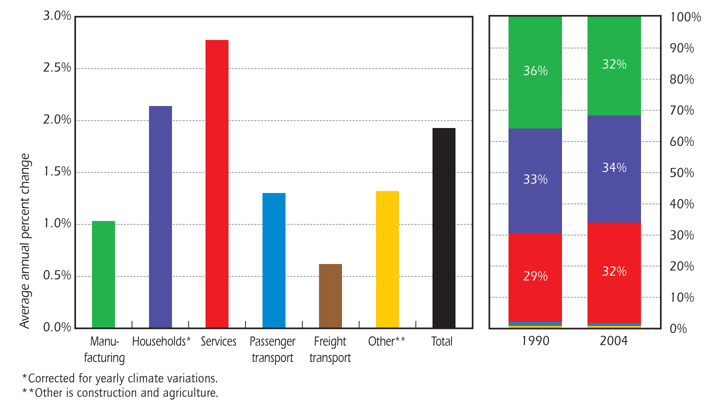
Regional Shares of TPES[3].

* Asia excludes China.

** Includes international aviation and international marine bunkers.

[3] *Key World Energy Statistics 2012* (2012). International Energy Agency.

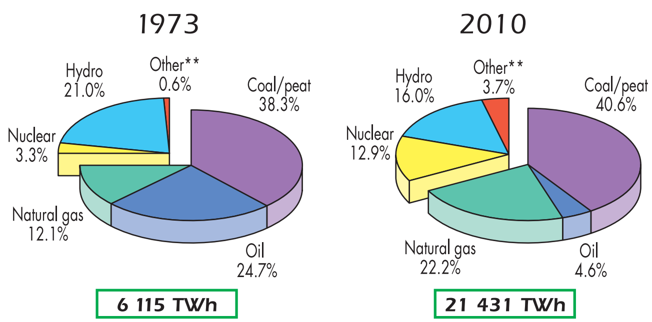
Electricity Demand and Electricity Shares by Sector[4]



Solar energy can significantly replace energy required in all sectors.

[4] *Energy Use in the New Millennium: Trends in IEA Countries* (2007). International Energy Agency.

Electricity Generartion by Energy Source

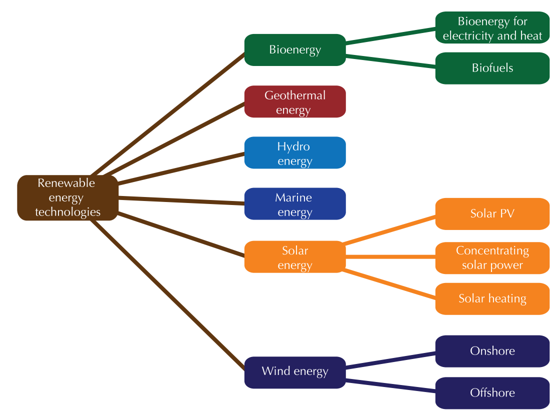


Fuel shares of electricity generation[5].

* Other includes renewable energy, e.g. geothermal, solar, wind, bio-fuels and waste heat etc.

[5] *Key World Energy Statistics 2012* (2012). International Energy Agency.

Renewable Energy Sources & Technologies

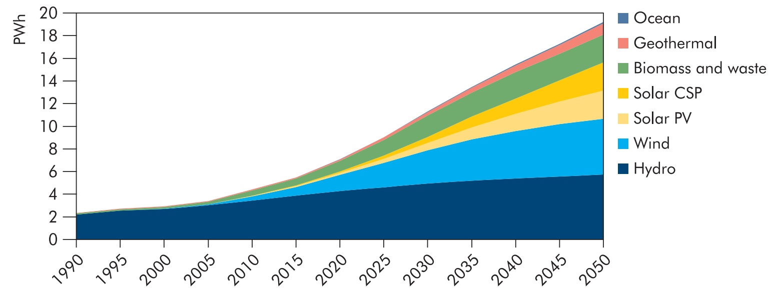


Different renewable energy technologies and resources exist for electricity, heat and biofuel production[6].

[6] *Renewable Energy: Markets and Prospect by Technology* (2011). International Energy Agency.

IEA Technolgy Roadmaps for Solar Energy

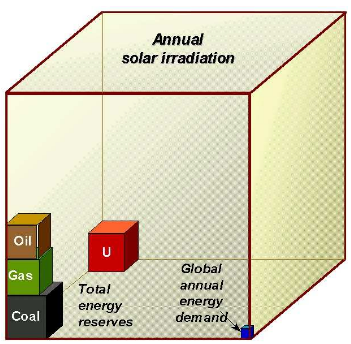
1. *Technology Roadmap - Concentrating Solar Power* (2010). International Energy Agency
2. *Technology Roadmap: Solar Photovoltaic Energy* (2010). International Energy Agency
3. *Technology Roadmap: Solar Heating and Cooling* (2012). International Energy Agency



Growth of renewable power generation in the BLUE Map scenario[7].

- At present, Solar PV provides only 0.1% of total global electricity generation.
- According to IEA PV roadmap[8] : PV is expected to provide
  - 5% of global electricity generation in 2030.
  - 11% of global electricity generation in 2050.

[7] *Key World Energy Statistics 2012* (2012). International Energy Agency.
[8] *Technology Roadmap: Solar Photovoltaic Energy* (2010). International Energy Agency.



- Solar energy is the largest energy resource on Earth – and is inexhaustible[9].
- The energy that hits the earth's surface in one hour is about the same as the amount consumed by all human activities in a year[10].

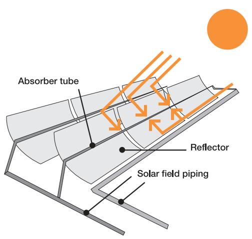
[9] V. Quaschning (2005). *Understanding Renewable Energy Systems.* Earthscan.
[10] *Technology Roadmap - Concentrating Solar Power* (2010). International Energy Agency.

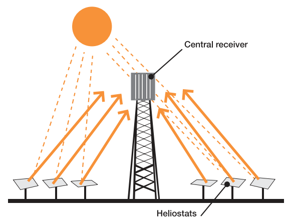
Solar Energy Technology: Classifications[11]

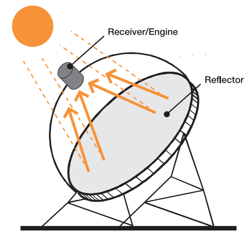
- Based on conversion:
  - Solar thermal technology
  - Solar photovoltaic (PV)
- Based on grid-connection:
  - Stand-alone system
    - Off-grid domestic systems provide electricity to households and villages that are not connected to the utility electricity network.
    - Off-grid non-domestic installations were the first commercial application for terrestrial PV systems.
  - Grid tied system
    - Grid-connected distributed PV systems are installed to provide power to a grid-connected customer or directly to the electricity network.
    - Grid-connected centralized systems perform the functions of centralized power stations.

[11] *Trends in Photovoltaic Applications: Survey report of selected IEA countries between 1992 and 2011* (2011). International Energy Agency.

Capturing the Sun[12]







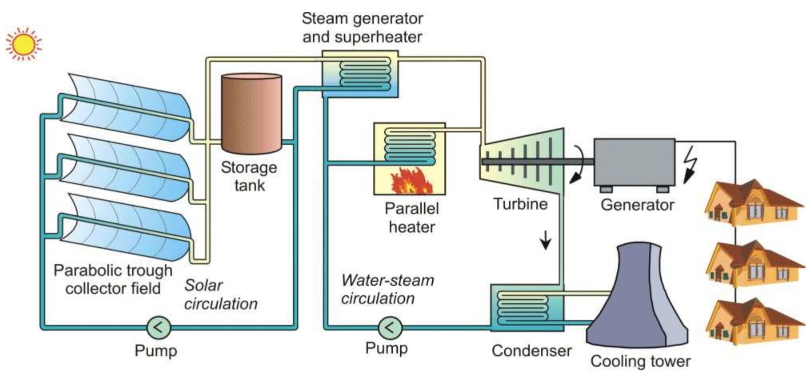
Parabolic Trough Central Receiver Parabolic Dish

[12] G. Brakmann et al. (2005). *Concentrated Solar Thermal Power – Now* European Solar Thermal Industry Association, IEA SolarPACES, and Greenpeace.

	Parabolic Trough	Central Receiver	Parabolic Dish
Applications	Grid-connected plants, mid- to high-process heat (Highest single unit solar capacity to date: 80 MWe.) Total capacity built: 354 MW	Grid-connected plants, high temperature process heat (Highest single unit solar capacity to date: 10 MWe, with another 10 MW currently under construction.)	Stand-alone, small off-grid power systems or clustered to larger grid-connected dish parks (Highest single unit solar capacity to date: 25 kWe; recent designs have about 10 kW unit size.)
Advantages	• Commercially available – over 12 billion kWh of operational experience; operating temperature potential up to 500°C (400°C commercially proven) • Commercially proven annual net plant efficiency of 14% (solar radiation to net electric output) • Commercially proven investment and operating costs • Modularity • Best land-use factor of all solar technologies • Lowest materials demand • Hybrid concept proven • Storage capability	• Good mid-term prospects for high conversion efficiencies, operating temperature potential beyond 1,000°C (565°C proven at 10 MW scale) • Storage at high temperatures • Hybrid operation possible	• Very high conversion efficiencies – peak solar to net electric conversion over 30% • Modularity • Hybrid operation possible • Operational experience of first demonstration projects
Disadvantages	• The use of oil-based heat transfer media restricts operating temperatures today to 400°C, resulting in only moderate steam qualities	• Projected annual performance values, investment and operating costs still need to be proven in commercial operation	• Reliability needs to be improved • Projected cost goals of mass production still need to be achieved

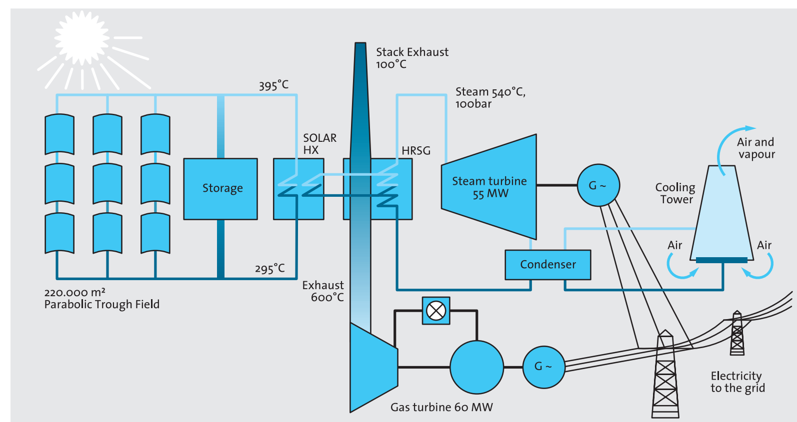
Comparison of solar thermal power technologies[13].

[13] G. Brakmann et al. (2005). *Concentrated Solar Thermal Power – Now* European Solar Thermal Industry Association, IEA SolarPACES, and Greenpeace.



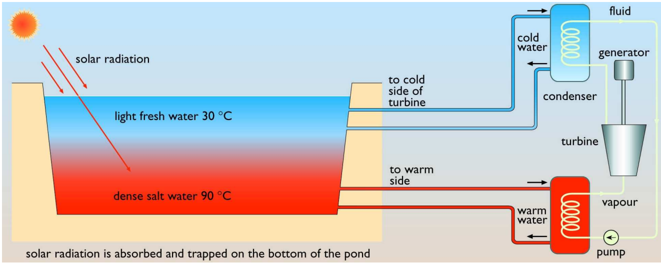
A Parabolic Trough Solar Power Plant[14].

[14] V. Quaschning (2005). *Understanding Renewable Energy Systems.* Earthscan.



Integrated Solar/Combined Cycle system (ISCC)[15]

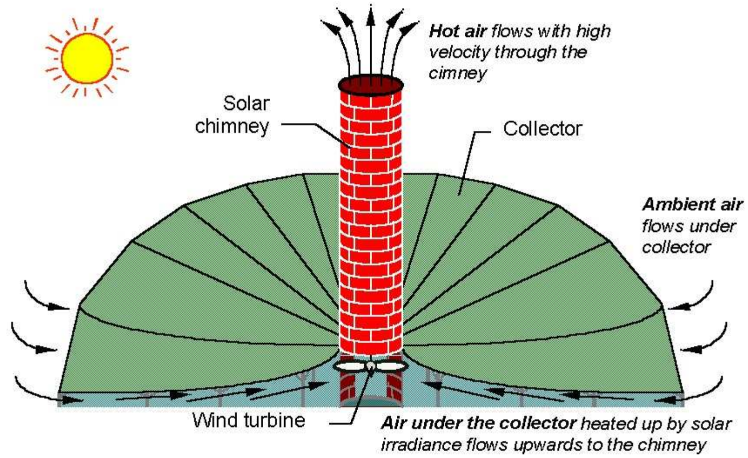
[15] G. Brakmann et al. (2005). *Concentrated Solar Thermal Power – Now* European Solar Thermal Industry Association, IEA SolarPACES, and Greenpeace.



A Solar Pond Used to Drive a Vapour Cycle Turbine[16].

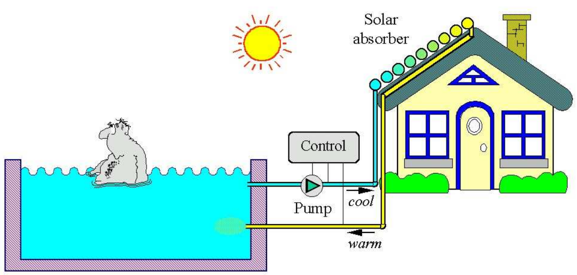
The upper layers of water effectively act as an insulating blanket and the temperatures at the bottom of the pond may reach 90°C. This is high enough temperature to run an organic rankine cycle (ORC). A system of 50 MW electrical energy has been demonstrated.

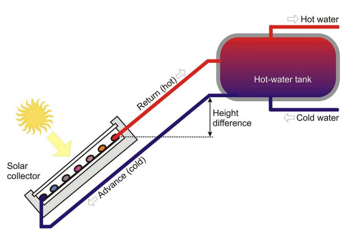
[16] G. Boyle (2004). *Renewable Energy*. Oxford University Press, USA.

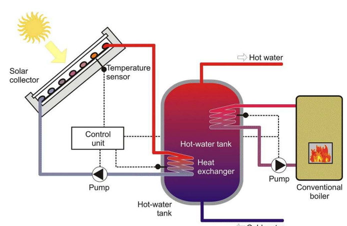


Solar Chimney Power Plant[17].

[17] V. Quaschning (2005). *Understanding Renewable Energy Systems*. Earthscan.





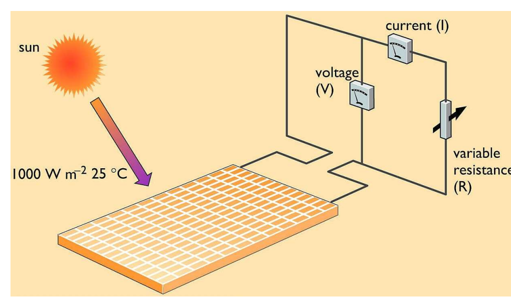


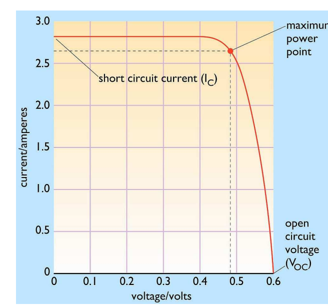
Electricity generation may not be the ONLY option[18].

[18] V. Quaschning (2005). *Understanding Renewable Energy Systems*. Earthscan.

Solar Photovoltaic Cells & Module[19]

- The basic building block of a PV system is the PV cell, which converts solar energy into DC electricity.
- PV cells are interconnected to form a PV module (50-200 W).





[19] G. Boyle (2004). *Renewable Energy*. Oxford University Press, USA.

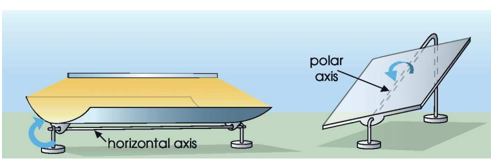
PV module powering a solar home system in Bolivia[20]

[20] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics*. Wiley.

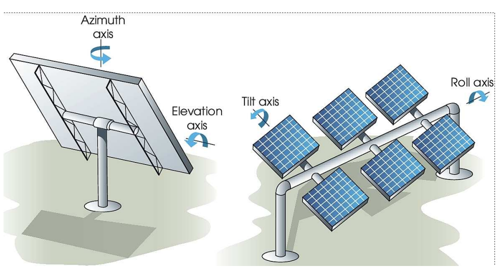
Each of these PV modules contains 72 monocrystalline silicon solar cells[21].

[21] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics*. Wiley.

Sunlight Concentration & Tracking[22]



One - axis tracking.

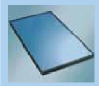


Two - axis tracking.

[22] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics*. Wiley.

This impressive two - axis tracker in Las Vegas, USA, supports multiple point - focus concentrator modules solar cells and is rated at 53 kW[23].

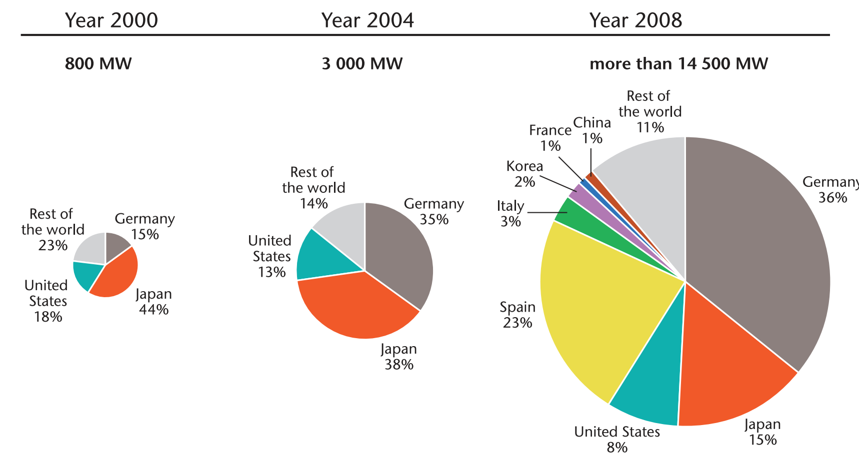
[23] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics*. Wiley.

Property	PV cell type		
	Monocrystalline silicon	Polycrystalline silicon	Thin film amorphous silicon
Appearance			
Cell efficiency at standard test conditions[1]	15–17%	14–15%	8–12%
Module efficiency	13–15%	12–14%	5–7%
Area of modules required per kW_p[2]	7 m²	8 m²	16 m²
Area per kW_p[2] of building materials incorporating PV cells	Glass–glass laminates: 8–30 m² (depends on cell spacing)	Glass–glass laminates: 10–30 m² (depends on cell spacing)	Solar metal roofing: 23.5 m² Glass–glass laminates 25 m²
Advantages/disadvantages	Most efficient but highest cost	Cheaper than monocrystalline but slightly less efficient	Considerably cheaper but about half the efficiency of monocrystalline. Offers the widest range of options for integration into building elements

Properties of common types of PV cells[24].

[24] R. Rawlings and K. Butcher (2009). *Capturing Solar Energy*. CIBSE knowledge series. Chartered Inst. of Building Services Engineers.

Solar PV Installed Capacities[25]



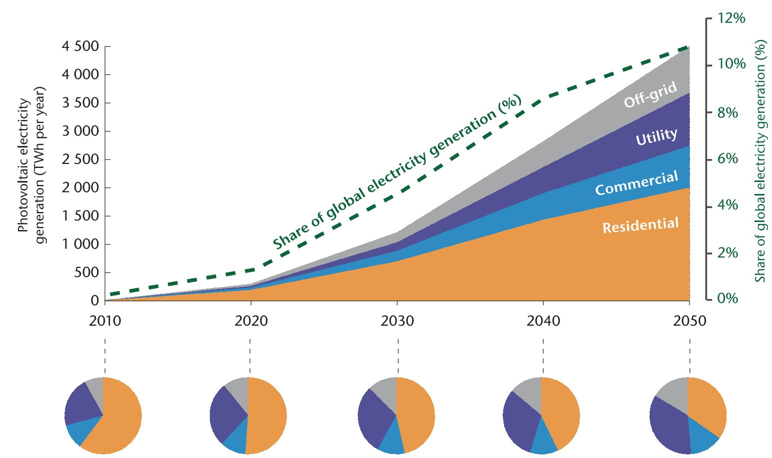
[25] *Technology Roadmap: Solar Photovoltaic Energy* (2010). International Energy Agency.

PV Electricity Generation by End-use Sectors

There are 4 end-use sectors with distinct markets for PV[26]:

1. Residential systems : typically up to 20 kWp systems on individual buildings/dwellings.
2. Commercial systems: typically up to 1 MWp systems for commercial office buildings, schools, hospitals and retail.
3. Utility scale systems: starting at 1 MWp, mounted on buildings or directly on the ground.
4. Off-grid applications: varying sizes.

[26] *Technology Roadmap: Solar Photovoltaic Energy* (2010). International Energy Agency.



There will be a shift from residential to large-scale PV applications over time[27].

[27] *Technology Roadmap - Concentrating Solar Power* (2010). International Energy Agency.

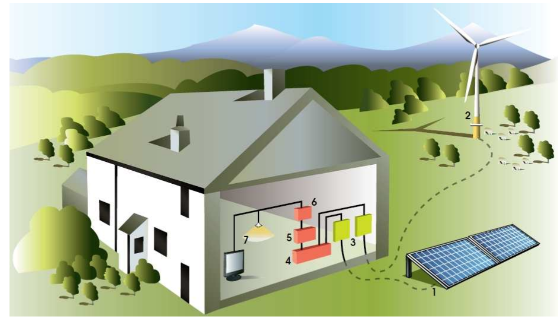
Annual PV power generation (TWh) by end-use sector

Annual electricity generation (TWh)	2010	2020	2030	2040	2050
Residential	23	153	581	1244	1794
Commercial	4	32	144	353	585
Utility	8	81	368	910	1498
Off-grid	3	32	154	401	695
Total	*37*	*298*	*1247*	*2907*	*4572*

Cumulative installed PV capacity (GW) by end-use sector

PV capacity (GW)	2010	2020	2030	2040	2050
Residential	17	118	447	957	1380
Commercial	3	22	99	243	404
Utility	5	49	223	551	908
Off-grid	2	21	103	267	463
Total	*27*	*210*	*872*	*2019*	*3155*

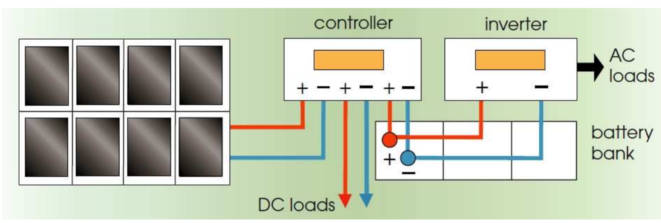
Stand-alone PV System



1. PV array
2. Wind generator
3. Charge controllers
4. Battery bank
5. Inverter
6. Fusebox
7. AC appliances

Remote and independent: a stand - alone system for a farmhouse[28].

[28] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics.* Wiley.



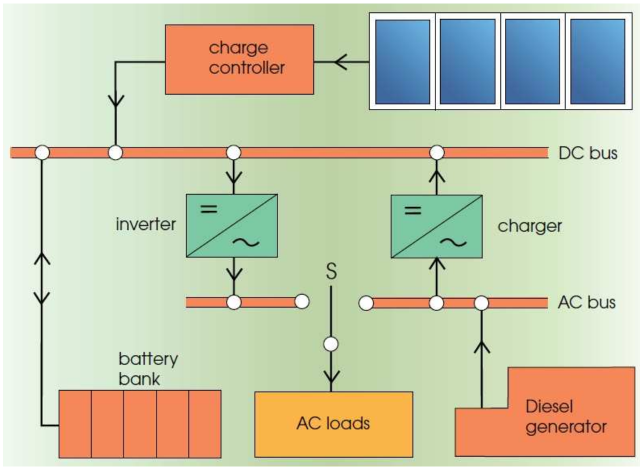
Typical connections for a mid - range stand - alone system[29].

- PV is an array rather than a single module.
- Battery bank replaces a single battery, giving more storage capacity.
- Charge controller has an electronic display indicating parameters such as battery voltage, PV current and load current etc.
- Inverter, connected directly to the battery bank, also indicates its operating conditions.

[29] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics.* Wiley.

PV for a village water supply in Niger[30].

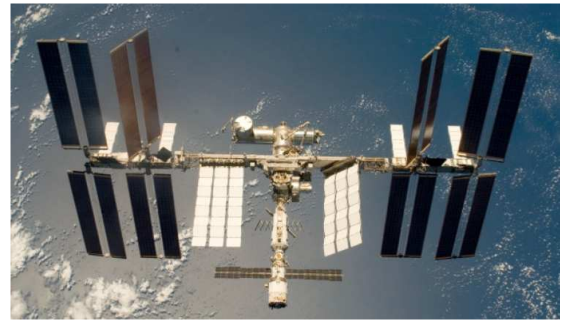
[30] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics.* Wiley.



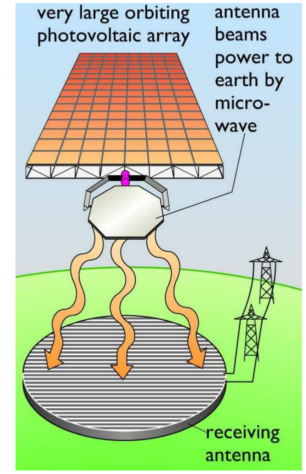
A PV-diesel hybrid system may improve reliability and reduce overall costs in rural areas[31].

[31] P. Lynn (2010). *Electricity from Sunlight: An Introduction to Photovoltaics.* Wiley.

Connectivity may not be a good option.

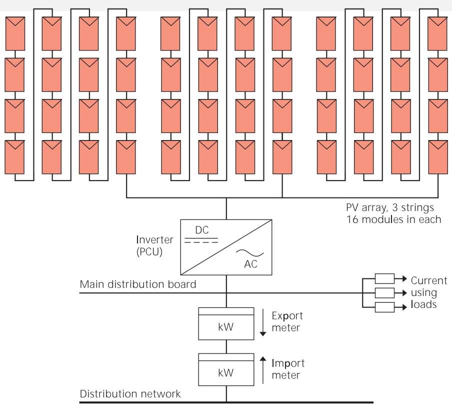


The International Space Station, photographed in 2009.



Satelite solar power station concept.

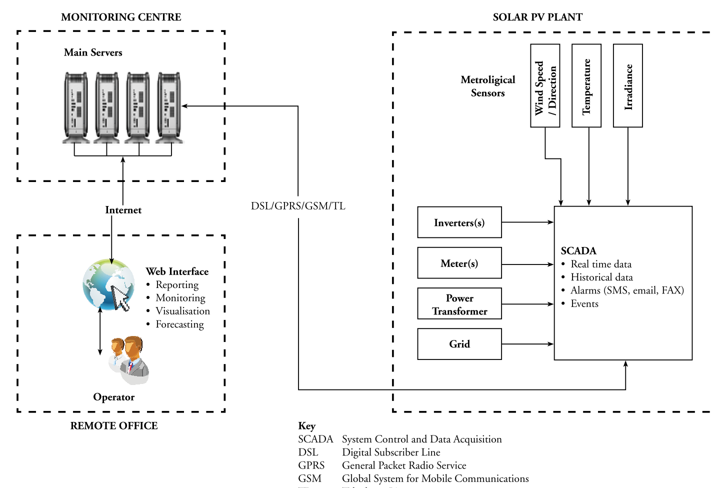
Grid Connected PV Systems



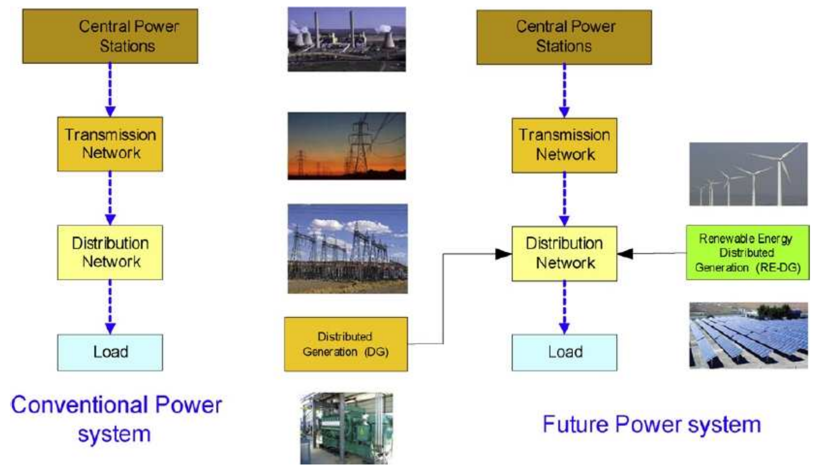
A power conditioning unit (PCU), i.e. an inverter, that converts the DC power to an alternating current (AC) synchronised with the grid and at the correct voltage and frequency[32].

[32] R. Rawlings and K. Butcher (2009). *Capturing Solar Energy.* CIBSE knowledge series. Chartered Inst. of Building Services Engineers.

Smart Grid Connected PV Systems[33]



[33] *Utility Scale Solar Power Plants: A Guide for Developers and Investors* (2012). International Finance Corporation (World Bank Group).



Conventional and future power system accommodating renewable energy[34].

[34] A. Zahedi (2011). 'A review of drivers, benefits, and challenges in integrating renewable energy sources into electricity grid'. In: *Renewable and Sustainable Energy Reviews* 15.9, pp. 4775 –4779.

Main Drivers of RE-DG Growth[35]

- Using RE-DG allow us to gradually move from high to low carbon technologies.
- As RE-DG are connected to the distribution network and are closer to the load, therefore, using RE-DG eliminates need for transmission line, which results in saving costs and minimizing power loss.
- RE-DG will be able to reduce number of customers without power in case of power outage, if the RE-DG is allowed and able to stay.
- RE-DG protects non-renewable and limited sources.

[35] A. Zahedi (2011). 'A review of drivers, benefits, and challenges in integrating renewable energy sources into electricity grid'. In: *Renewable and Sustainable Energy Reviews* 15.9, pp. 4775 –4779.

PV Support Mechanisms in Place in the IEA PVPS Countries During 2011[36]

Enhanced feed-in tariff	an explicit monetary reward is provided for producing PV electricity; paid (usually by the electricity utility) at a rate per kWh initially higher than the retail electricity rates being paid by the customer, but now sometimes similar or lower
Capital subsidies	direct financial subsidies aimed at tackling the up-front cost barrier, either for specific equipment or total installed PV system cost
Green electricity schemes	allows customers to purchase green electricity based on renewable energy from the electricity utility, usually at a premium price
PV-specific green electricity schemes	allows customers to purchase green electricity based on PV electricity from the electricity utility, usually at a premium price
Renewable portfolio standards (RPS)	a mandated requirement that the electricity utility (often the electricity retailer) source a portion of their electricity supplies from renewable energies (usually characterized by a broad, least-cost approach favouring hydro, wind and biomass)
PV requirement in RPS	a mandated requirement that a portion of the RPS be met by PV electricity supplies (often called a set-aside)

[36] *Trends in Photovoltaic Applications: Survey report of selected IEA countries between 1992 and 2011* (2011). International Energy Agency.

· contd.

Investment funds for PV	share offerings in private PV investment funds plus other schemes that focus on wealth creation and business success using PV as a vehicle to achieve these ends
Income tax credits	allows some or all expenses associated with PV installation to be deducted from taxable income streams
Net metering	in effect the system owner receives retail value for any excess electricity fed into the grid, as recorded by a bi-directional electricity meter and netted over the billing period
Net billing	the electricity taken from the grid and the electricity fed into the grid are tracked separately, and the electricity fed into the grid is valued at a given price
Commercial bank activities	includes activities such as preferential home mortgage terms for houses including PV systems and preferential green loans for the installation of PV systems
Electricity utility activities	includes 'green power' schemes allowing customers to purchase green electricity, large-scale utility PV plants, various PV ownership and financing options with select customers and PV electricity power purchase models
Sustainable building requirements	includes requirements on new building developments (residential and commercial) and also in some cases on properties for sale, where the PV may be included as one option for reducing the building's energy foot print or may be specifically mandated as an inclusion in the building development

Thanks A Lot