Renewable Energy Technologies

Renewable Energy

Mainly concerned with producing **electricity** from sustainable sources

- Biomass
- Fuel Cells
- Geothermal
- Hydro-electricity
- Solar photovoltaics (PV)
- Tidal
- Wave
- Wind power
  - Onshore
  - Offshore

But can provide feedstock for

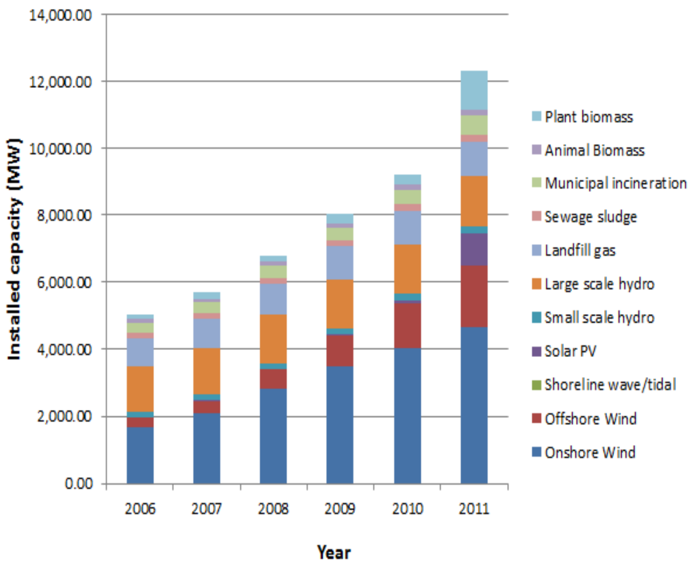
- **Heat**
- **Transport** Fuels

Renewable Energy in UK

UK Renewable Energy Production (Ktoe)

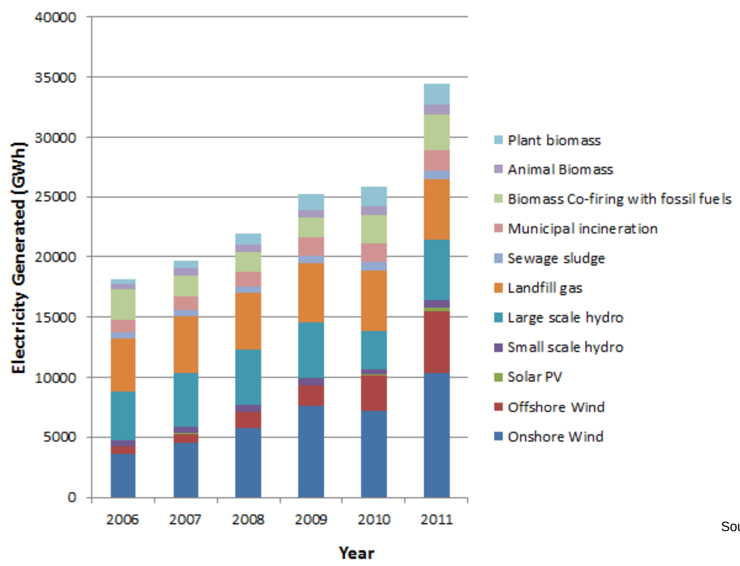
	1990	1995	2000	2005	2011
Solar Heating & PV	6.4	8.1	11.2	30.1	130
Wind & Wave	0.8	33.7	81.3	250.1	1400
Hydro – small scale	10.9	14.2	18.4	40.2	130
Hydro – large scale	436.8	401.7	418.8	386.4	425
Biomass - heat	345.8	878.4	583.7	454.3	6688
Biomass - electricity	219.0	588.7	1380.8	3083.7	
Geothermal	0.8	0.8	0.8	0.8	0.8
Total	**1020.5**	**1925.7**	**2495.2**	**4244.7**	**8674**

Renewable Energy



Source: BP 2012

Renewable Energy



Source: BP 2012

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Renewables

Electricity	Heat	Transport Fuels
Biomass c	Biomass c	Biomass c
Fuel Cells c	Geothermal c	Fuel Cells c
Geothermal c	Solar v	
Hydro m		C – Continuous
Solar v		I – Intermittent
Tidal r		M – Moderate
Wave power v		R – Regular
Wind power i		V – Variable

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Biomass

Biomass

- **Biomass**
  - Organic matter from plants or animals which can be used as a store of chemical energy to provide heat, electricity or transport fuels.
- **Bioenergy**
  - The energy sources produced from the conversion of biomass
- **Biofuels**
  - Fuels sourced from biomass which are used for transportation.
    - *Biodiesel from vegetable oils (Rapeseed), algae, recycled vegetable and animal oils*
    - *Bioethanol from Sugarcane & Corn or ligno-cellulosic materials (Wood & Straw)*
    - *Biobutanol from Sugarbeet or ligno-cellulosic materials (Wood & Straw)*
    - *Biomethanol from synthesis gas or biogas*
    - *Pyrolysis Oils from range of feedstock*

Differentiators

Different from other renewables

Can control the inputs through the production systems

Can produce a range of energy sources depending on conversion technology

Sources of Biomass

- **Co-products**
  - Agriculture – cereal straw
  - Food processing
  - Forestry – harvesting co-products, mill co-products
  - Seaweed processing co-products
- **Conventional crops for non-food use**
  - Oil, Sugar & Starch crops (e.g. - oil seed rape, sugar cane, maize, wheat, corn, barley)
- **Dedicated crops**
  - Short rotation forestry (willow, poplar)
  - Energy grasses (Switchgrass, Miscanthus)
  - Macro & micro algae
  - Jatropha

Co-products

- **Forest operations**
  - Harvesting co-products
- **Forest products industry**
  - Chips & sawdust
- **Agricultural operations**
  - Straw
  - Bagasse
  - Animal wastes
- **Restaurants**
  - Old cooking oil
- **Seaweed processing industry**



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Oil-rich plants for biodiesel

Oil Seed Rape

Karanj


Oil Palm

Microalgae

Jatropha

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Sugar & Starch Feedstocks

Sugar beet


Wheat

Ideal feedstocks for bioethanol but competes with food

Sugar cane


Corn

Lignocellulosic Feedstocks

Willow coppice

Miscanthus

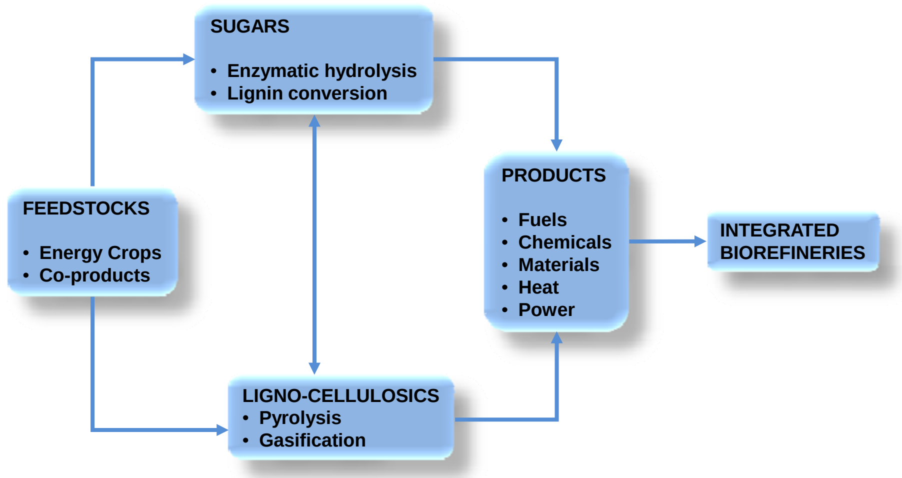
Forest residues

Reed canary grass

Corn stovers

Switch grass

Conversion Technologies



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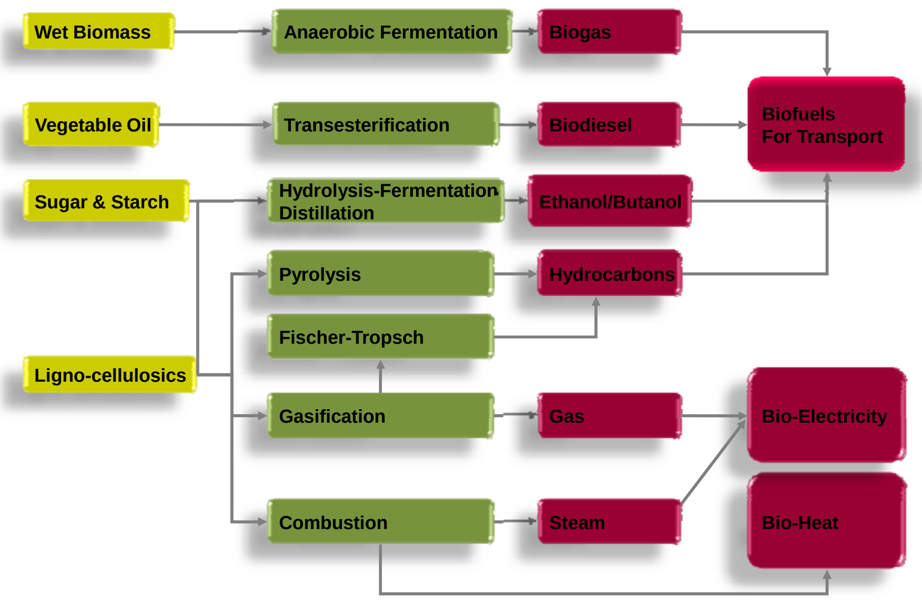
Conversion Technologies



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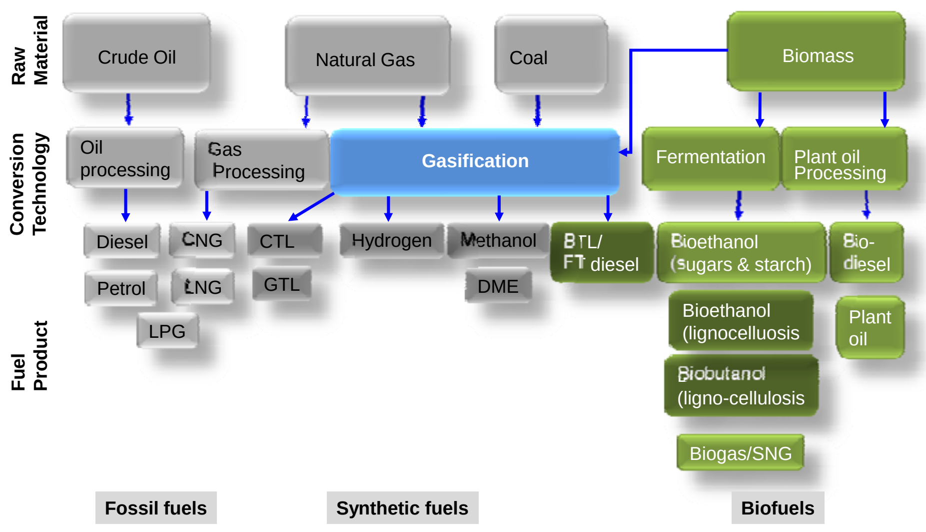
Fuel Types



Fuel Cells

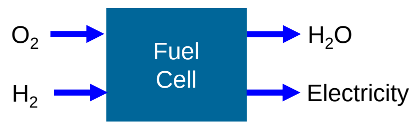
Fuel Cells

- Produces electricity from the electrochemical reaction between hydrogen and oxygen
- Similar to electrolysis, but in reverse
- Gases such as hydrogen or oxygen pumped in, DC electricity output
- Only by-product water
- Voltage from one cell low (0.8 volts) so use multiple cells
- Potential applications:
    - Battery replacement
    - Residential scale CHP
    - Vehicles

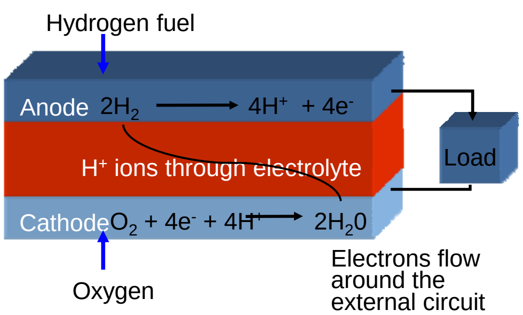
Fuel Cells

How they work

A fuel cell works by electro-catalysis, separating the component electrons and protons of the reactant fuel and forcing the electrons to travel through a circuit hence converting them to electrical power



An Acid Electrolyte Fuel Cell



Fuel Cells

Five Main Types of Fuel Cell

	Type	Abbreviation	Operating Temperature
Low Temp	Alkaline	AFC	60 – 250 °C
	Polymer	PEMFC	80 - 120 °C
	Phosphoric Acid	PAFC	150 – 220 °C
High Temp	Molten Carbonate	MCFC	600 – 700 °C
	Solid Oxide	SOFC	600 – 1000 °C

Fuel Cells

Low Temperature Fuel Cells

- Require relatively pure supply of hydrogen as fuel
  - AFCs sensitive to CO_2
  - PEMFCs sensitive to CO
- Incorporate precious metal electro-catalysts to improve performance
- Have fast start-up times
- Available commercially (AFC, PAFC) - approaching commercialisation (PEMFC)

http://www.nasa.gov/

Fuel Cells

High Temperature Fuel Cells

- Have fuel flexibility – can operate on a range of hydrocarbon fuels
- Increased operating temperature reduces need for expensive electro-catalysts
- Generate heat and suited for CHP
- Slow start up times
- Require expensive materials
- Reliability and durability concerns, due to high temperatures
- Suitable for integration with gas turbines
- Further from commercialisation but demonstrations working


http://www.doitpoms.ac.uk

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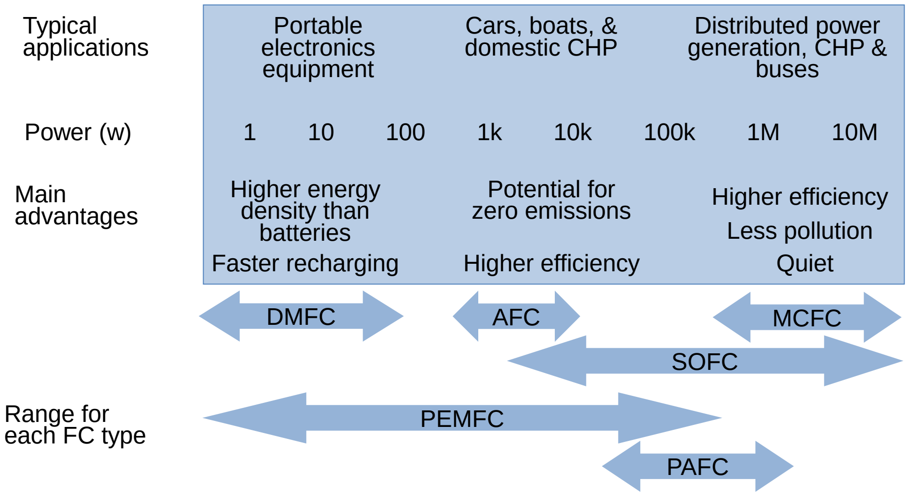
Applications for Fuel Cells



Source: Larmine & Dicks 2003

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Fuel Cells

Fuel cells have two fundamental flaws that prevent rapid development of the technology:

- Slow reaction rate, leading to low currents & power
- Hydrogen is not readily available, or easily stored

Geothermal

Geothermal Energy

Heat content of the Earth:
- 12.6 x 10^{24} MJ
- 5.4 x 10^{21} MJ stored in crust

The deeper you go, the hotter it gets
Average geothermal gradient 2.5 – 3.0°C per 100m

Big variation around the world, hottest at edge of tectonic plates

- Ranks 4th in World alternative energy league table
- Biomass
- Hydro
- Wind
- Geothermal

Geothermal

Installed Geothermal Capacity (MWe)

	1990	1995	2000	2005	2010
Iceland	44.6	50.0	170.0	322.0	575.0
Indonesia	144.8	310.0	589.5	797.0	1197.0
Italy	545.0	632.0	785.0	790.0	843.0
Japan	214.6	414.0	546.9	535.3	536.0
Mexico	700.0	753.0	755.0	953.0	958.0
New Zealand	283.2	286.0	437.0	435.0	628.0
Philippines	891.0	1227.0	1909.0	1931.0	1904.0
USA	2774.6	2816.0	2228.0	2544.0	3093.0
World	**5832.0**	**687.0**	**7974.0**	**9064.0**	**10717.0**

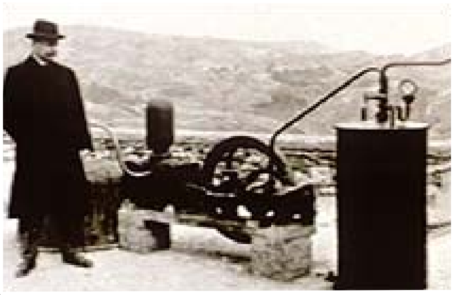
Geothermal Energy

Lardarello Geothermal Plant - Italy

First exploited in 1904

Dry steam plant

Now generates 790 MW



1904

Geothermal Energy

Three main technologies

Geothermal Electricity Production	Generating electricity from the earth's heat
Geothermal Direct Use	Producing heat directly from hot water within the earth
Geothermal Heat Pumps	Using the shallow ground to heat and cool buildings

Geothermal Electricity

Geothermal Electricity Production

Three types of geothermal power plants

Dry steam

The Geysers, California

Flash Steam

Otake, Japan

Binary cycle

Nevada, USA

Geothermal Energy

Geothermal Direct Use

Wet steam or warm water used for:

- Industrial
- Domestic
- Leisure (balneology)
- District heating schemes

New Zealand

Iceland

Main applications in Iceland, Italy, Japan & New Zealand

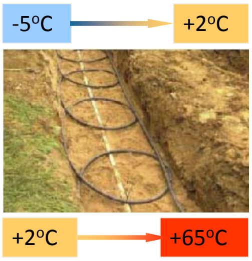
In Europe often exploit low temperature resources in sedimentary basins – Paris and Southampton

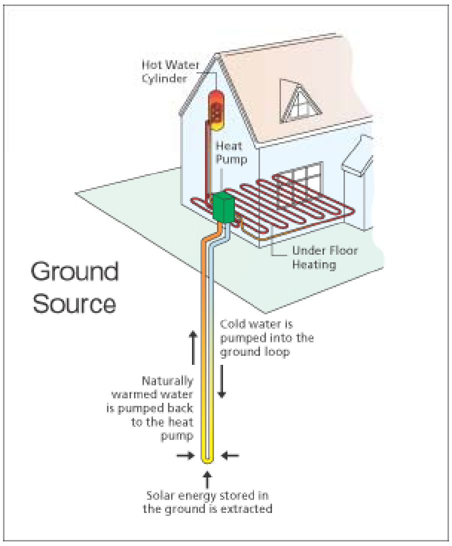
Geothermal Energy

Geothermal Heat Pumps

The ground a couple of metres deep has a nearly constant temperature of around 10 – 16ºC

Relies on heat transfer by conduction from the walls of the bore hole or pipe





Hydropower

History

- Hydropower used since ancient times to grind flour and perform others tasks
- 1770s, Bernard Forest de Belidor, a French engineer, published *Architecture Hydraulique and* described vertical- and horizontal-axis hydraulic machines.
- Late 19th century, electrical generator developed which could be coupled with hydraulics
- 1878 - the world's first house to be powered with hydroelectricity
  - Cragside, Northumberland
- 1881 Schoellkopf Power station near Niagara Falls starts generating electricity
- **2010 – 16% of global electricity production**

Hydro

Conventional

Grand Coulee Dam

Hoover Dam

- Most hydroelectric power comes from potential energy of dammed water driving a water turbine and generator.
- Power extracted depends on the volume and on the difference in height between the source and the waters outflow – the "Head"
- Amount of potential energy is proportional to the head.

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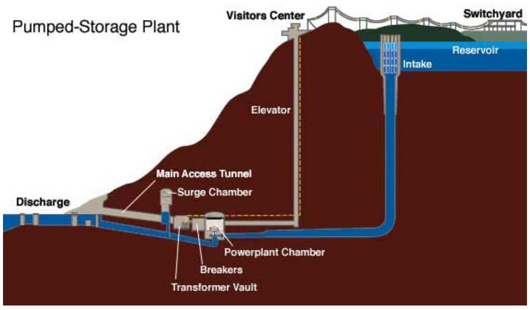
Hydro

Pumped storage



Ffestiniog Pumped Storage Scheme in N Wales
Can generate 360 MW within 60 seconds of demand rising

- Produces electricity to supply high peak demands by moving water between reservoirs at different elevations
- When demand is low excess capacity used to pump water to a higher reservoir
- When demand high water released to lower reservoir through a turbine

Hydro

Run-of-the-river

- Hydroelectric stations with smaller reservoir capacities, where it is not possible to store water

Hydro - Size

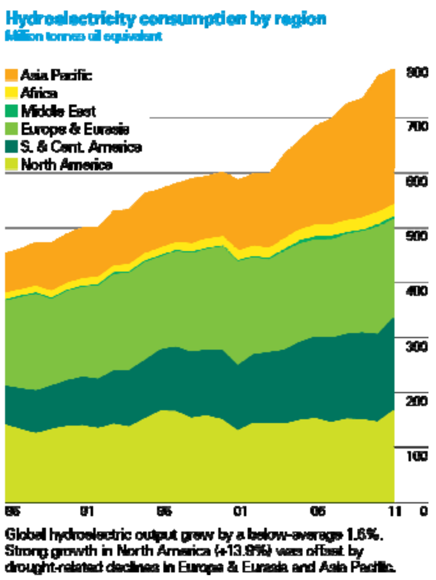
Large
- Over a few hundred MW to >10GW
  - Three Gorges Dam - 22.5 GW
  - Itaipu Dam -14 GW
  - Guri Dam - 10.2GW
- Supply electrical networks or dedicated to an industrial enterprise

Small
- Up to 10MW
- Supply small community or Industrial plant

Micro
- Up to 100KW
- Supply community or Network

Pico
- Under 5KW
- Supply to small remote communities

Hydroelectricity consumption by region 2011



BP Statistical Review of World Energy 2012

Hydroelectricity consumption by region (TWh)

	1970	1980	1990	2000	2010
N America	423.8	521.4	616.3	669.5	650.5
S & Cent America	66.2	200.2	363.3	551.4	743.5
Europe & Eurasia	486.3	658.0	734.6	859.5	867.8
Middle East	3.4	9.9	8.5	8.1	21.9
Africa	25.0	47.5	58.8	77.6	101.5
Asia Pacific	185.7	275.0	406.7	531.0	1096.5
World	**1190.5**	**1711.9**	**2188.6**	**2697.6**	**3442.4**

Key countries

Largest Hydroelectricity Producers 2009

	Annual Production (TWh)*	Installed Capacity (GW)	Capacity Factor	% Total Capacity
China	652.05	196.79	0.37	22.25
Canada	369.5	88.974	0.59	61.12
Brazil	363.8	69.080	0.56	85.56
USA	250.6	79.511	0.42	5.74
Russia	167.0	45.000	0.42	17.64
Norway	140.5	27.528	0.49	98.25
India	115.6	33.600	0.43	15.80
Venezuela	86.0	14.622	0.67	69.20
Japan	69.2	27.229	0.37	7.21
Sweden	65.5	16.209	0.46	44.34

Largest hydroelectric power stations

Name	Country	Year of completion	Total Capacity (MW)	Max Ann Electricity Production (TW-hour)	Area flooded (km²)
Three Gorges	China	2012	22,500	84.4	632
Itaipu	Brazil/Paraguay	1984-1991-2003	14,000	94.7	1,350
Guri	Venezuela	1986	10,200	53.4	4,250
Tucurui	Brazil	1984	8,370	41.4	3,014
Grand Coulee	USA	1942/1980	6,890	20	324
Krasnoyarskaya	Russia	1972	6,000	20.4	2,000

- There are 50 hydroelectricity stations with capacities >2000MW

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SOLAR ENERGY

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SOLAR ENERGY

Solar Timeline

400 BC	Greeks oriented houses to make most of sun in winter
1767	Horace-Benedict de Saussure invented First Solar Collector using 3 layers of glass to absorb solar energy
1839	Becquerel – light shining on an electrode submerged in conductive solution creates an electric current
1860	Auguste Mouchet – worked on solar motor to make France independent of fossil fuels
1865	Auguste Mouchet created solar powered steam engine
1873	Willoughby Smith discovered photoconductivity of selenium
1876	William Adams & Richard Day discovered that illuminating a junction between selenium and platinum gave a PV effect
1883	Charles Fritz built first true PV cell – made from selenium wafers and 2% efficient

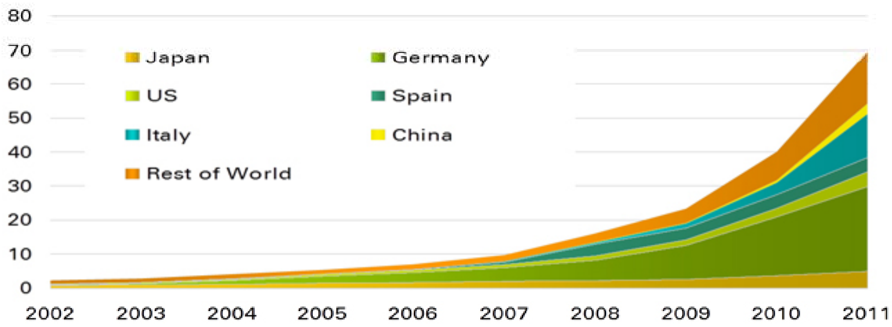
Solar Photovoltaics

Installed Solar PV (kW)

	1994 (kW)	2004	2010 (GW)
North America	68130	397266	2.5
Western Europe	51934	1006912	29.3
Germany	12440	794000	17.0
Spain	5660	3700	3.8
RoW	43771	1195069	3.2
Japan	31240	1131991	3.6
World	**163835**	**1195069**	**40.0**

Solar Photovoltaics

Installed Solar PV Capacity



Source: BP 2012

Photovoltaics

World PV Installed	Capacity (GW peak)
2005	5.4
2006	7.0
2007	9.4
2008	15.7
2009	22.9
2010	39.7
2011	67.4

5 Leading countries account for ~74% installed capacity in 2011:

- Germany
- Spain
- Japan
- Italy
- USA

Photovoltaic Installed Capacity

	Total MWp 2010	Off-grid	On-grid
World	39778		
EU	29328	154.4	29173
Germany	17370	50	17320
Japan	3618	98.8	3519
Spain	3808	21.1	3787
Italy	3478	13.5	3465
USA	2534	440	2094

Solar Photovoltaics

- The direct conversion of solar radiation into electricity by the interaction of light with the electrons in a semi-conductor device or cell
- Operate at 10% efficiency
- Costs have fallen substantially over last 25 years
- Most schemes too small to generate the minimum of 0.5MWh a month to qualify for a ROC
- Vast arrays are required to make a significant impact
  - 1000 MW plant @10% efficiency would cover 10km^2

Solar Photovoltaics

Passive Solar	Converts solar radiation into heat by means of the building structure itself. The building envelope is the absorber and the building structure the heat store
Solar Thermal Heat Utilisation	Solar collectors convert solar radiation into heat to heat swimming pools, provide space heating and domestic hot water
Solar Thermal Power Plants	Power plants which convert solar radiation to heat which in turn is converted to mechanical energy and then electrical energy. Two main types: concentrating and no-concentrating systems
Photovoltaic Power Generation	Solar energy is directly converted into electrical energy

SOLAR ENERGY

PV in Buildings

- Building-integrated photovoltaics (BIPV)
- Array incorporated into roof or walls
- Power output usually kW peak

Concentrated Solar Power

CSP – concentrated solar power

- Uses mirrors or lenses to concentrate large area of sunlight onto a small area
- Used to heat up a working fluid
- Drives a steam turbine to generate electricity

19.9 MW Gemasolar Plant, Spain

Photovoltaics

The sun provides about 100,000 Terawatts (TW) each year
World energy consumption is 15TW

Photovoltaics Conversion of solar energy directly into electricity in a solid state device

Photovoltaic cell Mainly silicon, the second most abundant element

Process Generated electrons are transferred between different bands (from valence to conductor bands) within the material thus building up a voltage between the 2 electrodes

Photovoltaics

The sun provides about 100,000 Terawatts (TW) each year
World energy consumption is 14TW

Photovoltaics Conversion of solar energy directly into electricity in a solid state device

Photovoltaic cell Mainly silicon, the second most abundant element

Photovoltaic effect Discovered by French physicist Edmund Becquerel in 1839
Conducted experiments with "wet cell" battery
Found that battery voltage increased when its silver plates were exposed to sunlight

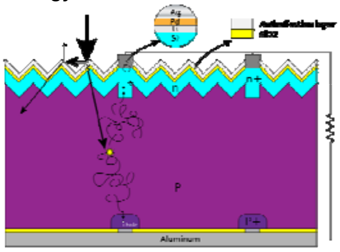
Photovoltaics

First PV effect in solid substance	Adams & Day demonstrated variations in electrical properties of selenium when exposed to light (1877)
Breakthrough in development of PV cells	Development of semi-conductors – non metallic materials such as germanium and silicon
Doping	Tiny particles of impurities such as boron and phosphorous diffused into the silicon
First demonstration	1954 in Bell Labs
First application	1958 – Vanguard 1 space satellite

Photovoltaics

How a solar cell works:

- Photons hit solar panel and absorbed by semi-conducting materials, e.g. silicon
- Electrons knocked loose from their atoms:
  - Electrons flow through the material to produce electricity
  - Composition of semi-conductor means that electrons only move in one direction
- An array converts solar energy into direct current electricity



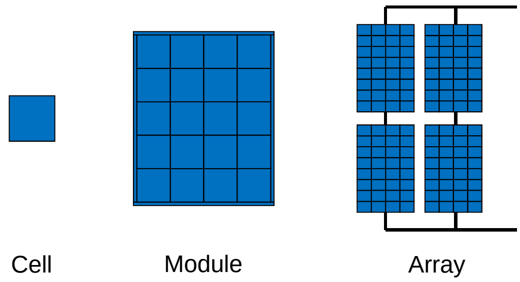
Photovoltaics

PV efficiency

Percentage of solar energy falling on its surface that is converted into electrical energy

- In laboratory ~ 24%
- Commercially available units ~ 17%

Single conventional PV cells gives 1.5 watts
Groups of cells connected together to form modules
Modules mounted side by side to give arrays



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Materials

- Have different efficiencies and costs
- Must match available spectrum
- Can use multiple physical configurations to take advantage of different light absorption and charge separation mechanism

  - Monocrystalline silicon
  - Polycrystalline silicon
  - Amorphous silicon
  - Cadmium telluride
  - Copper indium selenide/sulphide
  - Thin film layers
  - Organic dyes
  - Organic polymers
  - Nanocrystals used as quantum dots

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Solar PV Power Plants (50MW)

PV power station	Country	DC Peak Power (MWp)	Year
Agua Caliente Solar Project	USA	>200 (397 when complete)	
Charanka Solar Park	India	214	2012
Golmud Solar Park	China	200	2011
Sarna PV plant	Canada	97	2010
Montalto di Castro	Italy	84.2	2010
Finsterwalde Solar park	Germany	80.7	2010
Okhotnykovo Solar Park	Ukraine	80	2011
Solarpark Senftenberg	Germany	78	2011
Lieberose PV Park	Germany	71.8	
Rovigo PV Plant	Italy	70	2010
Olmedilla PV Park	Spain	60	2008
Strasskirchen Solar Park	Germany	54	
Puertollano PV Park	Spain	50	2008

Solar PV Power Plants

Lieberose 70.8 MW PV Park
900,000 solar panels

Senftenberg 78 MW PV Plant
330,000 PV modules
Plans to expand to 148MW

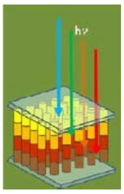
Waldpolenz 52 MWp Solar Park – uses 550,000 CdTe thin film PV panels

Development of Photovoltaic Cells

1st Generation
- Single crystal
- Polycrystalline (silicon)

2nd Generation
- Amorphous Si
- Thin film Si
- CuIn(Ga)Se_2 (copper indium gallium selenide), CdTe (cadmium telluride)
- Dye-sensitized nano-crystalline Cells (DSC)
- Organic PV

3rd Generation
- Multi-gap tandem cells
- Hot electron converters
- Carrier multiplication cells
- Mid-band PV
- Quantum Dot Solar Cells



Marine Energy

Marine Energy

Types of Marine Energy





- ***Thermal Energy*** from the sun's heat:
  - Ocean Thermal Energy Conversion
- ***Mechanical Energy*** from the tides and waves:
  - Tidal barrages
  - Tidal lagoons
  - Tidal fences
  - Tidal stream devices
  - Wave energy devices
- **Osmotic Power**

- Tides are driven by the gravitational pull of the moon
- Waves driven primarily by the wind

Marine Energy

Potential of Ocean Energy

Form	Capacity (GW)	Annual Generation (TW.h)
Osmotic Power	20	2,000
Ocean Thermal Energy	1,000	10,000
Tidal Power	90	800
Wave Power	1,000 – 9,000	8,000 – 80,000

Theoretical potential 4 – 18 ToE

Ocean Thermal Energy Conversion

Concept first proposed in 1881 and first plant built at Matanzas Bay, Cuba in 1930 using a low pressure turbine – 22kW output

Operates on the concept of heat engine:

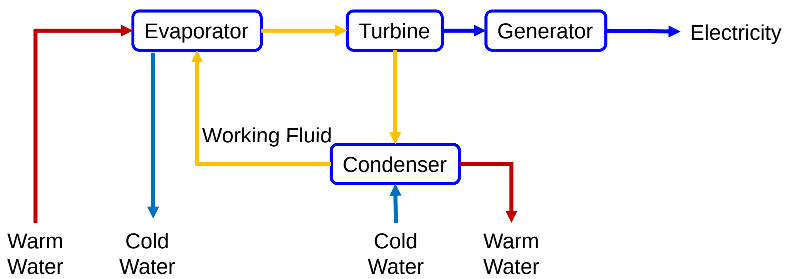
- A device placed between a high temperature reservoir and a low temperature reservoir
- As heat flows from one to other the engine extracts some of the heat in the form of work

1930 : Expérience de mise à l'eau d'un tube de 1,60 m de diamètre et de 2 km de long, à Cuba (Georges Claude).

Ocean Thermal Energy Conversion

To convert thermal gradient into electrical energy:

- Warm water used to heat and vaporize a liquid (“working fluid”)
- Working fluid develops pressure as it evaporates
- Expanding vapour runs through turbine-generator
- Vapour condensed back to water and discharged back to ocean



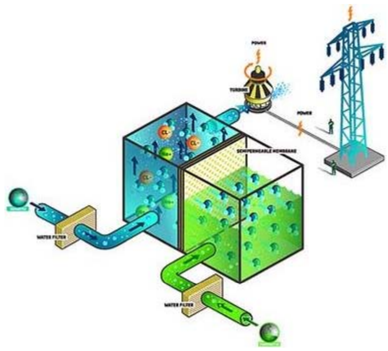
Osmotic Power

Osmotic power or Salinity Gradient Power

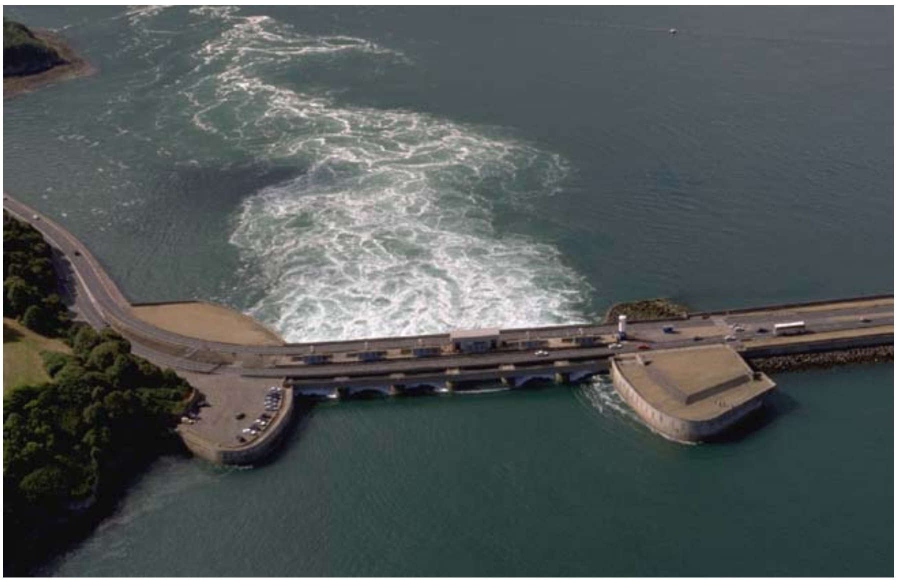
Energy available from the difference in salt concentration between sea and river water

Two practical methods, both rely on osmosis with ion specific membranes:

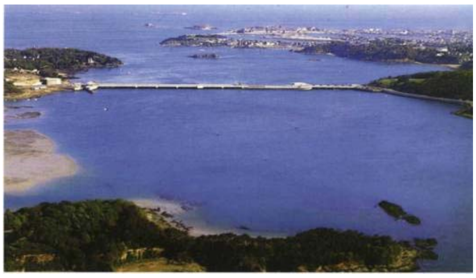
- Reverse electro-dialysis (RED) – being developed in Netherlands
- Pressure retarded osmosis (PRO) – being developed in Norway



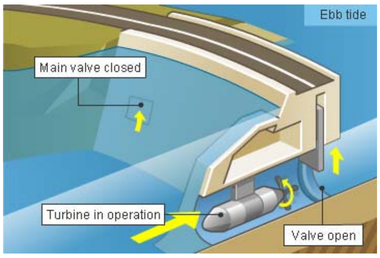
Tidal Energy



Tidal Barrages



- Limited number of sites on global scale where tidal range is sufficient to justify investment
- Need tidal range of at least 5m
- La Rance – in France built 1961 – 1966. Still running, generates 240MW
- Bay of Fundy – Nova Scotia - generates 20MW
- Bay of Kisalaya Guba, Murmansk, Russia – generates 1.7MW
- Jiang Xia, East China Sea – generates 3.2MW



Tidal Barrages

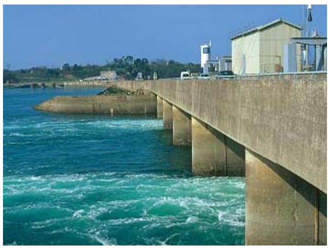
Station	Country	Size (MW)	Start Year
Annapolis Royal	Canada	20	1984
Jiangxia	China	3.2	1980
Kisalaya Guba	Russia	1.7	2004
La Rance	France	240	1966
Sihwa Lake	S Korea	254*	2011
Incheon	S Korea	1320**	2017

* 10 x 25.4 bulb turbines
** 44 x 30MW turbines

Tidal Barrages

Drawbacks

- High capital costs for initial construction
- Limited number of potential sites only 6 identified:
- Potential for negative environmental impacts
  - Water quality
  - Estuarine feeding areas for birds and other animals
  - Passage of migratory fish
- Local tides changed only slightly at La Rance barrage, environmental impact negligible.
- Very little is understood about how altering the tides can affect incredibly complex aquatic and shoreline ecosystems



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Tidal Stream

TIDAL STREAM

- Tidal stream turbines look like wind turbines
- Arrayed under water like wind farms
- Work best where coastal currents run at 2 – 3m/sec
- Generate 4 – 13 kW/m^2
- 14m current turbine generates as much electricity as a 60m diam wind turbine
- Ideal locations close to shore (1km) and in depths of 20 – 30m
- Tidal currents are predictable and reliable

Scotrenewables SR250

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Tidal Stream

Most common types:

- Horizontal axis turbine (axial flow turbine)
- Vertical axis turbines (cross flow turbine)

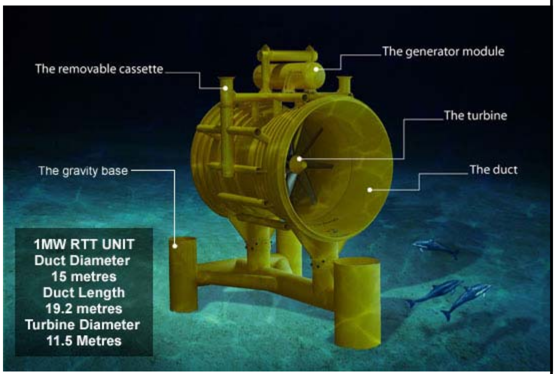
Andriz Hydro Hammerfest HS1000 – 1 MW

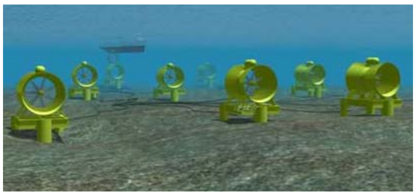
Wave rotor

Tidal Stream

Lunar Energy

Fully submerged ducted turbine with the power conversion system inserted in a slot in the duct as a cassette



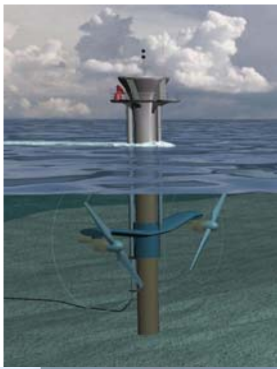


Tidal Stream

Marine Current Turbines

SeaGen

- Two horizontal axis rotors and power trains (gearbox & generator)
- Each rotor rated at 500kW
- Attached to supporting monopile by a cross arm
- Monopile has integrated lifting mechanism to lift rotors and power trains out of the water for maintenance

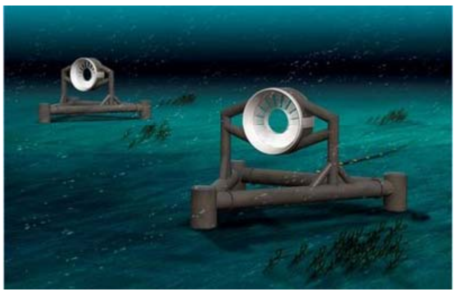


Tidal Stream

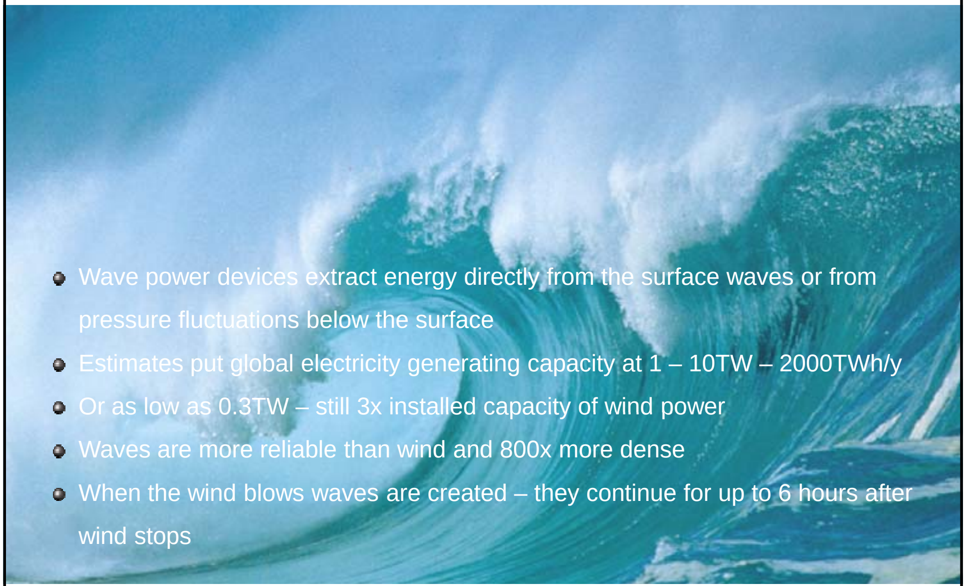
Open Hydro

250kw device tested at EMEC

Next steps:
- 1MW for Bay of Fundy & Channel Islands
- 10 turbines for 4MW off Brittany



Wave Energy



- Wave power devices extract energy directly from the surface waves or from pressure fluctuations below the surface
- Estimates put global electricity generating capacity at 1 – 10TW – 2000TWh/y
- Or as low as 0.3TW – still 3x installed capacity of wind power
- Waves are more reliable than wind and 800x more dense
- When the wind blows waves are created – they continue for up to 6 hours after wind stops

Wave Energy

- First patent for wave device in 1799 but never constructed
- There are some 50 different types being developed currently
- Fall into 6 main types:
  - Attenuator – e.g. Pelamis
  - Point Absorber – e.g. Wave Star
  - Oscillating wave surge converter – e.g. Oyster
  - Oscillating Water Column – e.g. Limpet
  - Overtopping Device – e.g. Sea Dragon
  - Submerged pressure differential – e.g. CETO
- Cannot be harvested everywhere – wave rich countries:
  - Western coast of Scotland
  - Northern Canada
  - Southern Africa
  - Australia
  - NE and NW coasts of USA

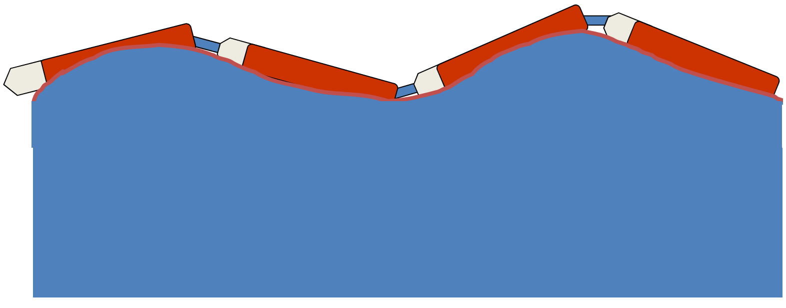
Wave Energy

Wave Energy Levels (kW/m of Wave Front)

Wave Energy

Attenuator

This floating device effectively "rides" the waves, flexing as they pass



Attenuator Pelamis

Wave Energy

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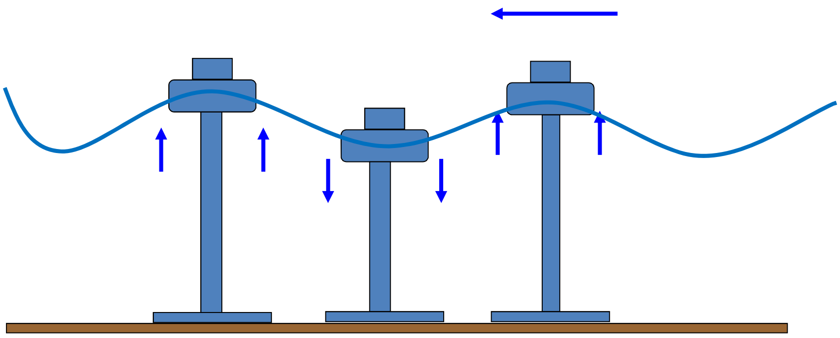
Wave Energy

Point Absorber

This float absorbs wave energy from all directions as it bobs up and down



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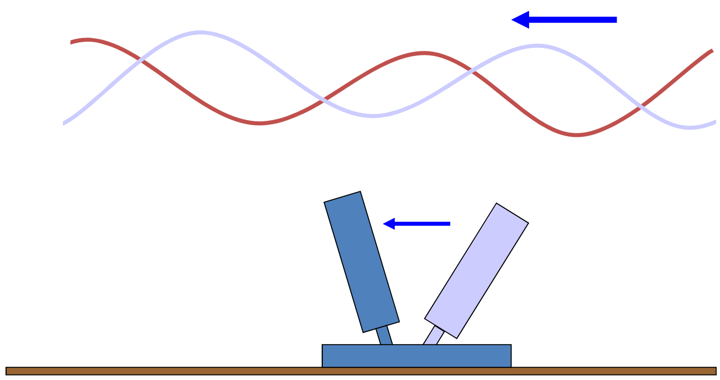
Wave Energy

Wave Energy

Oscillating wave surge converter

The tethered arm acts as a pendulum in response to wave surges

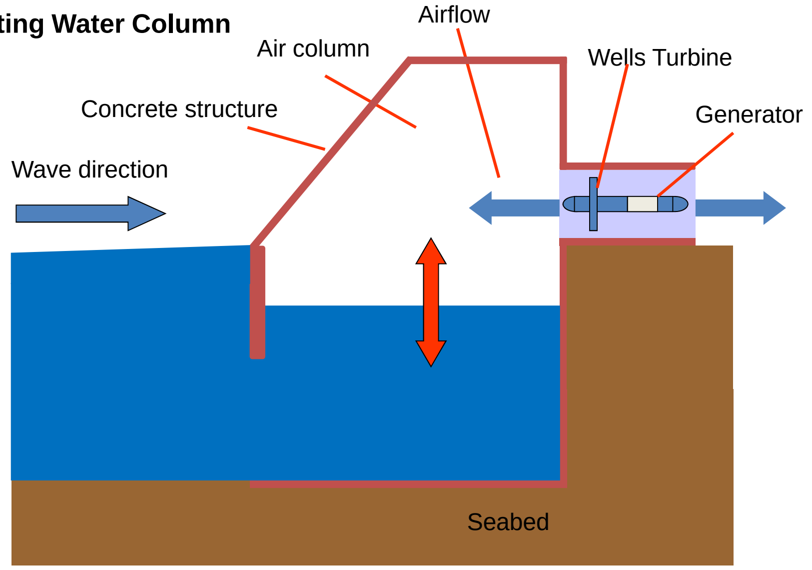


Wave Energy

Aquamarine Power

Wave Energy

Oscillating Water Column



Wave Energy

Wavegen - Limpet Land Installed Marine Powered Energy Transformer

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Wave Energy

Energetech wave powered generator off the coast at Port Kembla NSW Australia.

- Based on Oscillating water column.
- Power take off located at the focus of a parabolic-shaped wave deflector

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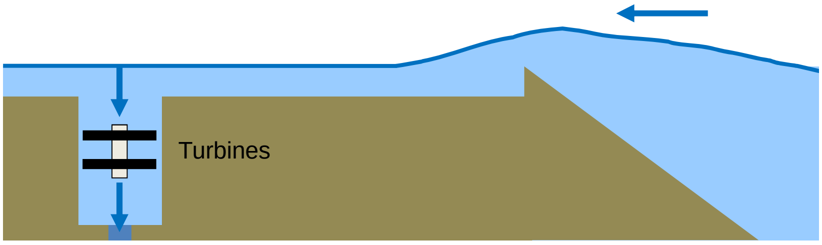
Wave Energy

Overtopping Device



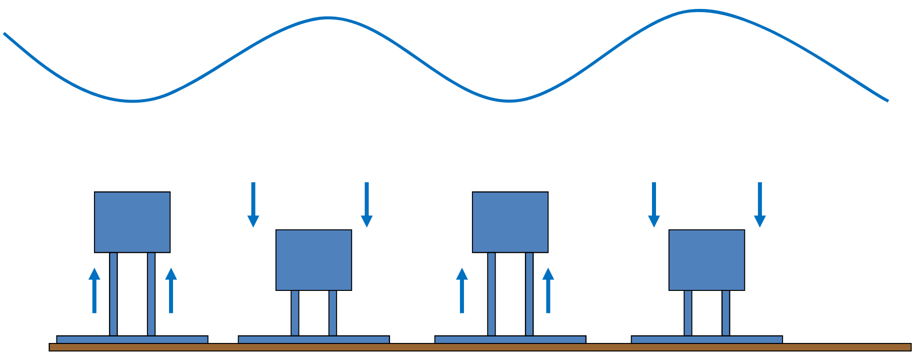
Wave Energy

Wave Dragon

Wave Energy

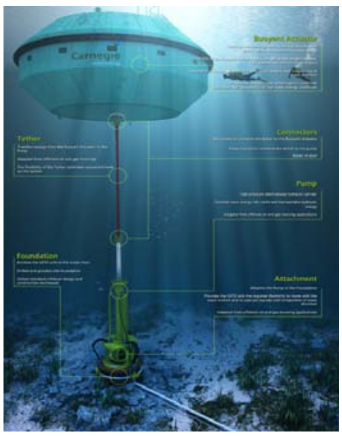
Submerged pressure differential

As this device responds to waves a pressure differential is set up inside it which is used to pump fluid and so generate electricity



Wave Energy

CETO



CETO 5 – 240kw

http://www.ceto.com.au/home.php

Wind Power

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Wind Power

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Wind Power

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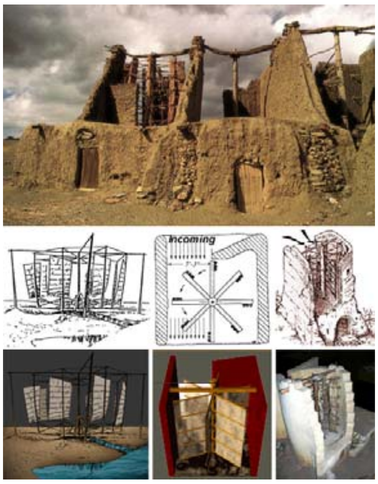
Wind Power

Windmills been used since the 7th Century



Early Persian Wind Turbines

USA water pumping windmills opened up the territory

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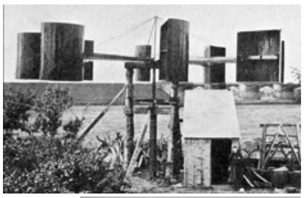
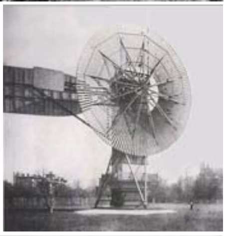
Wind Power

Scotland 1887: James Blyth windpower experiments, patent in 1891



USA1887-1900 Charles Bush uses windpower to produce electricity



Denmark 1890s Poul La Cour built first wind turbine to generate electricity - used to electrolyse water to produce hydrogen for gas lights in the local school

Wind Power

Total global economically extractable wind power:

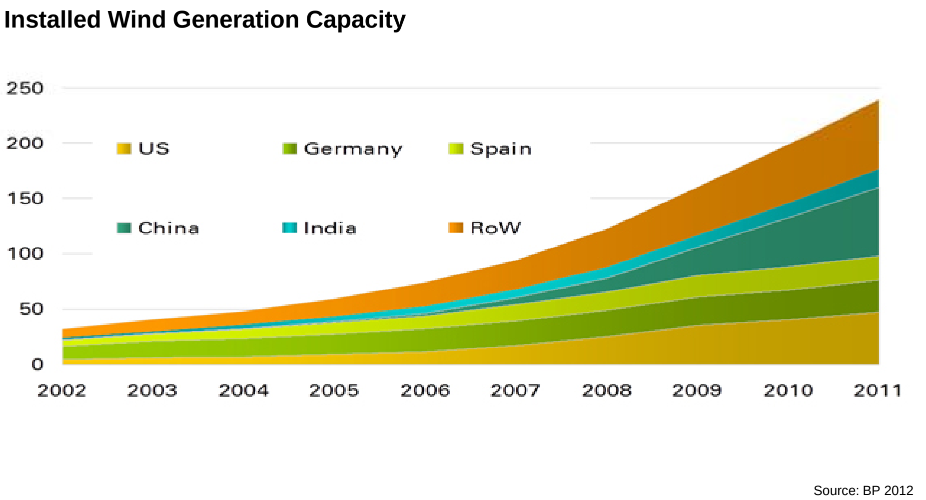
- 72TW *cf* 15TW current consumption
- 72TW equivalent to 54,000 MTOE
- Practical limit set by economics and environmental issues

Global Capacity 2011:

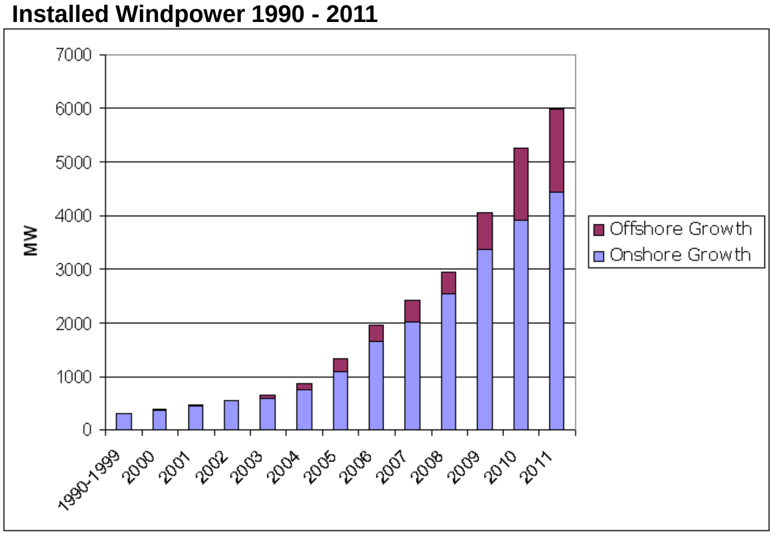
- 238 GW – 273GW expected by end 2012
- Produced 430TWh (2.5% of electricity)
- 83 countries have commercial wind farms

- Denmark 28%
- Ireland 14%
- Portugal 19%
- Spain 16%
- Germany 8%

Wind Power



Wind Power



Wind Power

Rank	Country	Installed Capacity (GW)			
		2005	2007	2009	2011
1	USA	9.1	16.8	35.2	46.9
2	Germany	18.4	22.2	25.8	29.0
3	China	1.3	5.9	25.1	62.7
4	Spain	10.0	15.1	19.1	21.7
5	India	4.4	7.9	10.9	16.1
8	UK	1.4	2.4	4.1	6.5
	World	**59.0**	**93.9**	**157.9**	**238.4**

Wind Power

Horizontal axis wind turbines

The shaft from the blades to the generator is horizontal, so the blades rotate vertically. The tall tower means the turbine can use higher wind speeds found higher up - near the ground, friction reduces the speed of the wind. They need a mechanism to keep the blades pointing into the wind

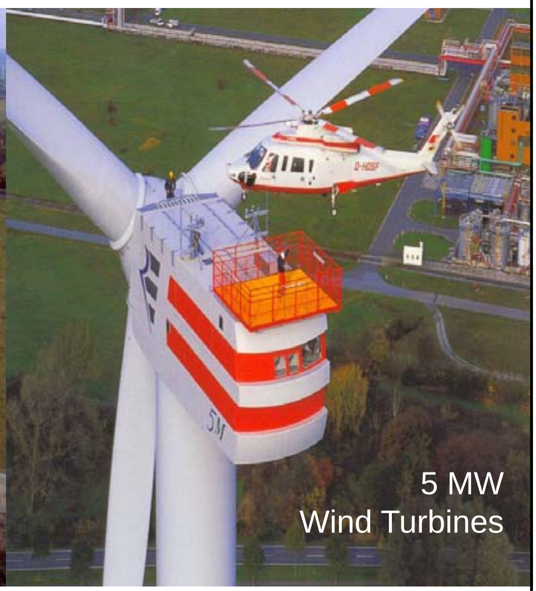
Vertical axis wind turbines

The shaft from the blades to the generating equipment is vertical, and the blades go round it horizontally. This means that the generator and/or gearbox can be placed at the bottom, near the ground, so the tower doesn't need to support it, and that the turbine doesn't need to be pointed into the wind

Onshore Wind

- Commercially available technology
- Modern turbines are very quiet in operation
- Wildlife impacts are small
- Visual intrusion is an issue

Onshore Wind



Potential in UK

UK's annual demand for electricity ~350TWh/y

UK's wind technical potential ~ 1000TWh/y

However, accessible/economic potential ~ 150TWh/y

- Onshore – 50 TWh/y
- Offshore – 100TWh/y

- 600 5MW turbines replaces 1000 MW conventional generation
- Would meet 27% of Scottish peak electricity demand

Wind Power

Wind energy in UK September 2012	
Operational Wind farms	357
Turbines Sept 2012	3873
Onshore installed capacity end 2012	5028 MW
Offshore installed capacity end 2012	2372
Total installed capacity Sept 2012	6858

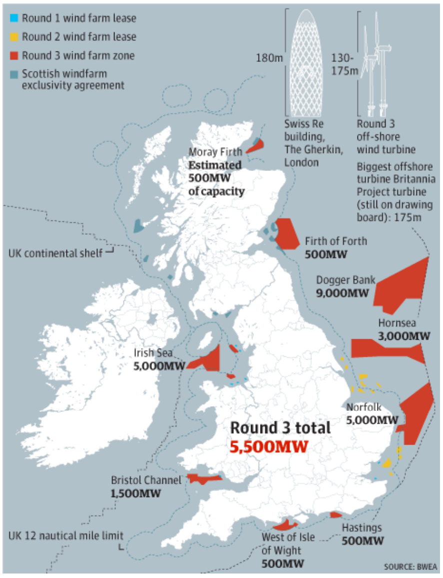
Offshore Wind farms		
Round 1	11 projects	1.1 GW
Round 2	15 projects	7.2 GW
Rounds 1 & 2 extensions		2GW
Round 3		32.2 GW
Scottish Territorial Waters	5 projects	25 GW projected

Offshore wind

Offshore Wind

- Greater wind speeds and less turbulence off-shore prolongs life
- Lower visual intrusion
- Wildlife issues – birds, sea mammals

Offshore Wind



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Offshore Wind

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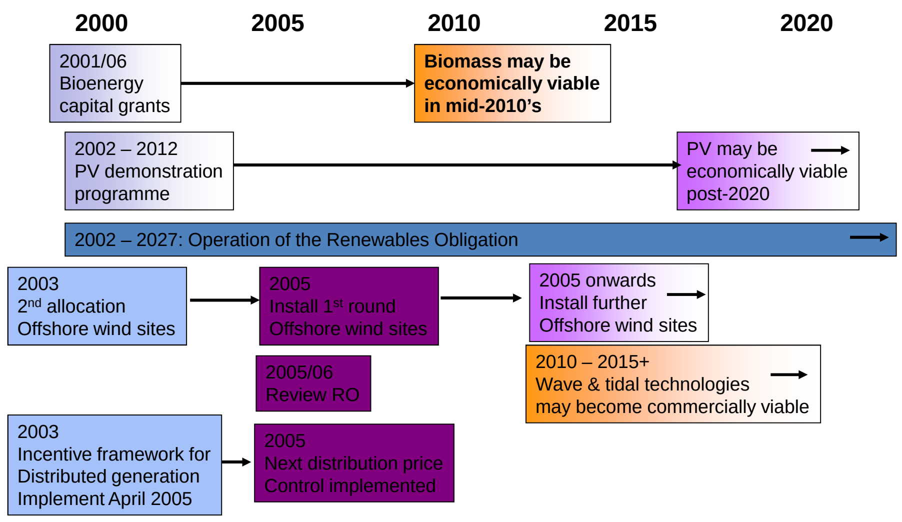
Timeline



Renewables

Electricity	Heat	Transport Fuels
Biomass [c]	Biomass [c]	Biomass [c]
Fuel Cells [c]	Geothermal [c]	Fuel Cells [c]
Geothermal [c]	Solar [v]	
Hydro [m]		C – Continuous
Solar [v]		I – Intermittent
Tidal [r]		M – Moderate
Wave power [v]		R – Regular
Wind power [i]		V – Variable

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