Steam engines are external combustion engines, where the working fluid is separate from the combustion products. Non-combustion heat sources such as solar power, nuclear power or geothermal energy may be used. The ideal thermodynamic cycle used to analyze this process is called the Rankine cycle. In the cycle, water is heated and transforms into steam within a boiler operating at a high pressure. When expanded through pistons or turbines, mechanical work is done. The reduced-pressure steam is then condensed and pumped back into the boiler.

The first commercially successful true engine, in that it could generate power and transmit it to a machine, was the atmospheric engine, invented by Thomas Newcomen around 1712. It was an improvement over Savery's steam pump, using a piston as proposed by Papin. Newcomen's engine was relatively inefficient, and in most cases was used for pumping water. It worked by creating a partial vacuum by condensing steam under a piston within a cylinder. It was employed for draining mine workings at depths hitherto impossible, and also for providing a reusable water supply for driving waterwheels at factories sited away from a suitable "head". Water that had passed over the wheel was pumped back up into a storage reservoir above the wheel.

The first full-scale working railway steam locomotive was built by Richard Trevithick in the United Kingdom and, on 21 February 1804, the world's first railway journey took place as Trevithick's unnamed steam locomotive hauled a train along the tramway from the Pen-y-darren ironworks, near Merthyr Tydfil to Abercynon in south Wales. The design incorporated a number of important innovations that included using high-pressure steam which reduced the weight of the engine and increased its efficiency. Trevithick visited the Newcastle area later in 1804 and the colliery railways in north-east England became the leading centre for experimentation and development of steam locomotives.

The Rankine cycle and most practical steam engines have a water pump to recycle or top up the boiler water, so that they may be run continuously. Utility and industrial boilers commonly use multi-stage centrifugal pumps; however, other types are used. Another means of supplying lower-pressure boiler feed water is an injector, which uses a steam jet usually supplied from the boiler. Injectors became popular in the 1850s but are no longer widely used, except in applications such as steam locomotives.

It is a logical extension of the compound engine (described above) to split the expansion into yet more stages to increase efficiency. The result is the multiple expansion engine. Such engines use either three or four expansion stages and are known as triple and quadruple expansion engines respectively. These engines use a series of cylinders of progressively increasing diameter. These cylinders are designed to divide the work into equal shares for each expansion stage. As with the double expansion engine, if space is at a premium, then two smaller cylinders may be used for the low-pressure stage. Multiple expansion engines typically had the cylinders arranged inline, but various other formations were used. In the late 19th century, the Yarrow-Schlick-Tweedy balancing 'system' was used on some marine triple expansion engines. Y-S-T engines divided the low-pressure expansion stages between two cylinders, one at each end of the engine. This allowed the crankshaft to be better balanced, resulting in a smoother, faster-responding engine which ran with less vibration. This made the 4-cylinder triple-expansion engine popular with large passenger liners (such as the Olympic class), but this was ultimately replaced by the virtually vibration-free turbine engine.[citation needed]

In the 1840s and 50s, there were attempts to overcome this problem by means of various patent valve gears with a separate, variable cutoff expansion valve riding on the back of the main slide valve; the latter usually had fixed or limited cutoff. The combined setup gave a fair approximation of the ideal events, at the expense of increased friction and wear, and the mechanism tended to be complicated. The usual compromise solution has been to provide lap by lengthening rubbing surfaces of the valve in such a way as to overlap the port on the admission side, with the effect that the exhaust side remains open for a longer period after cut-off on the admission side has occurred. This expedient has since been generally considered satisfactory for most purposes and makes possible the use of the simpler Stephenson, Joy and Walschaerts motions. Corliss, and later, poppet valve gears had separate admission and exhaust valves driven by trip mechanisms or cams profiled so as to give ideal events; most of these gears never succeeded outside of the stationary marketplace due to various other issues including leakage and more delicate mechanisms.

Lead fusible plugs may be present in the crown of the boiler's firebox. If the water level drops, such that the temperature of the firebox crown increases significantly, the lead melts and the steam escapes, warning the operators, who may then manually suppress the fire. Except in the smallest of boilers the steam escape has little effect on dampening the fire. The plugs are also too small in area to lower steam pressure significantly, depressurizing the boiler. If they were any larger, the volume of escaping steam would itself endanger the crew.[citation needed]

In 1781 James Watt patented a steam engine that produced continuous rotary motion. Watt's ten-horsepower engines enabled a wide range of manufacturing machinery to be powered. The engines could be sited anywhere that water and coal or wood fuel could be obtained. By 1883, engines that could provide 10,000 hp had become feasible. The stationary steam engine was a key component of the Industrial Revolution, allowing factories to locate where water power was unavailable. The atmospheric engines of Newcomen and Watt were large compared to the amount of power they produced, but high pressure steam engines were light enough to be applied to vehicles such as traction engines and the railway locomotives.

The history of the steam engine stretches back as far as the first century AD; the first recorded rudimentary steam engine being the aeolipile described by Greek mathematician Hero of Alexandria. In the following centuries, the few steam-powered "engines" known were, like the aeolipile, essentially experimental devices used by inventors to demonstrate the properties of steam. A rudimentary steam turbine device was described by Taqi al-Din in 1551 and by Giovanni Branca in 1629. Jerónimo de Ayanz y Beaumont received patents in 1606 for fifty steam powered inventions, including a water pump for draining inundated mines. Denis Papin, a Huguenot refugee, did some useful work on the steam digester in 1679, and first used a piston to raise weights in 1690.

Near the end of the 19th century compound engines came into widespread use. Compound engines exhausted steam in to successively larger cylinders to accommodate the higher volumes at reduced pressures, giving improved efficiency. These stages were called expansions, with double and triple expansion engines being common, especially in shipping where efficiency was important to reduce the weight of coal carried. Steam engines remained the dominant source of power until the early 20th century, when advances in the design of electric motors and internal combustion engines gradually resulted in the replacement of reciprocating (piston) steam engines, with shipping in the 20th-century relying upon the steam turbine.

The final major evolution of the steam engine design was the use of steam turbines starting in the late part of the 19th century. Steam turbines are generally more efficient than reciprocating piston type steam engines (for outputs above several hundred horsepower), have fewer moving parts, and provide rotary power directly instead of through a connecting rod system or similar means. Steam turbines virtually replaced reciprocating engines in electricity generating stations early in the 20th century, where their efficiency, higher speed appropriate to generator service, and smooth rotation were advantages. Today most electric power is provided by steam turbines. In the United States 90% of the electric power is produced in this way using a variety of heat sources. Steam turbines were extensively applied for propulsion of large ships throughout most of the 20th century.

The heat required for boiling the water and supplying the steam can be derived from various sources, most commonly from burning combustible materials with an appropriate supply of air in a closed space (called variously combustion chamber, firebox). In some cases the heat source is a nuclear reactor, geothermal energy, solar energy or waste heat from an internal combustion engine or industrial process. In the case of model or toy steam engines, the heat source can be an electric heating element.

The most useful instrument for analyzing the performance of steam engines is the steam engine indicator. Early versions were in use by 1851, but the most successful indicator was developed for the high speed engine inventor and manufacturer Charles Porter by Charles Richard and exhibited at London Exhibition in 1862. The steam engine indicator traces on paper the pressure in the cylinder throughout the cycle, which can be used to spot various problems and calculate developed horsepower. It was routinely used by engineers, mechanics and insurance inspectors. The engine indicator can also be used on internal combustion engines. See image of indicator diagram below (in Types of motor units section).

With two-cylinder compounds used in railway work, the pistons are connected to the cranks as with a two-cylinder simple at 90° out of phase with each other (quartered). When the double expansion group is duplicated, producing a 4-cylinder compound, the individual pistons within the group are usually balanced at 180°, the groups being set at 90° to each other. In one case (the first type of Vauclain compound), the pistons worked in the same phase driving a common crosshead and crank, again set at 90° as for a two-cylinder engine. With the 3-cylinder compound arrangement, the LP cranks were either set at 90° with the HP one at 135° to the other two, or in some cases all three cranks were set at 120°.[citation needed]

In most reciprocating piston engines, the steam reverses its direction of flow at each stroke (counterflow), entering and exhausting from the cylinder by the same port. The complete engine cycle occupies one rotation of the crank and two piston strokes; the cycle also comprises four events – admission, expansion, exhaust, compression. These events are controlled by valves often working inside a steam chest adjacent to the cylinder; the valves distribute the steam by opening and closing steam ports communicating with the cylinder end(s) and are driven by valve gear, of which there are many types.[citation needed]

Uniflow engines attempt to remedy the difficulties arising from the usual counterflow cycle where, during each stroke, the port and the cylinder walls will be cooled by the passing exhaust steam, whilst the hotter incoming admission steam will waste some of its energy in restoring working temperature. The aim of the uniflow is to remedy this defect and improve efficiency by providing an additional port uncovered by the piston at the end of each stroke making the steam flow only in one direction. By this means, the simple-expansion uniflow engine gives efficiency equivalent to that of classic compound systems with the added advantage of superior part-load performance, and comparable efficiency to turbines for smaller engines below one thousand horsepower. However, the thermal expansion gradient uniflow engines produce along the cylinder wall gives practical difficulties.[citation needed]. The Quasiturbine is a uniflow rotary steam engine where steam intakes in hot areas, while exhausting in cold areas.

An oscillating cylinder steam engine is a variant of the simple expansion steam engine which does not require valves to direct steam into and out of the cylinder. Instead of valves, the entire cylinder rocks, or oscillates, such that one or more holes in the cylinder line up with holes in a fixed port face or in the pivot mounting (trunnion). These engines are mainly used in toys and models, because of their simplicity, but have also been used in full size working engines, mainly on ships where their compactness is valued.[citation needed]

The working fluid in a Rankine cycle can operate as a closed loop system, where the working fluid is recycled continuously, or may be an "open loop" system, where the exhaust steam is directly released to the atmosphere, and a separate source of water feeding the boiler is supplied. Normally water is the fluid of choice due to its favourable properties, such as non-toxic and unreactive chemistry, abundance, low cost, and its thermodynamic properties. Mercury is the working fluid in the mercury vapor turbine. Low boiling hydrocarbons can be used in a binary cycle.

The efficiency of a Rankine cycle is usually limited by the working fluid. Without the pressure reaching supercritical levels for the working fluid, the temperature range the cycle can operate over is quite small; in steam turbines, turbine entry temperatures are typically 565 °C (the creep limit of stainless steel) and condenser temperatures are around 30 °C. This gives a theoretical Carnot efficiency of about 63% compared with an actual efficiency of 42% for a modern coal-fired power station. This low turbine entry temperature (compared with a gas turbine) is why the Rankine cycle is often used as a bottoming cycle in combined-cycle gas turbine power stations.[citation needed]

Steam engines can be said to have been the moving force behind the Industrial Revolution and saw widespread commercial use driving machinery in factories, mills and mines; powering pumping stations; and propelling transport appliances such as railway locomotives, ships, steamboats and road vehicles. Their use in agriculture led to an increase in the land available for cultivation. There have at one time or another been steam-powered farm tractors, motorcycles (without much success) and even automobiles as the Stanley Steamer.

Trevithick continued his own experiments using a trio of locomotives, concluding with the Catch Me Who Can in 1808. Only four years later, the successful twin-cylinder locomotive Salamanca by Matthew Murray was used by the edge railed rack and pinion Middleton Railway. In 1825 George Stephenson built the Locomotion for the Stockton and Darlington Railway. This was the first public steam railway in the world and then in 1829, he built The Rocket which was entered in and won the Rainhill Trials. The Liverpool and Manchester Railway opened in 1830 making exclusive use of steam power for both passenger and freight trains.

A method to lessen the magnitude of this heating and cooling was invented in 1804 by British engineer Arthur Woolf, who patented his Woolf high-pressure compound engine in 1805. In the compound engine, high-pressure steam from the boiler expands in a high-pressure (HP) cylinder and then enters one or more subsequent lower-pressure (LP) cylinders. The complete expansion of the steam now occurs across multiple cylinders and as less expansion now occurs in each cylinder less heat is lost by the steam in each. This reduces the magnitude of cylinder heating and cooling, increasing the efficiency of the engine. By staging the expansion in multiple cylinders, torque variability can be reduced. To derive equal work from lower-pressure steam requires a larger cylinder volume as this steam occupies a greater volume. Therefore, the bore, and often the stroke, are increased in low-pressure cylinders resulting in larger cylinders.

The main use for steam turbines is in electricity generation (in the 1990s about 90% of the world's electric production was by use of steam turbines) however the recent widespread application of large gas turbine units and typical combined cycle power plants has resulted in reduction of this percentage to the 80% regime for steam turbines. In electricity production, the high speed of turbine rotation matches well with the speed of modern electric generators, which are typically direct connected to their driving turbines. In marine service, (pioneered on the Turbinia), steam turbines with reduction gearing (although the Turbinia has direct turbines to propellers with no reduction gearbox) dominated large ship propulsion throughout the late 20th century, being more efficient (and requiring far less maintenance) than reciprocating steam engines. In recent decades, reciprocating Diesel engines, and gas turbines, have almost entirely supplanted steam propulsion for marine applications.

The Rankine cycle is the fundamental thermodynamic underpinning of the steam engine. The cycle is an arrangement of components as is typically used for simple power production, and utilizes the phase change of water (boiling water producing steam, condensing exhaust steam, producing liquid water)) to provide a practical heat/power conversion system. The heat is supplied externally to a closed loop with some of the heat added being converted to work and the waste heat being removed in a condenser. The Rankine cycle is used in virtually all steam power production applications. In the 1990s, Rankine steam cycles generated about 90% of all electric power used throughout the world, including virtually all solar, biomass, coal and nuclear power plants. It is named after William John Macquorn Rankine, a Scottish polymath.

The historical measure of a steam engine's energy efficiency was its "duty". The concept of duty was first introduced by Watt in order to illustrate how much more efficient his engines were over the earlier Newcomen designs. Duty is the number of foot-pounds of work delivered by burning one bushel (94 pounds) of coal. The best examples of Newcomen designs had a duty of about 7 million, but most were closer to 5 million. Watt's original low-pressure designs were able to deliver duty as high as 25 million, but averaged about 17. This was a three-fold improvement over the average Newcomen design. Early Watt engines equipped with high-pressure steam improved this to 65 million.

Reciprocating piston type steam engines remained the dominant source of power until the early 20th century, when advances in the design of electric motors and internal combustion engines gradually resulted in the replacement of reciprocating (piston) steam engines in commercial usage, and the ascendancy of steam turbines in power generation. Considering that the great majority of worldwide electric generation is produced by turbine type steam engines, the "steam age" is continuing with energy levels far beyond those of the turn of the 19th century.

The first commercial steam-powered device was a water pump, developed in 1698 by Thomas Savery. It used condensing steam to create a vacuum which was used to raise water from below, then it used steam pressure to raise it higher. Small engines were effective though larger models were problematic. They proved only to have a limited lift height and were prone to boiler explosions. It received some use in mines, pumping stations and for supplying water wheels used to power textile machinery. An attractive feature of the Savery engine was its low cost. Bento de Moura Portugal introduced an ingenious improvement of Savery's construction "to render it capable of working itself", as described by John Smeaton in the Philosophical Transactions published in 1751. It continued to be manufactured until the late 18th century. One engine was still known to be operating in 1820.

Around 1800 Richard Trevithick and, separately, Oliver Evans in 1801 introduced engines using high-pressure steam; Trevithick obtained his high-pressure engine patent in 1802. These were much more powerful for a given cylinder size than previous engines and could be made small enough for transport applications. Thereafter, technological developments and improvements in manufacturing techniques (partly brought about by the adoption of the steam engine as a power source) resulted in the design of more efficient engines that could be smaller, faster, or more powerful, depending on the intended application.

Although the reciprocating steam engine is no longer in widespread commercial use, various companies are exploring or exploiting the potential of the engine as an alternative to internal combustion engines. The company Energiprojekt AB in Sweden has made progress in using modern materials for harnessing the power of steam. The efficiency of Energiprojekt's steam engine reaches some 27-30% on high-pressure engines. It is a single-step, 5-cylinder engine (no compound) with superheated steam and consumes approx. 4 kg (8.8 lb) of steam per kWh.[not in citation given]

Where CHP is not used, steam turbines in power stations use surface condensers as a cold sink. The condensers are cooled by water flow from oceans, rivers, lakes, and often by cooling towers which evaporate water to provide cooling energy removal. The resulting condensed hot water output from the condenser is then put back into the boiler via a pump. A dry type cooling tower is similar to an automobile radiator and is used in locations where water is costly. Evaporative (wet) cooling towers use the rejected heat to evaporate water; this water is kept separate from the condensate, which circulates in a closed system and returns to the boiler. Such towers often have visible plumes due to the evaporated water condensing into droplets carried up by the warm air. Evaporative cooling towers need less water flow than "once-through" cooling by river or lake water; a 700 megawatt coal-fired power plant may use about 3600 cubic metres of make-up water every hour for evaporative cooling, but would need about twenty times as much if cooled by river water.[citation needed]

The centrifugal governor was adopted by James Watt for use on a steam engine in 1788 after Watt’s partner Boulton saw one at a flour mill Boulton & Watt were building. The governor could not actually hold a set speed, because it would assume a new constant speed in response to load changes. The governor was able to handle smaller variations such as those caused by fluctuating heat load to the boiler. Also, there was a tendency for oscillation whenever there was a speed change. As a consequence, engines equipped only with this governor were not suitable for operations requiring constant speed, such as cotton spinning. The governor was improved over time and coupled with variable steam cut off, good speed control in response to changes in load was attainable near the end of the 19th century.

The adoption of compounding was common for industrial units, for road engines and almost universal for marine engines after 1880; it was not universally popular in railway locomotives where it was often perceived as complicated. This is partly due to the harsh railway operating environment and limited space afforded by the loading gauge (particularly in Britain, where compounding was never common and not employed after 1930). However, although never in the majority, it was popular in many other countries.

The simplest valve gears give events of fixed length during the engine cycle and often make the engine rotate in only one direction. Most however have a reversing mechanism which additionally can provide means for saving steam as speed and momentum are gained by gradually "shortening the cutoff" or rather, shortening the admission event; this in turn proportionately lengthens the expansion period. However, as one and the same valve usually controls both steam flows, a short cutoff at admission adversely affects the exhaust and compression periods which should ideally always be kept fairly constant; if the exhaust event is too brief, the totality of the exhaust steam cannot evacuate the cylinder, choking it and giving excessive compression ("kick back").[citation needed]

Using boiling water to produce mechanical motion goes back over 2000 years, but early devices were not practical. The Spanish inventor Jerónimo de Ayanz y Beaumont obtained the first patent for a steam engine in 1606. In 1698 Thomas Savery patented a steam pump that used steam in direct contact with the water being pumped. Savery's steam pump used condensing steam to create a vacuum and draw water into a chamber, and then applied pressurized steam to further pump the water. Thomas Newcomen's atmospheric engine was the first commercial true steam engine using a piston, and was used in 1712 for pumping in a mine.

A steam turbine consists of one or more rotors (rotating discs) mounted on a drive shaft, alternating with a series of stators (static discs) fixed to the turbine casing. The rotors have a propeller-like arrangement of blades at the outer edge. Steam acts upon these blades, producing rotary motion. The stator consists of a similar, but fixed, series of blades that serve to redirect the steam flow onto the next rotor stage. A steam turbine often exhausts into a surface condenser that provides a vacuum. The stages of a steam turbine are typically arranged to extract the maximum potential work from a specific velocity and pressure of steam, giving rise to a series of variably sized high- and low-pressure stages. Turbines are only efficient if they rotate at relatively high speed, therefore they are usually connected to reduction gearing to drive lower speed applications, such as a ship's propeller. In the vast majority of large electric generating stations, turbines are directly connected to generators with no reduction gearing. Typical speeds are 3600 revolutions per minute (RPM) in the USA with 60 Hertz power, 3000 RPM in Europe and other countries with 50 Hertz electric power systems. In nuclear power applications the turbines typically run at half these speeds, 1800 RPM and 1500 RPM. A turbine rotor is also only capable of providing power when rotating in one direction. Therefore, a reversing stage or gearbox is usually required where power is required in the opposite direction.[citation needed]

The weight of boilers and condensers generally makes the power-to-weight ratio of a steam plant lower than for internal combustion engines. For mobile applications steam has been largely superseded by internal combustion engines or electric motors. However, most electric power is generated using steam turbine plant, so that indirectly the world's industry is still dependent on steam power. Recent concerns about fuel sources and pollution have incited a renewed interest in steam both as a component of cogeneration processes and as a prime mover. This is becoming known as the Advanced Steam movement.[citation needed]

It is possible to use a mechanism based on a pistonless rotary engine such as the Wankel engine in place of the cylinders and valve gear of a conventional reciprocating steam engine. Many such engines have been designed, from the time of James Watt to the present day, but relatively few were actually built and even fewer went into quantity production; see link at bottom of article for more details. The major problem is the difficulty of sealing the rotors to make them steam-tight in the face of wear and thermal expansion; the resulting leakage made them very inefficient. Lack of expansive working, or any means of control of the cutoff is also a serious problem with many such designs.[citation needed]

The next major step occurred when James Watt developed (1763–1775) an improved version of Newcomen's engine, with a separate condenser. Boulton and Watt's early engines used half as much coal as John Smeaton's improved version of Newcomen's. Newcomen's and Watt's early engines were "atmospheric". They were powered by air pressure pushing a piston into the partial vacuum generated by condensing steam, instead of the pressure of expanding steam. The engine cylinders had to be large because the only usable force acting on them was due to atmospheric pressure.

Steam engines frequently possess two independent mechanisms for ensuring that the pressure in the boiler does not go too high; one may be adjusted by the user, the second is typically designed as an ultimate fail-safe. Such safety valves traditionally used a simple lever to restrain a plug valve in the top of a boiler. One end of the lever carried a weight or spring that restrained the valve against steam pressure. Early valves could be adjusted by engine drivers, leading to many accidents when a driver fastened the valve down to allow greater steam pressure and more power from the engine. The more recent type of safety valve uses an adjustable spring-loaded valve, which is locked such that operators may not tamper with its adjustment unless a seal illegally is broken. This arrangement is considerably safer.[citation needed]

The acme of the horizontal engine was the Corliss steam engine, patented in 1849, which was a four-valve counter flow engine with separate steam admission and exhaust valves and automatic variable steam cutoff. When Corliss was given the Rumford medal the committee said that "no one invention since Watt's time has so enhanced the efficiency of the steam engine". In addition to using 30% less steam, it provided more uniform speed due to variable steam cut off, making it well suited to manufacturing, especially cotton spinning.

The steam engine contributed much to the development of thermodynamic theory; however, the only applications of scientific theory that influenced the steam engine were the original concepts of harnessing the power of steam and atmospheric pressure and knowledge of properties of heat and steam. The experimental measurements made by Watt on a model steam engine led to the development of the separate condenser. Watt independently discovered latent heat, which was confirmed by the original discoverer Joseph Black, who also advised Watt on experimental procedures. Watt was also aware of the change in the boiling point of water with pressure. Otherwise, the improvements to the engine itself were more mechanical in nature. The thermodynamic concepts of the Rankine cycle did give engineers the understanding needed to calculate efficiency which aided the development of modern high-pressure and -temperature boilers and the steam turbine.

One of the principal advantages the Rankine cycle holds over others is that during the compression stage relatively little work is required to drive the pump, the working fluid being in its liquid phase at this point. By condensing the fluid, the work required by the pump consumes only 1% to 3% of the turbine power and contributes to a much higher efficiency for a real cycle. The benefit of this is lost somewhat due to the lower heat addition temperature. Gas turbines, for instance, have turbine entry temperatures approaching 1500 °C. Nonetheless, the efficiencies of actual large steam cycles and large modern gas turbines are fairly well matched.[citation needed]

Other components are often present; pumps (such as an injector) to supply water to the boiler during operation, condensers to recirculate the water and recover the latent heat of vaporisation, and superheaters to raise the temperature of the steam above its saturated vapour point, and various mechanisms to increase the draft for fireboxes. When coal is used, a chain or screw stoking mechanism and its drive engine or motor may be included to move the fuel from a supply bin (bunker) to the firebox. See: Mechanical stoker

Land-based steam engines could exhaust much of their steam, as feed water was usually readily available. Prior to and during World War I, the expansion engine dominated marine applications where high vessel speed was not essential. It was however superseded by the British invention steam turbine where speed was required, for instance in warships, such as the dreadnought battleships, and ocean liners. HMS Dreadnought of 1905 was the first major warship to replace the proven technology of the reciprocating engine with the then-novel steam turbine.[citation needed]

Virtually all nuclear power plants generate electricity by heating water to provide steam that drives a turbine connected to an electrical generator. Nuclear-powered ships and submarines either use a steam turbine directly for main propulsion, with generators providing auxiliary power, or else employ turbo-electric transmission, where the steam drives a turbo generator set with propulsion provided by electric motors. A limited number of steam turbine railroad locomotives were manufactured. Some non-condensing direct-drive locomotives did meet with some success for long haul freight operations in Sweden and for express passenger work in Britain, but were not repeated. Elsewhere, notably in the U.S.A., more advanced designs with electric transmission were built experimentally, but not reproduced. It was found that steam turbines were not ideally suited to the railroad environment and these locomotives failed to oust the classic reciprocating steam unit in the way that modern diesel and electric traction has done.[citation needed]

The Rankine cycle is sometimes referred to as a practical Carnot cycle because, when an efficient turbine is used, the TS diagram begins to resemble the Carnot cycle. The main difference is that heat addition (in the boiler) and rejection (in the condenser) are isobaric (constant pressure) processes in the Rankine cycle and isothermal (constant temperature) processes in the theoretical Carnot cycle. In this cycle a pump is used to pressurize the working fluid which is received from the condenser as a liquid not as a gas. Pumping the working fluid in liquid form during the cycle requires a small fraction of the energy to transport it compared to the energy needed to compress the working fluid in gaseous form in a compressor (as in the Carnot cycle). The cycle of a reciprocating steam engine differs from that of turbines because of condensation and re-evaporation occurring in the cylinder or in the steam inlet passages.