

**LECTURER NOTES  
ON**

**EE2252 POWER PLANT ENGINEERING**

**II YEAR /IV SEMESTER EEE  
ACADEMIC YEAR 2012-2013**

**EE2252 POWER PLANT ENGINEERING**

**SYLLABUS 3 1 0 4**

**AIM**

**Expose the students to basics of various power plants so that they will have the**

**comprehensive idea of power system operation.**

**OBJECTIVES**

**To become familiar with operation of various power plants.**

**1 THERMAL POWER PLANTS**

Basic thermodynamic cycles, various components of steam power plant- layout pulverized coal burners- Fluidized bed combustion-coal handling systems- ash handling systems- Forced draft and induced draft fans- Boilers-feed pumps- super heater-regenerator-condenser- deaerators-cooling tower

## **2 HYDRO ELECTRIC POWER PLANTS**

Layout-dams-selection of [water](#) turbines-types-pumped [storage](#) hydel plants

## **3 NUCLEAR POWER PLANTS**

Principles of nuclear energy- Fission reactions-nuclear reactor-nuclear power plants

## **4 GAS AND DIESEL POWER PLANTS**

Types, open and closed cycle gas turbine, work output & thermal efficiency, methods to improve performance-reheating, intercoolings, regeneration- advantage and disadvantages- Diesel engine power plant-component and layout

## **5 NON-CONVENTIONAL POWER GENERATION**

Solar energy collectors, OTEC, wind power plants, tidal power plants and geothermal resources, fuel cell, MHD power generation-principle, thermoelectric power generation, thermionic power generation

### **TEXT [BOOKS](#)**

- **A Course in Power Plant Engineering by Arora and Domkundwar, Dhanpat Rai and**

**Co.Pvt.Ltd., New Delhi.**

- **Power Plant Engineering by P.K. Nag, Tata McGraw Hill, Second Edition , Fourth reprint 2003.**

### **REFERENCES<sub>0</sub>**

- **Power station Engineering and Economy by Bernhardt G.A.Skrotzki and William A.**

**Vopat- Tata McGraw Hill Publishing Company Ltd., New Delhi, 20<sup>th</sup> reprint 2002.**

- An introduction to power plant technology by G.D. Rai-Khanna Publishers, Delhi-

- 005.

- Power Plant Technology, M.M. El-Wakil McGraw Hill 1984.

## EE2252 POWER PLANT ENGINEERING

### UNIT-I INTRODUCTION TO POWER PLANTS AND BOILERS

#### STEAM POWER PLANT:

A thermal power station is a [power plant](#) in which the [prime mover](#) is [steam](#) driven. Water is heated, turns into steam and spins a [steam turbine](#) which drives an [electrical generator](#). After it passes through the turbine, the steam is [condensed](#) in a [condenser](#) and recycled to where it was heated; this is known as a [Rankine cycle](#). The greatest variation in the design of thermal power stations is due to the different fuel sources. Some prefer to use the term *energy center* because such facilities convert forms of [heat energy](#) into electricity. Some thermal power plants also deliver heat energy for industrial purposes, for [district heating](#), or for [desalination](#) of water as well as delivering electrical power. A large proportion of CO<sub>2</sub> is produced by the world's fossil fired thermal power plants; efforts to reduce these outputs are various and widespread.



The four main circuits one would come across in any thermal power plant layout are

-Coal andAshCircuit

-AirandGasCircuit

- Feed Water and Steam Circuit
- Cooling Water Circuit

### **Coal and Ash Circuit**

Coal and Ash circuit in a thermal power plant layout mainly takes care of feeding the boiler with coal from the storage for combustion. The ash that is generated during combustion is collected at the back of the boiler and removed to the ash storage by scrap conveyors. The combustion in the Coal and Ash circuit is controlled by regulating the speed and the quality of coal entering the grate and the damper openings.

### **Air and Gas Circuit**

Air from the atmosphere is directed into the furnace through the air preheated by the action of a forced draught fan or induced draught fan. The dust from the air is removed

before it enters the combustion chamber of the thermal power plant layout. The exhaust gases from the combustion heat the air, which goes through a heat exchanger and is finally let off into the environment.

### **Feed Water and Steam Circuit**

The steam produced in the boiler is supplied to the turbines to generate power. The steam that is expelled by the prime mover in the thermal power plant layout is then condensed in a condenser for re-use in the boiler. The condensed water is forced through a pump into the feed water heaters where it is heated using the steam from different points in the turbine. To make up for the lost steam and water while passing through the various components of the thermal power plant layout, feed water is supplied through external sources. Feed water is purified in a purifying plant to reduce the dissolve salts that could scale the boiler tubes.

### **Cooling Water Circuit**

The quantity of cooling water required to cool the steam in a thermal power plant layout is significantly high and hence it is supplied from a natural water source like a lake or a river. After passing through screens that remove particles that can plug the condenser tubes in a thermal power plant layout, it is passed through the condenser where the steam is condensed. The water is finally discharged back into the water source after cooling. Cooling water circuit can also be a closed system where the cooled water is sent through cooling towers for re-use in the power plant. The cooling water circulation in the condenser of a thermal power plant layout helps in maintaining a low pressure in the condenser all throughout.

All these circuits are integrated to form a thermal power plant layout that generates electricity to meet our needs.

### **LAYOUT OF HYDEL POWER PLANT:**



Hydroelectric power plants convert the hydraulic potential energy from water into electrical energy. Such plants are suitable where water with suitable *head* is available. The layout covered in this article is just a simple one and only covers the important parts of a hydroelectric plant. The different parts of a hydroelectric power plant are

### **(1) Dam**

Dams are structures built over rivers to stop the water flow and form a reservoir. The reservoir stores the water flowing down the river. This water is diverted to turbines in

power stations. The dams collect water during the rainy season and stores it, thus allowing for a steady flow through the turbines throughout the year. Dams are also used for controlling floods and irrigation. The dams should be water-tight and should be able to withstand the pressure exerted by the water on it. There are different types of dams such as arch dams, gravity dams and buttress dams. The height of water in the dam is called *head race*.

## **(2) Spillway**

A spillway as the name suggests could be called as a way for spilling of water from dams.

It is used to provide for the release of flood water from a dam. It is used to prevent overtopping of the dams which could result in damage or failure of dams. Spillways could be controlled type or uncontrolled type. The uncontrolled types start releasing water upon water rising above a particular level. But in case of the controlled type, regulation of flow is possible.

## **(3) Penstock and Tunnel**

Penstocks are pipes which carry water from the reservoir to the turbines inside power station. They are usually made of steel and are equipped with gate systems. Water under high pressure flows through the penstock. A tunnel serves the same purpose as a penstock. It is used when an obstruction is present between the dam and power station such as a mountain.

## **(4) Surge Tank**

Surge tanks are tanks connected to the water conductor system. It serves the purpose of reducing water hammering in pipes which can cause damage to pipes. The sudden surges of water in penstock is taken by the surge tank, and when the water requirements increase, it supplies the collected water thereby regulating water flow and pressure inside the penstock.

## **(5) Power Station**

Power station contains a turbine coupled to a generator. The water brought to the power station rotates the vanes of the turbine producing torque and rotation of turbine shaft. This rotational torque is transferred to the generator and is converted into electricity. The used water is released through the *tail race*. The difference between head race and tail race is called gross head and by subtracting the frictional losses we get the net head available to the turbine for generation of electricity.

## **DIESEL POWER PLANT**

Diesel power plants produce power from a diesel engine. Diesel electric plants in the range of 2 to 50 MW capacities are used as central stations for small electric supply

networks and used as a standby to hydro electric or thermal plants where continuous power supply is needed. Diesel power plant is not economical compared to other power plants.

The diesel power plants are cheaply used in the fields mentioned below. Peak load plants

- Mobile electric plants
- Standby units
- Emergency power plants
- Starting stations of existing plants
- Central power station etc.

### ***General Layout of Diesel power plants***



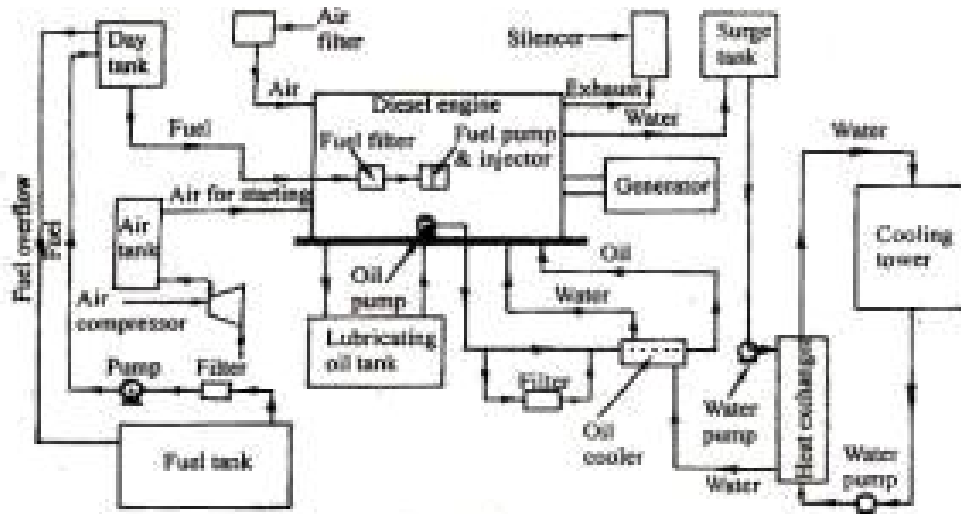


Figure 5.3

## General Layout of Diesel power plants

Figure shows the arrangements of the engine and its auxiliaries in a diesel power plant. The major components of the plant are:

### *a) Engine*

Engine is the heart of a diesel power plant. Engine is directly connected through a gear box to the generator. Generally two-stroke engines are used for power generation. Now a

days, advanced super & turbo charged high speed engines are available for power production.

***b) Air supply system***

Air inlet is arranged outside the engine room. Air from the atmosphere is filtered by air filter and conveyed to the inlet manifold of engine. In large plants supercharger/turbocharger is used for increasing the pressure of input air which increases the power output.

***c) Exhaust System***

This includes the silencers and connecting ducts. The heat content of the exhaust gas is utilized in a turbine in a turbocharger to compress the air input to the engine.

***d) Fuel System***

Fuel is stored in a tank from where it flows to the fuel pump through a filter. Fuel is injected to the engine as per the load requirement.

***e) Cooling system***

This system includes water circulating pumps, cooling towers, water filter etc. Cooling water is circulated through the engine block to keep the temperature of the engine in the safe range.

***f) Lubricating system***

Lubrication system includes the air pumps, oil tanks, filters, coolers and pipe lines. Lubricant is given to reduce friction of moving parts and reduce the wear and tear of the engine parts.

***g) Starting System***

There are three commonly used starting systems, they are;

- A petrol driven auxiliary engine,
- Use of electric motors,

3) Use of compressed air from an air compressor at a pressure of 20 Kg/cm<sup>2</sup> ||

#### ***h) Governing system***

The function of a governing system is to maintain the speed of the engine constant irrespective of load on the plant. This is done by varying fuel supply to the engine according to load.

#### ***Advantages of diesel power plants***

- More efficient than thermal plant
- Design, Layout etc are simple and cheap
- Part load efficiency is very high
- It can be started quickly
- Simple & easy maintenance
- No problem with fuel & dust handling
- It can be located in the heart of town
- Less cooling water required.

#### ***Disadvantages***

- There is a limitation for size of a diesel engine
- Life of plant is comparatively less
- Noise pollution is very high
- Repair cost is very high
- High lubrication cost

#### **NUCLEAR POWER PLANT:**

**Nuclear power** is the use of sustained [Nuclear fission](#) to generate heat and do useful work. Nuclear Electric Plants, Nuclear Ships and Submarines use controlled nuclear energy to heat water and produce [steam](#), while in space, nuclear energy decays naturally in a [radioisotope thermoelectric generator](#). Scientists are experimenting with [fusion](#) energy for future generation, but these experiments do not currently generate useful energy.

Nuclear power provides about 6% of the world's energy and 13–14% of the world's electricity, with the [U.S.](#), [France](#), and [Japan](#) together accounting for about 50% of nuclear generated electricity. Also, more than 150 naval vessels using [nuclear propulsion](#) have been built.

Just as many conventional [thermal power stations](#) generate electricity by harnessing the [thermal energy](#) released from burning [fossil fuels](#), nuclear power plants convert the energy released from the nucleus of an atom, typically via [nuclear fission](#).

### **Nuclear reactor technology**

When a relatively large [fissile atomic nucleus](#) (usually [uranium-235](#) or [plutonium-239](#)) absorbs a [neutron](#), a fission of the atom often results. Fission splits the atom into two or more smaller [nuclei](#) with [kinetic energy](#) (known as [fission products](#)) and also releases [gamma radiation](#) and [free neutrons](#).<sup>[59]</sup> A portion of these neutrons may later be absorbed by other fissile atoms and create more fissions, which release more neutrons, and so on.

This [nuclear chain reaction](#) can be controlled by using [neutron poisons](#) and [neutron moderators](#) to change the portion of neutrons that will go on to cause more fissions.<sup>[60]</sup> Nuclear reactors generally have automatic and manual systems to shut the fission reaction down if unsafe conditions are detected.

Three nuclear powered ships, (top to bottom) nuclear cruisers [USS Bainbridge](#) and [USS Long Beach](#) with [USS Enterprise](#) the first nuclear powered aircraft carrier in 1964. Crew members are spelling out [Einstein's mass-energy equivalence](#) formula  $E = mc^2$  on the flight deck.

There are many different reactor designs, utilizing different fuels and coolants and incorporating different control schemes. Some of these designs have been engineered to meet a specific need. Reactors for [nuclear submarines](#) and large naval ships, for example, commonly use [highly enriched uranium](#) as a fuel. This fuel choice increases the reactor's power density and extends the usable life of the nuclear fuel load, but is more expensive and a greater risk to nuclear proliferation than some of the other nuclear fuels.

A number of new designs for nuclear power generation, collectively known as the [Generation IV reactors](#), are the subject of active research and may be used for practical power generation in the future. Many of these new designs specifically attempt to make fission reactors cleaner, safer and/or less of a risk to the proliferation of nuclear weapons. [Passively safe](#) plants (such as the [ESBWR](#)) are available to be built and other designs that are believed to be nearly fool-proof are being pursued. [Fusion reactors](#), which may be viable in the future, diminish or eliminate many of the risks associated with nuclear fission. There are trades to be made between safety, economic and technical properties of different reactor designs for particular applications. Historically these decisions were often made in private by scientists, regulators and engineers, but this may be considered problematic, and since Chernobyl and Three Mile Island, many involved now consider informed consent and morality should be primary considerations.

## **Cooling system**

A cooling system removes heat from the reactor core and transports it to another area of the plant, where the thermal energy can be harnessed to produce electricity or to do other useful work. Typically the hot coolant will be used as a heat source for a [boiler](#), and the pressurized steam from that boiler will power one or more [steam turbine](#)

driven [electrical generators](#).

### **Flexibility of nuclear power plants**

It is often claimed that nuclear stations are inflexible in their output, implying that other forms of energy would be required to meet peak demand. While that is true for the vast majority of reactors, this is no longer true of at least some modern designs. Nuclear plants are routinely used in load following mode on a large scale in France. Unit A at the German [Biblis Nuclear Power Plant](#) is designed to in- and decrease

his output 15 % per minute between 40 and 100 % of it's nominal power. Boiling water reactors normally have load-following capability, implemented by varying the recirculation water flow.

### **GASS TURBINE POWER PLANT:**

A **gas turbine**, also called a **combustion turbine**, is a type of [internal combustion engine](#). It has an upstream rotating [compressor](#) coupled to a downstream [turbine](#), and a [combustion chamber](#) in-between.

[Energy](#) is added to the gas stream in the [combustor](#), where [fuel](#) is mixed with [air](#) and [ignited](#). In the high pressure environment of the combustor, combustion of the fuel increases the [temperature](#). The products of the combustion are forced into the turbine section. There, the high [velocity](#) and [volume](#) of the gas flow is directed through a [nozzle](#) over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas.

### **COMBINED POWER CYCLES:**

In [electric power generation](#) a **combined cycle** is an assembly of [heat engines](#) that work in tandem off the same source of heat, converting it into mechanical energy, which in turn

usually drives [electrical generators](#). The principle is that the exhaust of one heat engine is used as the heat source for another, thus extracting more useful energy from the heat, increasing the system's overall efficiency. This works because heat engines are only able to use a portion of the energy their fuel generates (usually less than 50%).

The remaining heat (e.g., hot exhaust fumes) from combustion is generally wasted. Combining two or more thermodynamic cycles results in improved overall efficiency, reducing fuel costs. In stationary power plants, a successful, common combination is the [Brayton cycle](#) (in the form of a turbine burning [natural gas](#) or [synthesis gas](#) from [coal](#)) and the [Rankine cycle](#) (in the form of a steam power plant). Multiple stage turbine or steam cylinders are also common.

### **LOAD DURATION CURVE:**

A **load duration curve** (LDC) is used in [electric power generation](#) to illustrate the relationship between generating capacity requirements and capacity utilization.

A LDC is similar to a [load curve](#) but the demand data is ordered in descending order of magnitude, rather than chronologically. The LDC curve shows the capacity utilization requirements for each increment of load. The height of each slice is a measure of capacity, and the width of each slice is a measure of the utilization rate or capacity factor. The product of the two is a measure of electrical energy (e.g. kilowatthours).

### **HIGH PRESSURE BOILERS:**

A **boiler** is a closed [vessel](#) in which [water](#) or other [fluid](#) is heated. The heated or vaporized fluid exits the boiler for use in various processes or heating applications.

Most boilers produce steam to be used at [saturation temperature](#); that is, saturated steam. Superheated steam boilers vaporize the water and then further heat the steam in a *superheater*. This provides steam at much higher temperature, but can decrease the overall thermal efficiency of the steam generating plant because the higher steam temperature requires a higher flue gas exhaust temperature. There are several ways to

circumvent this problem, typically by providing an *economizer* that heats the feed water, a combustion air heater in the hot flue gas exhaust path, or both. There are advantages to superheated steam that may, and often will, increase overall efficiency of both steam generation and its utilisation: gains in input temperature to a turbine should outweigh any cost in additional boiler complication and expense. There may also be practical limitations in using *wet* steam, as entrained condensation droplets will damage turbine blades.

Superheated steam presents unique safety concerns because, if any system component fails and allows steam to escape, the high pressure and temperature can cause serious, instantaneous harm to anyone in its path. Since the escaping steam will initially

be completely superheated vapor, detection can be difficult, although the intense heat and sound from such a leak clearly indicates its presence.

Superheater operation is similar to that of the coils on an air conditioning unit, although for a different purpose. The steam piping is directed through the flue gas path in the boiler furnace. The temperature in this area is typically between 1,300–1,600 degrees [Celsius](#). Some superheaters are radiant type; that is, they absorb heat by radiation. Others are convection type, absorbing heat from a fluid. Some are a combination of the two types. Through either method, the extreme heat in the flue gas path will also heat the superheater steam piping and the steam within. While the temperature of the steam in the superheater rises, the pressure of the steam does not: the turbine or moving pistons offer a *continuously expanding space* and the pressure remains the same as that of the boiler. Almost all steam superheater system designs remove droplets entrained in the steam to prevent damage to the turbine blading and associated piping.

## **SUPERCritical BOILER:**

[Supercritical](#) steam generators (also known as [Benson](#) boilers) are frequently used for the production of electric power. They operate at "supercritical pressure". In contrast to a "subcritical boiler", a supercritical steam generator operates at such a high pressure (over 3,200 psi/22.06 MPa or 220.6 bar) that actual boiling ceases to occur, and



the boiler has no water - steam separation. There is no generation of steam bubbles within the water, because the pressure is above the "critical pressure" at which steam bubbles can form. It passes below the critical point as it does work in the high pressure turbine and enters the generator's condenser. This is more efficient, resulting in slightly less fuel use. The term "boiler" should not be used for a supercritical pressure steam generator, as no "boiling" actually occurs in this device.

### **FLUIDIZED BED BOILERS:**

The major portion of the coal available in India is of low quality, high ash content and low calorific value. The traditional grate fuel firing systems have got limitations and are techno-economically unviable to meet the challenges of future. Fluidized bed

combustion has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits – compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SO<sub>x</sub> and NO<sub>x</sub>. The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse & other agricultural wastes. The fluidized bed boilers have a wide capacity range- 0.5 T/hr to over 100 T/hr.

## **UNIT-II STEAM POWER PLANT**

Coal needs to be stored at various stages of the preparation process, and conveyed around the CPP facilities. Coal handling is part of the larger field of [bulk material handling](#), and is a complex and vital part of the CPP.

### **Stockpiles**

Stockpiles provide surge capacity to various parts of the CPP. ROM coal is delivered with large variations in production rate of tonnes per hour (tph). A ROM stockpile is used to allow the washplant to be fed coal at lower, constant rate. A

simple stockpile is formed by machinery dumping coal into a pile, either from [dump trucks](#), pushed into heaps with [bulldozers](#) or from [conveyor](#) booms. More controlled stockpiles are formed using [stackers](#) to form piles along the length of a conveyor, and

[reclaimers](#) to retrieve the coal when required for product loading, etc. Taller and wider stockpiles reduce the land area required to store a set tonnage of coal. Larger coal stockpiles have a reduced rate of heat lost, leading to a higher risk of spontaneous combustion.

## **Stacking**

Travelling, lugging boom stackers that straddle a feed conveyor are commonly used to create coal stockpiles.

## **Reclaiming**

Tunnel conveyors can be fed by a continuous slot hopper or bunker beneath the stockpile to reclaim material. Front-end loaders and bulldozers can be used to push the coal into feeders. Sometimes front-end loaders are the only means of reclaiming coal from the stockpile. This has a low up-front capital cost, but much higher operating costs, measured in dollars per tonne handled. High-capacity stockpiles are commonly reclaimed using bucket-wheel [reclaimers](#). These can achieve very high rates

## **ASH HANDLING SYSTEMS:**

Ash Handling Systems is the none / un combusted portion or residue, after taking combustion of any solid fuel.

Solid fuel is usually coal. And any coal contains some non combustible portion which is called ash. Content of that coal.

There are different types of ashes.

- Bottom ash

- fly ash.

Bottom ash is the residue which remains in the solid form at the bottom and fly ash is the light particle which goes out along with exhaust gases, and usually they are collected in chimneys.

Taking their so formed ash away from the Plant / Boiler is called – "ASH HANDLING SYSTEM" This is done in either

- Mechanical conveying
- Pneumatic conveying

Mechanical system requires conveyors, and Pneumatic system requires – compressed air to carry out the ash.

[Ash Handling Systems](#)

[Bulk Material Handling Systems](#)

[Conveyors And Material Handling Equipments](#)

[Process Equipments And Storage Equipments](#)

[Portable Handling Equipments](#)

[Rotary Equipments](#)

[Pneumatic Conveying Systems](#)

[Magnetic Equipments](#)

[Vibratory Equipments](#)

[Spares](#)

[Overhead Bag Handling Systems](#)

## COMBUSTION EQUIPMENTS:

Combustion control options range from electro / mechanical through to full microprocessor control systems to match both application and customer needs.

Cochran supply an extensive range of fuel handling equipment to complement and help ensure that the optimum performance from the combustion and control equipment is maintained. Fuel handling equipment includes gas boosters, oil pumping and heating stations, fuel metering and instrumentation packages are available to match individual installation requirements.

## STOCKERS:

A mechanical stoker is a device which feeds coal into the firebox of a boiler. It is standard equipment on large stationary boilers and was also fitted to large steam locomotives to ease the burden of the fireman. The locomotive type has a [screw conveyor](#) (driven by an auxiliary steam engine) which feeds the coal into the firebox. The coal is then distributed across the grate by steam jets, controlled by the fireman. Power stations usually use [pulverized coal-fired boilers](#).

## PULVERISER:

A **pulverizer** or **grinder** is a mechanical device for the grinding of many different types of materials. For example, they are used to pulverize [coal](#) for [combustion](#) in the steam-generating [furnaces](#) of [fossil fuel power plants](#).

### Types of pulverizers

#### Ball and tube mills

A ball mill is a pulverizer that consists of a horizontal rotating cylinder, up to three diameters in length, containing a charge of tumbling or cascading steel balls, pebbles, or rods.

A tube mill is a revolving cylinder of up to five diameters in length used for fine pulverization of ore, rock, and other such materials; the material, mixed with water, is fed into the chamber from one end, and passes out the other end as slime (slurry).

### **Ring and ball mill**

This type of mill consists of two rings separated by a series of large balls. The lower ring rotates, while the upper ring presses down on the balls via a set of spring and adjuster assemblies. The material to be pulverized is introduced into the center or side of the pulverizer (depending on the design) and is ground as the lower ring rotates causing the balls to orbit between the upper and lower rings. The pulverized material is carried out of the mill by the flow of air moving through it. The size of the pulverized particles released from the grinding section of the mill is determined by a classifier separator.

### **Vertical roller mill**

Similar to the ring and ball mill, this mill uses large "tires" to crush the coal. These are usually found in utility plants.

Raw coal is gravity-fed through a central feed pipe to the grinding table where it flows outwardly by centrifugal action and is ground between the rollers and table. Hot primary air for drying and coal transport enters the windbox plenum underneath the grinding table and flows upward through a swirl ring having multiple sloped nozzles surrounding the grinding table. The air mixes with and dries coal in the grinding zone and carries pulverized coal particles upward into a classifier.

Fine pulverized coal exits the outlet section through multiple discharge coal pipes leading to the burners, while oversized coal particles are rejected and returned to the grinding zone for further grinding. Pyrites and extraneous dense impurity material fall through the nozzle ring and are plowed, by scraper blades attached to the grinding table, into the pyrites chamber to be removed. Mechanically, the vertical roller mill is categorized as an applied force mill. There are three grinding roller wheel assemblies in the mill grinding

section, which are mounted on a loading frame via pivot point. The fixed-axis roller in each roller wheel assembly rotates on a segmentally-lined grinding table that is supported and driven by a planetary gear reducer direct-coupled to a motor. The grinding force for coal pulverization is applied by a loading frame. This frame is connected by vertical tension rods to three hydraulic cylinders secured to the mill foundation. All forces used in the pulverizing process are transmitted to the foundation via the gear reducer and loading elements. The pendulum movement of the roller wheels provides a freedom for wheels to move in a radial direction, which results in no radial loading against the mill housing during the pulverizing process.

Depending on the required coal fineness, there are two types of classifier that may be selected for a vertical roller mill. The dynamic classifier, which consists of a stationary angled inlet vane assembly surrounding a rotating vane assembly or cage, is capable of producing micron fine pulverized coal with a narrow particle size distribution. In addition, adjusting the speed of the rotating cage can easily change the intensity of the centrifugal force field in the classification zone to achieve coal fineness control real-time to make immediate accommodation for a

change in fuel or boiler load conditions. For the applications where a micron fine pulverized coal is not necessary, the static classifier, which consists of a cone equipped with adjustable vanes, is an option at a lower cost since it contains no moving parts. With adequate mill grinding capacity, a vertical mill equipped with a static classifier is capable of producing a coal fineness up to 99.5% or higher <50 mesh and 80% or higher <200 mesh, while one equipped with a dynamic classifier produces coal fineness levels of 100% <100 mesh and 95% <200 mesh, or better.

### **Bowl mill**

Similar to the vertical roller mill, it also uses tires to crush coal. There are two types, a deep bowl mill, and a shallow bowl mill.

### **Demolition pulverizer**

An attachment fitted to an excavator. Commonly used in demolition work to break up large pieces of concrete.

## **ELECTROSTATIC PRECIPITATOR:**

An **electrostatic precipitator** (ESP), or **electrostatic air cleaner** is a [particulate](#) collection device that removes particles from a flowing gas (such as air) using the force of an induced [electrostatic charge](#). Electrostatic precipitators are highly efficient [filtration](#) devices that minimally impede the flow of gases through the device, and can easily remove fine particulate matter such as dust and smoke from the air stream. <sup>[1]</sup> In contrast to wet scrubbers which apply energy directly to the flowing fluid medium, an ESP applies energy only to the particulate matter being collected and therefore is very efficient in its consumption of energy (in the form of electricity).

### **Modern industrial electrostatic precipitators**

ESPs continue to be excellent devices for control of many industrial particulate emissions, including smoke from electricity-generating utilities (coal and oil fired),

salt cake collection from [black liquor](#) boilers in pulp mills, and catalyst collection from fluidized bed catalytic cracker units in oil refineries to name a few. These devices treat gas volumes from several hundred thousand [ACFM](#) to 2.5 million ACFM (1,180 m<sup>3</sup>/s) in the largest coal-fired boiler applications. For a coal-fired boiler the collection is usually performed downstream of the air preheater at about 160 °C (320 deg.F) which provides optimal resistivity of the coal-ash particles. For some difficult applications with low-sulfur fuel hot-end units have been built operating above 371 °C (700 deg.F).

The original parallel plate–weighted wire design (described above) has evolved as more efficient (and robust) discharge electrode designs were developed, today focusing on rigid (pipe-frame) discharge electrodes to which many sharpened spikes are attached (barbed wire), maximizing [corona](#) production. Transformer-rectifier systems apply voltages of 50

– 100 [kV](#) at relatively high current densities. Modern controls, such as an [automatic voltage control](#), minimize [electric sparking](#) and prevent arcing (sparks are quenched within 1/2 cycle of the TR set), avoiding damage to the components. Automatic plate-rapping systems and hopper-evacuation systems remove the collected particulate matter while on line, theoretically allowing ESPs to stay in operation for years at a time.

### **Wet electrostatic precipitator**

A wet electrostatic precipitator (WESP or wet ESP) operates with saturated air streams (100% relative humidity). WESPs are commonly used to remove liquid droplets such as sulfuric acid mist from industrial process gas streams. The WESP is also commonly used where the gases are high in moisture content, contain combustible particulate, have particles that are sticky in nature.

The preferred and most modern type of WESP is a downflow tubular design. This design allows the collected moisture and particulate to form a slurry that helps to keep the collection surfaces clean.

Plate style and upflow design WESPs are very unreliable and should not be used in applications where particulate is sticky in nature.

### **Consumer-oriented electrostatic air cleaners**

Plate precipitators are commonly marketed to the public as [air purifier](#) devices or as a permanent replacement for furnace filters, but all have the undesirable attribute of being somewhat messy to clean. A negative side-effect of electrostatic precipitation devices is the production of toxic [ozone](#) and [NO<sub>x</sub>](#). However, electrostatic precipitators offer benefits over other air purifications technologies, such as [HEPA](#) filtration, which require expensive filters and can become "production sinks" for many harmful forms of bacteria.

The two-stage design (charging section ahead of collecting section) has the benefit of minimizing ozone production which would adversely affect health of personnel working in enclosed spaces. For shipboard engine rooms where gearboxes generate an oil fog, two-



stage ESP's are used to clean the air improving the operating environment and preventing buildup of flammable oil fog accumulations. Collected oil is returned to the gear lubricating system.

With electrostatic precipitators, if the collection plates are allowed to accumulate large amounts of particulate matter, the particles can sometimes bond so tightly to the metal plates that vigorous washing and scrubbing may be required to completely clean the collection plates. The close spacing of the plates can make thorough cleaning difficult, and the stack of plates often cannot be easily disassembled for cleaning. One solution, suggested by several manufacturers, is to wash the collector plates in a dishwasher.

Some consumer precipitation filters are sold with special soak-off cleaners, where the entire plate array is removed from the precipitator and soaked in a large container overnight, to help loosen the tightly bonded particulates.

A study by the [Canada Mortgage and Housing Corporation](#) testing a variety of [forced-air](#) furnace filters found that ESP filters provided the best, and most cost-effective means of cleaning air using a forced-air system.

## **DRAUGHT:**

Most boilers now depend on mechanical draught equipment rather than natural draught. This is because natural draught is subject to outside air conditions and temperature of flue gases leaving the furnace, as well as the chimney height. All these factors make proper draught hard to attain and therefore make mechanical draught equipment much more economical.

There are three types of mechanical draught:

***Induced draught:*** This is obtained one of three ways, the first being the "stack effect" of a heated chimney, in which the flue gas is less dense than the ambient air surrounding the boiler. The denser column of ambient air forces combustion air into and through the boiler. The second method is through use of a steam jet. The steam jet oriented in the

direction of flue gas flow induces flue gasses into the stack and allows for a greater flue gas velocity increasing the overall draught in the furnace. This method was common on steam driven locomotives which could not have tall chimneys. The third method is by simply using an induced draught fan (ID fan) which removes flue gases from the furnace and forces the exhaust gas up the stack. Almost all induced draught furnaces operate with a slightly negative pressure.

***Forced draught:*** Draught is obtained by forcing air into the furnace by means of a fan (FD fan) and ductwork. Air is often passed through an air heater; which, as the name suggests, heats the air going into the furnace in order to increase the overall efficiency of the boiler. Dampers are used to control the quantity of air admitted to the furnace. Forced draught furnaces usually have a positive pressure.

***Balanced draught:*** Balanced draught is obtained through use of both induced and forced draught. This is more common with larger boilers where the flue gases have to travel a long distance through many boiler passes. The induced draught fan works in conjunction with the forced draught fan allowing the furnace pressure to be maintained slightly below atmospheric.

## **SURFACE CONDENSER:**

**Surface condenser** is the commonly used term for a water-cooled [shell and tube heat exchanger](#) installed on the exhaust [steam](#) from a [steam turbine](#) in [thermal power stations](#). These [condensers](#) are [heat exchangers](#) which convert steam from its gaseous to its liquid state at a pressure below [atmospheric pressure](#). Where cooling water is in short supply, an air-cooled condenser is often used. An air-cooled condenser is however significantly more expensive and cannot achieve as low a steam turbine exhaust pressure as a water cooled surface condenser.

Surface condensers are also used in applications and industries other than the condensing of steam turbine exhaust in power plants.

In thermal power plants, the primary purpose of a surface condenser is to [condense](#) the

exhaust steam from a steam turbine to obtain maximum [efficiency](#) and also to convert the turbine exhaust steam into pure water (referred to as steam condensate) so that it may be reused in the [steam generator](#) or [boiler](#) as boiler feed water.

The steam turbine itself is a device to convert the [heat](#) in steam to mechanical [power](#). The difference between the heat of steam per unit weight at the inlet to the turbine and the heat of steam per unit weight at the outlet to the turbine represents the heat which is converted to mechanical power. Therefore, the more the conversion of heat per [pound](#) or [kilogram](#) of steam to mechanical power in the turbine, the better is its efficiency. By condensing the exhaust steam of a turbine at a pressure below atmospheric pressure, the steam pressure drop between the inlet and exhaust of the turbine is increased, which increases the amount of heat available for conversion to mechanical power. Most of the heat liberated due to

[condensation](#) of the exhaust steam is carried away by the cooling medium (water or air) used by the surface condenser

## **COOLING TOWERS:**

**Cooling towers** are heat removal devices used to transfer process waste heat to the [atmosphere](#). Cooling towers may either use the [evaporation](#) of water to remove process heat and cool the working fluid to near the [wet-bulb air temperature](#) or in the case of "Close Circuit Dry Cooling Towers" rely solely on air to cool the working fluid to near the [dry-bulb air temperature](#). Common applications include cooling the circulating water used in [oil refineries](#), [chemical plants](#), [power stations](#) and building cooling. The towers vary in size from small roof-top units to very large [hyperboloid structures](#) that can be up to 200 metres tall and 100 metres in diameter, or rectangular structures that can be over 40 metres tall and 80 metres long. Smaller towers are normally factory-built, while larger ones are constructed on site. They are often associated with nuclear power plants in popular culture, although cooling towers are constructed on many types of buildings.

### **Industrial cooling towers**

Industrial cooling towers can be used to remove heat from various sources such as machinery or heated process material. The primary use of large, industrial cooling towers is to remove the heat absorbed in the circulating cooling water systems used in [power plants](#), [petroleum refineries](#), [petrochemical](#) plants, [natural gas](#) processing plants, food processing plants, semi-conductor plants, and for other industrial facilities such as in condensers of distillation columns, for cooling liquid in crystallization, etc. <sup>[2]</sup> The circulation rate of cooling water in a typical 700 MW [coal-fired power plant](#) with a cooling tower amounts to about 71,600 cubic metres an hour (315,000 U.S. gallons per minute) <sup>[3]</sup> and the circulating water requires a supply water make-up rate of perhaps 5 percent (i.e., 3,600 cubic metres an hour).

If that same plant had no cooling tower and used **once-through cooling** water, it would require about 100,000 cubic metres an hour <sup>[4]</sup> and that amount of water

would have to be continuously returned to the ocean, lake or river from which it was obtained and continuously re-supplied to the plant. Furthermore, discharging large amounts of hot water may raise the temperature of the receiving river or lake to an unacceptable level for the local ecosystem. Elevated water temperatures can kill [fish](#) and other aquatic organisms. (See [thermal pollution](#).) A cooling tower serves to dissipate the heat into the atmosphere instead and wind and air diffusion spreads the heat over a much larger area than hot water can distribute heat in a body of water. Some coal-fired and [nuclear power plants](#) located in [coastal](#) areas do make use of once-through ocean water. But even there, the offshore discharge water outlet requires very careful design to avoid environmental problems.

Petroleum refineries also have very large cooling tower systems. A typical large refinery processing 40,000 metric tonnes of crude oil per day (300,000 barrels (48,000 m<sup>3</sup>) per day) circulates about 80,000 cubic metres of water per hour through its cooling tower system.

The world's tallest cooling tower is the 200 metre tall cooling tower of [Niederaussem Power Station](#).

## Heat transfer methods

With respect to the [heat transfer](#) mechanism employed, the main types are:

- *Wet cooling towers* or simply *open circuit cooling towers* operate on the principle of [evaporation](#). The working fluid and the evaporated fluid (usually H<sub>2</sub>O) are one and the same.
- *Dry Cooling Towers* operate by [heat transfer](#) through a surface that separates the working fluid from ambient air, such as in a tube to air [heat exchanger](#), utilizing convective heat transfer. They do not use evaporation.
- *Fluid coolers* or *Closed Circuit Cooling Towers* are hybrids that pass the working fluid through a tube bundle, upon which clean water is sprayed and a fan-induced draft applied. The resulting heat transfer performance is much closer to that of a

wet cooling tower, with the advantage provided by a dry cooler of protecting the working fluid from environmental exposure and contamination.

In a wet cooling tower (or Open Circuit Cooling Tower), the warm water can be cooled to a temperature lower than the ambient air dry-bulb temperature, if the air is relatively dry. (see: [dew point](#) and [psychrometrics](#)). As ambient air is drawn past a flow of water, a small portion of the water evaporate, the energy required by that portion of the water to evaporate is taken from the remaining mass of water reducing its temperature (approximately by 970 BTU for each pound of evaporated water). Evaporation results in saturated air conditions, lowering the temperature of the water process by the tower to a value close to [wet bulb](#) air temperature, which is lower than the ambient dry bulb air temperature, the difference determined by the humidity of the ambient air.

To achieve better performance (more cooling), a medium called *fill* is used to increase the surface area and the time of contact between the air and water flows.

*Splash fill* consists of material placed to interrupt the water flow causing splashing.

*Film fill* is composed of thin sheets of material (usually PVC) upon which the water flows. Both methods create increased surface area and time of contact between the fluid (water) and the gas (air).

### **Air flow generation methods**

With respect to drawing air through the tower, there are three types of cooling towers:

*Natural draft*, which utilizes buoyancy via a tall chimney. Warm, moist air *naturally* rises due to the density differential to the dry, cooler outside air. Warm moist air is less dense than drier air at the same pressure. This moist air buoyancy produces a current of air through the tower.

*Mechanical draft*, which uses power driven fan motors to force or draw air through the tower.

*Induced draft*: A mechanical draft tower with a fan at the discharge which pulls air through tower. The fan *induces* hot moist air out the discharge. This produces low entering and high exiting air velocities, reducing the possibility of *recirculation* in which discharged air flows back into the air intake. This fan/fin arrangement is also known as *draw-through*. (see Image 2, 3)

*Forced draft*: A mechanical draft tower with a blower type fan at the intake. The fan *forces* air into the tower, creating high entering and low exiting air velocities. The low exiting velocity is much more susceptible to recirculation. With the fan on the air intake, the fan is more susceptible to complications due to freezing conditions. Another disadvantage is that a forced draft design typically requires more motor horsepower than an equivalent induced draft design. The forced draft benefit is its ability to work with high static pressure. They can be installed in more confined spaces and even in some indoor situations. This fan/fill geometry is also known as *blow-through*. (see Image 4)

Fan assisted natural draft. A hybrid type that appears like a natural draft though airflow is

assisted by a fan.

[Hyperboloid](#) (a.k.a. hyperbolic) cooling towers (Image 1) have become the design standard for all natural-draft cooling towers because of their structural strength and minimum usage of material. The hyperboloid shape also aids in accelerating the upward [convective](#) air flow, improving cooling efficiency. They are popularly associated with [nuclear power plants](#). However, this association is misleading, as the same kind of cooling towers are often used at large coal-fired power plants as well. Similarly, not all nuclear power plants have cooling towers, instead cooling their heat exchangers with lake, river or ocean water.

### **Categorization by air-to-water flow**

#### **Crossflow**

Crossflow is a design in which the air flow is directed perpendicular to the water flow (see diagram below). Air flow enters one or more vertical faces of the cooling tower to meet the fill material. Water flows (perpendicular to the air) through the fill by gravity. The air continues through the fill and thus past the water flow into an open plenum area. A *distribution or hot water basin* consisting of a deep pan with holes or *nozzles* in the bottom is utilized in a crossflow tower. Gravity distributes the water through the nozzles uniformly across the fill material.

#### **Counterflow**

In a counterflow design the air flow is directly opposite to the water flow (see diagram below). Air flow first enters an open area beneath the fill media and is then drawn up vertically. The water is sprayed through pressurized nozzles and flows downward through the fill, opposite to the air flow.

Common to both designs:

The interaction of the air and water flow allow a partial equalization and evaporation of water.

The air, now saturated with water vapor, is discharged from the cooling tower.

A *collection* or *cold water basin* is used to contain the water after its interaction with the air flow.

Both crossflow and counterflow designs can be used in natural draft and mechanical draft cooling towers.

### UNIT-III NUCLEAR AND HYDEL POWER PLANT

#### NUCLEAR ENERGY:

**Nuclear Energy** is the use of sustained [Nuclear fission](#) to generate heat and do useful work. Nuclear Electric Plants, Nuclear Ships and Submarines use controlled nuclear energy to heat water and produce [steam](#), while in space, nuclear energy decays naturally in a [radioisotope thermoelectric generator](#). Scientists are experimenting with [fusion](#) energy for future generation, but these experiments do not currently generate useful energy.

Nuclear power provides about 6% of the world's energy and 13–14% of the world's electricity, with the [U.S.](#), [France](#), and [Japan](#) together accounting for about 50% of nuclear generated electricity. Also, more than 150 naval vessels using [nuclear propulsion](#) have been built.

Nuclear power is controversial and there is an ongoing debate about the use of nuclear energy. Proponents, such as the [World Nuclear Association](#) and [IAEA](#), contend that nuclear power is a [sustainable energy](#) source that reduces [carbon emissions](#). [Opponents](#), such as [Greenpeace International](#) and [NIRS](#), believe that nuclear power poses many threats to people and the environment.

Some serious [nuclear and radiation accidents](#) have occurred. [Nuclear power plant](#)



accidents include the [Chernobyl disaster](#) (1986), [Fukushima I nuclear accidents](#) (2011), and the [Three Mile Island accident](#) (1979).<sup>[10]</sup> [Nuclear-powered submarine](#) mishaps include the [K-19](#) reactor accident (1961), the [K-27](#) reactor accident (1968), and the [K-431](#) reactor accident (1985). International research is continuing into safety improvements such as [passively safe](#) plants, and the possible future use of [nuclear fusion](#).

## NUCLEAR FISSION:

In [nuclear physics](#) and [nuclear chemistry](#), **nuclear fission** is a [nuclear reaction](#) in which the [nucleus](#) of an atom splits into smaller parts (lighter [nuclei](#)), often producing free [neutrons](#) and [photons](#) (in the form of [gamma rays](#)). The two nuclei produced are most often of comparable size, typically with a mass ratio around 3:2 for common [fissile](#) isotopes.<sup>[1][2]</sup> Most fissions are binary fissions, but occasionally (2 to 4 times per 1000 events), three positively-charged fragments are produced in a ternary fission. The smallest of these ranges in size from a proton to an argon nucleus.

Fission is usually an energetic [nuclear reaction](#) induced by a neutron, although it is occasionally seen as a form of spontaneous [radioactive decay](#), especially in very high-mass-number isotopes. The unpredictable composition of the products (which vary in a broad probabilistic and somewhat chaotic manner) distinguishes fission from purely quantum-tunnelling processes such as [proton emission](#), [alpha decay](#) and [cluster decay](#), which give the same products every time.

Fission of heavy elements is an [exothermic reaction](#) which can release large amounts of [energy](#) both as [electromagnetic radiation](#) and as [kinetic energy](#) of the fragments ([heating](#) the bulk material where fission takes place). In order for fission to produce energy, the total [binding energy](#) of the resulting elements must be less than that of the starting element. Fission is a form of [nuclear transmutation](#) because the resulting fragments are not the same [element](#) as the original atom.

## NUCLEAR FUSION:

In [nuclear physics](#), [nuclear chemistry](#) and [astrophysics](#) **nuclear fusion** is the process by which two or more [atomic nuclei](#) join together, or "fuse", to form a single heavier nucleus. This is usually accompanied by the release or absorption of large quantities of [energy](#). Large-scale thermonuclear fusion processes, involving

many nuclei fusing at once, must occur in matter at very high [densities](#) and [temperatures](#).

The fusion of two nuclei with lower masses than [iron](#) (which, along with [nickel](#), has the largest [binding energy](#) per nucleon) generally releases energy while the fusion of nuclei heavier than iron absorbs energy. The opposite is true for the reverse process, [nuclear fission](#).

In the simplest case of hydrogen fusion, two protons must be brought close enough for the [weak nuclear force](#) to convert either of the identical protons into a neutron, thus forming the [hydrogen isotope deuterium](#). In more complex cases of [heavy ion](#) fusion involving two or more [nucleons](#), the [reaction mechanism](#) is different, but the same result occurs— smaller nuclei are combined into larger nuclei.

Nuclear fusion occurs naturally in all active [stars](#). Synthetic fusion as a result of human actions has also been achieved, although this has not yet been completely controlled as a source of [nuclear power](#) (see: [fusion power](#)). In the [laboratory](#), successful nuclear physics experiments have been carried out that involve the fusion of many different varieties of nuclei, but the energy output has been negligible in these studies. In fact, the amount of energy put into the process has always exceeded the energy output.

Uncontrolled nuclear fusion has been carried out many times in [nuclear weapons testing](#), which results in a deliberate [explosion](#). These explosions have always used the heavy [isotopes](#) of [hydrogen](#), deuterium (H-2) and [tritium](#) (H-3), and never the much more common isotope of hydrogen (H-1), sometimes called "protium".

Building upon the [nuclear transmutation](#) experiments by [Ernest Rutherford](#), carried

out several years earlier, the fusion of the light nuclei ([hydrogen isotopes](#)) was first accomplished by [Mark Oliphant](#) in 1932. Then, the steps of the main cycle

of nuclear fusion in stars were first worked out by [Hans Bethe](#) throughout the remainder of that decade.

Research into fusion for military purposes began in the early 1940s as part of the [Manhattan Project](#), but this was not accomplished until 1951 (see the [Greenhouse Item](#) nuclear test), and nuclear fusion on a large scale in an explosion was first carried out on [November 1, 1952](#), in the [Ivy Mike hydrogen bomb](#) test. Research into developing [controlled thermonuclear fusion](#) for civil purposes also began in the 1950s, and it continues to this day.

## **TYPES OF REACTORS:**

**Pressurized water reactors (PWRs)** constitute a majority of all western [nuclear power plants](#) and are one of two types of [light water reactor](#) (LWR), the other type being [boiling water reactors](#) (BWRs). In a PWR the primary coolant ([water](#)) is pumped under high pressure to the reactor core where it is heated by the energy generated by the [fission](#) of atoms. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spins an electric generator. In contrast to a boiling water reactor, pressure in the primary coolant loop prevents the water from boiling within the reactor. All LWRs use ordinary [light water](#) as both coolant and [neutron moderator](#).

PWRs were originally designed to serve as [nuclear propulsion](#) for [nuclear submarines](#) and were used in the original design of the second commercial power plant at [Shippingport Atomic Power Station](#).

PWRs currently operating in the United States are considered [Generation II reactors](#). Russia's [VVER](#) reactors are similar to U.S. PWRs. [France operates many PWRs](#) to generate the bulk of their electricity

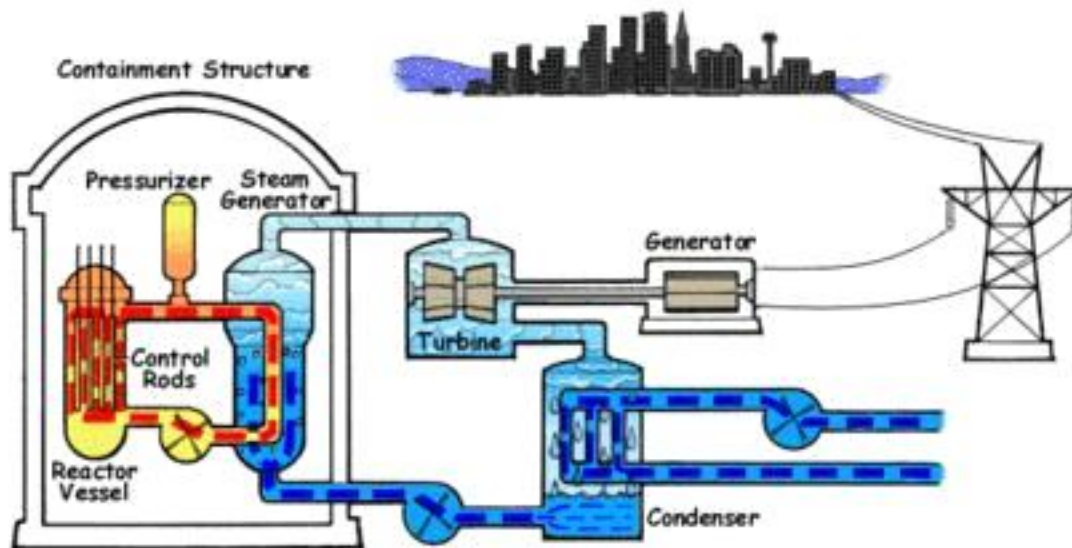
Several hundred PWRs are used for marine propulsion in [aircraft carriers](#), nuclear submarines and [ice breakers](#). In the US, they were originally designed at the [Oak](#)

Ridge National Laboratory for use as a nuclear submarine power plant. Follow-on work was conducted by Westinghouse [Bettis Atomic Power Laboratory](#). <sup>[1]</sup> The first commercial nuclear power plant at Shippingport Atomic Power Station was originally designed as a pressurized water reactor, on insistence from [Admiral Hyman G. Rickover](#) that a viable commercial plant would include none of the "crazy thermodynamic cycles that everyone else wants to build."

The US [Army Nuclear Power Program](#) operated pressurized water reactors from 1954 to 1974.

[Three Mile Island Nuclear Generating Station](#) initially operated two pressurized water reactor plants, TMI-1 and TMI-2. The [partial meltdown of TMI-2 in 1979](#) essentially ended the growth in new construction nuclear power plants in the United States.

## Design



Pictorial explanation of power transfer in a pressurized water reactor. Primary coolant is in orange and the secondary coolant (steam and later feedwater) is in blue.

[Nuclear fuel](#) in the reactor vessel is engaged in a [fission chain reaction](#), which produces heat, heating the water in the primary coolant loop by thermal conduction through the fuel cladding. The hot primary coolant is pumped into a [heat exchanger](#)

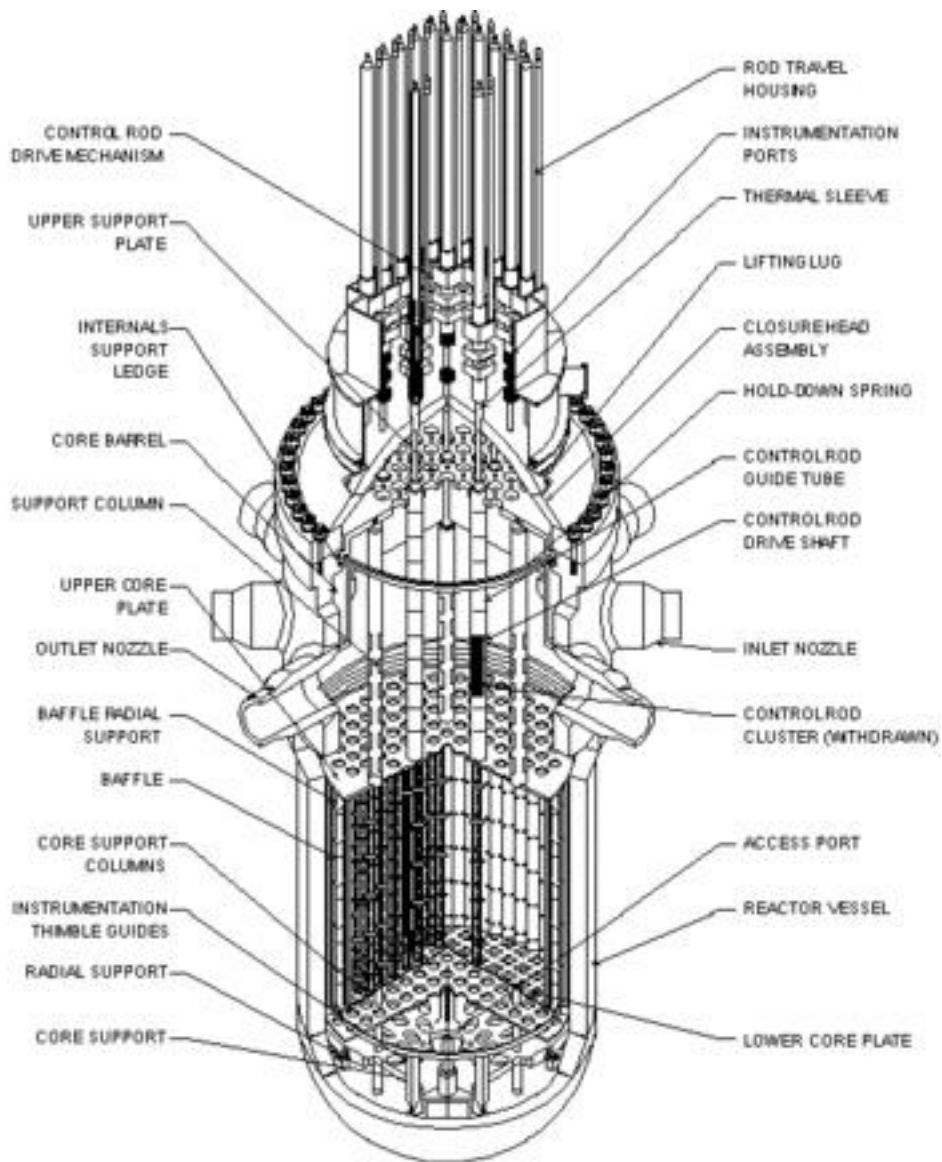
called the [steam generator](#), where it flows through hundreds or thousands of tubes (usually 3/4 inch in diameter). Heat is transferred through the walls of these tubes to the lower pressure secondary coolant located on the sheet side of the exchanger where it evaporates to pressurized steam. The transfer of heat is accomplished without mixing the two fluids, which is desirable since the primary coolant might become radioactive. Some common steam generator arrangements are u-tubes or single pass heat exchangers. In a nuclear power station, the pressurized steam is fed through a steam turbine which drives an [electrical generator](#) connected to the electric grid for distribution. After passing through the turbine the secondary coolant (water-steam mixture) is cooled down and condensed in a [condenser](#). The condenser converts the steam to a liquid so that it can be pumped back into the steam generator, and maintains a vacuum at the turbine outlet so that the pressure drop across the turbine, and hence the energy extracted from the steam, is maximized. Before being fed into the steam generator, the condensed steam (referred to as feedwater) is sometimes preheated in order to minimize thermal shock.

The steam generated has other uses besides power generation. In nuclear ships and submarines, the steam is fed through a steam turbine connected to a set of speed reduction [gears](#) to a shaft used for [propulsion](#). Direct mechanical action by expansion of the steam can be used for a steam-powered [aircraft catapult](#) or similar applications. [District heating](#) by the steam is used in some countries and direct heating is applied to internal plant applications.

Two things are characteristic for the pressurized water reactor (PWR) when compared with other reactor types: coolant loop separation from the steam system and pressure inside the primary coolant loop. In a PWR, there are two separate coolant loops (primary and secondary), which are both filled with demineralized/deionized water. A boiling water reactor, by contrast, has only one coolant loop, while more exotic designs such as [breeder reactors](#) use substances other than water for coolant and moderator (e.g. sodium in its liquid state as coolant or graphite as a moderator). The pressure in the primary coolant loop is typically

15–16 [megapascals](#) (150–160 [bar](#)), which is notably higher than in other [nuclear reactors](#), and nearly twice that of a boiling water reactor (BWR). As an effect of this, only localized boiling occurs and steam will recondense promptly in the bulk fluid. By contrast, in a boiling water reactor the primary coolant is designed to boil.

### **PWR Reactor Design**



## **PWR Reactor Vessel**

### **Coolant**

[Light water](#) is used as the primary coolant in a PWR. It enters the bottom of the reactor core at about 275 °C (530 °F) and is heated as it flows upwards through the reactor core to a temperature of about 315 °C (600 °F). The water remains liquid

despite the high temperature due to the high pressure in the primary coolant loop, usually around 155 bar (15.5 MPa 153 atm, 2,250 psig). In water, the [critical point](#) occurs at around 647 K (374 °C or 705 °F) and 22.064 MPa (3200 PSIA or 218 atm).<sup>[7]</sup>

Pressure in the primary circuit is maintained by a [pressurizer](#), a separate vessel that is connected to the primary circuit and partially filled with water which is heated to the saturation temperature (boiling point) for the desired pressure by submerged electrical heaters. To achieve a pressure of 155 bar, the pressurizer temperature is maintained at 345



[°C](#), which gives a subcooling margin (the difference between the pressurizer temperature and the highest temperature in the reactor core) of 30 [°C](#). Thermal transients in the reactor coolant system result in large swings in pressurizer liquid volume, total pressurizer volume is designed around absorbing these transients without uncovering the heaters or emptying the pressurizer. Pressure transients in the primary coolant system manifest as temperature transients in the pressurizer and are controlled through the use of automatic heaters and water spray, which raise and lower pressurizer temperature, respectively.

To achieve maximum heat transfer, the primary circuit temperature, pressure and flow rate are arranged such that subcooled [nucleate boiling](#) takes place as the coolant passes over the nuclear fuel rods.

The coolant is pumped around the primary circuit by powerful pumps, which can consume up to 6 [MW](#) each. After picking up heat as it passes through the reactor core, the primary coolant transfers heat in a steam generator to water in a lower pressure secondary circuit, evaporating the secondary coolant to saturated steam — in most designs 6.2 MPa (60 atm, 900 [psia](#)), 275 °C (530 °F) — for use in the steam turbine. The cooled primary coolant is then returned to the reactor vessel to be heated again.

## **Moderator**

Pressurized water reactors, like all [thermal reactor](#) designs, require the fast fission neutrons to be slowed down (a process called moderation or thermalization) in order to interact with the nuclear fuel and sustain the chain reaction. In PWRs the coolant water is used as a [moderator](#) by letting the neutrons undergo multiple collisions with light hydrogen atoms in the water, losing speed in the process. This "moderating" of neutrons will happen more often when the water is denser (more collisions will occur). The use of water as a moderator is an important safety feature of PWRs, as an increase in temperature may cause the water to turn to steam - thereby reducing the extent to which neutrons are slowed down and hence reducing the reactivity in the reactor. Therefore, if reactivity increases beyond normal, the reduced moderation of neutrons will cause the chain reaction to slow down, producing less heat. This property, known as the negative [temperature coefficient](#) of reactivity, makes PWR reactors very stable.

In contrast, the [RBMK](#) reactor design used at Chernobyl, which uses graphite instead of water as the moderator and uses boiling water as the coolant, has a large positive thermal coefficient of reactivity, that increases heat generation when coolant water temperatures increase. This makes the RBMK design less stable than pressurized water reactors. In addition to its property of slowing down neutrons when serving as a moderator, water also has a property of absorbing neutrons, albeit to a lesser degree. When the coolant water temperature increases, the boiling increases, which creates voids. Thus there is less water to absorb thermal neutrons that have already been slowed down by the graphite moderator, causing an increase in reactivity. This property is called the [void coefficient](#) of reactivity, and in an RBMK reactor like Chernobyl, the void coefficient is positive, and fairly large, causing rapid transients. This design characteristic of the RBMK reactor is generally seen as one of several causes of the [Chernobyl accident](#). [10]

[Heavy water](#) has very low neutron absorption, so [heavy water reactors](#) such as [CANDU reactors](#) also have a positive void coefficient, though it is not as large as that of an RBMK like Chernobyl; these reactors are designed with a number of

safety systems not found in the original RBMK design, which are designed to handle or react to this as needed.

PWRs are designed to be maintained in an undermoderated state, meaning that there is room for increased water volume or density to further increase moderation, because if moderation were near saturation, then a reduction in density of the moderator/coolant could reduce neutron absorption significantly while reducing moderation only slightly, making the void coefficient positive. Also, light water is actually a somewhat stronger moderator of neutrons than heavy water, though heavy water's neutron absorption is much lower. Because of these two facts, light water reactors have a relatively small moderator volume and therefore have compact cores. One next generation design, the [supercritical water reactor](#), is even less moderated. A less moderated neutron energy spectrum does worsen the capture/fission ratio for  $^{235}\text{U}$  and especially  $^{239}\text{Pu}$ , meaning that more fissile nuclei fail to fission on neutron absorption and instead capture the neutron to become a heavier nonfissile isotope, wasting one or more neutrons and increasing accumulation of

heavy transuranic actinides, some of which have long half-lives.

## Fuel

**PWR fuel bundle** This fuel bundle is from a pressurized water reactor of the nuclear passenger and cargo ship [NS Savannah](#). Designed and built by the Babcock and Wilcox Company.

After enrichment the uranium dioxide (UO<sub>2</sub>) powder is fired in a high-temperature, [sintering](#) furnace to create hard, ceramic pellets of enriched uranium dioxide. The cylindrical pellets are then clad in a corrosion-resistant zirconium metal alloy [Zircaloy](#) which are backfilled with helium to aid heat conduction and detect leakages. [Zircaloy](#) is chosen because of its mechanical properties and its low absorption cross section. The finished fuel rods are grouped in fuel assemblies, called fuel bundles, that are then used to build the core of the reactor. A typical PWR has fuel assemblies of 200 to 300 rods each, and a large reactor would have

about 150–250 such assemblies with 80–100 tonnes of uranium in all. Generally, the fuel bundles consist of fuel rods bundled  $14 \times 14$  to  $17 \times 17$ . A PWR produces on the order of 900 to 1,500 MW<sub>e</sub>. PWR fuel bundles are about 4 meters in length.

Refuelings for most commercial PWRs is on an 18–24 month cycle. Approximately one third of the core is replaced each refueling, though some more modern refueling schemes may reduce refuel time to a few days and allow refueling to occur on a shorter periodicity.

## Control

In PWRs reactor power can be viewed as following steam (turbine) demand due to the reactivity feedback of the temperature change caused by increased or decreased steam flow. (See: [Negative temperature coefficient](#).) Boron and control rods are used to maintain primary system temperature at the desired point. In order to decrease power, the operator throttles shut turbine inlet valves. This would result in less steam being

drawn from the steam generators. This results in the primary loop increasing in temperature. The higher temperature causes the reactor to fission less and decrease in power. The operator could then add boric acid and/or insert control rods to decrease temperature to the desired point.

Reactivity adjustment to maintain 100% power as the fuel is burned up in most commercial PWRs is normally achieved by varying the concentration of [boric acid](#) dissolved in the primary reactor coolant. Boron readily absorbs neutrons and increasing or decreasing its concentration in the reactor coolant will therefore affect the neutron activity correspondingly. An entire control system involving high pressure pumps (usually called the charging and letdown system) is required to remove water from the high pressure primary loop and re-inject the water back in with differing concentrations of boric acid. The reactor control rods, inserted through the reactor vessel head directly into the fuel bundles, are moved for the following reasons:

- To start up the reactor.

To shut down the primary nuclear reactions in the reactor.

- To accommodate short term transients such as changes to load on the turbine.

The control rods can also be used:

- To compensate for [nuclear poison](#) inventory.
- To compensate for [nuclear fuel](#) depletion.

but these effects are more usually accommodated by altering the primary coolant boric acid concentration.

In contrast, [BWRs](#) have no boron in the reactor coolant and control the reactor power by adjusting the reactor coolant flow rate.

### **Advantages:**

PWR reactors are very stable due to their tendency to produce less power as temperatures increase; this makes the reactor easier to operate from a stability standpoint as long as the post shutdown period of 1 to 3 years [\[citation needed\]](#) has pumped cooling.

PWR turbine cycle loop is separate from the primary loop, so the water in the secondary loop is not contaminated by radioactive materials.

PWRs can passively scram the reactor in the event that offsite power is lost to immediately stop the primary nuclear reaction. The control rods are held by electromagnets and fall by gravity when current is lost; full insertion safely shuts down the primary nuclear reaction. However, nuclear reactions of the fission products continue to generate [decay heat](#) at initially roughly 7% of full power level, which requires 1 to 3 years of water pumped cooling. If cooling fails during this post-shutdown period, the reactor can still overheat and meltdown. Upon loss of coolant the decay heat can raise the rods above 2200 degrees Celsius, where upon the hot [Zirconium alloy](#) metal used for casing the nuclear fuel rods spontaneously explodes in contact with the cooling water or steam, which leads to the separation

of water in to its constituent elements ([hydrogen](#) and [oxygen](#)). In this event there is a high danger of hydrogen explosions, threatening structural damage and/or the exposure of highly radioactive stored fuel rods in the vicinity outside the plant in pools (approximately 15 tons of fuel is replenished each year to maintain normal PWR operation).

### **Disadvantages**

The coolant water must be highly pressurized to remain liquid at high temperatures. This requires high strength piping and a heavy pressure vessel and hence increases construction costs. The higher pressure can increase the consequences of a [loss-of- coolant accident](#).  
[\[14\]](#) The reactor pressure vessel is manufactured from ductile steel but, as the plant is operated, neutron flux from the reactor causes this steel to become less ductile. Eventually the [ductility](#) of the steel will reach limits determined by the applicable boiler and pressure

vessel standards, and the pressure vessel must be repaired or replaced. This might not be practical or economic, and so determines the life of the plant.

Additional high pressure components such as reactor coolant pumps, pressurizer, steam generators, etc. are also needed. This also increases the capital cost and complexity of a PWR power plant.

The high temperature water coolant with [boric acid](#) dissolved in it is corrosive to [carbon steel](#) (but not [stainless steel](#)); this can cause radioactive corrosion products to circulate in the primary coolant loop. This not only limits the lifetime of the reactor, but the systems that filter out the corrosion products and adjust the boric acid concentration add significantly to the overall cost of the reactor and to radiation exposure. Occasionally, this has resulted in severe corrosion to control rod drive mechanisms when the boric acid solution leaked through the seal between the mechanism itself and the primary system.

Natural uranium is only 0.7% uranium-235, the isotope necessary for thermal reactors. This makes it necessary to enrich the uranium fuel, which increases the

costs of fuel production. If [heavy water](#) is used, it is possible to operate the reactor with natural uranium, but the production of heavy water requires large amounts of energy and is hence expensive.

Because water acts as a neutron moderator, it is not possible to build a [fast neutron reactor](#) with a PWR design. A [reduced moderation water reactor](#) may however achieve a [breeding ratio](#) greater than unity, though this reactor design has disadvantages of its own.

### **Boiling Water Reactor:**

The **boiling water reactor (BWR)** is a type of [light water nuclear reactor](#) used for the generation of electrical power. It is the second most common type of electricity-generating nuclear reactor after the [pressurized water reactor \(PWR\)](#), also a type of light water nuclear reactor. The BWR was developed by the [Idaho National Laboratory](#) and [General Electric](#) in the mid-1950s. The main present manufacturer is [GE Hitachi Nuclear](#)

[Energy](#), which specializes in the design and construction of this type of reactor.

## **Early concepts**

The BWR concept was developed slightly later than the PWR concept. Development of the BWR started in the early 1950s, and was a collaboration between GE and several US national laboratories.

Research into nuclear power in the US was led by the 3 military services. The Navy, seeing the possibility of turning submarines into full-time underwater vehicles, and ships that could steam around the world without refueling, sent their man in engineering, [Captain Hyman Rickover](#) to run their nuclear power program. Rickover decided on the PWR route for the Navy, as the early researchers in the field of nuclear power feared that the direct production of steam within a reactor would cause instability, while they knew that the use of pressurized water would definitively work as a means of heat transfer. This concern led to the US's first

research effort in nuclear power being devoted to the PWR, which was highly suited for naval vessels (submarines, especially), as space was at a premium, and PWRs could be made compact and high-power enough to fit in such, in any event.

But other researchers wanted to investigate whether the supposed instability caused by boiling water in a reactor core would really cause instability. In particular, [Samuel Untermyer II](#), a researcher at [Idaho National Laboratory](#) (INL), proposed and oversaw a series of experiments: the [BORAX experiments](#)—to see if a boiling water reactor would be feasible for use in energy production. He found that it was, after subjecting his reactors to quite strenuous tests, proving the safety principles of the BWR.

Following this series of tests, [GE](#) got involved and collaborated with [INL](#) to bring this technology to market. Larger-scale tests were conducted through the late 1950s/early/mid-1960s that only partially used directly-generated (primary) nuclear boiler system steam to feed the turbine and incorporated heat exchangers for the generation of

secondary steam to drive separate parts of the turbines. The literature does not indicate why this was the case, but it was eliminated on production models of the BWR.

### **First series of production BWRs (BWR/1–BWR/6)**

The first generation of production boiling water reactors saw the incremental development of the unique and distinctive features of the BWR: the [torus](#) (used to quench steam in the event of a transient requiring the quenching of steam), as well as the drywell, the elimination of the heat exchanger, the steam dryer, the distinctive general layout of the reactor building, and the standardization of reactor control and safety systems. The first, General Electric, series of production BWRs evolved through 6 iterative design phases, each termed BWR/1 through BWR/6. (BWR/4s, BWR/5s, and BWR/6s are the most common types in service today.) The vast majority of BWRs in service throughout the world belong to one of these design phases.

1st generation BWR: BWR/1 with [Mark I](#) containment.

2nd generation BWRs: BWR/2, BWR/3 and some BWR/4 with [Mark I](#) containment.

Other BWR/4, and BWR/5 with [Mark-II](#) containment.

3rd generation BWRs: BWR/6 with Mark-III containment.

[Browns Ferry](#) Unit 1 drywell and wetwell under construction, a BWR/4 using the Mark I containment

Containment variants were constructed using either concrete or steel for the Primary Containment, Drywell and Wetwell in various combinations. [\[5\]](#)

Apart from the GE designs there were others by ABB, MITSU, Toshiba and KWU. See [List of boiling water reactors](#).

### **The advanced boiling water reactor (ABWR)**



A newer design of BWR is known as the [Advanced Boiling Water Reactor](#) (ABWR). The ABWR was developed in the late 1980s and early 1990s, and has been further improved to the present day. The ABWR incorporates advanced technologies in the design, including computer control, plant automation, control rod removal, motion, and insertion, in-core pumping, and nuclear safety to deliver improvements over the original series of production BWRs, with a high power output (1350 MWe per reactor), and a significantly lowered probability of core damage. Most significantly, the ABWR was a completely standardized design, that could be made for series production. [\[citation needed\]](#)

The ABWR was approved by the U.S. Nuclear Regulatory Commission for production as a standardized design in the early 1990s. Subsequently, numerous ABWRs were built in Japan. One development spurred by the success of the ABWR in Japan is that GE's nuclear energy division merged with Hitachi

Corporation's nuclear energy division, forming GE Hitachi, who is now the major worldwide developer of the BWR design.

### **The simplified boiling water reactor (SBWR)**

[General Electric](#) (GE) also developed a different concept for a new boiling water reactor (BWR) at the same time as the ABWR, known as the simplified boiling water reactor (SBWR). This smaller (600 [megawatt electrical](#) (MWe) per reactor) was notable for its incorporation—for the first time ever in a light water reactor— of "passive safety" design principles. The concept of passive safety means that the reactor, rather than requiring the intervention of active systems, such as emergency injection pumps, to keep the reactor within safety margins, was instead designed to return to a safe state solely through operation of natural forces if a safety-related contingency developed.

For example, if the reactor got too hot, it would trigger a system that would release soluble neutron absorbers (generally a solution of borated materials, or a solution of [borax](#)), or materials that greatly hamper a chain reaction by absorbing neutrons, into the reactor core. The tank containing the soluble neutron absorbers would be located above the reactor, and the absorption solution, once the system was triggered, would flow into the core through force of gravity, and bring the reaction to a near-complete stop. Another example was the Isolation Condenser system, which relied on the principle of hot water/steam rising to bring hot coolant into large heat exchangers located above the reactor in very deep tanks of water, thus accomplishing residual heat removal. Yet another example was the omission of recirculation pumps within the core; these pumps were used in other BWR designs to keep cooling water moving; they were expensive, hard to reach to repair, and could occasionally fail; so as to improve reliability, the ABWR incorporated no less than 10 of these recirculation pumps, so that even if several failed, a sufficient

number would remain serviceable so that an unscheduled shutdown would not be necessary, and the pumps could be repaired during the next refueling outage. Instead, the designers of the Simplified Boiling Water Reactor used thermal analysis to design the reactor core such that natural circulation (cold water falls, hot water rises) would bring water to the center of the core to be boiled.

The ultimate result of the passive safety features of the SBWR would be a reactor that would not require human intervention in the event of a major safety contingency for at least 48 hours following the safety contingency; thence, it would only require periodic refilling of cooling water tanks located completely outside of the reactor, isolated from the cooling system, and designed to remove reactor waste heat through evaporation. The Simplified Boiling Water Reactor was submitted to the United States [Nuclear Regulatory Commission](#), however, it was withdrawn prior to approval; still, the concept remained intriguing to General Electric's designers, and served as the basis of future developments.

### **The economic simplified boiling water reactor (ESBWR)**

During a period beginning in the late 1990s, GE engineers proposed to combine the features of the advanced boiling water reactor design with the distinctive safety features of the simplified boiling water reactor design, along with scaling up the resulting design to a larger size of 1,600 MWe (4,500 MWth). This [Economic Simplified Boiling Water Reactor](#) design has been submitted to the U.S. Nuclear Regulatory Commission for approval, and the subsequent Final Design Review is near completion.

Reportedly, this design has been advertised as having a [core damage probability](#) of only  $3 \times 10^{-8}$  core damage events per reactor-year. [\[citation needed\]](#) (That is, there would need to be 3 million ESBWRs operating before one would expect a single core-damaging event during their 100-year lifetimes. Earlier designs of the BWR (the BWR/4) had core damage probabilities as high as  $1 \times 10^{-5}$  core-damage events per reactor-year.) [\[6\]](#) This extraordinarily low CDP for the ESBWR far exceeds the other large LWRs on the market.

## **Advantages and disadvantages**

### **Advantages**

- The reactor vessel and associated components operate at a substantially lower pressure (about 75 times atmospheric pressure) compared to a PWR (about 158 times atmospheric pressure).
- Pressure vessel is subject to significantly less irradiation compared to a PWR, and so does not become as brittle with age.

- Operates at a lower nuclear fuel temperature.
- Fewer components due to no steam generators and no pressurizer vessel. (Older BWRs have external recirculation loops, but even this piping is eliminated in modern BWRs, such as the [ABWR](#).)
- Lower risk (probability) of a rupture causing loss of coolant compared to a PWR, and lower risk of core damage should such a rupture occur. This is due to fewer pipes, fewer large diameter pipes, fewer welds and no steam generator tubes.
- NRC assessments of limiting fault potentials indicate if such a fault occurred, the average BWR would be less likely to sustain core damage than the average PWR due to the robustness and redundancy of the [Emergency Core Cooling System \(ECCS\)](#).
- Unlike PWRs, BWRs have at least a few steam-turbine driven ECCS systems that can be directly operated by steam produced after a reactor

shutdown, and require no electrical power. This results in less dependence on emergency diesel generators—of which there are four—in any event.

- Measuring the water level in the pressure vessel is the same for both normal and emergency operations, which results in easy and intuitive assessment of emergency conditions.
- Can operate at lower core power density levels using natural circulation without forced flow.
- A BWR may be designed to operate using only natural circulation so that recirculation pumps are eliminated entirely. (The new ESBWR design uses natural circulation.)
- BWRs do not use [boric acid](#) to control fission burn-up, leading to less possibility of corrosion within the reactor vessel and piping. (Corrosion from boric acid must be carefully monitored in PWRs; it has been demonstrated that reactor vessel head corrosion can occur if the reactor vessel head is not properly maintained. See [Davis-Besse](#). Since BWRs do not utilize boric acid, these contingencies are eliminated.)

- BWRs generally have  $N-2$  redundancy on their major safety-related systems, which normally consist of four "trains" of components. This generally means that up to two of the four components of a safety system can fail and the system will still perform if called upon.
- Due to their single major vendor (GE/Hitachi), the current fleet of BWRs have predictable, uniform designs that, while not completely standardized, generally are very similar to one another. The ABWR/ESBWR designs are completely standardized. Lack of standardization remains a problem with PWRs, as, at least in the United States, there are three design families represented among the current PWR fleet (Combustion Engineering, Westinghouse, and Babcock & Wilcox), within these families, there are quite divergent designs.
- Additional families of PWRs are being introduced. For example, Mitsubishi's [APWR](#), Areva's US- [EPR](#), and Westinghouse's AP1000/AP600 will add diversity and complexity to an already diverse crowd, and possibly

cause customers seeking stability and predictability to seek other designs,

such as the BWR.

- BWRs are overrepresented in imports, if the importing nation doesn't have a nuclear navy (PWRs are favored by nuclear naval states due to their compact, high-power design used on nuclear-powered vessels; since naval reactors are generally not exported, they cause national skill to be developed in PWR design, construction, and operation), or special national aspirations (special national aspirations lead to a marked preference for the [CANDU](#) reactor type due to special features of that type). This may be due to the fact that BWRs are ideally suited for peaceful uses like power generation, process/industrial/district heating, and desalinization, due to low cost, simplicity, and safety focus, which come at the expense of larger size and slightly lower thermal efficiency.
- Sweden is standardized mainly on BWRs.
- Mexico's only two reactors are BWRs.

- Japan experimented with both PWRs and BWRs, but most builds as of late have been of BWRs, specifically ABWRs.
- In the [CEGB](#) open competition in the early 1960s for a standard design for UK 2nd-generation power reactors, the PWR didn't even make it to the final round, which was a showdown between the BWR (preferred for its easily understood design as well as for being predictable and "boring") and the [AGCR](#), a uniquely British design; the indigenous design won, possibly on technical merits, possibly due to the proximity of a general election.

### **Disadvantages**

- Much larger pressure vessel than for a PWR of similar power, with correspondingly higher cost. (However, the overall cost is reduced because a modern Complex calculations for managing consumption of nuclear fuel during operation due to "two phase (water and steam) fluid flow" in the upper part of the core. This requires more instrumentation in the reactor core. The innovation of computers, however, makes this less of an issue.

BWR has no main steam generators and associated piping.)

- Contamination of the turbine by short-lived [activation products](#). This means that shielding and access control around the steam turbine are required during normal operations due to the radiation levels arising from the steam entering directly from the reactor core. This is a moderately minor concern, as most of the radiation flux is due to [Nitrogen-16](#), which has a half-life measured in seconds, allowing the turbine chamber to be entered into within minutes of shutdown.
- Though the present fleet of BWRs are said to be less likely to suffer core damage from the "1 in 100,000 reactor-year" limiting fault than the present fleet of PWRs are (due to increased ECCS robustness and redundancy) there have been concerns raised about the pressure containment ability of the as-built, unmodified Mark I containment – that such may be insufficient to contain pressures generated by a limiting fault combined with

complete ECCS failure that results in extremely severe core damage. In this double failure scenario, assumed to be extremely unlikely prior to the [Fukushima I nuclear accidents](#), an unmodified Mark I containment can allow some degree of radioactive release to occur. This is supposed to be mitigated by the modification of the Mark I containment; namely, the addition of an outgas stack system that, if containment pressure exceeds critical setpoints, is supposed to allow the orderly discharge of pressurizing gases after the gases pass through activated carbon filters designed to trap radionuclides. [\[7\]](#)

- A BWR requires active cooling for a period of several hours to several days following shutdown, depending on its power history. Full insertion of BWRs control rods safely shuts down the primary nuclear reaction. However, radioactive decay of the fission products in the fuel will continue to actively generate [decay heat](#) at a gradually decreasing rate, requiring pumping of cooling water for an initial period to prevent overheating of the fuel. If active cooling fails during this post-shutdown period, the reactor can still overheat to a temperature high enough that zirconium in the fuel cladding will react with water and steam, producing hydrogen gas. In this

event there is a high danger of hydrogen explosions, threatening structural damage to the reactor and/or associated safety systems and/or the exposure of highly radioactive spent fuel rods that may be stored in the reactor building (approx 15 tons of fuel is replenished each year to maintain normal BWR operation) as happened with the [Fukushima I nuclear accidents](#).

- Control rods are inserted from below for current BWR designs. There are two available hydraulic power sources that can drive the control rods into the core for a BWR under emergency conditions. There is a dedicated high pressure hydraulic accumulator and also the pressure inside of the reactor pressure vessel available to each control rod. Either the dedicated accumulator (one per rod) or reactor pressure is capable of fully inserting each rod. Most other reactor types use top entry control rods that are held up in the withdrawn position by electromagnets, causing them to fall into the reactor by gravity if power is lost.

## **NUCLEAR WASTE AND ITS DISPOSAL:**

**Radioactive waste** is a [waste](#) product containing [radioactive](#) material. It is usually the product of a nuclear process such as [nuclear fission](#), though industries not directly connected to the [nuclear power industry](#) may also produce radioactive waste.

[Radioactivity](#) diminishes over [time](#), so in principle the waste needs to be isolated for a period of time until it no longer poses a [hazard](#). This can mean hours to years for some common medical or industrial radioactive wastes, or thousands of years for [high-level wastes](#) from [nuclear power plants](#) and [nuclear weapons](#) reprocessing.

The majority of radioactive waste is ["low-level waste"](#), meaning it has low levels of radioactivity per [mass](#) or [volume](#).

The main approaches to managing radioactive waste to date have been segregation and storage for short-lived wastes, near-surface disposal for low and some

intermediate level wastes, and deep burial or transmutation for the long-lived, high-level wastes.

A summary of the amounts of radioactive wastes and management approaches for most developed countries are presented and reviewed periodically as part of the [IAEA](#) Joint Convention on Safety of Spent Fuel Management and the Safety of Radioactive Waste Management.

## **Types of radioactive waste**

Although not significantly radioactive, *uranium mill tailings* are waste. They are byproduct material from the rough processing of uranium-bearing ore. They are sometimes referred to as 11(e)2 wastes, from the section of the U.S. Atomic Energy Act that defines them. Uranium mill tailings typically also contain chemically hazardous heavy metals such as [lead](#) and [arsenic](#). Vast mounds of uranium mill tailings are left at many old mining sites, especially in [Colorado](#), [New Mexico](#), and [Utah](#).



Low level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters, etc., which contain small amounts of mostly short-lived radioactivity. Commonly, LLW is designated as such as a precautionary measure if it originated from any region of an 'Active Area', which frequently includes offices with only a remote possibility of being contaminated with radioactive materials. Such LLW typically exhibits no higher radioactivity than one would expect from the same material disposed of in a non-active area, such as a normal office block. Some high activity LLW requires shielding during handling and transport but most LLW is suitable for shallow land burial. To reduce its volume, it is often compacted or incinerated before disposal. Low level waste is divided into four classes, class A, B, C and GTCC, which means "Greater Than Class C".

*Intermediate level waste (ILW)* contains higher amounts of radioactivity and in some cases requires shielding. ILW includes resins, chemical sludge and metal

reactor fuel cladding, as well as contaminated materials from reactor decommissioning. It may be solidified in concrete or bitumen for disposal. As a general rule, short-lived waste (mainly non-fuel materials from reactors) is buried in shallow repositories, while long-lived waste (from fuel and fuel-reprocessing) is deposited in deep underground facilities. U.S. regulations do not define this category of waste; the term is used in Europe and elsewhere.

Spent Fuel Flasks are transported by railway in the United Kingdom. Each flask is constructed of 14 in (360 mm) thick solid steel and weighs in excess of 50 tons

High level waste (HLW) is produced by nuclear reactors. It contains fission products and transuranic elements generated in the reactor core. It is highly radioactive and often thermally hot. HLW accounts for over 95% of the total radioactivity produced in the process of nuclear electricity generation. The amount of HLW worldwide is currently increasing by about 12,000 metric tons every year, which is the equivalent to about 100 double-decker buses or a two-story structure with a footprint the size of a basketball court. A 1000-MWe nuclear power plant produces about 27 tonnes of spent nuclear fuel (unreprocessed) every year.

Transuranic waste (TRUW) as defined by U.S. regulations is, without regard to form or origin, waste that is contaminated with alpha-emitting transuranic radionuclides with half-lives greater than 20 years, and concentrations greater than 100 nCi/g (3.7 MBq/kg), excluding High Level Waste. Elements that have an atomic number greater than uranium are called transuranic ("beyond uranium"). Because of their long half-lives, TRUW is disposed more cautiously than either low level or intermediate level waste. In the US it arises mainly from weapons production, and consists of clothing, tools, rags, residues, debris and other items contaminated with small amounts of radioactive elements (mainly plutonium).

Under US law, transuranic waste is further categorized into "contact-handled" (CH) and "remote-handled" (RH) on the basis of radiation dose measured at the surface of the waste container. CH TRUW has a surface dose rate not greater than 200

mrem per hour (2 mSv/h), whereas RH TRUW has a surface dose rate of 200 mrem per hour (2 mSv/h) or greater. CH TRUW does not have the very high radioactivity of high level waste, nor its high heat generation, but RH TRUW can be highly radioactive, with surface dose rates up to 1000000 mrem per hour (10000 mSv/h). The US currently permanently disposes of defense-related TRUW at the Waste Isolation Pilot Plant.

## **Preventing of Waste**

Due to the many advances in reactor design, it is today possible to reduce the radioactive waste by a factor 100. This can be done by using new reactor types such as Generation IV reactor. This reduction of nuclear waste is possible these new reactor types are capable of burning the lower actinides.

## **Management of Waste**

Modern medium to high level transport container for nuclear waste.

See also: High-level radioactive waste management, List of nuclear waste treatment technologies, and Environmental effects of nuclear power

Of particular concern in nuclear waste management are two long-lived fission products, Tc-99 (half-life 220,000 years) and I-129 (half-life 17 million years), which dominate spent fuel radioactivity after a few thousand years. The most troublesome transuranic elements in spent fuel are Np-237 (half-life two million years) and Pu-239 (half life 24,000 years). Nuclear waste requires sophisticated treatment and management to successfully isolate it from interacting with the [biosphere](#). This usually necessitates treatment, followed by a long-term management strategy involving storage, disposal or transformation of the waste into a non-toxic form. Governments around the world are considering a range of waste management and disposal options, though there has been limited progress toward long-term waste management solutions.

## **Initial treatment of waste**

### **Vitrification**

Long-term storage of radioactive waste requires the stabilization of the waste into a form which will neither react nor degrade for extended periods of time. One way to do this is through [vitrification](#).<sup>[23]</sup> Currently at [Sellafield](#) the high-level waste ([PUREX](#) first cycle raffinate) is mixed with [sugar](#) and then calcined. [Calcination](#) involves passing the waste through a heated, rotating tube. The purposes of calcination are to evaporate the water from the waste, and de-nitrate the fission products to assist the stability of the glass produced.

The 'calcine' generated is fed continuously into an induction heated furnace with fragmented [glass](#).<sup>[25]</sup> The resulting glass is a new substance in which the waste products are bonded into the glass matrix when it solidifies. This product, as a melt, is poured into [stainless steel](#) cylindrical containers ("cylinders") in a batch process. When cooled, the fluid solidifies ("vitrifies") into the glass. Such glass, after being formed, is highly resistant to water.

After filling a cylinder, a seal is [welded](#) onto the cylinder. The cylinder is then washed. After being inspected for external contamination, the steel cylinder is stored, usually in an underground repository. In this form, the waste products are expected to be immobilized

for a long period of time (many thousands of years).

The glass inside a cylinder is usually a black glossy substance. All this work (in the United Kingdom) is done using [hot cell](#) systems. The sugar is added to control the [ruthenium](#) chemistry and to stop the formation of the volatile [RuO<sub>4</sub>](#) containing [radioactive ruthenium isotopes](#). In the west, the glass is normally a [borosilicate glass](#) (similar to [Pyrex](#)), while in the former [Soviet](#) bloc it is normal to use a [phosphate glass](#). The amount of fission products in the glass must be limited because some ([palladium](#), the other Pt group metals, and [tellurium](#)) tend to form metallic phases which separate from the glass. Bulk vitrification uses electrodes to melt soil and wastes, which are then buried underground. <sup>[28]</sup> In Germany a

vitrification plant is in use; this is treating the waste from a small demonstration reprocessing plant which has since been closed down. <sup>[24][29]</sup>

### **Ion exchange**

It is common for medium active wastes in the nuclear industry to be treated with [ion exchange](#) or other means to concentrate the radioactivity into a small volume. The much less radioactive bulk (after treatment) is often then discharged. For instance, it is possible to use a [ferric hydroxide floc](#) to remove radioactive metals from aqueous mixtures. <sup>[30]</sup> After the radioisotopes are absorbed onto the ferric hydroxide, the resulting sludge can be placed in a metal drum before being mixed with cement to form a solid waste form. <sup>[31]</sup> In order to get better long-term performance (mechanical stability) from such forms, they may be made from a mixture of [fly ash](#), or [blast furnace slag](#), and [Portland cement](#), instead of normal [concrete](#) (made with Portland cement, gravel and sand).

### **Synroc**

The Australian [Synroc](#) (synthetic rock) is a more sophisticated way to immobilize such waste, and this process may eventually come into commercial use for civil wastes (it is currently being developed for US military wastes). Synroc was invented by the late Prof Ted Ringwood (a [geochemist](#)) at the [Australian National University](#). <sup>[32]</sup> The Synroc contains [pyrochlore](#) and cryptomelane type minerals. The original form of Synroc (Synroc C) was designed for the liquid high level waste (PUREX raffinate) from a [light water](#)

[reactor](#). The main minerals in this Synroc are hollandite ( $\text{BaAl}_2\text{Ti}_6\text{O}_{16}$ ), [zirconolite](#) ( $\text{CaZrTi}_2\text{O}_7$ ) and [perovskite](#) ( $\text{CaTiO}_3$ ). The zirconolite and perovskite are hosts for the [actinides](#). The [strontium](#) and [barium](#) will be fixed in the perovskite. The [caesium](#) will be fixed in the hollandite.

### **Long term management of Waste**

The time frame in question when dealing with radioactive waste ranges from 10,000 to 1,000,000 years, according to studies based on the effect of estimated radiation doses. Researchers suggest that forecasts of health detriment for such periods should be examined critically. Practical studies only consider up to 100 years as far as effective planning and cost evaluations are concerned. Long term behavior of radioactive wastes remains a subject for ongoing research projects.

### **Geologic disposal**

The process of selecting appropriate [deep final repositories](#) for high level waste and spent fuel is now under way in several countries ([Schacht Asse II](#) and the Waste Isolation Pilot Plant) with the first expected to be commissioned some time after 2010. The basic concept is to locate a large, stable geologic formation and use mining technology to excavate a tunnel, or large-bore [tunnel boring machines](#) (similar to those used to drill the [Channel Tunnel](#) from England to France) to drill a shaft 500–1,000 meters below the surface where rooms or vaults can be excavated for disposal of high-level radioactive waste. The goal is to permanently isolate nuclear waste from the human environment. Many people remain uncomfortable with the immediate [stewardship cessation](#) of this disposal system, suggesting perpetual management and monitoring would be more prudent.

Because some radioactive species have half-lives longer than one million years, even very low container leakage and radionuclide migration rates must be taken into account. Moreover, it may require more than one half-life until some nuclear materials lose enough radioactivity to cease being lethal to living things. A 1983 review of the Swedish radioactive waste disposal program by the National

Academy of Sciences found that country's estimate of several hundred thousand years—

perhaps up to one million years—being necessary for waste isolation —fully justified. || Storing high level nuclear waste above ground for a century or so is considered appropriate by many scientists. This allows the material to be more

easily observed and any problems detected and managed, while decay of radionuclides over this time period significantly reduces the level of radioactivity and associated harmful effects to the container material. It is also considered likely that over the next century newer materials will be developed which will not break down as quickly when exposed to a high neutron flux, thus increasing the longevity of the container once it is permanently buried.

Sea-based options for disposal of radioactive waste <sup>[42]</sup> include burial beneath a stable [abyssal plain](#), burial in a [subduction](#) zone that would slowly carry the waste downward into the [Earth's mantle](#), and burial beneath a remote natural or human-made island. While these approaches all have merit and would facilitate an international solution to the problem of disposal of radioactive waste, they would require an amendment of the [Law of the Sea](#).

Article 1 (Definitions), 7., of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, (the London Dumping Convention) states:

—Sea || means all marine waters other than the internal waters of States, as well as the seabed and the subsoil thereof; it does not include sub-seabed repositories accessed only from land. ||

The proposed land-based subductive waste disposal method disposes of nuclear waste in a [subduction](#) zone accessed from land, and therefore is not prohibited by international agreement. This method has been described as the most viable means of disposing of radioactive waste, and as the state-of-the-art as of 2001 in nuclear waste disposal technology. Another approach termed Remix & Return would blend high-level waste with [uranium mine](#) and mill tailings down to the level of the original radioactivity of the [uranium ore](#), then replace it in inactive uranium mines. This approach has the merits of

providing jobs for miners who would double as disposal staff, and of facilitating a cradle-to-grave cycle for radioactive materials,

but would be inappropriate for spent reactor fuel in the absence of reprocessing, due to the presence in it of highly toxic radioactive elements such as plutonium.

[Deep borehole disposal](#) is the concept of disposing of high-level radioactive waste from nuclear reactors in extremely deep boreholes. Deep borehole disposal seeks to place the waste as much as five kilometers beneath the surface of the Earth and relies primarily on the immense natural geological barrier to confine the waste safely and permanently so that it should never pose a threat to the environment.

## **Transmutation**

There have been proposals for reactors that consume nuclear waste and transmute it to other, less-harmful nuclear waste. In particular, the [Integral Fast Reactor](#) was a proposed nuclear reactor with a nuclear fuel cycle that produced no transuranic waste and in fact, could consume transuranic waste. It proceeded as far as large-scale tests, but was then canceled by the US Government. Another approach, considered safer but requiring more development, is to dedicate [subcritical reactors](#) to the [transmutation](#) of the left-over transuranic elements.

An isotope that is found in nuclear waste and that represents a concern in terms of proliferation is Pu-239. The estimated world total of plutonium in the year 2000 was of 1,645 MT, of which 210 MT had been separated by reprocessing. The large stock of plutonium is a result of its production inside uranium-fueled reactors and of the reprocessing of weapons-grade plutonium during the weapons program. An option for getting rid of this plutonium is to use it as a fuel in a traditional Light Water Reactor (LWR). Several fuel types with differing plutonium destruction efficiencies are under study. See [Nuclear transmutation](#).

Transmutation was banned in the US in April 1977 by President Carter due to the danger of plutonium proliferation, but President Reagan rescinded the ban in 1981. [\[51\]](#) Due to

the economic losses and risks, construction of reprocessing plants during this time did not resume. Due to high energy demand, work on the method has continued in the [EU](#). This has resulted in a practical nuclear research reactor

called [Myrrha](#) in which transmutation is possible. Additionally, a new research program called ACTINET has been started in the [EU](#) to make transmutation possible on a large, industrial scale. According to President Bush's Global Nuclear Energy Partnership (GNEP) of 2007, the US is now actively promoting research on transmutation technologies needed to markedly reduce the problem of nuclear waste treatment.

There have also been theoretical studies involving the use of [fusion reactors](#) as so called "actinide burners" where a fusion reactor [plasma](#) such as in a [tokamak](#), could be "doped" with a small amount of the "minor" transuranic atoms which would be transmuted (meaning fissioned in the actinide case) to lighter elements upon their successive bombardment by the very high energy neutrons produced by the fusion of [deuterium](#) and [tritium](#) in the reactor. A study at [MIT](#) found that only 2 or 3 fusion reactors with parameters similar to that of the [International Thermonuclear Experimental Reactor](#) (ITER) could transmute the entire annual [minor actinide](#) production from all of the [light water reactors](#) presently operating in the [United States fleet](#) while simultaneously generating approximately 1 [gigawatt](#) of power from each reactor.

## **Re-use of Waste**

Main article: [Nuclear reprocessing](#)

Another option is to find applications for the isotopes in nuclear waste so as to [re-use](#) them. Already, [caesium-137](#), [strontium-90](#) and a few other isotopes are extracted for certain industrial applications such as [food irradiation](#) and [radioisotope thermoelectric generators](#). While re-use does not eliminate the need to manage radioisotopes, it reduces the quantity of waste produced.

The Nuclear Assisted Hydrocarbon Production Method, [\[55\]](#) Canadian patent application 2,659,302, is a method for the temporary or permanent storage of nuclear waste materials



comprising the placing of waste materials into one or more repositories or boreholes constructed into an [unconventional oil](#) formation. The

thermal flux of the waste materials fracture the formation, alters the chemical and/or physical properties of hydrocarbon material within the subterranean formation to allow removal of the altered material. A mixture of hydrocarbons, hydrogen, and/or other formation fluids are produced from the formation. The radioactivity of high-level radioactive waste affords proliferation resistance to plutonium placed in the periphery of the repository or the deepest portion of a borehole.

Breeder reactors can run on U-238 and transuranic elements, which comprise the majority of spent fuel radioactivity in the 1000-100000 year time span.

### **Space disposal**

Space disposal is an attractive notion because it permanently removes nuclear waste from the environment. It has significant disadvantages, not least of which is the potential for catastrophic failure of a [launch vehicle](#) which would spread radioactive material into the atmosphere and around the world. The high number of launches that would be required (because no individual rocket would be able to carry very much of the material relative to the total which needs to be disposed of) makes the proposal impractical (for both economic and risk-based reasons). To further complicate matters, international agreements on the regulation of such a program would need to be established.

### **HYDEL POWER PLANT:**

**Hydroelectricity** is the term referring to [electricity](#) generated by [hydropower](#); the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of [renewable energy](#). Once a hydroelectric complex is constructed, the project produces no direct waste, and has a considerably lower output level of the [greenhouse gas carbon dioxide](#) (CO<sub>2</sub>) than [fossil fuel](#) powered energy plants. Worldwide, an installed capacity of 777 [GWe](#) supplied 2998 TWh of hydroelectricity in 2006. This was approximately 20% of

the world's electricity, and accounted for about 88% of electricity from renewable sources.

## **Conventional (dams)**

Most hydroelectric power comes from the [potential energy](#) of [dammed](#) water driving a [water turbine](#) and [generator](#). The power extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the [head](#). The amount of [potential energy](#) in water is proportional to the head. A large pipe (the ["penstock"](#)) delivers water to the turbine.

## **Pumped-storage**

This method produces electricity to supply high peak demands by moving water between [reservoirs](#) at different elevations. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine. Pumped-storage schemes currently provide the most commercially important means of large-scale [grid energy storage](#) and improve the daily [capacity factor](#) of the generation system.

## **Run-of-the-river**

Run-of-the-river hydroelectric stations are those with small or no reservoir capacity, so that the water coming from upstream must be used for generation at that moment, or must be allowed to bypass the dam.

## **Tide**

A [tidal power](#) plant makes use of the daily rise and fall of ocean water due to tides; such sources are highly predictable, and if conditions permit construction of reservoirs, can also be [dispatchable](#) to generate power during high demand periods.

Less common types of hydro schemes use water's [kinetic energy](#) or undammed sources such as undershot [waterwheels](#).

## Underground

An [underground power station](#) makes use of a large natural height difference between two waterways, such as a waterfall or mountain lake. An underground tunnel is constructed to take water from the high reservoir to the generating hall built in an underground cavern near the lowest point of the water tunnel and a horizontal tailrace taking water away to the lower outlet waterway.

### Sizes and capacities of hydroelectric facilities

#### Large and specialized industrial facilities



The [Three Gorges Dam](#) is the largest operating hydroelectric power station, at 22,500 MW.

Although no official definition exists for the capacity range of large hydroelectric power

stations, facilities from over a few hundred [megawatts](#) to more than 10 [GW](#) are generally considered large hydroelectric facilities. Currently, only three facilities over 10 [GW](#) (10,000 [MW](#)) are in operation worldwide; [Three Gorges Dam](#) at 22.5 GW, [Itaipu Dam](#) at 14 GW, and [Guri Dam](#) at 10.2 GW. Large-scale hydroelectric power stations are more commonly seen as the largest power producing facilities in the world, with some hydroelectric facilities capable of generating more than double the installed capacities of the current [largest nuclear power stations](#).

While many hydroelectric projects supply public electricity networks, some are created to serve specific [industrial](#) enterprises. Dedicated hydroelectric projects are often built to provide the substantial amounts of electricity needed for [aluminium](#) electrolytic plants, for example. The [Grand Coulee Dam](#) switched to support [Alcoa](#) aluminium in [Bellingham, Washington, United States](#) for American [World War II](#) airplanes before it was allowed to provide irrigation and power to citizens (in addition to aluminium power) after the war. In [Suriname](#), the [Brokopondo Reservoir](#) was constructed to provide electricity for the [Alcoa](#) aluminium industry. [New Zealand's Manapouri Power Station](#) was constructed to supply electricity to the [aluminium smelter](#) at [Tiwai Point](#).

The construction of these large hydroelectric facilities, and their changes on the environment, are also often on grand scales, creating as much damage to the environment as it helps it by being a [renewable resource](#). Many specialized organizations, such as the [International Hydropower Association](#), look into these matters on a global scale.

## **Small**

Small hydro is the development of [hydroelectric power](#) on a scale serving a small community or industrial plant. The definition of a small hydro project varies but a generating capacity of up to 10 [megawatts](#) (MW) is generally accepted as the upper limit of what can be termed small hydro. This may be stretched to 25 MW and 30 MW in [Canada](#) and the [United States](#). Small-scale hydroelectricity production grew by 28% during 2008 from 2005, raising the total world small-hydro capacity to 85 [GW](#). Over 70% of this was in [China](#) (65 GW), followed by [Japan](#) (3.5 GW), the [United States](#) (3

GW), and [India](#) (2 GW).<sup>[10]</sup>

Small hydro plants may be connected to conventional electrical distribution networks as a source of low-cost renewable energy. Alternatively, small hydro projects may be built in isolated areas that would be uneconomic to serve from a network, or in areas where there is no national electrical distribution network. Since

small hydro projects usually have minimal reservoirs and civil construction work, they are seen as having a relatively low environmental impact compared to large hydro. This decreased environmental impact depends strongly on the balance between stream flow and power production.

### **Micro**



A micro-hydro facility in [Vietnam](#)

Micro hydro is a term used for [hydroelectric power](#) installations that typically produce up to 100 [KW](#) of power. These installations can provide power to an isolated home or small community, or are sometimes connected to electric power networks. There are many of these installations around the world, particularly in developing nations as they can provide an economical source of energy without purchase of fuel. [\[11\]](#) Micro hydro systems complement [photovoltaic](#) solar energy systems because in many areas, water flow, and thus available hydro power, is highest in the winter when solar energy is at a minimum.

## Pico

Pico hydro is a term used for [hydroelectric power](#) generation of under 5 [KW](#). It is useful in small, remote communities that require only a small amount of electricity. For example, to power one or two fluorescent light bulbs and a TV or radio for a few homes. [\[12\]](#) Even smaller turbines of 200-300W may power a single home in a developing country with a drop of only 1 m (3 ft). Pico-hydro setups typically are [run-of-the-river](#), meaning that dams are not used, but rather pipes divert some of

the flow, drop this down a gradient, and through the turbine before returning it to the stream.

### Calculating the amount of available power

A simple formula for approximating electric power production at a hydroelectric plant is:  $P = \rho h r g k$ , where

- $P$  is Power in watts,
- $\rho$  is the density of water ( $\sim 1000 \text{ kg/m}^3$ ),
- $h$  is height in meters,
- $r$  is flow rate in cubic meters per second,
- $g$  is acceleration due to [gravity](#) of  $9.8 \text{ m/s}^2$ ,

- $k$  is a coefficient of efficiency ranging from 0 to 1. Efficiency is often higher (that is, closer to 1) with larger and more modern turbines.

Annual electric energy production depends on the available water supply. In some installations the water flow rate can vary by a factor of 10:1 over the course of a year.

### **Advantages and disadvantages of hydroelectricity**

#### **Advantages**



The [Ffestiniog Power Station](#) can generate 360 [MW](#) of electricity within 60 seconds of the demand arising.

#### **Economics**

The major advantage of hydroelectricity is elimination of the cost of fuel. The cost of operating a hydroelectric plant is nearly immune to increases in the cost of [fossil fuels](#) such as [oil](#), [natural gas](#) or [coal](#), and no imports are needed.

Hydroelectric plants have long economic lives, with some plants still in service after 50–100 years. <sup>[13]</sup> Operating labor cost is also usually low, as plants are automated and have few personnel on site during normal operation.

Where a dam serves multiple purposes, a hydroelectric plant may be added with relatively low construction cost, providing a useful revenue stream to offset the costs of dam

operation. It has been calculated that the sale of electricity from the [Three Gorges Dam](#) will cover the construction costs after 5 to 8 years of full generation. <sup>[14]</sup>

## **CO2 emissions**

Since hydroelectric dams do not burn fossil fuels, they do not directly produce [carbon dioxide](#). While some carbon dioxide is produced during manufacture and construction of the project, this is a tiny fraction of the operating emissions of equivalent fossil-fuel electricity generation. One measurement of greenhouse gas related and other externality comparison between energy sources can be found in the ExternE project by the [Paul Scherrer Institut](#) and the [University of Stuttgart](#) which was funded by the [European Commission](#). <sup>[15]</sup> According to that study, hydroelectricity produces the least amount of [greenhouse gases](#) and [externality](#) of any energy source. <sup>[16]</sup> Coming in second place was [wind](#), third was [nuclear energy](#), and fourth was [solar photovoltaic](#). <sup>[16]</sup> The extremely positive [greenhouse gas](#) impact of hydroelectricity is found especially in temperate climates. The above study was for local energy in [Europe](#); presumably similar conditions prevail in North America

and Northern Asia, which all see a regular, natural freeze/thaw cycle (with associated seasonal plant decay and regrowth).

## **Other uses of the reservoir**

Reservoirs created by hydroelectric schemes often provide facilities for [water sports](#), and become tourist attractions themselves. In some countries, [aquaculture](#) in reservoirs is common. [Multi-use dams](#) installed for [irrigation](#) support [agriculture](#) with a relatively constant water supply. Large hydro dams can control floods, which would otherwise affect people living downstream of the project.

## **Disadvantages**

### **Ecosystem damage and loss of land**





Hydroelectric power stations that use [dams](#) would submerge large areas of land due to the requirement of a [reservoir](#).

Large reservoirs required for the operation of hydroelectric power stations result in submersion of extensive areas upstream of the dams, destroying biologically rich and productive lowland and riverine valley forests, marshland and grasslands. The loss of land is often exacerbated by the fact that reservoirs cause [habitat fragmentation](#) of surrounding areas.

Hydroelectric projects can be disruptive to surrounding aquatic [ecosystems](#) both upstream and downstream of the plant site. For instance, studies have shown that

dams along the [Atlantic](#) and [Pacific](#) coasts of [North America](#) have reduced [salmon](#)

populations by preventing access to [spawning](#) grounds upstream, even though most dams in salmon habitat have [fish ladders](#) installed. Salmon spawn are also harmed on their migration to sea when they must pass through [turbines](#). This has led to some areas transporting smolt downstream by [barge](#) during parts of the year. In some cases dams, such as the [Marmot Dam](#), have been demolished due to the high impact on fish. <sup>[17]</sup> Turbine and power-plant designs that are easier on aquatic life are an active area of research. Mitigation measures such as fish ladders may be required at new projects or as a condition of re-licensing of existing projects.

Generation of hydroelectric power changes the downstream river environment. Water exiting a turbine usually contains very little suspended sediment, which can lead to scouring of river beds and loss of riverbanks. <sup>[18]</sup> Since turbine gates are often opened intermittently, rapid or even daily fluctuations in river flow are observed. For example, in the [Grand Canyon](#), the daily cyclic flow variation caused by [Glen Canyon Dam](#) was found to be contributing to erosion of sand bars. Dissolved [oxygen](#) content of the water may change from pre-construction conditions. Depending on the location, water exiting from turbines is typically much warmer than the pre-dam water, which can change aquatic faunal populations, including [endangered species](#), and prevent natural freezing processes from occurring. Some hydroelectric projects also use [canals](#) to divert a river at a shallower gradient to increase the head of the scheme. In some cases, the entire river may be diverted leaving a dry riverbed. Examples include the [Tekapo](#) and [Pukaki Rivers](#) in [New Zealand](#).

## **Siltation**

When water flows it has the ability to transport particles heavier than itself downstream. This has a negative effect on dams and subsequently their power stations, particularly those on rivers or within catchment areas with high siltation. [Siltation](#) can fill a reservoir and reduce its capacity to control floods along with causing additional horizontal pressure on the upstream portion of the dam.

Eventually, some reservoirs can become completely full of sediment and useless or over-

top during a flood and fail.<sup>[19][20]</sup> See [Risks to the Glen Canyon Dam](#) for a specific example.

## **Flow shortage**

Changes in the amount of river flow will correlate with the amount of energy produced by a dam. Lower river flows because of drought, climate change or upstream dams and diversions will reduce the amount of live storage in a reservoir therefore reducing the amount of water that can be used for hydroelectricity. The result of diminished river flow can be power shortages in areas that depend heavily on hydroelectric power.

## **Methane emissions (from reservoirs)**



The [Hoover Dam](#) in the [United States](#) is a large conventional dammed-hydro facility, with an installed capacity of 2,080 [MW](#).

See also: [Environmental impacts of reservoirs](#)

Lower positive impacts are found in the tropical regions, as it has been noted that the reservoirs of power plants in tropical regions may produce substantial amounts

of [methane](#). This is due to plant material in flooded areas decaying in an [anaerobic](#) environment, and forming methane, a potent [greenhouse gas](#). According to the [World Commission on Dams](#) report, <sup>[21]</sup> where the reservoir is large compared to the generating capacity (less than 100 watts per square metre of surface area) and no clearing of the forests in the area was undertaken prior to impoundment of the reservoir, greenhouse gas emissions from the reservoir may be higher than those of a conventional oil-fired thermal generation plant. <sup>[22]</sup> Although these emissions represent carbon already in the biosphere, not fossil deposits that had been sequestered from the carbon cycle, there is a greater amount of [methane](#) due to [anaerobic](#) decay, causing greater damage than would otherwise have occurred had the forest decayed naturally.

In [boreal](#) reservoirs of Canada and Northern Europe, however, greenhouse gas emissions are typically only 2% to 8% of any kind of conventional fossil-fuel thermal generation. A

new class of underwater logging operation that targets drowned forests can mitigate the effect of forest decay. [\[23\]](#)

In 2007, [International Rivers](#) accused hydropower firms of cheating with fake carbon credits under the [Clean Development Mechanism](#) for hydropower projects already finished or under construction at the moment they applied to join the CDM. These carbon credits – of hydropower projects under the CDM in developing countries – can be sold to companies and governments in rich countries, in order to comply with the [Kyoto protocol](#).

## **Relocation**

Another disadvantage of hydroelectric dams is the need to relocate the people living where the reservoirs are planned. In February 2008 it was estimated that 40-80 million people worldwide had been physically displaced as a direct result of dam construction. [\[25\]](#) In many cases, no amount of compensation can replace ancestral and cultural attachments to places that have spiritual value to the

displaced population. Additionally, historically and culturally important sites can be flooded and lost.

Such problems have arisen at the [Aswan Dam](#) in Egypt between 1960 and 1980, the [Three Gorges Dam](#) in China, the [Clyde Dam](#) in New Zealand, and the [Ilisu Dam](#) in Turkey.

## **Failure hazard**

Because large conventional dammed-hydro facilities hold back large volumes of water, a failure due to poor construction, terrorism, or other cause can be catastrophic to downriver settlements and infrastructure. Dam failures have been some of the largest man-made disasters in history. Also, good design and construction are not an adequate guarantee of safety. Dams are tempting industrial targets for wartime attack, [sabotage](#) and terrorism, such as [Operation Chastise](#) in [World War II](#).

The [Banqiao Dam](#) failure in Southern China directly resulted in the deaths of 26,000 people, and another 145,000 from epidemics. Millions were left homeless. Also, the creation of a dam in a geologically inappropriate location may cause disasters such as 1963 disaster at [Vajont Dam](#) in Italy, where almost 2000 people died.

Smaller dams and [micro hydro](#) facilities create less risk, but can form continuing hazards even after being decommissioned. For example, the small [Kelly Barnes Dam](#) failed in 1967, causing 39 deaths with the Toccoa Flood, ten years after its power plant was decommissioned. <sup>[</sup>

Most hydroelectric power comes from the [potential energy](#) of [dammed](#) water driving a [water turbine](#) and [generator](#). The power extracted from the water depends on the volume and on the difference in height between the source and the water's outflow. This height difference is called the [head](#). The amount of [potential energy](#)

in water is proportional to the head. A large pipe (the ["penstock"](#)) delivers water to the turbine.

## UNIT-IV DIESEL AND GAS TURBINE POWER PLANT

### DIESEL POWER PLANTS:

A **diesel generator** is the combination of a [diesel engine](#) with an [electrical generator](#) (often called an [alternator](#)) to generate electric energy. Diesel generating sets are used in places without connection to the [power grid](#) or as emergency power-supply if the grid fails. Small portable diesel generators range from about 1 kVA to 10 kVA may be used as power supplies on construction sites, or as auxiliary power for vehicles such as [mobile homes](#).

### Generator Rating Definitions

**Standby Rating based on** Applicable for supplying emergency power for the duration of

normal power interruption. No sustained overload capability is available for this rating. (Equivalent to Fuel Stop Power in accordance with ISO3046, AS2789, DIN6271 and BS5514). Nominally rated.

Typical application - emergency power plant in hospitals, offices, factories etc. Not connected to grid.

**Prime (Unlimited Running Time) Rating:** Should not be used for Construction Power applications. Output available with varying load for an unlimited time. Average power output is 70% of the prime rating. Typical peak demand 100% of prime-rated kW with 10% of overload capability for emergency use for a maximum of 1 hour in 12. A 10% overload capability is available for limited time. (Equivalent to Prime Power in accordance with ISO8528 and Overload Power in accordance with ISO3046, AS2789, DIN6271, and BS5514). This rating is not applicable to all generator set models.

Typical application - where the generator is the sole source of power for say a remote mining or construction site, fairground, festival etc.

**Base Load (Continuous) Rating based on:** Applicable for supplying power continuously to a constant load up to the full output rating for unlimited hours. No sustained overload capability is available for this rating. Consult authorized distributor for rating. (Equivalent to Continuous Power in accordance with ISO8528, ISO3046, AS2789, DIN6271, and BS5514). This rating is not applicable to all generator set models

Typical application - a generator running a continuous unvarying load, or paralleled with the mains and continuously feeding power at the maximum permissible level 8760 hours per year. This also applies to sets used for peak shaving /grid support even though this may only occur for say 200 hour per year.

As an example if in a particular set the Standby Rating were 1000 kW, then a Prime Power rating might be 850 kW, and the Continuous Rating 800 kW. However these ratings vary according to manufacturer and should be taken from the manufacturer's data sheet.

Often a set might be given all three ratings stamped on the data plate, but sometimes it may have only a standby rating, or only a prime rating.

### **Sizing**

Typically however it is the size of the maximum load that has to be connected and the acceptable maximum voltage drop which determines the set size, not the ratings themselves. If the set is required to start motors, then the set will have to be at least 3 times the largest motor, which is normally started first. This means it will be unlikely to operate at anywhere near the ratings of the chosen set.

Manufactures have sophisticated software that enables the correct choice of set for any given load combination.

### **GAS TURBINE POWER PLANT:**

A **gas turbine**, also called a **combustion turbine**, is a type of [internal combustion engine](#). It has an upstream rotating [compressor](#) coupled to a downstream [turbine](#), and a [combustion chamber](#) in-between.

[Energy](#) is added to the gas stream in the [combustor](#), where [fuel](#) is mixed with [air](#) and [ignited](#). In the high pressure environment of the combustor, combustion of the fuel increases the [temperature](#). The products of the combustion are forced into the turbine section. There, the high [velocity](#) and [volume](#) of the gas flow is directed through a [nozzle](#) over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas.

Energy can be extracted in the form of shaft power, compressed air or thrust or any combination of these and used to power [aircraft](#), [trains](#), [ships](#), [generators](#), or even [tanks](#).

### **Theory of operation**



Gasses passing through an ideal a gas turbine undergo three [thermodynamic](#) processes. These are [isentropic](#) compression, [isobaric](#) (constant pressure) combustion and isentropic expansion. Together these make up the [Brayton cycle](#).

In a practical gas turbine, gasses are first accelerated in either a centrifugal or radial [compressor](#). These gasses are then slowed using a diverging nozzle known as a [diffuser](#). these process increase the pressure and temperature of the flow. In an ideal system this is isentropic. However, in practice energy is lost to heat, due to friction and turbulence. Gasses then pass from the diffuser to a [combustion chamber](#), or similar device, where heat is added. In an ideal system this occurs at constant pressure (isobaric heat addition). As there is no change in pressure the [specific volume](#) of the gasses increases. In practical situations this process is usually

accompanied by a slight loss in pressure, due to friction. Finally, this larger volume of gasses is expanded and accelerated by nozzle guide vanes before energy is extracted by a [turbine](#). In an ideal system these are gasses expanded isentropically and leave the turbine at their original pressure. In practice this process is not isentropic as energy is once again lost to friction and turbulence.

If the device has been designed to power to a shaft as with an industrial generator or a [turboprop](#), the exit pressure will be as close to the entry pressure as possible. In practice it is necessary that some pressure remains at the outlet in order to fully expel the exhaust gasses. In the case of a [jet engine](#) only enough pressure and energy is extracted from the flow to drive the compressor and other components. The remaining high pressure gasses are accelerated to provide a jet that can, for example, be used to propel an aircraft.

### [Brayton cycle](#)

As with all cyclic [heat engines](#), higher combustion temperatures can allow for greater

[efficiencies](#). However, temperatures are limited by ability of the steel, nickel, ceramic, or other materials that make up the engine to withstand high temperatures and stresses. To combat this many turbines feature complex blade cooling systems.

As a general rule, the smaller the engine the higher the rotation rate of the shaft(s) needs to be to maintain tip speed. Blade tip speed determines the maximum pressure ratios that can be obtained by the turbine and the compressor. This in turn limits the maximum power and efficiency that can be obtained by the engine. In order for tip speed to remain constant, if the diameter of a rotor is reduced by half, the rotational speed must double. For example large [Jet engines](#) operate around 10,000 rpm, while [micro turbines](#) spin as fast as 500,000 rpm.

Mechanically, gas turbines can be considerably less complex than [internal combustion](#) piston engines. Simple turbines might have one moving part: the shaft/compressor/turbine/alternative-rotor assembly (see image above), not counting the fuel system. However, the required precision manufacturing for components and temperature resistant alloys necessary for high efficiency often make the construction of a simple turbine more complicated than piston engines.

More sophisticated turbines (such as those found in modern [jet engines](#)) may have multiple shafts (spools), hundreds of turbine blades, movable stator blades, and a vast system of complex piping, combustors and heat exchangers.

[Thrust bearings](#) and [journal bearings](#) are a critical part of design. Traditionally, they have been [hydrodynamic oil bearings](#), or oil-cooled [ball bearings](#). These bearings are being surpassed by [foil bearings](#), which have been successfully used in micro turbines and [auxiliary power units](#).

## **Types of gas turbines**

### **Jet engines**

Airbreathing [jet engines](#) are gas turbines optimized to produce thrust from the exhaust

gases, or from [ducted fans](#) connected to the gas turbines. Jet engines that produce thrust primarily from the direct impulse of exhaust gases are often called [turbojets](#), whereas those that generate most of their thrust from the action of a ducted fan are often called [turbofans](#) or (rarely) fan-jets.

Gas turbines are also used in many liquid propellant rockets, the gas turbines are used to power a [turbopump](#) to permit the use of lightweight, low pressure tanks, which saves considerable dry mass.

### **Aeroderivative gas turbines**

Aeroderivatives are also used in electrical power generation due to their ability to be shut down, and handle load changes more quickly than industrial machines.

They are also used in the marine industry to reduce weight. The [General Electric LM2500](#), [General Electric LM6000](#), [Rolls-Royce RB211](#) and [Rolls-Royce Avon](#) are common models of this type of machine.

### **Amateur gas turbines**

Increasing numbers of gas turbines are being used or even constructed by amateurs.

In its most straightforward form, these are commercial turbines acquired through military surplus or scrapyard sales, then operated for display as part of the hobby of engine collecting. In its most extreme form, amateurs have even rebuilt engines beyond professional repair and then used them to compete for the [Land Speed Record](#).

The simplest form of self-constructed gas turbine employs an automotive [turbocharger](#) as the core component. A combustion chamber is fabricated and plumbed between the compressor and turbine sections.

More sophisticated turbojets are also built, where their thrust and light weight are sufficient to power large model aircraft. The Schreckling design constructs the entire

engine from raw materials, including the fabrication of a centrifugal compressor wheel from plywood, epoxy and wrapped carbon fibre strands.

Like many technology based hobbies, they tend to give rise to manufacturing businesses over time. Several small companies now manufacture small turbines and parts for the amateur. Most turbojet-powered model aircraft are now using these commercial and semi-commercial microturbines, rather than a Schreckling-like home-build.

### **Auxiliary power units**

[APUs](#) are small gas turbines designed for auxiliary power of larger machines, such as those inside an [aircraft](#). They supply compressed air for aircraft ventilation (with an appropriate compressor design), start-up power for larger [jet engines](#), and electrical and hydraulic power.

### **Industrial gas turbines for power generation**

GE H series power generation gas turbine: in [combined cycle](#) configuration, this 480-[megawatt](#) unit has a rated [thermal efficiency](#) of 60%.

Industrial gas turbines differ from aeroderivative in that the frames, bearings, and blading is of heavier construction. Industrial gas turbines range in size from truck-mounted mobile plants to enormous, complex systems. [\[clarification needed\]](#) They can be particularly efficient—up to 60%—when waste heat from the gas turbine is recovered by a heat recovery steam generator to power a conventional steam turbine in a [combined cycle](#) configuration. They can also be run in a [cogeneration](#) configuration: the exhaust is used for space or water heating, or drives an [absorption chiller](#) for cooling or refrigeration. Such engines require a dedicated enclosure, both to protect the engine from the elements and the operators from the noise. [\[citation needed\]](#)

The construction process for gas turbines can take as little as several weeks to a few months, compared to years for [base load power plants](#). [\[citation needed\]](#) Their other main

advantage is the ability to be turned on and off within minutes, supplying power during peak demand. Since single cycle (gas turbine only) power plants are less efficient than combined cycle plants, they are usually used as [peaking power plants](#), which operate anywhere from several hours per day to a few dozen hours per year, depending on the electricity demand and the generating capacity of the region. In areas with a shortage of base load and [load following power plant](#) capacity or low fuel costs, a gas turbine power plant may regularly operate during most hours of the day. A large single cycle gas turbine typically produces 100 to 400 megawatts of power and have 35–40% [thermal efficiency](#).  
[\[15\]](#)

### **Compressed air energy storage**

One modern development seeks to improve efficiency in another way, by separating the compressor and the turbine with a compressed air store. In a conventional turbine, up to half the generated power is used driving the compressor. In a compressed air energy storage configuration, power, perhaps from a wind farm or bought on the open market at a time of low demand and low price, is used to drive the compressor, and the compressed air released to operate the turbine when required.

### **Turboshaft engines**

[Turboshaft](#) engines are often used to drive compression trains (for example in gas pumping stations or natural gas liquefaction plants) and are used to power almost all modern helicopters. The first shaft bears the compressor and the high speed turbine (often referred to as "Gas Generator" or "Ng"), while the second shaft bears the low speed turbine (or "Power Turbine" or "Nf" - the 'f' stands for 'free wheeling turbine' on helicopters specifically due to the fact that the gas generator turbine spins separately from the power turbine). This arrangement is used to increase speed and power output flexibility.

### **Radial gas turbines**

In 1963, [Jan Mowill](#) initiated the development at [Kongsberg Våpenfabrikk](#) in [Norway](#). Various successors have made good progress in the refinement of this mechanism. Owing

to a configuration that keeps heat away from certain bearings the durability of the machine is improved while the radial turbine is well matched in speed requirement.

### **Scale jet engines**

Scale jet engines are scaled down versions of this early full scale engine

Also known as miniature gas turbines or micro-jets.

With this in mind the pioneer of modern Micro-Jets, [Kurt Schreckling](#), produced one of the world's first Micro-Turbines, the FD3/67. This engine can produce up to 22 [newtons](#) of thrust, and can be built by most mechanically minded people with basic engineering tools, such as a [metal lathe](#).

## **UNIT-V OTHER POWER PLANTS AND ECONOMICS OF POWER PLANTS**

### **GEOTHERMAL POWER PLANT:**

**Geothermal electricity** is [electricity generated](#) from [geothermal energy](#). Technologies in use include dry steam power plants, flash steam power plants and binary cycle power plants. Geothermal electricity generation is currently used in 24 countries while [geothermal heating](#) is in use in 70 countries.

Estimates of the electricity generating potential of geothermal energy vary from 35 to 2000 GW. Current worldwide installed capacity is 10,715 [megawatts](#) (MW), with the largest capacity in the [United States](#) (3,086 MW), [Philippines](#), and [Indonesia](#).

Geothermal power is considered to be [sustainable](#) because the heat extraction is small compared with the Earth's heat content. The [emission intensity](#) of existing geothermal electric plants is on average 122 kg of CO<sub>2</sub> per megawatt-hour (MW·h) of electricity, about one-eighth of a conventional coal-fired plant.

### **OTEC:**

**Ocean thermal energy conversion (OTEC)** uses the difference between cooler deep and warmer shallow or surface [ocean](#) waters to run a [heat engine](#) and produce useful work, usually in the form of electricity.

A heat engine gives greater efficiency and power when run with a large [temperature](#) difference. In the oceans the temperature difference between surface and deep water is greatest in the [tropics](#), although still a modest 20°C to 25°C. It is therefore in the tropics that OTEC offers the greatest possibilities. OTEC has the

potential to offer global amounts of energy that are 10 to 100 times greater than other ocean energy options such as [wave power](#). OTEC plants can operate continuously providing a [base load](#) supply for an electrical power generation system.

The main technical challenge of OTEC is to generate significant amounts of power efficiently from small temperature differences. It is still considered an [emerging technology](#). Early OTEC systems were of 1 to 3% [thermal efficiency](#), well below the theoretical maximum for this temperature difference of between 6 and 7%. [\[2\]](#)

Current designs are expected to be closer to the maximum. The first operational system was built in Cuba in 1930 and generated 22 kW. Modern designs allow performance approaching the theoretical maximum [Carnot efficiency](#) and the largest built in 1999 by the USA generated 250 kW .

The most commonly used heat cycle for OTEC is the [Rankine cycle](#) using a low-pressure turbine. Systems may be either closed-cycle or open-cycle. Closed-cycle engines use working fluids that are typically thought of as [refrigerants](#) such as [ammonia](#) or [R-134a](#). Open-cycle engines use vapour from the [seawater](#) itself as the working fluid.

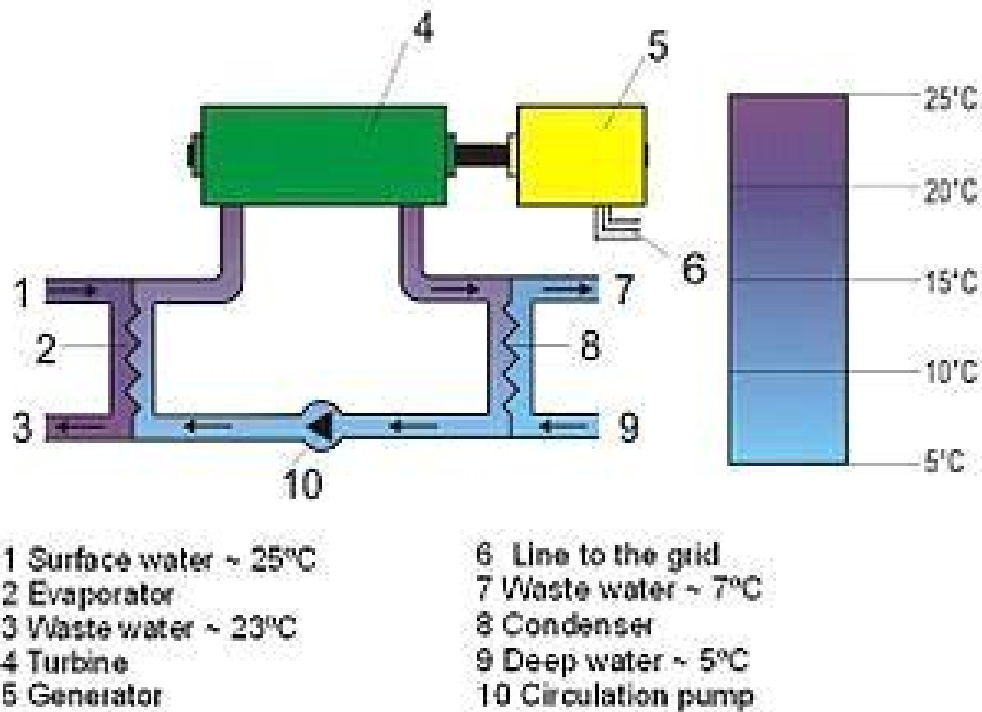
OTEC can also supply quantities of cold water as a by-product . This can be used for air conditioning and refrigeration and the fertile deep ocean water can feed biological technologies. Another by-product is fresh water distilled from the sea.

### **Cycle types**

Cold seawater is an integral part of each of the three types of OTEC systems: closed-cycle, open-cycle, and hybrid. To operate, the cold seawater must be brought to the surface. The primary approaches are active pumping and desalination. Desalinating seawater near the sea floor lowers its density, which causes it to rise to the surface.

The alternative to costly pipes to bring condensing cold water to the surface is to pump vaporized low boiling point fluid into the depths to be condensed, thus reducing pumping volumes and reducing technical and environmental problems and lowering costs.

### Closed



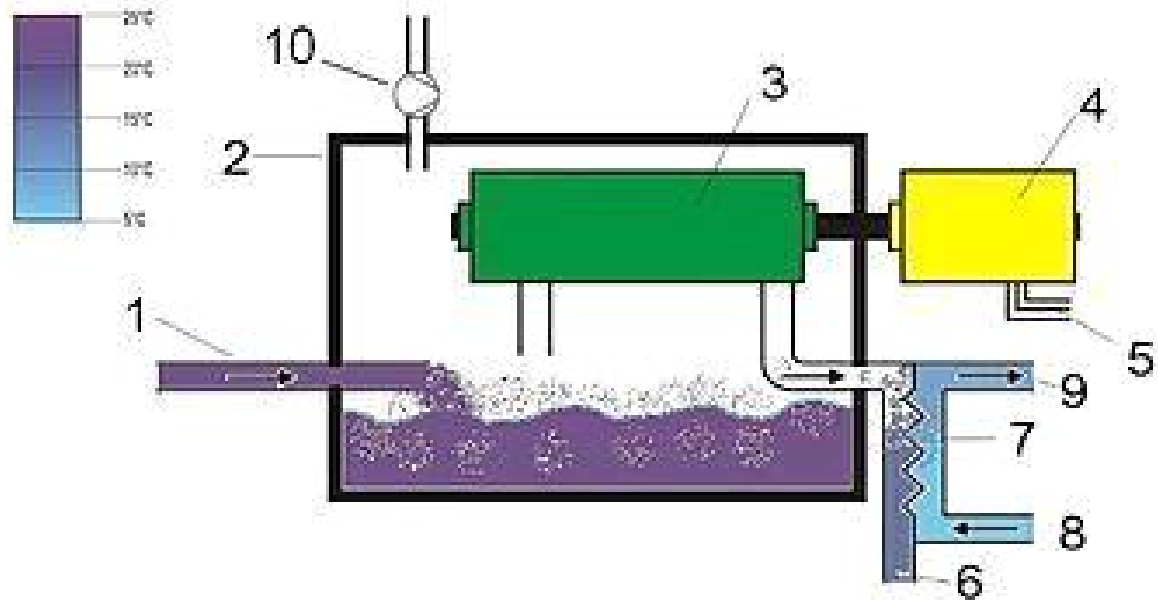


### Diagram of a closed cycle OTEC plant

Closed-cycle systems use fluid with a low boiling point, such as [ammonia](#), to power a [turbine](#) to generate electricity. Warm surface [seawater](#) is pumped through a [heat exchanger](#) to vaporize the fluid. The expanding vapor turns the turbo-generator. Cold water, pumped through a second heat exchanger, condenses the vapor into a liquid, which is then recycled through the system.

In 1979, the Natural Energy Laboratory and several private-sector partners developed the "mini OTEC" experiment, which achieved the first successful at-sea production of net electrical power from closed-cycle OTEC. [\[12\]](#) The mini OTEC vessel was moored 1.5 miles (2 km) off the Hawaiian coast and produced enough net electricity to illuminate the ship's light bulbs and run its computers and television.

**Open**



- 1 Surface water ~ 25°C
- 2 Vacuum chamber, 3 % to 1 % of atmospheric pressure
- 3 Turbine
- 4 Generator
- 5 Line to the grid

- 6 Desalinated water ~ 23°C
- 7 Condenser
- 8 Deep water ~ 5°C
- 9 Waste water ~ 7°C
- 10 Vacuum pump

### Diagram of an open cycle OTEC plant

Open-cycle OTEC uses warm surface water directly to make electricity. Placing warm seawater in a low-pressure container causes it to boil. The expanding [steam](#) drives a low-pressure turbine attached to an [electrical generator](#). The steam, which has left its [salt](#) and other contaminants in the low-pressure container, is pure [fresh water](#). It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces [desalinized](#) fresh water, suitable for [drinking water](#) or [irrigation](#).

In 1984, the *Solar Energy Research Institute* (now the [National Renewable Energy Laboratory](#)) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Conversion efficiencies were as high as 97% for seawater-to-steam conversion (overall efficiency using a vertical-spout evaporator would still only be a few per cent). In May 1993, an open-cycle OTEC

plant at Keahole Point, Hawaii, produced 50,000 [watts](#) of electricity during a net power-producing experiment. This broke the record of 40 kW set by a Japanese system in 1982.

### Hybrid

A hybrid cycle combines the features of the closed- and open-cycle systems. In a hybrid, warm seawater enters a vacuum chamber and is flash-evaporated, similar to the open-cycle evaporation process. The steam vaporizes the [ammonia](#) working fluid of a closed-cycle loop on the other side of an [ammonia](#) vaporizer. The vaporized fluid then drives a turbine to produce electricity. The steam condenses within the heat exchanger and provides [desalinated water](#).

### Working fluids

A popular choice of working fluid is [ammonia](#), which has superior transport properties, easy availability, and low cost. Ammonia, however, is toxic and flammable. Fluorinated carbons such as [asCFCs](#) and [HCFCs](#) are not toxic or flammable, but they contribute to ozone layer depletion. Hydrocarbons too are good candidates, but they are highly flammable; in addition, this would create competition for use of them directly as fuels. The power plant size is dependent upon the vapor pressure of the working fluid. With increasing vapor pressure, the size of the turbine and heat exchangers decreases while the wall thickness of the pipe and heat exchangers increase to endure high pressure especially on the evaporator side.

### **TIDEL POWER PLANT:**

**Tidal power**, also called **tidal energy**, is a form of [hydropower](#) that converts the energy of [tides](#) into electricity or other useful forms of power. The first large-scale tidal power plant (the [Rance Tidal Power Station](#)) started operation in 1966.

Although not yet widely used, tidal power has potential for future [electricity generation](#). Tides are more predictable than [wind energy](#) and [solar power](#). Among sources of [renewable energy](#), tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent technological developments and improvements, both in design (e.g. [dynamic tidal power](#), [tidal lagoons](#)) and turbine technology (e.g. new [axial turbines](#), [crossflow turbines](#)), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

Historically, [tide mills](#) have been used, both in Europe and on the Atlantic coast of North America. The earliest occurrences date from the [Middle Ages](#), or even from [Roman times](#).

Tidal power is extracted from the Earth's oceanic [tides](#); [tidal forces](#) are periodic variations in gravitational attraction exerted by celestial bodies. These forces create

corresponding motions or currents in the world's oceans. The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth, the [effects of Earth's rotation](#), and local [geography of the sea floor and coastlines](#).

Tidal power is the only technology that draws on energy inherent in the orbital characteristics of the [Earth– Moon](#) system, and to a lesser extent in the Earth– [Sun](#) system. Other natural energies exploited by human technology originate directly or indirectly with the Sun, including [fossil fuel](#), [conventional hydroelectric](#), [wind](#), [biofuel](#), [wave](#) and [solar energy](#). [Nuclear energy](#) makes use of Earth's mineral deposits of [fissionable](#) elements, while [geothermal power](#) taps the Earth's [internal heat](#), which comes from a combination of [residual heat from planetary accretion](#) (about 20%) and heat produced through [radioactive decay](#) (80%).

A tidal generator converts the energy of tidal flows into electricity. Greater tidal variation and higher tidal current velocities can dramatically increase the potential of a site for tidal electricity generation.

Because the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a [renewable energy](#) resource. Movement of tides causes a [loss of mechanical energy](#) in the Earth–Moon system: this is a result of pumping of water through natural restrictions around coastlines and consequent [viscous](#) dissipation at the [seabed](#) and in [turbulence](#). This loss of energy has caused the rotation of the Earth to slow in the 4.5 billion years since its formation. During the last 620 million years the period of rotation of the earth (length of a day) has increased from 21.9 hours to 24 hours; [\[4\]](#) in this period the Earth has lost 17% of its rotational energy. While tidal power may take additional energy from the system, the effect is negligible and would only be noticed over millions of years.

### **Generating methods**

The world's first commercial-scale and grid-connected tidal stream generator – SeaGen – in [Strangford Lough](#). The strong [wake](#) shows the power in the tidal current.

Top-down view of a DTP dam. Blue and dark red colors indicate low and high tides, respectively.

Tidal power can be classified into three generating methods:

### **Tidal stream generator**

Tidal stream generators (or TSGs) make use of the [kinetic energy](#) of moving water to power turbines, in a similar way to [wind turbines](#) that use moving air.

### **Tidal barrage**

Tidal barrages make use of the [potential energy](#) in the difference in height (or [head](#)) between high and low tides. Barrages are essentially [dams](#) across the full width of a tidal estuary.

### **Dynamic tidal power**

Dynamic tidal power (or DTP) is a theoretical generation technology that would exploit an interaction between potential and kinetic energies in tidal flows. It proposes that very long dams (for example: 30–50 km length) be built from coasts straight out into the sea or ocean, without enclosing an area. Tidal [phase differences](#) are introduced across the dam, leading to a significant water-level differential in shallow coastal seas – featuring strong coast-parallel oscillating tidal currents such as found in the UK, China and Korea.

### **PUMPED STORAGE:**

**Pumped-storage hydroelectricity** is a type of [hydroelectric power generation](#) used by some [power plants](#) for [load balancing](#). The method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through [turbines](#). Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases [revenue](#) by selling more electricity during periods of [peak demand](#), when electricity prices are highest. Pumped

storage is the largest-capacity form of [grid energy storage](#) now available.

### **SOLAR CENTRAL RECIVER SYSTEM:**

The **solar power tower** (also known as 'central tower' power plants or ['heliostat'](#) power plants or power towers) is a type of [solar furnace](#) using a tower to receive the focused sunlight. It uses an array of flat, movable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target). Concentrated solar thermal

is seen as one viable solution for renewable, pollution free energy production with currently available technology.

Early designs used these focused rays to heat water, and used the resulting [steam](#) to power a [turbine](#). Newer designs using liquid [sodium](#) has been demonstrated, and systems using molten salts (40% potassium nitrate, 60% sodium nitrate) as the working fluids are now in operation. These working fluids have high [heat capacity](#), which can be used to store the energy before using it to boil water to drive turbines. These designs allow power to be generated when the sun is not shining.

### **COST OF ELECTRICAL ENERGY:**

**Electric power transmission** or "high voltage electric transmission" is the bulk transfer of [electrical energy](#), from generating [power plants](#) to substations located near to population centers. This is distinct from the local wiring between high voltage substations and customers, which is typically referred to as [electricity distribution](#). Transmission lines, when interconnected with each other, become high voltage transmission networks. In the [US](#), these are typically referred to as "power grids" or just "the grid", while in the UK the network is known as the "national grid." [North America](#) has three major grids: The [Western Interconnection](#), The [Eastern Interconnection](#) and the [Electric Reliability Council of Texas](#) (or ERCOT) grid.

Historically, transmission and distribution lines were owned by the same company, but over the last decade or so many countries have [liberalized](#) the [electricity market](#) in ways

that have led to the separation of the electricity transmission business from the distribution business.

Transmission lines mostly use [three-phase alternating current](#) (AC), although [single phase](#) AC is sometimes used in [railway electrification systems](#). [High-voltage direct-current](#) (HVDC) technology is used only for very long distances (typically greater than 400 miles, or 600 km); [submarine power cables](#) (typically longer than 30 miles, or 50 km); or for connecting two AC networks that are not synchronized.

Electricity is transmitted at [high voltages](#) (110 kV or above) to reduce the energy lost in long distance transmission. Power is usually transmitted through [overhead power lines](#). Underground power transmission has a significantly higher cost and greater operational limitations but is sometimes used in urban areas or sensitive locations.

A key limitation in the distribution of electricity is that, with minor exceptions, electrical energy cannot be stored, and therefore must be generated as needed. A sophisticated system of control is therefore required to ensure electric generation very closely matches the demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout, such as occurred in [California](#) and the US Northwest in 1996 and in the US Northeast in 1965, 1977 and 2003. To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple [redundant](#) alternate routes for power to flow should (weather or equipment) failures occur. Much analysis is done by transmission companies to determine the maximum reliable capacity of each line which is mostly less than its physical or thermal limit, to ensure spare capacity is available should there be any such failure in another part of the network.

## **ENERGY RATES:**

**Electricity pricing** (sometimes referred to as **electricity tariff** or the **price of electricity**) varies widely from country to country, and may vary significantly from locality to locality



within a particular country. There are many reasons that account for these differences in price. The price of [power generation](#) depends largely on the type and [market price](#) of the fuel used, government subsidies, government and industry regulation, and even local weather patterns.

### **Basis of electricity rates**

Electricity prices vary all over the world, even within a single region or power-district of a single country. In standard [regulated monopoly](#) markets, they typically vary for residential, business, and industrial customers, and for any single customer class, might vary by [time-of-day](#) or by the capacity or nature of the supply circuit (e.g., 5 [kW](#), 12 kW, 18 kW, 24 kW are typical in some of the large developed countries); for industrial customers, single-phase vs. 3-phase, etc. If a specific market allows [real-time dynamic pricing](#), a more recent option in only a few markets to date, prices can vary by a factor of ten or so between times of low and high system-wide demand.

### **TYPES OF TARIFFS:**

In economic terms, [electricity](#) (both power and energy) is a [commodity](#) capable of being bought, sold and traded. An **electricity market** is a system for effecting purchases, through bids to buy; sales, through offers to sell; and [short-term trades](#), generally in the form of financial or obligation swaps. Bids and offers use [supply and demand](#) principles to set the price. Long-term trades are contracts similar to [power purchase agreements](#) and generally considered private bi-lateral transactions between counterparties.

Wholesale transactions (bids and offers) in electricity are typically cleared and settled by the market operator or a special-purpose independent entity charged exclusively with that function. Market operators do not clear trades but often require knowledge of the trade in order to maintain generation and load balance. The commodities within an electric market generally consist of two types: [Power](#) and [Energy](#). Power is the metered net electrical transfer rate at any given moment and is measured in [Megawatts](#) (MW). Energy is electricity that flows through a metered point for a given period and is measured in [Megawatt Hours](#) (MWh).

Markets for power related commodities are net generation output for a number of intervals usually in increments of 5, 15 and 60 minutes. Markets for energy related commodities required by, managed by (and paid for by) market operators to ensure

reliability, are considered Ancillary Services and include such names as spinning reserve, non-spinning reserve, [operating reserves](#), responsive reserve, regulation up, regulation down, and [installed capacity](#).

In addition, for most major operators, there are markets for transmission congestion and electricity [derivatives](#), such as electricity [futures](#) and [options](#), which are actively traded. These markets developed as a result of the restructuring