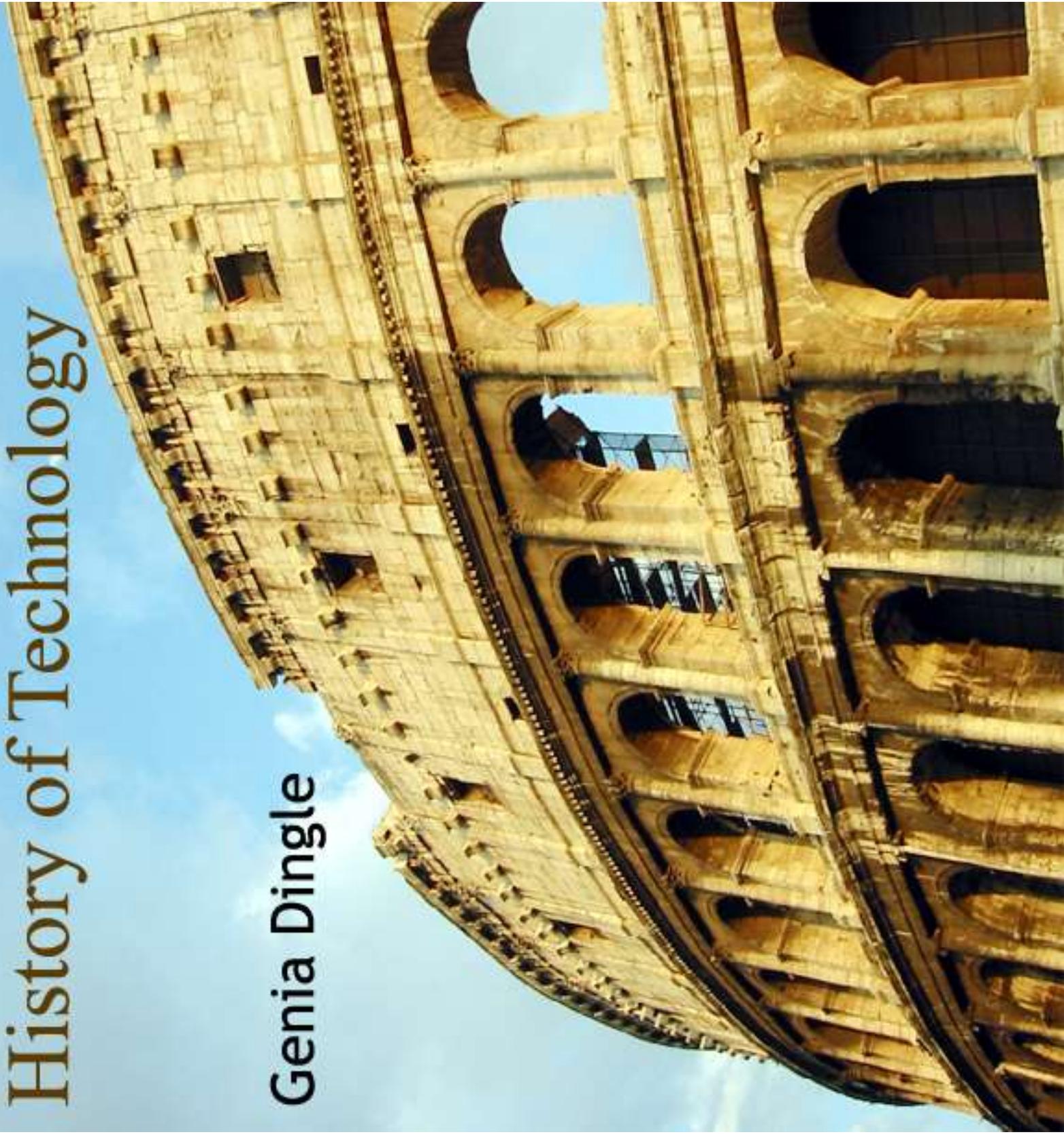


History of Technology

Genia Dingle



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WWT

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WORLD TECHNOLOGIES

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Chapter- 1

Roman Technology



The Pont du Gard in France is a Roman aqueduct built in ca. 19 BC.



Mercury gilded statue - Marcus Aurelius

Roman technology is the engineering practice which supported Roman civilization and made the expansion of Roman commerce and Roman military possible over nearly a thousand years.

The Roman Empire had the most advanced set of technologies of its time, some of which was lost during the turbulent eras of Late Antiquity and the early Middle Ages. Gradually, some of the technological feats of the Romans were rediscovered and/or improved upon, while others went ahead of what the Romans had done during the Middle Ages and the beginning of the Modern Era. Several Roman technological feats in different areas like civil engineering, construction materials, transport technology, and

some inventions such as the mechanical reaper, were surprising achievements until the 19th century, and some, such as the arch, have remained untouched to this day.

Innovation and progress

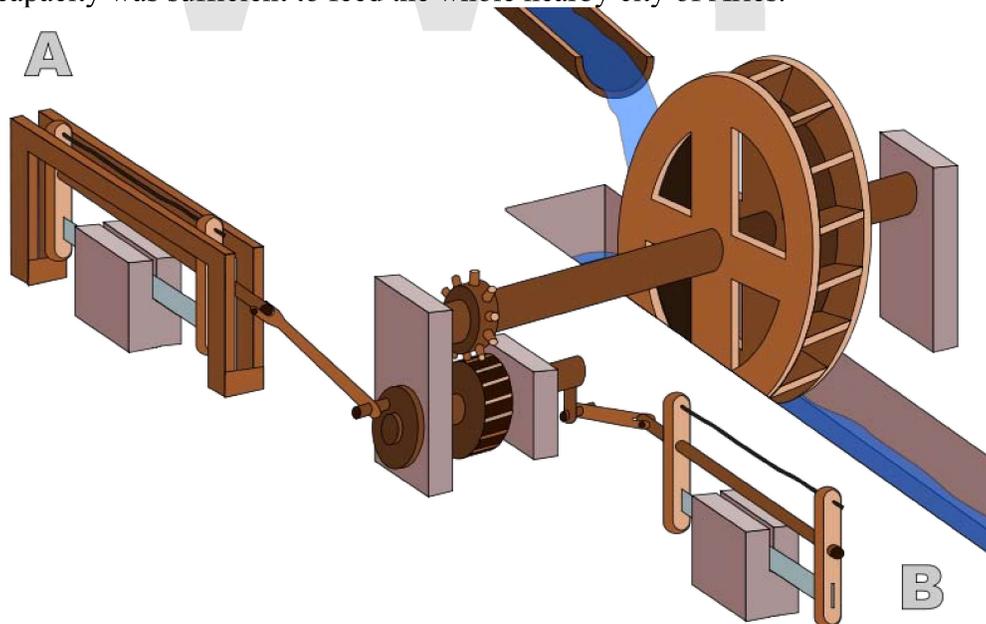
Small scale innovation was common as devices were gradually made more efficient, such as the improvement of the overshot water wheel and the improvements in wagon construction. Technology could and did evolve. The scale of the Empire encouraged the geographical spread of innovations. The ideal Roman citizen was an articulate veteran soldier who could wisely govern a large family household, which was supported by slave labor. Innovators did have some prestige; Pliny, for example, often records their names, or has some story to account for the innovation. Romans also knew enough history to be aware that technological change had occurred in the past and brought benefits. Military innovation was always valued. One text, *De Rebus Bellicis*, devoted to a number of innovations in military machinery, has survived.

The apparent period in which technological progress was fastest and greatest was during the 2nd century and 1st century BC, which was the period in which Roman power greatly increased. Innovation continued until the fall of the Empire, and it would take hundreds of years for all of its technological advancements to be rediscovered by other civilizations. Our understanding of Roman technology is provided by Pliny's *Naturalis Historia*, the *De Architectura* of Vitruvius and the *De aquaeductu* of Frontinus, all reliable works which give good information, and many inventions they mention have been confirmed by modern archaeology. By the beginning of the 1st century, most of what is considered today as typical Roman technology was already invented and refined, such as concrete, plumbing facilities, cranes, wagon technology, mechanized harvesting machines, domes, the arch in building practice, wine and oil presses, and glass blowing. They were also influenced by the Greeks.

The energy constraint



The sixteen overshot wheels at Barbegal are considered the biggest ancient mill complex. Their capacity was sufficient to feed the whole nearby city of Arles.



Scheme of the Roman Hierapolis sawmill, the earliest known machine to incorporate a crank and connecting rod mechanism.

All technology uses energy to transform the material into a desirable object. The cheaper energy is, the wider the class of technologies that are considered economic. This is why technological history can be seen as a succession of ages defined by energy type i.e. human, animal, water, peat, coal, and oil. The Romans had water power, and exploited wood and coal for heating. There were huge reserves of wood, peat and coal in the Roman Empire, but they were all in the wrong place. Wood could be floated down rivers to the major urban centres but otherwise it was a very poor fuel, being heavy for its calorific value. If this was improved by being processed into charcoal, it was bulky. Nor was wood ever available in any concentration. Diocletian's Price Edict can give us a glimpse of the economics of transporting wood. The maximum price of a wagon load of 1,200 lbs of wood was 150 d.(denari). The maximum freight charge per mile for the same wagon load was 20 d. per mile. Room heating was normally better done by charcoal braziers than hypocausts. But hypocausts did allow them to exploit any poor-quality smoky fuels like straw, vine prunings and small wood locally available. Hypocausts also allowed them to generate a humid heat for their baths.

The Romans worked almost all the coalfields of England that outcropped on the surface, by the end of the 2nd century (Smith 1997; 323). But there is no evidence that this exploitation was on any scale. After c.200 AD the commercial heart of the Empire was in Africa and the East where the climate severely limited timber growth. There was no large coalfield on the edge of the Mediterranean.

Nevertheless, the Romans were the first technological culture to assemble all essential components of the much later steam engine:

With the crank and connecting rod system, all elements for constructing a steam engine (invented in 1712) — Hero's aeolipile (generating steam power), the cylinder and piston (in metal force pumps), non-return valves (in water pumps), gearing (in water mills and clocks) — were known in Roman times.

This academic view is superficial, as denoted by the word essential. The aeolipile was a reaction engine, inefficient as a stationary engine. The first useful steam engine did not use steam pressure at all, but followed up a scientific advance in understanding air pressure.

Craft basis



Roman Cage Cup from the 4th century AD. Hypothesised as a floating wick oil lamp to give magical downwards lighting effects.

Roman technology was largely based on a system of crafts, although the term engineering is used today to describe the technical feats of the Romans. The Greek words used were mechanic or machine-maker or even mathematician which had a much wider meaning than now. There were a large number of engineers employed by the army. The most famous engineer of this period was Apollodorus of Damascus. Normally each trade, each group of artisans—stone masons, glass blowers, surveyors, etc.—within a project had its own practice of masters and apprentices, and many tried to keep their trade secrets,

passing them on solely by word of mouth, a system still in use today by those who do not want to patent their inventions. Writers such as Vitruvius, Pliny the Elder and Frontinus published widely on many different technologies, and there was a corpus of manuals on basic mathematics and science such as the many books by Archimedes, Ctesibius, Heron (a.k.a. Hero of Alexandria), Euclid and so on. Not all of the manuals which were available to the Romans have survived, as lost works illustrates.

Much of what is known of Roman technology comes indirectly from archaeology and from the third-hand accounts of Latin texts copied from Arabic texts, which were in turn copied from the Greek texts of scholars such as Hero of Alexandria or contemporary travelers who had observed Roman technologies in action. Writers like Pliny the Elder and Strabo had enough intellectual curiosity to make note of the inventions they saw during their travels, although their typically brief descriptions often arouse discussion as to their precise meaning. On the other hand, Pliny is perfectly clear when describing gold mining, his text in book xxxiii having been confirmed by archaeology and field-work at such sites as Las Medulas and Dolaucothi.

Engineering and construction



The Colosseum in Rome, Italy

The Romans made great use of aqueducts, dams, bridges, and amphitheaters. They were also responsible for many innovations to roads, sanitation, and construction in general. Roman architecture in general was greatly influenced by the Etruscans. Most of the columns and arches seen in famous Roman architecture were adopted from the Etruscan civilization.

In the Roman Empire, cements made from pozzolanic ash/pozzolana and an aggregate made from pumice were used to make a concrete very similar to modern Portland cement concrete. In 20s BC the architect Vitruvius described a low-water-content method for mixing concrete. The Romans found out that insulated glazing (or "double glazing") improved greatly on keeping buildings warm, and this technique was used in the construction of public baths.

Another truly original process which was born in the empire was the practice of glassblowing, which started in Syria and spread in about one generation in the empire.

Machines



Reconstruction of a 10.4-metre-high Roman construction crane at Bonn, Germany

There were many types of presses to press olives. In the 1st century, Pliny the Elder reported the invention and subsequent general use of the new and more compact screw presses. However, the screw press was almost certainly not a Roman invention. It was first described by Hero of Alexandria, but may have already been in use when he mentioned it in his *Mechanica III*.

Cranes were used for construction work and possibly to load and unload ships at their ports, although for the latter use there is according to the “present state of knowledge” still no evidence. Most cranes were capable of lifting about 6-7 tons of cargo, and according to a relief shown on Trajan's column were worked by treadwheel.

Roads



Via Appia, a road connecting the city of Rome to the Southern parts of Italy remains usable even today.

The Romans primarily built roads for their military. Their economic importance was probably also significant, although wagon traffic was often banned from the roads to preserve their military value. At its largest extent the total length of the Roman road network was 85,000 kilometres (53,000 mi).

Way stations providing refreshments were maintained by the government at regular intervals along the roads. A separate system of changing stations for official and private couriers was also maintained. This allowed a dispatch to travel a maximum of 800 kilometres (500 mi) in 24 hours by using a relay of horses.

The roads were constructed by digging a pit along the length of the intended course, often to bedrock. The pit was first filled with rocks, gravel or sand and then a layer of concrete.

Finally they were paved with polygonal rock slabs. Roman roads are considered the most advanced roads built until the early 19th century. Bridges were constructed over waterways. The roads were resistant to floods and other environmental hazards. After the fall of the Roman empire the roads were still usable and used for more than 1000 years.

Aqueducts



Aqueduct of Segovia

The Romans constructed numerous aqueducts to supply water. The city of Rome itself was supplied by eleven aqueducts that provided the city with over 1 million cubic metres of water each day, sufficient for 3.5 million people even in modern day times, and with a combined length of 350 kilometres (220 mi). Most aqueducts were constructed below the surface with only small portions above ground supported by arches. The longest Roman aqueduct, 178 kilometres (111 mi) in length, was traditionally assumed to be that which supplied the city of Carthage. The complex system built to supply Constantinople had its most distant supply drawn from over 120 km away along a sinuous route of more than 336 km.

Roman aqueducts were built to remarkably fine tolerances, and to a technological standard that was not to be equaled until modern times. Powered entirely by gravity, they transported very large amounts of water very efficiently. Sometimes, where depressions

deeper than 50 metres had to be crossed, inverted siphons were used to force water uphill. An aqueduct also supplied water for the overshot wheels at Barbegal in Roman Gaul, a complex of water mills hailed as "the greatest known concentration of mechanical power in the ancient world".

Bridges



1st century Roman bridge in Vaison la Romaine, France

Roman bridges were among the first large and lasting bridges built. They were built with stone and had the arch as its basic structure. Most utilized concrete as well. Built in 142 BC, the Pons Aemilius, later named *Ponte Rotto* (broken bridge) is the oldest Roman stone bridge in Rome, Italy. The biggest Roman bridge was Trajan's bridge over the lower Danube, constructed by Apollodorus of Damascus, which remained for over a millennium the longest bridge to have been built both in terms of overall and span length. They were most of the time at least 60 feet above the body of water.

An example of temporary military bridge construction are the two Caesar's Rhine bridges.

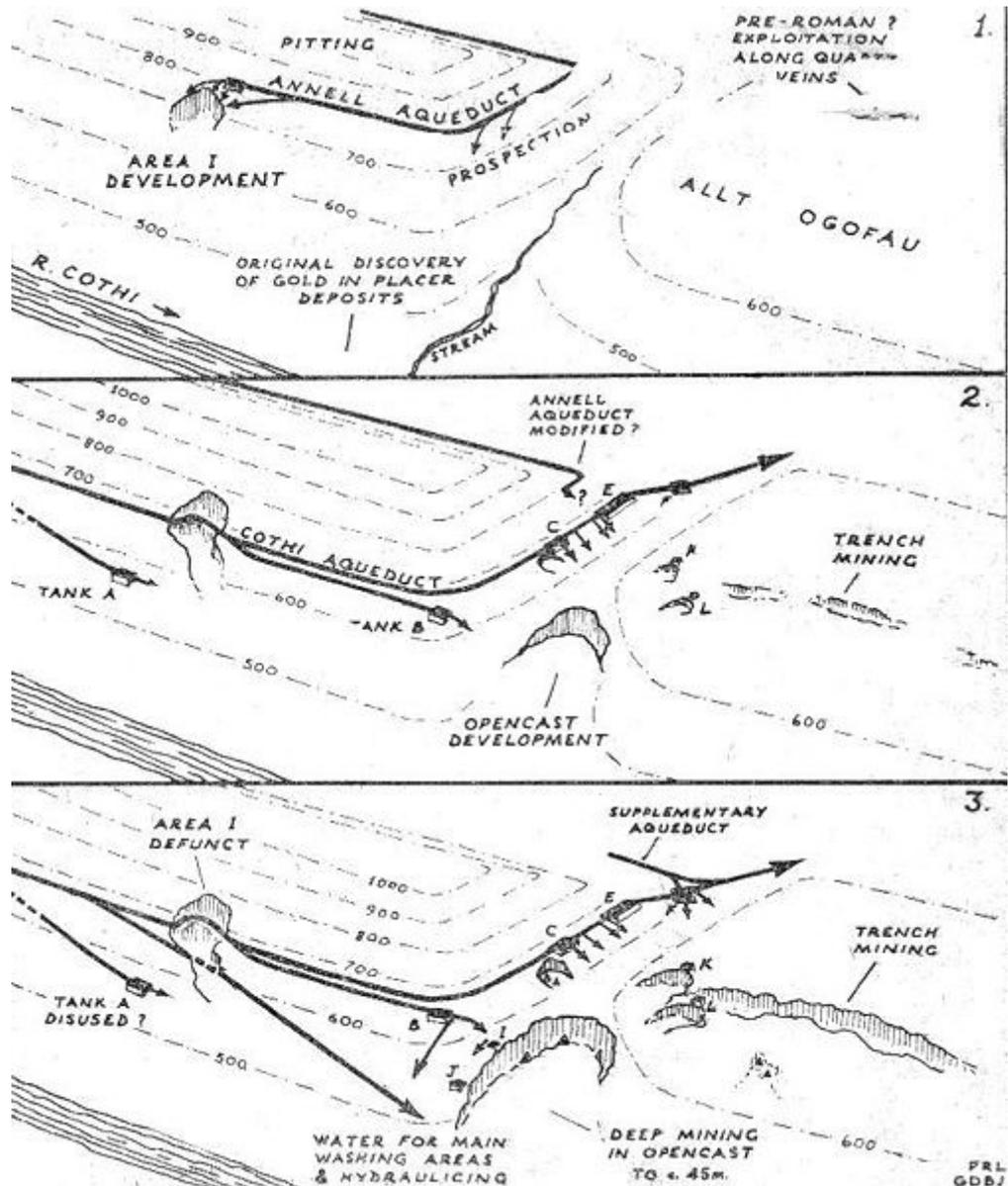
Dams



The sizable Roman Harbaqa Dam in Syria is 21 m high and 365 m long.

They also built many dams for water collection, such as the Subiaco Dams, two of which fed Anio Novus, one of the largest aqueducts of Rome. They built 72 dams in just one country, Spain and many more are known across the Empire, some of which are still in use. At one site, Montefurado in Galicia, they appear to have built a dam across the river Sil to expose alluvial gold deposits in the bed of the river. The site is near the spectacular Roman gold mine of Las Medulas. Several earthen dams are known from Britain, including a well-preserved example from Roman Lanchester, Longovicium, where it may have been used in industrial-scale smithing or smelting, judging by the piles of slag found at this site in northern England. Tanks for holding water are also common along aqueduct systems, and numerous examples are known from just one site, the gold mines at Dolaucothi in west Wales. Masonry dams were common in North Africa for providing a reliable water supply from the wadis behind many settlements.

Mining



Development of Dolaucothi mine

The Romans also made great use of aqueducts in their extensive mining operations across the empire, some sites such as Las Medulas in north-west Spain having at least 7 major channels entering the minehead. Other sites such as Dolaucothi in south Wales was fed by at least 5 leats, all leading to reservoirs and tanks or cisterns high above the present opencast. The water was used for hydraulic mining, where streams or waves of water are released onto the hillside, first to reveal any gold-bearing ore, and then to work the ore itself. Rock debris could be sluiced away by hushing, and the water also used to douse fires created to break down the hard rock and veins, a method known as fire-setting.

Alluvial gold deposits could be worked and the gold extracted without needing to crush the ore. Washing tables were fitted below the tanks to collect the gold-dust and any nuggets present. Vein gold needed crushing, and they probably used crushing or stamp mills worked by water-wheels to comminute the hard ore before washing. Large quantities of water were also needed in deep mining to remove waste debris and power primitive machines, as well as for washing the crushed ore. Pliny the Elder provides a detailed description of gold mining in book xxxiii of his *Naturalis Historia*, most of which has been confirmed by archaeology. That they used water mills on a large scale elsewhere is attested by the flour mills at Barbegal in southern France, and on the Janiculum in Rome.

Sanitation

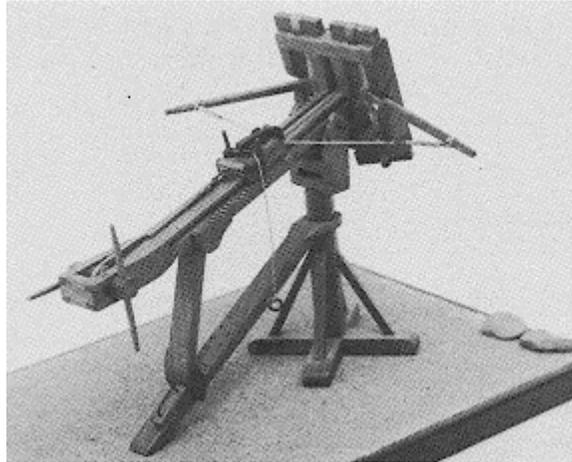


Roman public baths in Bath, England. The loss of the original roof has encouraged green algae growth.

The Romans were one of the first known civilizations to invent indoor plumbing. The Roman public baths, or *thermae* served hygienic, social and cultural functions. The baths contained three main facilities for bathing. After undressing in the apodyterium or changing room, Romans would proceed to the tepidarium or warm room. In the moderate dry heat of the tepidarium, some performed warm-up exercises and stretched while others oiled themselves or had slaves oil them. The tepidarium's main purpose was to promote sweating to prepare for the next room, the caldarium or hot room. The caldarium, unlike the tepidarium, was extremely humid and hot. Temperatures in the caldarium could reach

40 degrees Celsius (104 degrees Fahrenheit). Many contained steam baths and a cold-water fountain known as the labrum. The last room was the frigidarium or cold room, which offered a cold bath for cooling off after the caldarium. The Romans also had flush toilets.

Roman military technology



A Roman Ballista

The Roman military technology ranged from personal equipment and armament to deadly siege engines. They inherited almost all ancient weapons.

While heavy, intricate armour was not uncommon (cataphracts), the Romans perfected a relatively light, full torso armour made of segmented plates (lorica segmentata). This segmented armour provided flexibility and protection of most vital areas, and was not associated with the laborious craftwork that other armours (such as chainmail) were. Furthermore, the rest of the Roman soldier's equipment used similarly innovative and effective technology.

The Roman cavalry saddle had four horns and was believed to have been copied from Celtic peoples.

Roman siege engines such as ballistas, scorpions and onagers were not unique. But the Romans were probably the first people to put ballistas on carts for better mobility on campaigns. On the battlefield, it is thought that they were used to pick off enemy leaders. We have one account of the use of artillery in battle from Tacitus, Histories III,23:

On engaging they drove back the enemy, only to be driven back themselves, for the Vitellians had concentrated their artillery on the raised road that they might have free and open ground from which to fire; their earlier shots had been scattered and had struck the trees without injuring the enemy. A ballista of enormous size belonging to the Fifteenth legion began to do great harm to the

Flavians' line with the huge stones that it hurled; and it would have caused wide destruction if it had not been for the splendid bravery of two soldiers, who, taking some shields from the dead and so disguising themselves, cut the ropes and springs of the machine.

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Chapter- 2

Medieval Technology



Pumhart von Steyr, a 15th century supergun



Medieval port crane for mounting masts and lifting heavy cargo in the former Hanse town of Danzig

Medieval technology refers to the technology used in medieval Europe under Christian rule. After the Renaissance of the 12th century, medieval Europe saw a radical change in the rate of new inventions, innovations in the ways of managing traditional means of production, and economic growth. The period saw major technological advances, including the adoption of gunpowder, the invention of vertical windmills, spectacles, mechanical clocks, and greatly improved water mills, building techniques (Gothic style, medieval castle), agriculture in general (three-field crop rotation).

The development of water mills from its ancient origins was impressive, and extended from agriculture to sawmills both for timber and stone. By the time of the Domesday Book, most large villages had turnable mills, around 6,500 in England alone. Water-power was also widely used in mining for raising ore from shafts, crushing ore, and even powering bellows.

European technical advancements in the 12th to 14th centuries were either built on long-established techniques in medieval Europe, originating from Roman and Byzantine antecedents, or adapted from cross-cultural exchanges through trading networks with the Islamic world, China, and India. Often, the revolutionary aspect lay not in the act of invention itself, but in its technological refinement and application to political and

economic power. Though gunpowder had long been known to the Chinese, it was the Europeans who developed and perfected its military potential, precipitating European expansion and eventual imperialism in the Modern Era.

Also significant in this respect were advances in maritime technology. Advances in shipbuilding included the multi-masted ships with lateen sails, the sternpost-mounted rudder and the skeleton-first hull construction. Along with new navigational techniques such as the dry compass, the Jacob's staff and the astrolabe, these allowed economic and military control of all seas adjacent to Europe and enabled the global navigational achievements of the dawning Age of Exploration.

At the turn to the Renaissance, Gutenberg's invention of mechanical printing made possible a dissemination of knowledge to a wider population, that would not only lead to a gradually more egalitarian society, but one more able to dominate other cultures, drawing from a vast reserve of knowledge and experience. The technical drawings of late medieval artist-engineers Guido da Vigevano and Villard de Honnecourt can be viewed as forerunners of later Renaissance works such as Taccola or da Vinci.

Civil technologies

In the following, a list of some important medieval technology. The approximate date or first mention of a technology in Medieval Europe is given. Technologies were often a matter of cultural exchange and date and place of first inventions are not listed here.

Agriculture

Heavy plough (5th->8th)

The heavy wheeled plough with a mouldboard first appears in the 5th century in Slavic lands, is then introduced into Northern Italy (the Po Valley) and by the 8th century it was used in the Rhineland. Essential in the efficient use of the rich, heavy, often wet soils of Northern Europe, its use allowed the area's forests and swamps to be brought under cultivation.

Hops (11th)

Added to beer, importance lay primarily in its ability to preserve beer and improve transportability for trade.

Horse collar (6th->9th)

Multiple evolutions from Classical Harness (Antiquity), to Breast Strap Harness (6th) to Horse collar (9th). Allowed more horse pulling power, such as with heavy ploughs.

Horseshoes (9th)

Allowed horse to adapt to non-grassland terrains in Europe (rocky terrain, mountains) and carry heavier loads. Possibly known to the Romans and Celts as early as 50 BC.

Wine press (12th)

First practical means of applying pressure on a plane surface. The principle later used for printing press.

Architecture and construction

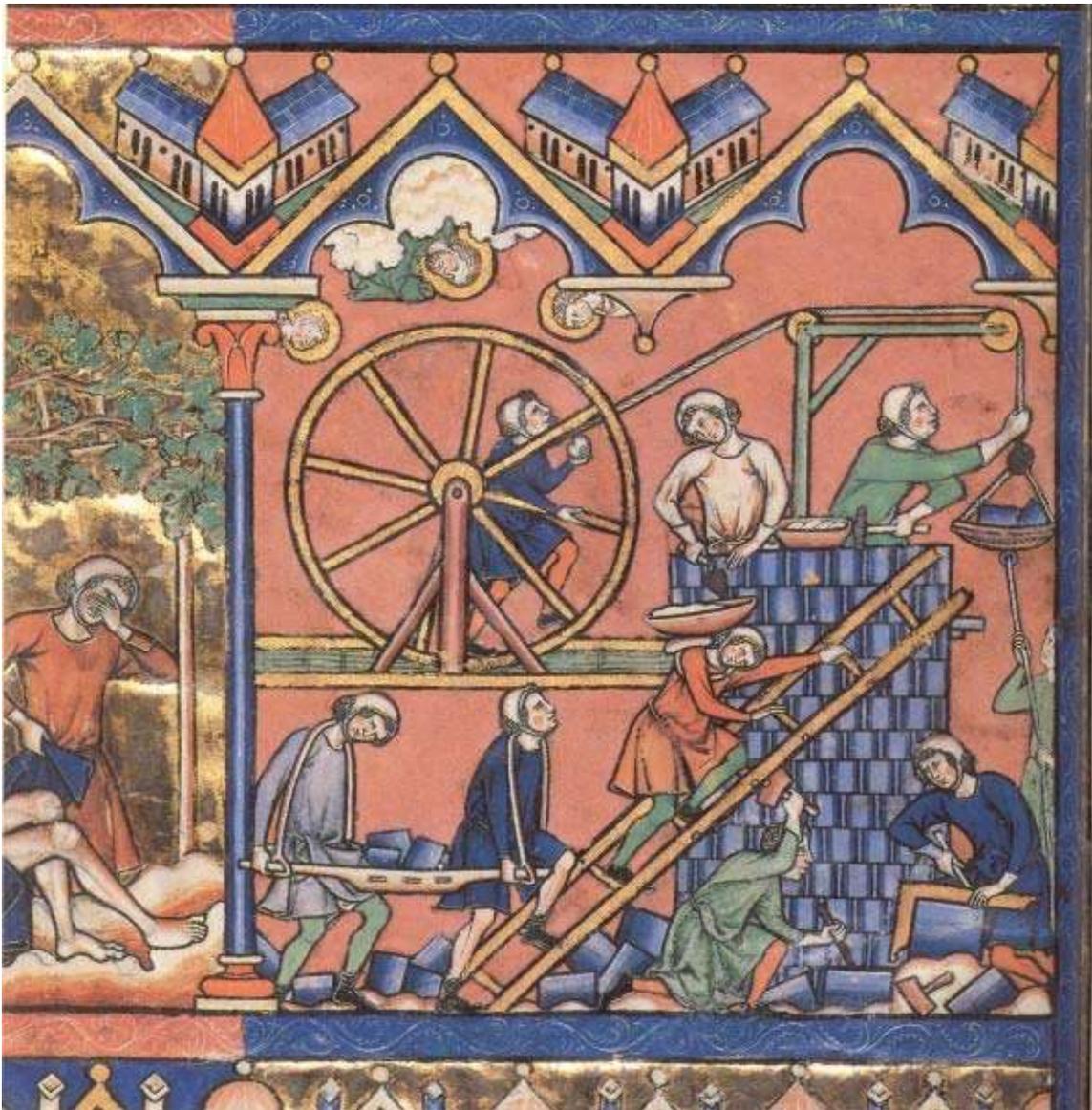
Artesian well (1126) A thin rod with a hard iron cutting edge is placed in the bore hole and repeatedly struck with a hammer, underground water pressure forces the water up the hole without pumping. Artesian wells are named after the town of Artois in France, where the first one was drilled by Carthusian monks in 1126.

Rib vault (12th)

Essential element for the rise of Gothic architecture. Allowed vaults to be built for the first time over rectangles of unequal lengths. Also greatly facilitated scaffolding. Largely replaced older groin vault.

Segmental arch bridge (1345)

The Ponte Vecchio in Florence is considered medieval Europe's first stone segmental arch bridge.



Treadwheel crane

Treadwheel crane (1220s)

Earliest reference to a treadwheel in archival literature in France about 1225, followed by an illuminated depiction in a manuscript of probably also French origin dating to 1240. Apart from tread-drums, windlasses and occasionally cranks were employed for powering cranes. However, such devices were probably used by the Romans.

Stationary harbor crane (1244)

Stationary harbor cranes are considered a new development of the Middle Ages, its earliest use being documented for Utrecht in 1244. The typical harbor crane was a pivoting structure equipped with double treadwheels. There were two types: wooden

gantry cranes pivoting on a central vertical axle and stone tower cranes which housed the windlass and treadwheels with only jib arm and roof rotating. These cranes were placed docksides for the loading and unloading of cargo where they replaced or complemented older lifting methods like see-saws, winches and yards. **Slewing cranes** which allowed a rotation of the load and were thus particularly suited for dockside work appeared as early as 1340.

Floating crane

Beside the stationary cranes, floating cranes which could be flexibly deployed in the whole port basin came into use by the 14th century.

Mast crane

Some harbour cranes were specialised at mounting masts to newly built sailing ships, such as in Danzig, Cologne and Bremen.

Wheelbarrow (1170s)

Proved useful in building construction, mining operations, and agriculture. Literary evidence for the use of wheelbarrows appeared between 1170 and 1250 in North-western Europe. First depiction in a drawing by Matthew Paris in the middle of the 13th century.

Art



Portrait of a Man in a Turban, oil painting by Jan van Eyck (1433)

Oil paint (ca. 1410)

As early as the 13th century, oil was used to add details to tempera paintings. Major breakthrough by Flemish painter Jan van Eyck around 1410 who is credited with introducing a stable oil mixture.

Clocks

Hourglass (1338)

Reasonably dependable, affordable and accurate measure of time. Unlike water in a clepsydra, the rate of flow of sand is independent of the depth in the upper reservoir, and the instrument is not liable to freeze. Hourglasses are a medieval innovation (first documented in Siena, Italy).

Mechanical clocks (13th->14th)

A European innovation, these weight-driven clocks were used primarily in clock towers.

Mechanics

Compound crank

The Italian physician Guido da Vigevano combines in his 1335 *Texaurus*, a collection of war machines intended for the recapture of the Holy Land, two simple cranks to form a compound crank for manually powering war carriages and paddle wheel boats. The devices were fitted directly to the vehicle's axle respectively to the shafts turning the paddle wheels.

Metallurgy

Blast furnace (1150-1350)

European cast iron first appears in Middle Europe (for instance Lapphyttan in Sweden, Dürstel in Switzerland and the Märkische Sauerland in Germany) around 1150, in some places according to recent research even before 1100. Technique considered to be an independent European development.

Milling

Paper mill (13th)

The first certain of a water-powered paper mill, evidence for which is elusive in both Chinese and Muslim papermaking, dates to 1282.

Rolling mill (15th)

Used on producing metal sheet of even thickness. First used on soft, malleable metals, such as lead, gold and tin. Leonardo da Vinci described rolling mill for wrought iron.

Tidal Mills (6th)

The earliest tide mills were excavated on the Irish coast where watermillers knew and employed the two main waterwheel types: a 6th century tide mill at Killoteran near Waterford was powered by a vertical waterwheel, while the tide changes at Little Island were exploited by a twin-flume horizontal-wheeled mill (c. 630) and a vertical undershot waterwheel alongside it. Another early example is the Nendrum Monastery mill from 787 which is estimated to have developed 7–8 HP at its peak.

Vertical windmills (1180s)

Invented in Europe as the pivotable post mill, first surviving mention of one comes from Yorkshire in England in 1185. Efficient at grinding grain or draining water. Later also as the stationary tower mill.

Water hammer (12th latest)

Used in metallurgy on forging the metal blooms from bloomeries and Catalan forges. Replaced manual hammerwork. Eventually superseded by steam hammers in the 19th century.

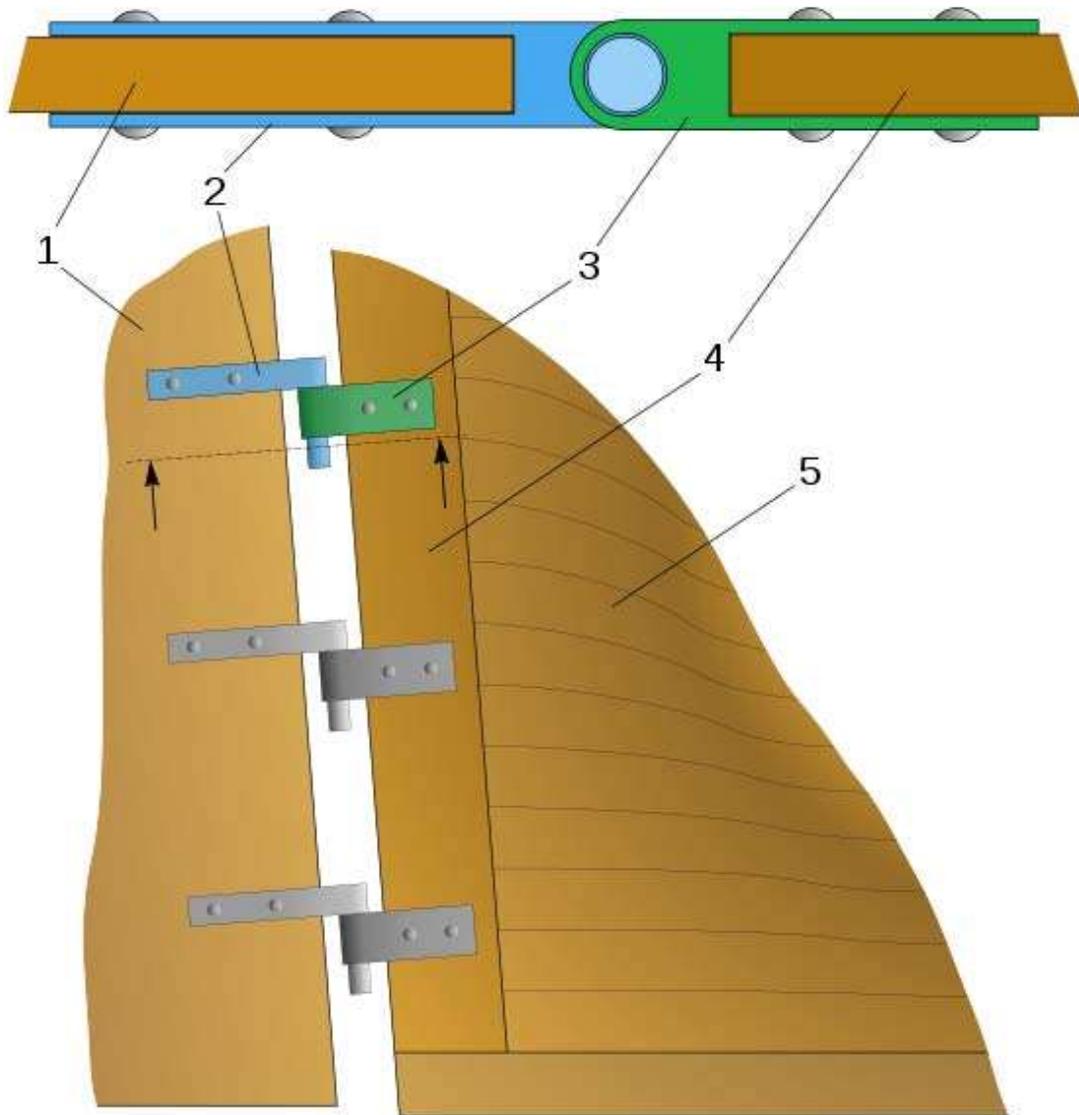
Navigation

Dry Compass (12th)

The first mention of the directional compass is in Alexander Neckam's *On the Natures of Things*, written in Paris around 1190. Either transmitted from China or the Arabs or an independent European innovation. Dry compass invented in the Mediterranean around 1300.

Astronomical compass (1269)

The French scholar Pierre de Maricourt describes in his experimental study *Epistola de magnete* (1269) three different compass designs he has devised for the purpose of astronomical observation.



Scheme of a sternpost-mounted medieval rudder

Stern-mounted rudders (1180s)

First depiction of a pintle-and gudgeon rudder on church carvings dating to around 1180. First appeared with cogs in the North and Baltic Sea, quickly spread to Mediterranean. The iron hinge system was the first stern rudder permanently attached to the ship hull and made a vital contribution to the navigation achievements of the age of discovery and thereafter.

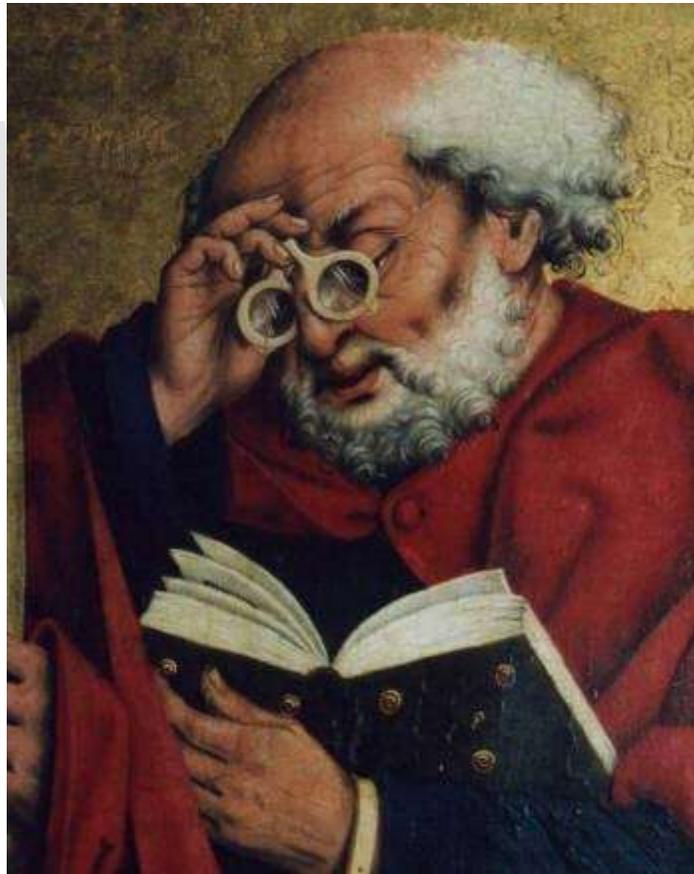
Printing, paper and reading

Movable type printing press (1440s)

Invented by Johannes Gutenberg. His great innovation was not the printing itself, but instead of using readily-carved plates as before, he used separate letters (*types*) from which the printing plates for pages were made up. This meant the types were recyclable and a page cast could be made up far faster than with readily-carved plates.

Paper (13th)

Invented in China, transmitted through Islamic Spain to Europe in the 13th century where the papermaking processes were mechanized by water-powered mills and paper presses.



Reading Saint Peter with eyeglasses (1466)

Spectacles (1280s)

European innovation. Florence, Italy. Convex lenses, of help only to the far-sighted. Concave lenses were not developed prior to the 15th century.

Watermark (1282)

Medieval innovation to mark paper products and to discourage counterfeiting. First introduced in Bologna, Italy.

Science and learning

Arabic Numerals (13th c.)

First recorded mention in Europe 976, first widely published in 1202 by Fibonacci with his *Liber Abaci*.

University

The first medieval universities were founded between the 11th and 13th century leading to a rise in literacy and learning. By 1500, the institution had spread throughout most of Europe and played a key role in the Scientific Revolution. Today, the educational concept and institution has been globally adopted.

First international banking system

The first international banking system was created by the Knights Templar to help provide them with financial support while they tried to protect the crusader states in the middle east. It also helped pilgrims in many ways including taking their valuables, then giving them a sealed document containing the items worth. The pilgrims then traveled to the holy land and gave the document to one of the many Templar stations in crusader held cities where they would receive the same worth of items. Services like this made the pilgrims less attractive targets to the many bandits that roamed the holy land.

Textile industry and garments

Functional button (13th)

Buttons with buttonholes used to fasten or close garment, being the most convenient method before the introduction of the zipper, appear in the 13th century Germany as indigenous innovation. Became soon widespread with the rise of snug-fitting clothing.

Horizontal loom (11th)

Horizontal and operated by foot-treadles, faster and more efficient.

Silk (6th)

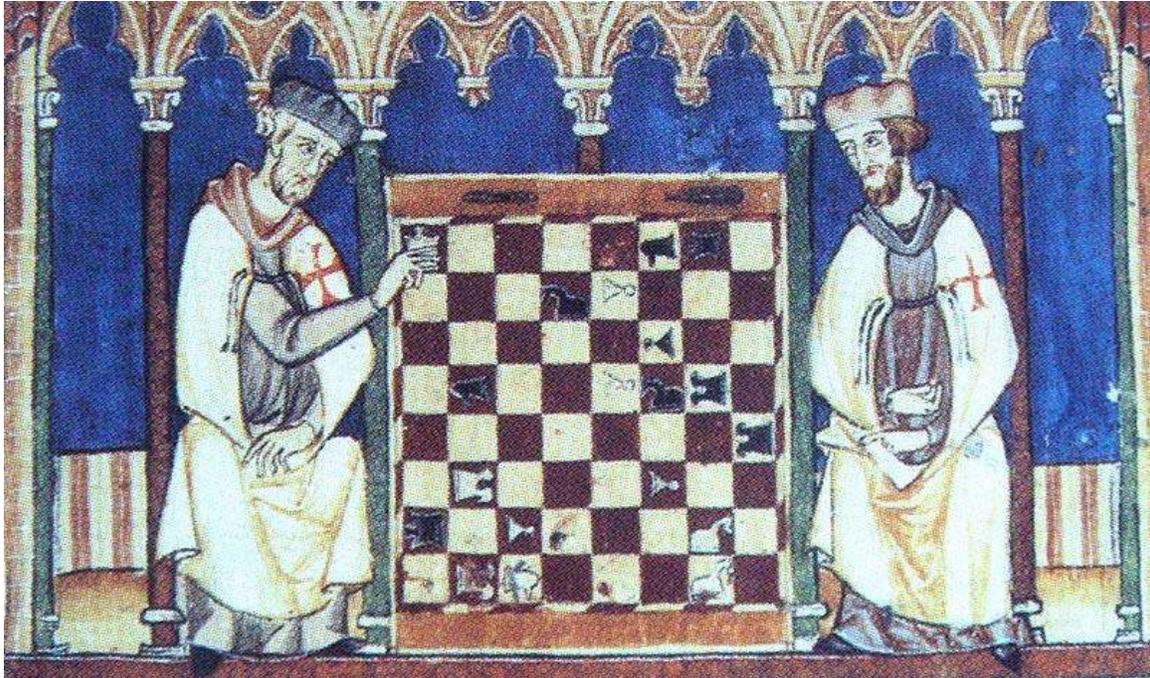
Manufacture of silk began in Eastern Europe in the 6th, in Western Europe in the 11th or 12th centuries. Imported over the Silk Road since antiquity. Technology of "silk

throwing" mastered in Tuscany in the 13th century. The silk works used waterpower and some regard these as the first mechanized textile mills.

Spinning wheel (13th)

Brought to Europe probably from India.

Miscellaneous



Knights Templar playing chess, *Libro de los juegos* (1283)

Chess (1450)

The earliest predecessors of the game originated in 6th century AD India and spread via Persia and the Muslim world to Europe. Here the game evolved into its current form in the 15th century.

Forest glass (ca. 1000)

Type of glass which uses wood ash and sand as the main raw materials and is characterised by a variety of greenish-yellow colours.

Grindstones (834)

Rough stone, usually sandstone, used to sharpen iron. The first rotary grindstone (turned with a leveraged handle) occurs in the *Utrecht Psalter*, illustrated between 816 and 834. According to Hägermann, the pen drawing is a copy of a late antique manuscript. A

second crank which was mounted on the other end of the axle is depicted in the *Luttrell Psalter* from around 1340.

Liquor (12th)

Alcohol distillation by way of Islamic alchemists, initially used as medicinal elixir. Popular remedy for the Black Death during the 14th century; "national" drinks like vodka, gin, brandy come into form.

Mirrors (1180)

First mention of "glass" mirror in 1180 by Alexander Neckham who said "Take away the lead which is behind the glass and there will be no image of the one looking in."

Illustrated surgical atlas (1345)

Guido da Vigevano (ca. 1280–1349) was the first author to add illustrations to his anatomical descriptions. His *Anathomia* provides pictures of neuroanatomical structures and techniques such as the dissection of the head by means of trephination, and depictions of the meninges, cerebrum, and spinal cord.

Quarantine (1377)

Initially a 40-day-period, the Quarantine was introduced by the Republic of Ragusa as measure of disease prevention related to the Black Death. Later adopted by Venice from where the practice spread all around in Europe.

Rat traps (1170s)

First mention of a rat trap in the medieval romance *Yvain, the Knight of the Lion* by Chrétien de Troyes.

Soap (9th)

Soap came into widespread European use in the 9th century in semi-liquid form, with hard soap perfected by the Arabs in the 12th century.

Military technologies

Armor



Jousting armor commissioned by Maximilian I in 1494

Plate armour (14th, late)

Apex of pre-industrial personal armour in terms of body protection and metallurgical skills involved. Large and complete full plates of armour appear by the end of the 14th century.

Cavalry

Arched saddle (1050s)

Enabled mounted knights to wield lance underarm and prevent the charge turning into an unintentional pole-vault. This innovation gave birth to true shock cavalry, enabling the knights to charge on full gallop, thus exceeding the shock value of the cataphracts.

Spurs (11th)

Invented by the Normans, appearing at the same time as cantled saddle. Enabled the knight to control his horse with his feet instead of hands, replacing the whip and leaving his arms free. Rowel spurs familiar from cowboy films were already known in the 13th century. Gilded spurs were the ultimate symbol of the knighthood - even today someone is said to "earn his spurs" by proving his or her worthiness.

Stirrup (6th)

Invented by the steppe nomads in what is today Mongolia and northern China in the 4th century and transmitted west. Appeared in Byzantium in the 6th, in the Carolingian Empire in the 8th century. Allowed mounted knight to wield sword and strike from a distance leading to a great advantage for mounted cavalry.

Gunpowder weapons

Cannon (1324)

Cannons are first recorded in Europe at the siege of Metz in 1324. In 1350 Petrarch wrote "these instruments which discharge balls of metal with most tremendous noise and flashes of fire...were a few years ago very rare and were viewed with greatest astonishment and admiration, but now they are become as common and familiar as any other kinds of arms."

Corned gunpowder (14th, late)

First practiced in Western Europe, corning the black powder allowed for more powerful and faster ignition of cannon. Also facilitated storage and transportation to operational area, thus constituting a crucial step in the evolution of gunpowder warfare.



Scottish bombard Mons Meg

Supergun (14th, late)

Extant examples include the wrought-iron Pumhart von Steyr, Dulle Griet and Mons Meg as well as the cast-bronze Faule Mette and Faule Grete (all 15th century).

Mechanical artillery

Counterweight trebuchet (12th)

Powered solely by the force of gravity, these catapults revolutionized medieval siege warfare and construction of fortifications by hurling huge stones unprecedented distances. Originating somewhere in the eastern Mediterranean basin, counterweight trebuchets were introduced in the Crusader states by the 1120s, Byzantium by the 1130s and in the Latin West by the second half of the century.

Missile weapons

Longbow with massed, disciplined archery (13th)

Having a high rate of fire and penetration power, the longbow contributed to the eventual demise of the medieval knight class. Used particularly by the English to great effect against the French cavalry during the Hundred Years' War (1337-1453).

Steel crossbow (14th, late)

European innovation. Came with several different cocking aids to enhance draw power, making the weapons also the first hand-held mechanical crossbows.

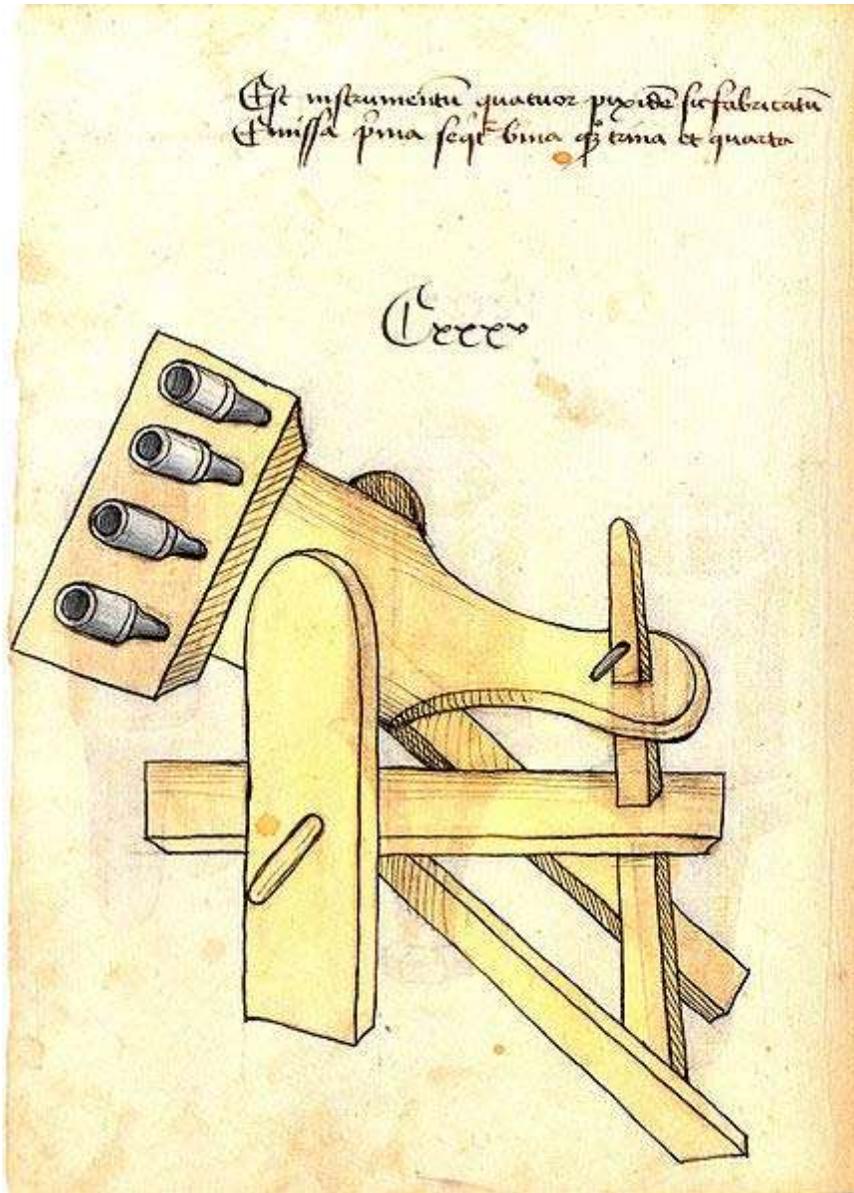
Miscellaneous

Combined arms tactics (1333)

The battle of Halidon Hill 1333 was the first battle where intentional and disciplined combined arms infantry tactics were employed. The English men-at-arms dismounted beside the archers, combining thus the staying power of super-heavy infantry and striking power of their two-handed weapons with the missiles and mobility of the archers. Combining dismounted knights and men-at-arms with archers was the archetypal Western Medieval battle tactics until the battle of Flodden 1513 and final emergence of firearms.



Cranked rack-and-pinion device for cocking a crossbow (ca. 1493)



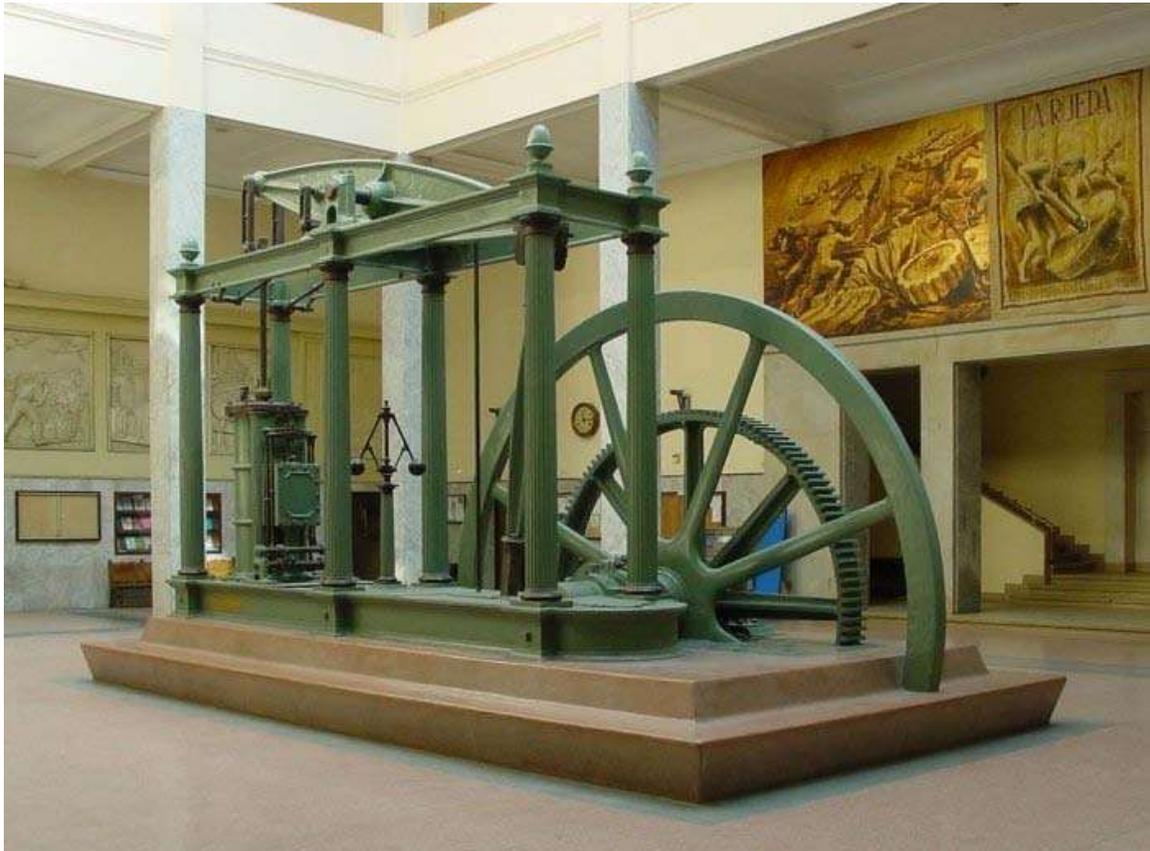
Organ gun in the *Bellifortis* (ca. 1405)

Renaissance technology

In the 15th century, the pace of technical advancements quickens with such diverse innovations like the printing press, linear perspectivity, patent law, double shell domes or bastions.

Chapter- 3

Industrial Revolution



A Watt steam engine, the steam engine fuelled primarily by coal that propelled the Industrial Revolution in Great Britain and the world.

The **Industrial Revolution** was a period from the 18th to the 19th century where major changes in agriculture, manufacturing, mining, transportation, and technology had a profound effect on the socioeconomic and cultural conditions of the times. It began in the United Kingdom, then subsequently spread throughout Europe, North America, and eventually the world.

The Industrial Revolution marks a major turning point in human history; almost every aspect of daily life was influenced in some way. Most notably, average income and

population began to exhibit unprecedented sustained growth. In the two centuries following 1800, the world's average per capita income increased over 10-fold, while the world's population increased over 6-fold. In the words of Nobel Prize winning Robert E. Lucas, Jr., "For the first time in history, the living standards of the masses of ordinary people have begun to undergo sustained growth. ... Nothing remotely like this economic behavior has happened before."

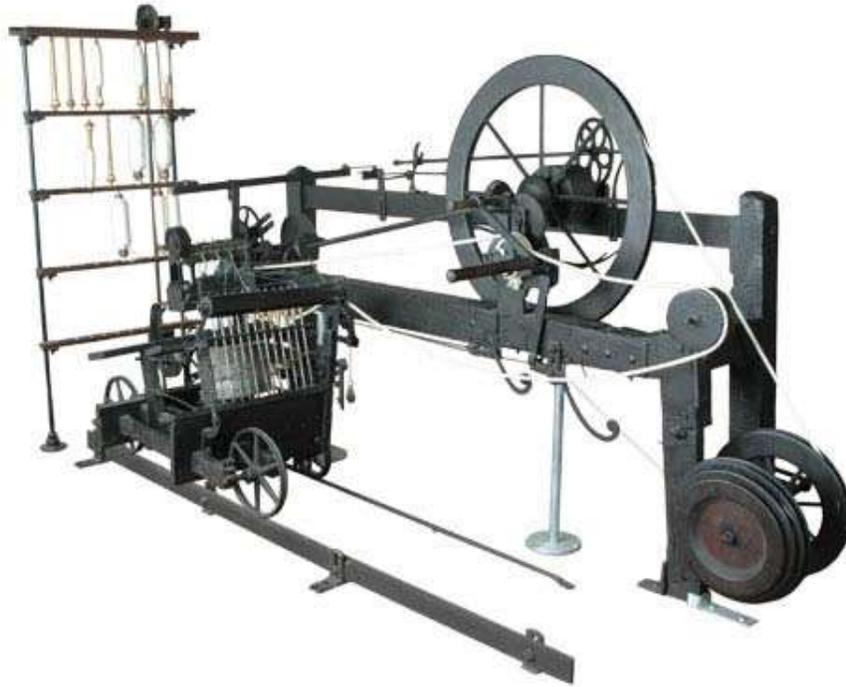
Starting in the later part of the 18th century, there began a transition in parts of Great Britain's previously manual labour and draft-animal-based economy towards machine-based manufacturing. It started with the mechanisation of the textile industries, the development of iron-making techniques and the increased use of refined coal. Trade expansion was enabled by the introduction of canals, improved roads and railways.

The introduction of steam power fuelled primarily by coal, wider utilisation of water wheels and powered machinery (mainly in textile manufacturing) underpinned the dramatic increases in production capacity. The development of all-metal machine tools in the first two decades of the 19th century facilitated the manufacture of more production machines for manufacturing in other industries. The effects spread throughout Western Europe and North America during the 19th century, eventually affecting most of the world, a process that continues as industrialisation. The impact of this change on society was enormous.

The first Industrial Revolution, which began in the 18th century, merged into the Second Industrial Revolution around 1850, when technological and economic progress gained momentum with the development of steam-powered ships, railways, and later in the 19th century with the internal combustion engine and electrical power generation. The period of time covered by the Industrial Revolution varies with different historians. Eric Hobsbawm held that it 'broke out' in Britain in the 1780s and was not fully felt until the 1830s or 1840s, while T. S. Ashton held that it occurred roughly between 1760 and 1830.

Some 20th century historians such as John Clapham and Nicholas Crafts have argued that the process of economic and social change took place gradually and the term *revolution* is a misnomer. This is still a subject of debate among historians. GDP per capita was broadly stable before the Industrial Revolution and the emergence of the modern capitalist economy. The Industrial Revolution began an era of per-capita economic growth in capitalist economies. Economic historians are in agreement that the onset of the Industrial Revolution is the most important event in the history of humanity since the domestication of animals and plants.

Innovations



The only surviving example of a Spinning Mule built by the inventor Samuel Crompton

The commencement of the Industrial Revolution is closely linked to a small number of innovations, made in the second half of the 18th century:

- **Textiles** – Cotton spinning using Richard Arkwright's water frame, James Hargreaves's Spinning Jenny, and Samuel Crompton's Spinning Mule (a combination of the Spinning Jenny and the Water Frame). This was patented in 1769 and so came out of patent in 1783. The end of the patent was rapidly followed by the erection of many cotton mills. Similar technology was subsequently applied to spinning worsted yarn for various textiles and flax for linen.
- **Steam power** – The improved steam engine invented by James Watt and patented in 1775 was initially mainly used for pumping out mines, but from the 1780s was applied to power machines. This enabled rapid development of efficient semi-automated factories on a previously unimaginable scale in places where waterpower was not available.
- **Iron making** – In the Iron industry, coke was finally applied to all stages of iron smelting, replacing charcoal. This had been achieved much earlier for lead and copper as well as for producing pig iron in a blast furnace, but the second stage in the production of bar iron depended on the use of potting and stamping (for which a patent expired in 1786) or puddling (patented by Henry Cort in 1783 and 1784).

These represent three 'leading sectors', in which there were key innovations, which allowed the economic take off by which the Industrial Revolution is usually defined. This is not to belittle many other inventions, particularly in the textile industry. Without some earlier ones, such as the spinning jenny and flying shuttle in the textile industry and the smelting of pig iron with coke, these achievements might have been impossible. Later inventions such as the power loom and Richard Trevithick's high pressure steam engine were also important in the growing industrialisation of Britain. The application of steam engines to powering cotton mills and ironworks enabled these to be built in places that were most convenient because other resources were available, rather than where there was water to power a watermill.

In the textile sector, such mills became the model for the organisation of human labour in factories, epitomised by Cottonopolis, the name given to the vast collection of cotton mills, factories and administration offices based in Manchester. The assembly line system greatly improved efficiency, both in this and other industries. With a series of men trained to do a single task on a product, then having it moved along to the next worker, the number of finished goods also rose significantly.

Also important was the 1756 rediscovery of concrete (based on hydraulic lime mortar) by the British engineer John Smeaton, which had been lost for 1300 years.

Transfer of knowledge



A Philosopher Lecturing on the Orrery (ca. 1766)
Informal philosophical societies spread scientific advances

Knowledge of innovation was spread by several means. Workers who were trained in the technique might move to another employer or might be poached. A common method was for someone to make a study tour, gathering information where he could. During the whole of the Industrial Revolution and for the century before, all European countries and America engaged in study-touring; some nations, like Sweden and France, even trained civil servants or technicians to undertake it as a matter of state policy. In other countries, notably Britain and America, this practice was carried out by individual manufacturers anxious to improve their own methods. Study tours were common then, as now, as was the keeping of travel diaries. Records made by industrialists and technicians of the period are an incomparable source of information about their methods.

Another means for the spread of innovation was by the network of informal philosophical societies, like the Lunar Society of Birmingham, in which members met to discuss 'natural philosophy' (*i.e.* science) and often its application to manufacturing. The Lunar Society flourished from 1765 to 1809, and it has been said of them, "They were, if you like, the revolutionary committee of that most far reaching of all the eighteenth century revolutions, the Industrial Revolution". Other such societies published volumes of proceedings and transactions. For example, the London-based Royal Society of Arts published an illustrated volume of new inventions, as well as papers about them in its annual *Transactions*.

There were publications describing technology. Encyclopaedias such as Harris's *Lexicon Technicum* (1704) and Abraham Rees's *Cyclopaedia* (1802–1819) contain much of value. *Cyclopaedia* contains an enormous amount of information about the science and technology of the first half of the Industrial Revolution, very well illustrated by fine engravings. Foreign printed sources such as the *Descriptions des Arts et Métiers* and Diderot's *Encyclopédie* explained foreign methods with fine engraved plates.

Periodical publications about manufacturing and technology began to appear in the last decade of the 18th century, and many regularly included notice of the latest patents. Foreign periodicals, such as the *Annales des Mines*, published accounts of travels made by French engineers who observed British methods on study tours.

Technological developments in Britain

Textile manufacture



Model of the spinning jenny in a museum in Wuppertal, Germany. The spinning jenny was one of the innovations that started the revolution

In the early 18th century, British textile manufacture was based on wool which was processed by individual artisans, doing the spinning and weaving on their own premises. This system is called a cottage industry. Flax and cotton were also used for fine materials, but the processing was difficult because of the pre-processing needed, and thus goods in these materials made only a small proportion of the output.

Use of the spinning wheel and hand loom restricted the production capacity of the industry, but incremental advances increased productivity to the extent that manufactured cotton goods became the dominant British export by the early decades of the 19th century. India was displaced as the premier supplier of cotton goods.

Lewis Paul patented the Roller Spinning machine and the flyer-and-bobbin system for drawing wool to a more even thickness, developed with the help of John Wyatt in Birmingham. Paul and Wyatt opened a mill in Birmingham which used their new rolling machine powered by a donkey. In 1743, a factory was opened in Northampton with fifty spindles on each of five of Paul and Wyatt's machines. This operated until about 1764. A similar mill was built by Daniel Bourn in Leominster, but this burnt down. Both Lewis Paul and Daniel Bourn patented carding machines in 1748. Using two sets of rollers that travelled at different speeds, it was later used in the first cotton spinning mill. Lewis's invention was later developed and improved by Richard Arkwright in his water frame and Samuel Crompton in his spinning mule.

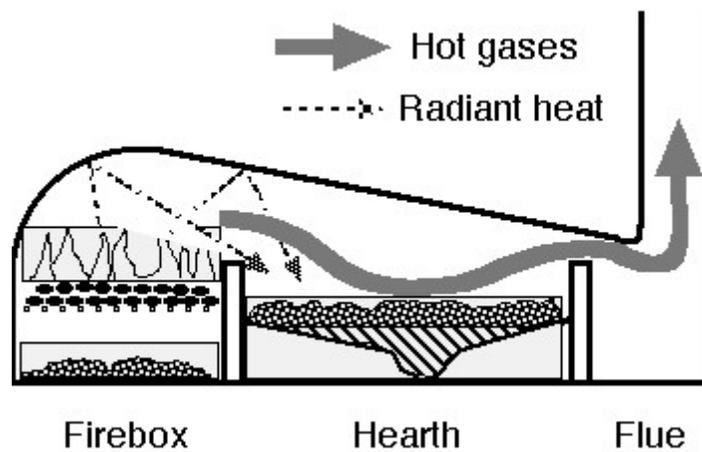
Other inventors increased the efficiency of the individual steps of spinning (carding, twisting and spinning, and rolling) so that the supply of yarn increased greatly, which fed a weaving industry that was advancing with improvements to shuttles and the loom or 'frame'. The output of an individual labourer increased dramatically, with the effect that the new machines were seen as a threat to employment, and early innovators were attacked and their inventions destroyed.

To capitalise upon these advances, it took a class of entrepreneurs, of which the most famous is Richard Arkwright. He is credited with a list of inventions, but these were actually developed by people such as Thomas Highs and John Kay; Arkwright nurtured the inventors, patented the ideas, financed the initiatives, and protected the machines. He created the cotton mill which brought the production processes together in a factory, and he developed the use of power—first horse power and then water power—which made cotton manufacture a mechanised industry. Before long steam power was applied to drive textile machinery.

Metallurgy



Coalbrookdale by Night, 1801, Philipp Jakob Louthembourg the Younger
Blast furnaces light the iron making town of Coalbrookdale



The Reverberatory Furnace could produce wrought iron using mined coal. The burning coal remained separate from the iron ore and so did not contaminate the iron with impurities like sulphur. This opened the way to increased iron production.

The major change in the metal industries during the era of the Industrial Revolution was the replacement of organic fuels based on wood with fossil fuel based on coal. Much of this happened somewhat before the Industrial Revolution, based on innovations by Sir Clement Clerke and others from 1678, using coal reverberatory furnaces known as cupolas. These were operated by the flames, which contained carbon monoxide, playing on the ore and reducing the oxide to metal. This has the advantage that impurities (such as sulphur) in the coal do not migrate into the metal. This technology was applied to lead from 1678 and to copper from 1687. It was also applied to iron foundry work in the 1690s, but in this case the reverberatory furnace was known as an air furnace. The foundry cupola is a different (and later) innovation.

This was followed by Abraham Darby, who made great strides using coke to fuel his blast furnaces at Coalbrookdale in 1709. However, the coke pig iron he made was used mostly for the production of cast iron goods such as pots and kettles. He had the advantage over his rivals in that his pots, cast by his patented process, were thinner and cheaper than theirs. Coke pig iron was hardly used to produce bar iron in forges until the mid 1750s, when his son Abraham Darby II built Horsehay and Ketley furnaces (not far from Coalbrookdale). By then, coke pig iron was cheaper than charcoal pig iron.

Bar iron for smiths to forge into consumer goods was still made in finery forges, as it long had been. However, new processes were adopted in the ensuing years. The first is referred to today as potting and stamping, but this was superseded by Henry Cort's puddling process. From 1785, perhaps because the improved version of potting and stamping was about to come out of patent, a great expansion in the output of the British iron industry began. The new processes did not depend on the use of charcoal at all and were therefore not limited by charcoal sources.

Up to that time, British iron manufacturers had used considerable amounts of imported iron to supplement native supplies. This came principally from Sweden from the mid-17th century and later also from Russia from the end of the 1720s. However, from 1785, imports decreased because of the new iron making technology, and Britain became an exporter of bar iron as well as manufactured wrought iron consumer goods.

Since iron was becoming cheaper and more plentiful, it also became a major structural material following the building of the innovative The Iron Bridge in 1778 by Abraham Darby III.



The Iron Bridge, Shropshire, England

An improvement was made in the production of steel, which was an expensive commodity and used only where iron would not do, such as for the cutting edge of tools and for springs. Benjamin Huntsman developed his crucible steel technique in the 1740s. The raw material for this was blister steel, made by the cementation process.

The supply of cheaper iron and steel aided the development of boilers and steam engines, and eventually railways. Improvements in machine tools allowed better working of iron and steel and further boosted the industrial growth of Britain.

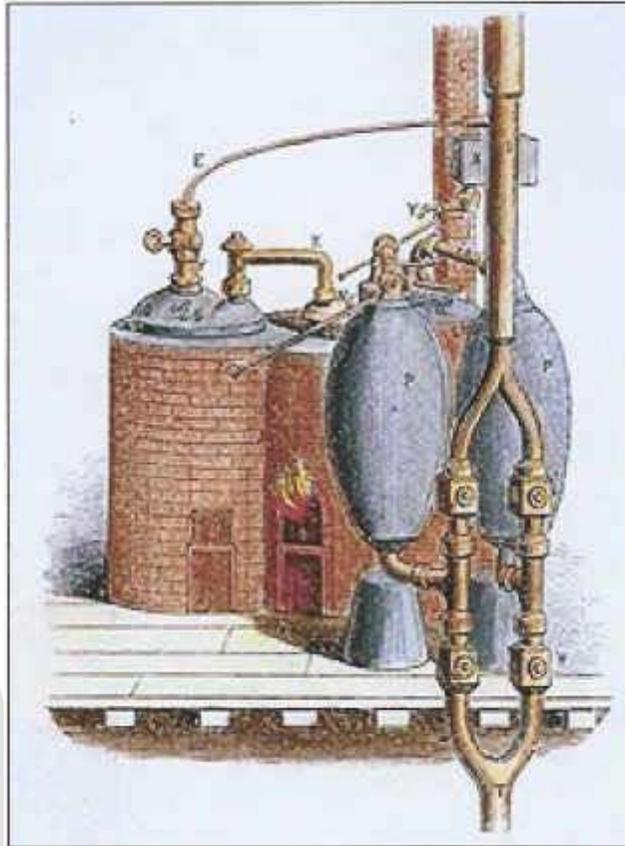
Mining



Men working their own coal mines. Early 1900s, USA

Coal mining in Britain, particularly in South Wales started early. Before the steam engine, pits were often shallow bell pits following a seam of coal along the surface, which were abandoned as the coal was extracted. In other cases, if the geology was favourable, the coal was mined by means of an adit or drift mine driven into the side of a hill. Shaft mining was done in some areas, but the limiting factor was the problem of removing water. It could be done by hauling buckets of water up the shaft or to a sough (a tunnel driven into a hill to drain a mine). In either case, the water had to be discharged into a stream or ditch at a level where it could flow away by gravity. The introduction of the steam engine greatly facilitated the removal of water and enabled shafts to be made deeper, enabling more coal to be extracted. These were developments that had begun before the Industrial Revolution, but the adoption of James Watt's more efficient steam engine from the 1770s reduced the fuel costs of engines, making mines more profitable. Coal mining was very dangerous owing to the presence of firedamp in many coal seams. Some degree of safety was provided by the safety lamp which was invented in 1816 by Sir Humphry Davy and independently by George Stephenson. However, the lamps proved a false dawn because they became unsafe very quickly and provided a weak light. Firedamp explosions continued, often setting off coal dust explosions, so casualties grew during the entire 19th century. Conditions of work were very poor, with a high casualty rate from rock falls.

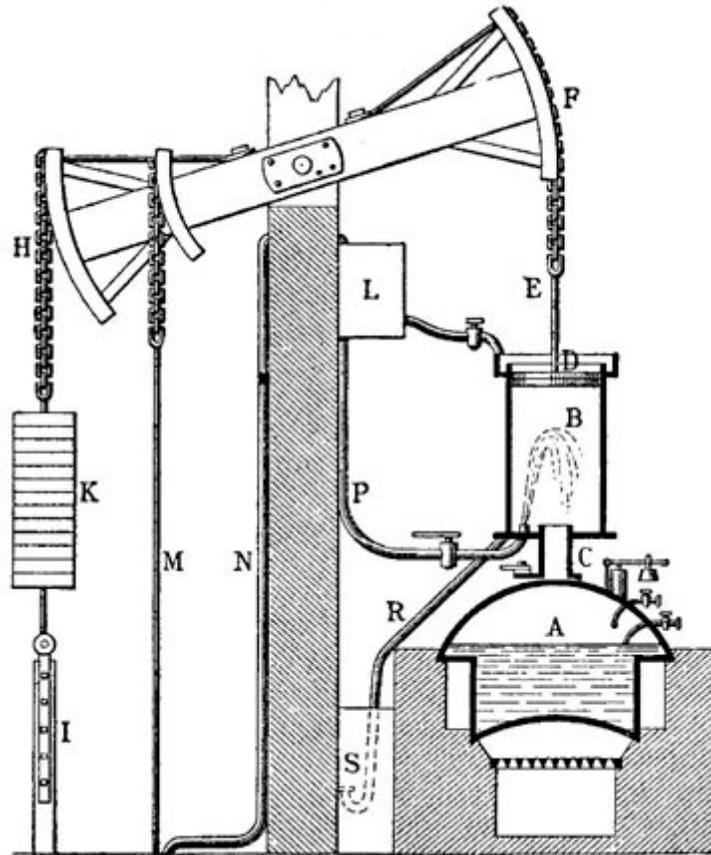
Steam power



The 1698 *Savery Engine* – the world's first commercially useful steam engine: built by Thomas Savery

The development of the stationary steam engine was an essential early element of the Industrial Revolution; however, for most of the period of the Industrial Revolution, the majority of industries still relied on wind and water power as well as horse- and man-power for driving small machines.

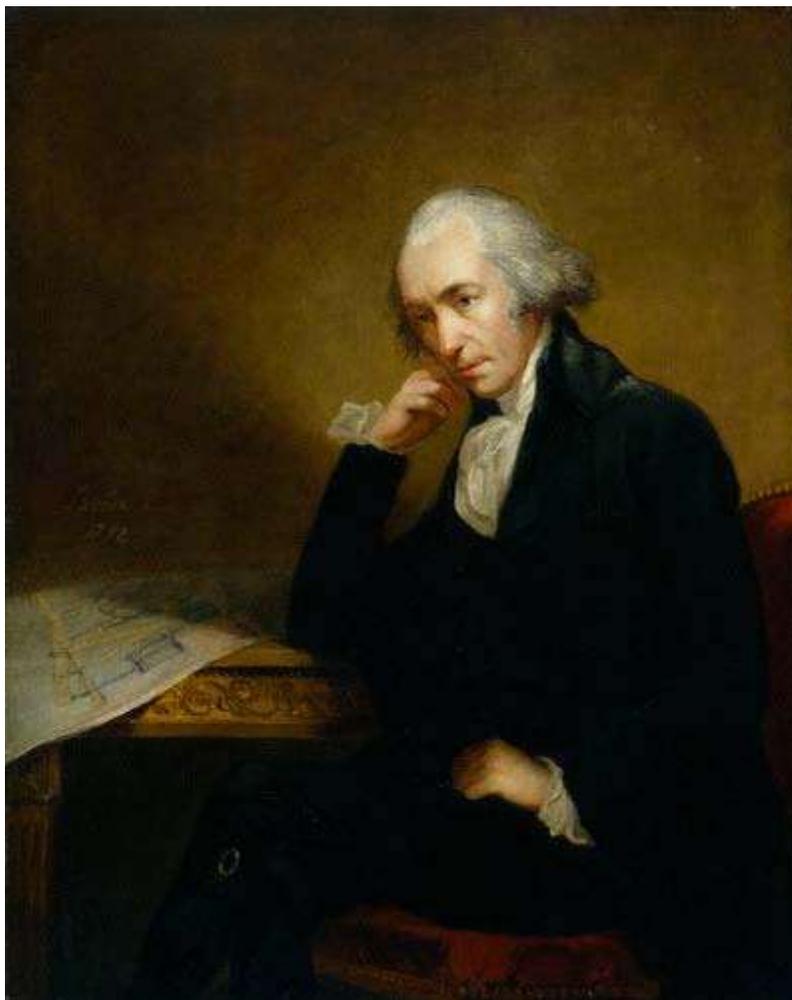
The first real attempt at industrial use of steam power was due to Thomas Savery in 1698. He constructed and patented in London a low-lift combined vacuum and pressure water pump, that generated about one horsepower (hp) and was used in numerous water works and tried in a few mines (hence its "brand name", *The Miner's Friend*), but it was not a success since it was limited in pumping height and prone to boiler explosions.



Newcomen's steam powered atmospheric engine was the first practical engine. Subsequent steam engines were to power the Industrial Revolution

The first safe and successful steam power plant was introduced by Thomas Newcomen before 1712. Newcomen apparently conceived the Newcomen steam engine quite independently of Savery, but as the latter had taken out a very wide-ranging patent, Newcomen and his associates were obliged to come to an arrangement with him, marketing the engine until 1733 under a joint patent. Newcomen's engine appears to have been based on Papin's experiments carried out 30 years earlier, and employed a piston and cylinder, one end of which was open to the atmosphere above the piston. Steam just above atmospheric pressure (all that the boiler could stand) was introduced into the lower half of the cylinder beneath the piston during the gravity-induced upstroke; the steam was then condensed by a jet of cold water injected into the steam space to produce a partial vacuum; the pressure differential between the atmosphere and the vacuum on either side of the piston displaced it downwards into the cylinder, raising the opposite end of a rocking beam to which was attached a gang of gravity-actuated reciprocating force pumps housed in the mineshaft. The engine's downward power stroke raised the pump, priming it and preparing the pumping stroke. At first the phases were controlled by hand, but within ten years an escapement mechanism had been devised worked by a vertical *plug tree* suspended from the rocking beam which rendered the engine self-acting.

A number of Newcomen engines were successfully put to use in Britain for draining hitherto unworkable deep mines, with the engine on the surface; these were large machines, requiring a lot of capital to build, and produced about 5 hp (3.7 kW). They were extremely inefficient by modern standards, but when located where coal was cheap at pit heads, opened up a great expansion in coal mining by allowing mines to go deeper. Despite their disadvantages, Newcomen engines were reliable and easy to maintain and continued to be used in the coalfields until the early decades of the 19th century. By 1729, when Newcomen died, his engines had spread (first) to Hungary in 1722, Germany, Austria, and Sweden. A total of 110 are known to have been built by 1733 when the joint patent expired, of which 14 were abroad. In the 1770s, the engineer John Smeaton built some very large examples and introduced a number of improvements. A total of 1,454 engines had been built by 1800.



James Watt

A fundamental change in working principles was brought about by James Watt. In close collaboration with Matthew Boulton, he had succeeded by 1778 in perfecting his steam engine, which incorporated a series of radical improvements, notably the closing off of

the upper part of the cylinder thereby making the low pressure steam drive the top of the piston instead of the atmosphere, use of a steam jacket and the celebrated separate steam condenser chamber. All this meant that a more constant temperature could be maintained in the cylinder and that engine efficiency no longer varied according to atmospheric conditions. These improvements increased engine efficiency by a factor of about five, saving 75% on coal costs.

Nor could the atmospheric engine be easily adapted to drive a rotating wheel, although Wasborough and Pickard did succeed in doing so towards 1780. However by 1783 the more economical Watt steam engine had been fully developed into a double-acting rotative type, which meant that it could be used to directly drive the rotary machinery of a factory or mill. Both of Watt's basic engine types were commercially very successful, and by 1800, the firm Boulton & Watt had constructed 496 engines, with 164 driving reciprocating pumps, 24 serving blast furnaces, and 308 powering mill machinery; most of the engines generated from 5 to 10 hp (7.5 kW).

The development of machine tools, such as the lathe, planing and shaping machines powered by these engines, enabled all the metal parts of the engines to be easily and accurately cut and in turn made it possible to build larger and more powerful engines.

Until about 1800, the most common pattern of steam engine was the beam engine, built as an integral part of a stone or brick engine-house, but soon various patterns of self-contained portable engines (readily removable, but not on wheels) were developed, such as the table engine. Towards the turn of the 19th century, the Cornish engineer Richard Trevithick, and the American, Oliver Evans began to construct higher pressure non-condensing steam engines, exhausting against the atmosphere. This allowed an engine and boiler to be combined into a single unit compact enough to be used on mobile road and rail locomotives and steam boats.

In the early 19th century after the expiration of Watt's patent, the steam engine underwent many improvements by a host of inventors and engineers.

Chemicals



The Thames Tunnel (opened 1843)
Cement was used in the world's first underwater tunnel

The large scale production of chemicals was an important development during the Industrial Revolution. The first of these was the production of sulphuric acid by the lead chamber process invented by the Englishman John Roebuck (James Watt's first partner) in 1746. He was able to greatly increase the scale of the manufacture by replacing the relatively expensive glass vessels formerly used with larger, less expensive chambers made of riveted sheets of lead. Instead of making a small amount each time, he was able to make around 100 pounds (50 kg) in each of the chambers, at least a tenfold increase.

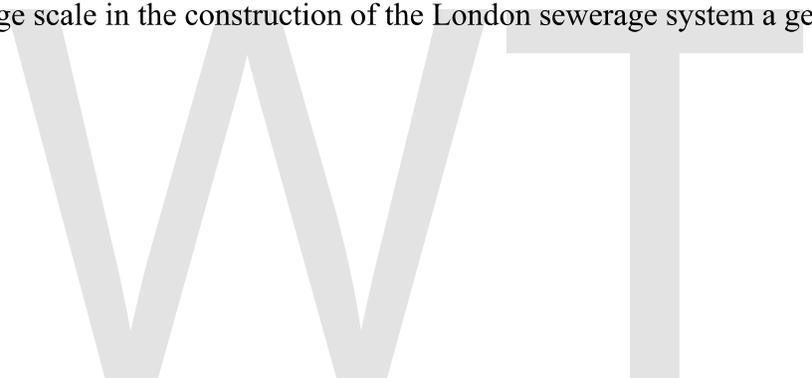
The production of an alkali on a large scale became an important goal as well, and Nicolas Leblanc succeeded in 1791 in introducing a method for the production of sodium carbonate. The Leblanc process was a reaction of sulphuric acid with sodium chloride to give sodium sulphate and hydrochloric acid. The sodium sulphate was heated with limestone (calcium carbonate) and coal to give a mixture of sodium carbonate and calcium sulphide. Adding water separated the soluble sodium carbonate from the calcium sulphide. The process produced a large amount of pollution (the hydrochloric acid was initially vented to the air, and calcium sulphide was a useless waste product). Nonetheless, this synthetic soda ash proved economical compared to that from burning specific plants (barilla) or from kelp, which were the previously dominant sources of soda ash, and also to potash (potassium carbonate) derived from hardwood ashes.

These two chemicals were very important because they enabled the introduction of a host of other inventions, replacing many small-scale operations with more cost-effective and controllable processes. Sodium carbonate had many uses in the glass, textile, soap, and

paper industries. Early uses for sulphuric acid included pickling (removing rust) iron and steel, and for bleaching cloth.

The development of bleaching powder (calcium hypochlorite) by Scottish chemist Charles Tennant in about 1800, based on the discoveries of French chemist Claude Louis Berthollet, revolutionised the bleaching processes in the textile industry by dramatically reducing the time required (from months to days) for the traditional process then in use, which required repeated exposure to the sun in bleach fields after soaking the textiles with alkali or sour milk. Tennant's factory at St Rollox, North Glasgow, became the largest chemical plant in the world.

In 1824 Joseph Aspdin, a British bricklayer turned builder, patented a chemical process for making portland cement which was an important advance in the building trades. This process involves sintering a mixture of clay and limestone to about 1,400 °C (2,552 °F), then grinding it into a fine powder which is then mixed with water, sand and gravel to produce concrete. Portland cement was used by the famous English engineer Marc Isambard Brunel several years later when constructing the Thames Tunnel. Cement was used on a large scale in the construction of the London sewerage system a generation later.



Machine tools

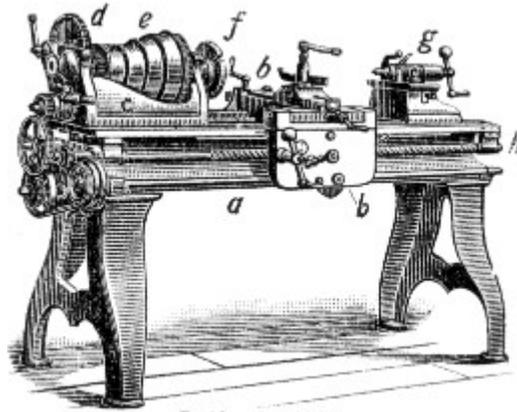


Sir Joseph Whitworth

The Industrial Revolution could not have developed without machine tools, for they enabled manufacturing machines to be made. They have their origins in the tools developed in the 18th century by makers of clocks and watches and scientific instrument makers to enable them to batch-produce small mechanisms. The mechanical parts of early textile machines were sometimes called 'clock work' because of the metal spindles and gears they incorporated. The manufacture of textile machines drew craftsmen from these trades and is the origin of the modern engineering industry.

Machines were built by various craftsmen—carpenters made wooden framings, and smiths and turners made metal parts. A good example of how machine tools changed manufacturing took place in Birmingham, England, in 1830. The invention of a new machine by Joseph Gillott, William Mitchell and James Stephen Perry allowed mass manufacture of robust, cheap steel pen nibs; the process had been laborious and expensive. Because of the difficulty of manipulating metal and the lack of machine tools, the use of metal was kept to a minimum. Wood framing had the disadvantage of changing dimensions with temperature and humidity, and the various joints tended to rack (work

loose) over time. As the Industrial Revolution progressed, machines with metal frames became more common, but they required machine tools to make them economically. Before the advent of machine tools, metal was worked manually using the basic hand tools of hammers, files, scrapers, saws and chisels. Small metal parts were readily made by this means, but for large machine parts, production was very laborious and costly.



Lathe, p. 1218.

A lathe from 1911, a machine tool able to shape parts (usually metal) for other machines

Apart from workshop lathes used by craftsmen, the first large machine tool was the cylinder boring machine used for boring the large-diameter cylinders on early steam engines. The planing machine, the slotting machine and the shaping machine were developed in the first decades of the 19th century. Although the milling machine was invented at this time, it was not developed as a serious workshop tool until during the Second Industrial Revolution.

Military production, as well, had a hand in the development of machine tools. Henry Maudslay, who trained a school of machine tool makers early in the 19th century, was employed at the Royal Arsenal, Woolwich, as a young man where he would have seen the large horse-driven wooden machines for cannon boring made and worked by the Verbruggans. He later worked for Joseph Bramah on the production of metal locks, and soon after he began working on his own. He was engaged to build the machinery for making ships' pulley blocks for the Royal Navy in the Portsmouth Block Mills. These were all metal and were the first machines for mass production and making components with a degree of interchangeability. The lessons Maudslay learned about the need for stability and precision he adapted to the development of machine tools, and in his workshops he trained a generation of men to build on his work, such as Richard Roberts, Joseph Clement and Joseph Whitworth.

James Fox of Derby had a healthy export trade in machine tools for the first third of the century, as did Matthew Murray of Leeds. Roberts was a maker of high-quality machine tools and a pioneer of the use of jigs and gauges for precision workshop measurement.

Gas lighting

Another major industry of the later Industrial Revolution was gas lighting. Though others made a similar innovation elsewhere, the large scale introduction of this was the work of William Murdoch, an employee of Boulton and Watt, the Birmingham steam engine pioneers. The process consisted of the large scale gasification of coal in furnaces, the purification of the gas (removal of sulphur, ammonia, and heavy hydrocarbons), and its storage and distribution. The first gas lighting utilities were established in London between 1812-20. They soon became one of the major consumers of coal in the UK. Gas lighting had an impact on social and industrial organisation because it allowed factories and stores to remain open longer than with tallow candles or oil. Its introduction allowed night life to flourish in cities and towns as interiors and streets could be lighted on a larger scale than before.

Glass making



The Crystal Palace held the Great Exhibition of 1851

A new method of producing glass, known as the cylinder process, was developed in Europe during the early 19th century. In 1832, this process was used by the Chance Brothers to create sheet glass. They became the leading producers of window and plate glass. This advancement allowed for larger panes of glass to be created without interruption, thus freeing up the space planning in interiors as well as the fenestration of buildings. The Crystal Palace is the supreme example of the use of sheet glass in a new and innovative structure.

Paper machine

A machine for making a continuous sheet of paper on a loop of wire fabric was patented in 1798 by Nicholas Louis Robert who worked for Saint-Léger Didot family in France. The paper machine is known as a Fourdrinier after the financiers, brothers Sealy and Henry Fourdrinier, who were stationers in London. Although greatly improved and with many variations, the Fourdrinier machine is the predominant means of paper production today.

Effects on agriculture

The invention of machinery played a big part in driving forward the British Agricultural Revolution. Agricultural improvement began in the centuries before the Industrial revolution got going and it may have played a part in freeing up labour from the land to work in the new industrial mills of the 18th century. As the revolution in industry progressed a succession of machines became available which increased food production with ever fewer labourers.

Jethro Tull's seed drill invented in 1701 was a mechanical seeder which distributed seeds efficiently across a plot of land. Joseph Foljambe's Rotherham plough of 1730, was the first commercially successful iron plough. Andrew Meikle's threshing machine of 1784 was the final straw for many farm labourers, and led to the 1830 agricultural rebellion of the Swing Riots.

Transport in Britain

At the beginning of the Industrial Revolution, inland transport was by navigable rivers and roads, with coastal vessels employed to move heavy goods by sea. Railways or wagon ways were used for conveying coal to rivers for further shipment, but canals had not yet been constructed. Animals supplied all of the motive power on land, with sails providing the motive power on the sea.

The Industrial Revolution improved Britain's transport infrastructure with a turnpike road network, a canal and waterway network, and a railway network. Raw materials and finished products could be moved more quickly and cheaply than before. Improved transportation also allowed new ideas to spread quickly.

Coastal sail

Sailing vessels had long been used for moving goods round the British coast. The trade transporting coal to London from Newcastle had begun in medieval times. The transport of goods coastwise by sea within Britain was common during the Industrial Revolution, as for centuries before. This became less important with the growth of the railways at the end of the period.

Navigable rivers

All the major rivers of the United Kingdom were navigable during the Industrial Revolution. Some were anciently navigable, notably the Severn, Thames, and Trent. Some were improved, or had navigation extended upstream, but usually in the period before the Industrial Revolution, rather than during it.

The Severn, in particular, was used for the movement of goods to the Midlands which had been imported into Bristol from abroad, and for the export of goods from centres of production in Shropshire (such as iron goods from Coalbrookdale) and the Black Country. Transport was by way of trows—small sailing vessels which could pass the various shallows and bridges in the river. The trows could navigate the Bristol Channel to the South Wales ports and Somerset ports, such as Bridgwater and even as far as France.

Canals



Pontcysyllte Aqueduct, Llangollen, Wales

Canals began to be built in the late 18th century to link the major manufacturing centres in the Midlands and north with seaports and with London, at that time itself the largest manufacturing centre in the country. Canals were the first technology to allow bulk materials to be easily transported across the country. A single canal horse could pull a

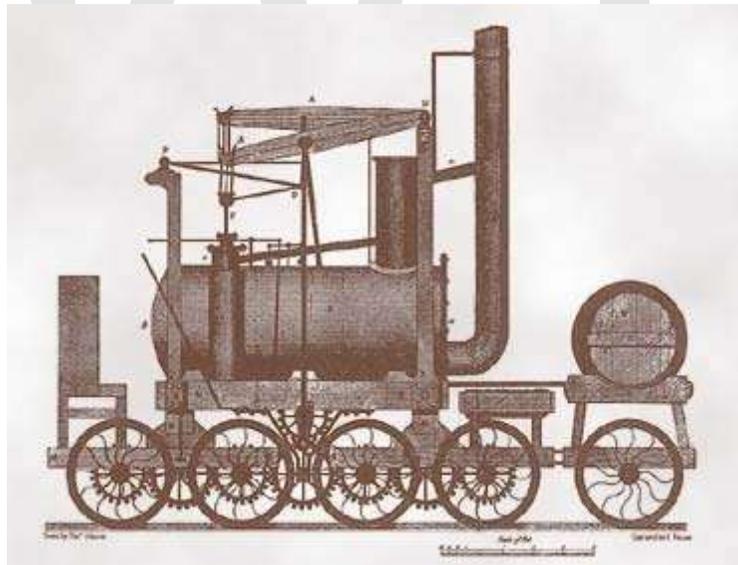
load dozens of times larger than a cart at a faster pace. By the 1820s, a national network was in existence. Canal construction served as a model for the organisation and methods later used to construct the railways. They were eventually largely superseded as profitable commercial enterprises by the spread of the railways from the 1840s on.

Britain's canal network, together with its surviving mill buildings, is one of the most enduring features of the early Industrial Revolution to be seen in Britain.

Roads

Much of the original British road system was poorly maintained by thousands of local parishes, but from the 1720s (and occasionally earlier) turnpike trusts were set up to charge tolls and maintain some roads. Increasing numbers of main roads were turnpiked from the 1750s to the extent that almost every main road in England and Wales was the responsibility of some turnpike trust. New engineered roads were built by John Metcalf, Thomas Telford and John Macadam. The major turnpikes radiated from London and were the means by which the Royal Mail was able to reach the rest of the country. Heavy goods transport on these roads was by means of slow, broad wheeled, carts hauled by teams of horses. Lighter goods were conveyed by smaller carts or by teams of pack horse. Stage coaches carried the rich, and the less wealthy could pay to ride on carriers carts.

Railways



Puffing Billy, an early railway steam locomotive, constructed in 1813-1814 for colliery work.

Wagonways for moving coal in the mining areas had started in the 17th century and were often associated with canal or river systems for the further movement of coal. These were all horse drawn or relied on gravity, with a stationary steam engine to haul the wagons back to the top of the incline. The first applications of the steam locomotive were on

wagon or plate ways (as they were then often called from the cast iron plates used). Horse-drawn public railways did not begin until the early years of the 19th century. Steam-hauled public railways began with the Stockton and Darlington Railway in 1825 and the Liverpool and Manchester Railway in 1830. Construction of major railways connecting the larger cities and towns began in the 1830s but only gained momentum at the very end of the first Industrial Revolution.

After many of the workers had completed the railways, they did not return to their rural lifestyles but instead remained in the cities, providing additional workers for the factories.

Railways helped Britain's trade enormously, providing a quick and easy way of transport and an easy way to transport mail and news.

Social effects

In terms of social structure, the Industrial Revolution witnessed the triumph of a middle class of industrialists and businessmen over a landed class of nobility and gentry.

Ordinary working people found increased opportunities for employment in the new mills and factories, but these were often under strict working conditions with long hours of labour dominated by a pace set by machines. However, harsh working conditions were prevalent long before the Industrial Revolution took place. Pre-industrial society was very static and often cruel—child labour, dirty living conditions, and long working hours were just as prevalent before the Industrial Revolution.

Factories and urbanisation



Manchester, England ("Cottonopolis"), pictured in 1840, showing the mass of factory chimneys

Industrialisation led to the creation of the factory. Arguably the first was John Lombe's water-powered silk mill at Derby, operational by 1721. However, the rise of the factory came somewhat later when cotton spinning was mechanised.

The factory system was largely responsible for the rise of the modern city, as large numbers of workers migrated into the cities in search of employment in the factories. Nowhere was this better illustrated than the mills and associated industries of Manchester, nicknamed "Cottonopolis", and arguably the world's first industrial city. For much of the 19th century, production was done in small mills, which were typically water-powered and built to serve local needs. Later each factory would have its own steam engine and a chimney to give an efficient draft through its boiler.

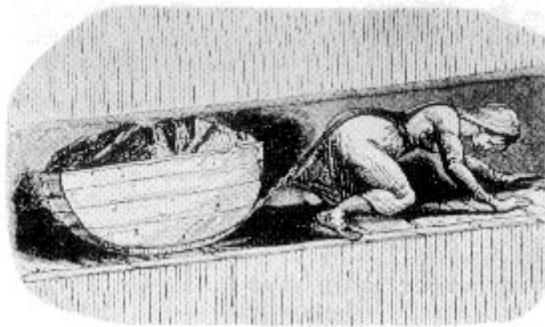
The transition to industrialisation was not without difficulty. For example, a group of English workers known as Luddites formed to protest against industrialisation and sometimes sabotaged factories.

In other industries the transition to factory production was not so divisive. Some industrialists themselves tried to improve factory and living conditions for their workers. One of the earliest such reformers was Robert Owen, known for his pioneering efforts in

improving conditions for workers at the New Lanark mills, and often regarded as one of the key thinkers of the early socialist movement.

By 1746, an integrated brass mill was working at Warmley near Bristol. Raw material went in at one end, was smelted into brass and was turned into pans, pins, wire, and other goods. Housing was provided for workers on site. Josiah Wedgwood and Matthew Boulton were other prominent early industrialists, who employed the factory system.

Child labour



A young "drawer" pulling a coal tub along a mine gallery

The Industrial Revolution led to a population increase, but the chances of surviving childhood did not improve throughout the Industrial Revolution (although *infant* mortality rates were reduced markedly). There was still limited opportunity for education, and children were expected to work. Employers could pay a child less than an adult even though their productivity was comparable; there was no need for strength to operate an industrial machine, and since the industrial system was completely new there were no experienced adult labourers. This made child labour the labour of choice for manufacturing in the early phases of the Industrial Revolution between the 18th and 19th centuries. In England and Scotland in 1788, two-thirds of the workers in 143 water-powered cotton mills were described as children.

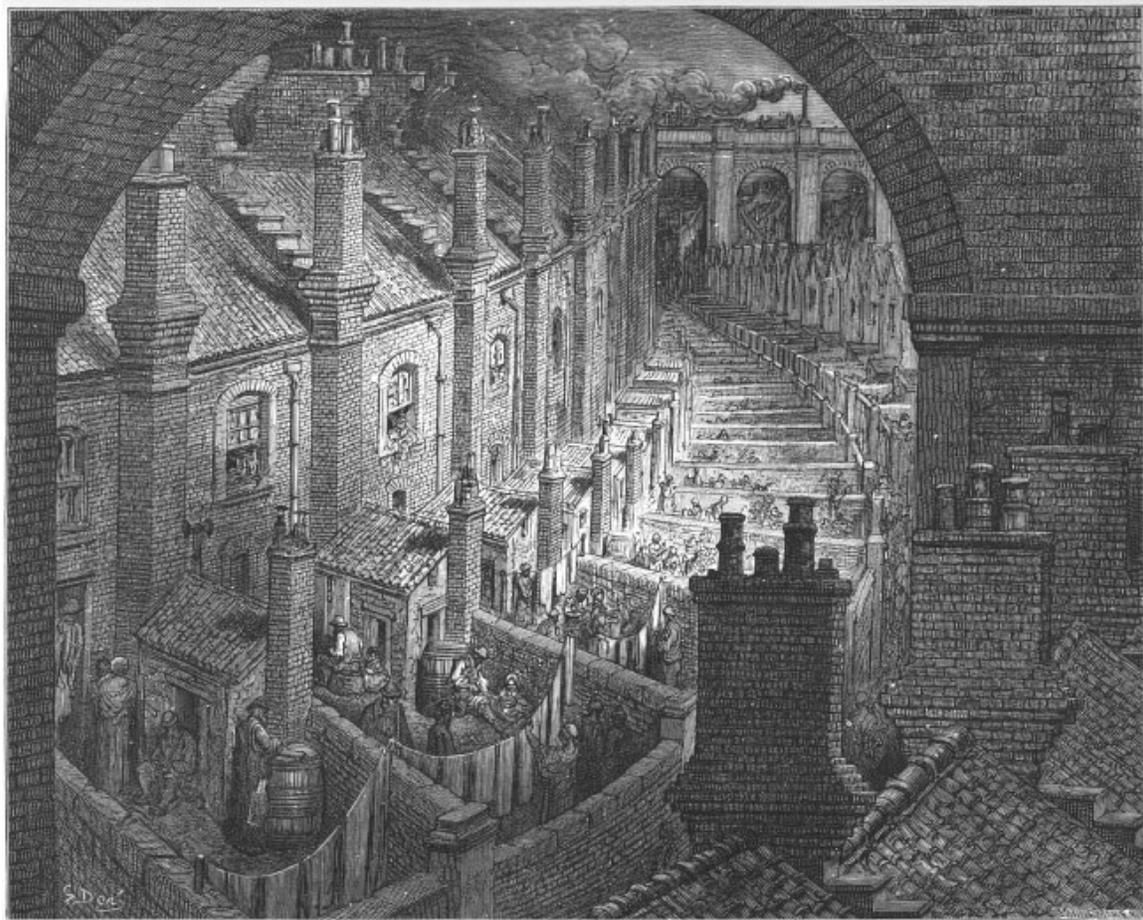
Child labour had existed before the Industrial Revolution, but with the increase in population and education it became more visible. Many children were forced to work in relatively bad conditions for much lower pay than their elders, 10-20% of an adult male's wage. Children as young as four were employed. Beatings and long hours were common, with some child coal miners working from 4 am until 5 pm. Conditions were dangerous, with some children killed when they dozed off and fell into the path of the carts, while others died from gas explosions. Many children developed lung cancer and other diseases and died before the age of 25. Workhouses would sell orphans and abandoned children as "pauper apprentices", working without wages for board and lodging. Those who ran away would be whipped and returned to their masters, with some masters shackling them to prevent escape. Children employed as "scavengers" by cotton mills would climb under machinery to pick up cotton, working 14 hours a day, six days a week. Some lost hands or limbs, others were crushed under the machines, and some were decapitated. Young

girls worked at match factories, where phosphorous fumes would cause many to develop phosphy jaw. Children employed at glassworks were regularly burned and blinded, and those working at potteries were vulnerable to poisonous clay dust.

Reports were written detailing some of the abuses, particularly in the coal mines and textile factories and these helped to popularise the children's plight. The public outcry, especially among the upper and middle classes, helped stir change in the young workers' welfare.

Politicians and the government tried to limit child labour by law, but factory owners resisted; some felt that they were aiding the poor by giving their children money to buy food to avoid starvation, and others simply welcomed the cheap labour. In 1833 and 1844, the first general laws against child labour, the Factory Acts, were passed in England: Children younger than nine were not allowed to work, children were not permitted to work at night, and the work day of youth under the age of 18 was limited to twelve hours. Factory inspectors supervised the execution of the law, however, their scarcity made enforcement difficult. About ten years later, the employment of children and women in mining was forbidden. These laws decreased the number of child labourers; however, child labour remained in Europe and the United States up to the 20th century. By 1900, there were 1.7 million child labourers reported in American industry under the age of fifteen.

Housing



OVER LONDON - BY RAIL

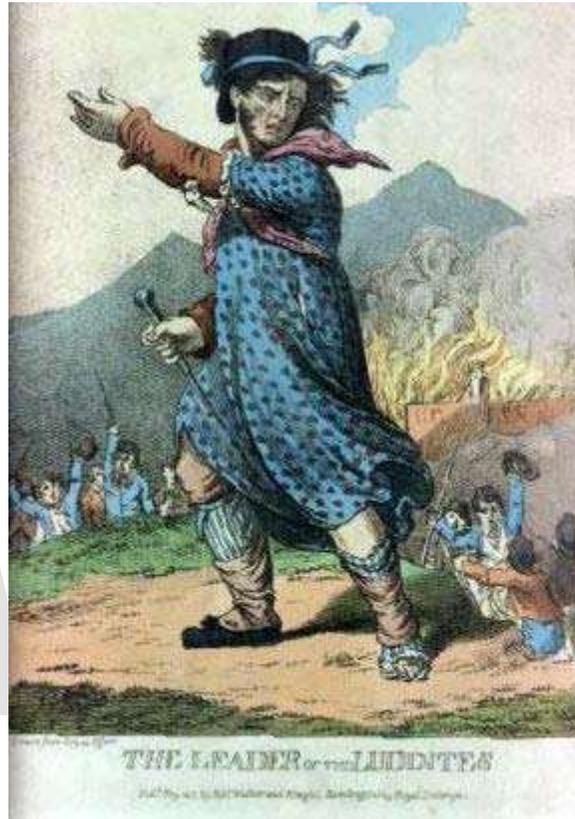
Over London by Rail Gustave Doré c. 1870. Shows the densely populated and polluted environments created in the new industrial cities

Living conditions during the Industrial Revolution varied from the splendour of the homes of the owners to the squalor of the lives of the workers. Poor people lived in very small houses in cramped streets. These homes would share toilet facilities, have open sewers and would be at risk of damp. Disease was spread through a contaminated water supply. Conditions did improve during the 19th century as public health acts were introduced covering things such as sewage, hygiene and making some boundaries upon the construction of homes. Not everybody lived in homes like these. The Industrial Revolution created a larger middle class of professionals such as lawyers and doctors. The conditions for the poor improved over the course of the 19th century because of government and local plans which led to cities becoming cleaner places, but life had not been easy for the poor before industrialisation. However, as a result of the Revolution, huge numbers of the working class died due to diseases spreading through the cramped living conditions. Chest diseases from the mines, cholera from polluted water and typhoid

were also extremely common, as was smallpox. Accidents in factories with child and female workers were regular. Strikes and riots by workers were also relatively common.

A description of housing of the mill workers in England in 1844 was given by Fredrick Engels.

Luddites



The Leader of the luddites, engraving of 1812

The rapid industrialisation of the English economy cost many craft workers their jobs. The movement started first with lace and hosiery workers near Nottingham and spread to other areas of the textile industry owing to early industrialisation. Many weavers also found themselves suddenly unemployed since they could no longer compete with machines which only required relatively limited (and unskilled) labour to produce more cloth than a single weaver. Many such unemployed workers, weavers and others, turned their animosity towards the machines that had taken their jobs and began destroying factories and machinery. These attackers became known as Luddites, supposedly followers of Ned Ludd, a folklore figure. The first attacks of the Luddite movement began in 1811. The Luddites rapidly gained popularity, and the British government took drastic measures using the militia or army to protect industry. Those rioters who were caught were tried and hanged, or transported for life.

Unrest continued in other sectors as they industrialised, such as agricultural labourers in the 1830s, when large parts of southern Britain were affected by the Captain Swing disturbances. Threshing machines were a particular target, and rick burning was a popular activity. However the riots led to the first formation of trade unions, and further pressure for reform.

Organisation of labour



The Great Chartist Meeting on Kennington Common, 1848

The Industrial Revolution concentrated labour into mills, factories and mines, thus facilitating the organisation of *combinations* or trade unions to help advance the interests of working people. The power of a union could demand better terms by withdrawing all labour and causing a consequent cessation of production. Employers had to decide between giving in to the union demands at a cost to themselves or suffering the cost of the lost production. Skilled workers were hard to replace, and these were the first groups to successfully advance their conditions through this kind of bargaining.

The main method the unions used to effect change was strike action. Many strikes were painful events for both sides, the unions and the management. In England, the Combination Act forbade workers to form any kind of trade union from 1799 until its repeal in 1824. Even after this, unions were still severely restricted.

In 1832, the year of the Reform Act which extended the vote in England but did not grant universal suffrage, six men from Tolpuddle in Dorset founded the Friendly Society of Agricultural Labourers to protest against the gradual lowering of wages in the 1830s. They refused to work for less than 10 shillings a week, although by this time wages had been reduced to seven shillings a week and were due to be further reduced to six shillings. In 1834 James Frampton, a local landowner, wrote to the Prime Minister, Lord Melbourne, to complain about the union, invoking an obscure law from 1797 prohibiting people from swearing oaths to each other, which the members of the Friendly Society had done. James Brine, James Hammett, George Loveless, George's brother James Loveless, George's brother-in-law Thomas Standfield, and Thomas's son John Standfield were arrested, found guilty, and transported to Australia. They became known as the Tolpuddle martyrs. In the 1830s and 1840s the Chartist movement was the first large scale organised working class political movement which campaigned for political equality and social justice. Its *Charter* of reforms received over three million signatures but was rejected by Parliament without consideration.

Working people also formed friendly societies and co-operative societies as mutual support groups against times of economic hardship. Enlightened industrialists, such as Robert Owen also supported these organisations to improve the conditions of the working class.

Unions slowly overcame the legal restrictions on the right to strike. In 1842, a General Strike involving cotton workers and colliers was organised through the Chartist movement which stopped production across Great Britain.

Eventually effective political organisation for working people was achieved through the trades unions who, after the extensions of the franchise in 1867 and 1885, began to support socialist political parties that later merged to become the British Labour Party.

Standards of living

The history of the change of living conditions during the industrial revolution has been very controversial, and was the topic that from the 1950s to the 1980s caused most heated debate among economic and social historians. A series of 1950s essays by Henry Phelps Brown and Sheila V. Hopkins later set the academic consensus that the bulk of the population, that was at the bottom of the social ladder, suffered severe reductions in their living standards.

Chronic hunger and malnutrition were the norm for the majority of the population of the world including England and France, until the latter part of the 19th century. Until about 1750, in large part due to malnutrition, life expectancy in France was about 35 years, and only slightly higher in England. The U.S. population of the time was adequately fed, were much taller and had life expectancies of 45–50 years. A vivid description of living standards of the mill workers in England in 1844 was given by Fredrick Engels.

During the period 1813-1913 there was a significant increase in worker wages .

Population increase

According to Robert Hughes in *The Fatal Shore*, the population of England and Wales, which had remained steady at 6 million from 1700 to 1740, rose dramatically after 1740. The population of England had more than doubled from 8.3 million in 1801 to 16.8 million in 1851 and, by 1901, had nearly doubled again to 30.5 million. As living conditions and health care improved during the 19th century, Britain's population doubled every 50 years. Europe's population doubled during the 18th century, from roughly 100 million to almost 200 million, and doubled again during the 19th century, to around 400 million.

Other effects

The application of steam power to the industrial processes of printing supported a massive expansion of newspaper and popular book publishing, which reinforced rising literacy and demands for mass political participation.

During the Industrial Revolution, the life expectancy of children increased dramatically. The percentage of the children born in London who died before the age of five decreased from 74.5% in 1730–1749 to 31.8% in 1810–1829.

The growth of modern industry from the late 18th century onward led to massive urbanisation and the rise of new great cities, first in Europe and then in other regions, as new opportunities brought huge numbers of migrants from rural communities into urban areas. In 1800, only 3% of the world's population lived in cities, a figure that has risen to nearly 50% at the beginning of the 21st century. In 1717 Manchester was merely a market town of 10,000 people, but by 1911 it had a population of 2.3 million.

The greatest killer in the cities was tuberculosis (TB). By the late 19th century, 70 to 90% of the urban populations of Europe and North America were infected with *M. tuberculosis*, and about 40% of working-class deaths in cities were from TB.

Continental Europe

The Industrial Revolution on Continental Europe came a little later than in Great Britain. In many industries, this involved the application of technology developed in Britain in new places. Often the technology was purchased from Britain or British engineers and entrepreneurs moved abroad in search of new opportunities. By 1809 part of the Ruhr Valley in Westphalia was called 'Miniature England' because of its similarities to the industrial areas of England. The German, Russian and Belgian governments all provided state funding to the new industries. In some cases (such as iron), the different availability of resources locally meant that only some aspects of the British technology were adopted.

Wallonia, Belgium



Lifts on Canal du Centre (1888 - 1917) near La Louvière, Wallonia



Workers' housing at Bois-du-Luc (1838-1853) in La Louvière

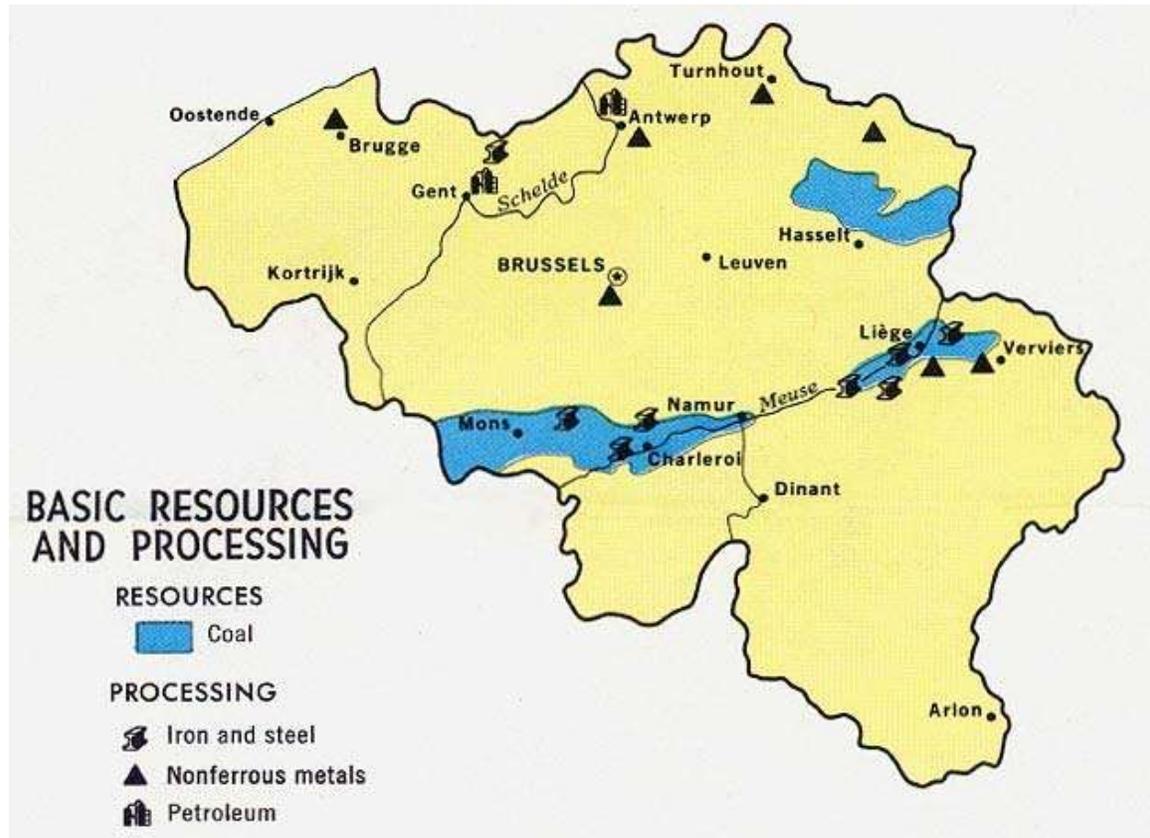
Renowned for its coal and steel, Wallonia has experienced strong industrial growth since the Middle Ages. For many years, heavy industry was the driving force behind the region's economy. Indeed, Wallonia was the birthplace of the industrial revolution on continental Europe:

Before railway construction on the Continent demanded huge quantities of malleable iron mainly for rails, for which low quality iron sufficed, Wallonia was the only Continental region to follow the British model successfully. Since the middle of the 1820s, numerous works comprising coke blast furnaces as well as puddling and rolling mills were built in the coal mining areas around Liège and Charleroi. Excelling all others, John Cockerill's factories at Seraing integrated all stages of production, from engineering to the supply of raw materials, as early as 1825.

Wallonia came to be regarded as an example of the radical evolution of industrial expansion. Thanks to coal (the French word "houille" was coined in Wallonia), the region geared up to become the 2nd industrial power in the world after England. But it is also pointed out by many researchers, with its *Sillon industriel*, 'Especially in the Haine, Sambre and Meuse valleys, between the Borinage and Liège, (...) there was a huge industrial development based on coal-mining and iron-making...'. Philippe Raxhon wrote about the period after 1830: "It was not propaganda but a reality the Walloon regions were becoming the second industrial power all over the world after England." "The sole industrial centre outside the collieries and blast furnaces of Walloon was the old cloth making town of Ghent." Michel De Coster, Professor at the Université de Liège wrote

also: "The historians and the economists say that Belgium was the second industrial power of the world, in proportion to its population and its territory (...) But this rank is the one of Wallonia where the coal-mines, the blast furnaces, the iron and zinc factories, the wool industry, the glass industry, the weapons industry... were concentrated"

Demographic effects



Wallonia's Sillon industriel (the blue area in the north is not in Wallonia)



Gallow frame of the Crachet in Frameries IN Wallonia's French Châssis à molettes or Belfleur



Official Poster of the Liège's World fair in 1905

Wallonia was also the birthplace of a strong Socialist party and strong trade-unions in a particular sociological landscape. At the left, the *Sillon industriel*, which runs from Mons in the west, to Verviers in the east (except part of North Flanders, in another period of the industrial revolution, after 1920). Even if Wallonia is the second industrial country after England, the effect of the industrial revolution there was very different. In 'Breaking stereotypes', Muriel Neven and Isabelle Devios say:

The industrial revolution changed a mainly rural society into an urban one, but with a strong contrast between northern and southern Belgium. During the Middle Ages and the Early Modern Period, Flanders was characterised by the presence of large urban centres (...) at the beginning of the nineteenth century this region (Flanders), with an urbanisation degree of more than 30 per cent, remained one of the most urbanised in the world. By comparison, this proportion reached only 17 per cent in Wallonia, barely 10 per cent in most West European countries, 16 per cent in France and 25 per cent in England. Nineteenth century industrialisation did not affect the traditional urban infrastructure, except in Ghent (...) Also, in Wallonia the traditional urban network was largely unaffected by the industrialisation process, even though the proportion of city-dwellers rose from 17 to 45 per cent between 1831 and 1910. Especially in the Haine, Sambre and Meuse valleys, between the Borinage and Liège, where there was a huge industrial development based on coal-mining and iron-making, urbanisation was rapid. During

these eighty years the number of municipalities with more than 5,000 inhabitants increased from only 21 to more than one hundred, concentrating nearly half of the Walloon population in this region. Nevertheless, industrialisation remained quite traditional in the sense that it did not lead to the growth of modern and large urban centres, but to a conurbation of industrial villages and towns developed around a coal-mine or a factory. Communication routes between these small centres only became populated later and created a much less dense urban morphology than, for instance, the area around Liège where the old town was there to direct migratory flows.

France

The industrial revolution in France was a particular process for it did not correspond to the main model followed by other countries. Notably, most French historians argue that France did not go through a clear *take-off*. Instead, France's economic growth and industrialisation process was slow and steady along the 18th and 19th centuries. However, some stages were identified by Maurice Lévy-Leboyer :

- French Revolution and Napoleonic wars (1789–1815),
- industrialisation, along with Britain (1815–1860),
- economic slowdown (1860–1905),
- renewal of the growth after 1905.

United States



Slater's Mill

The United States originally used horse-powered machinery to power its earliest factories, but eventually switched to water power, with the consequence that industrialisation was essentially limited to New England and the rest of the Northeastern United States, where fast-moving rivers were located. Horse-drawn production proved to be economically challenging and a more difficult alternative to the newer water-powered production lines. However, the raw materials (cotton) came from the Southern United States. It was not until after the Civil War in the 1860s that steam-powered manufacturing overtook water-powered manufacturing, allowing the industry to fully spread across the nation.

Thomas Somers and the Cabot Brothers founded the Beverly Cotton Manufactory in 1787, the first cotton mill in America, the largest cotton mill of its era, and a significant milestone in the research and development of cotton mills in the future. This cotton mill was designed to utilise horse-powered production, however the operators quickly learned that the economic stability of their horse-drawn platform was unstable, and had fiscal issues for years after it was built. Despite the losses, the Manufactory served as a

playground of innovation, both in turning a large amount of cotton, but also developing the water-powered milling structure used in Slater's Mill.



Bethlehem Steel, founded in 1857, was once the second-largest manufacturer of steel in the United States; its Bethlehem, Pennsylvania, location has been transformed into a casino.

Samuel Slater (1768–1835) is the founder of the Slater Mill. As a boy apprentice in Derbyshire, England, he learned of the new techniques in the textile industry and defied laws against the emigration of skilled workers by leaving for New York in 1789, hoping to make money with his knowledge. Slater founded Slater's Mill at Pawtucket, Rhode Island, in 1793. He went on to own thirteen textile mills. Daniel Day established a wool carding mill in the Blackstone Valley at Uxbridge, Massachusetts in 1809, the third woollen mill established in the U.S. (The first was in Hartford, Connecticut, and the second at Watertown, Massachusetts.) The John H. Chafee Blackstone River Valley National Heritage Corridor retraces the history of "America's Hardest-Working River", the Blackstone. The Blackstone River and its tributaries, which cover more than 45 miles (72 km) from Worcester to Providence, was the birthplace of America's Industrial Revolution. At its peak over 1100 mills operated in this valley, including Slater's mill, and with it the earliest beginnings of America's Industrial and Technological Development.

While on a trip to England in 1810, Newburyport merchant Francis Cabot Lowell was allowed to tour the British textile factories, but not take notes. Realising the War of 1812

had ruined his import business but that a market for domestic finished cloth was emerging in America, he memorised the design of textile machines, and on his return to the United States, he set up the Boston Manufacturing Company. Lowell and his partners built America's second cotton-to-cloth textile mill at Waltham, Massachusetts, second to the Beverly Cotton Manufactory. After his death in 1817, his associates built America's first planned factory town, which they named after him. This enterprise was capitalised in a public stock offering, one of the first uses of it in the United States. Lowell, Massachusetts, utilising 5.6 miles (9.0 km) of canals and ten thousand horsepower delivered by the Merrimack River, is considered by some to be a major contributor to the success of the American Industrial Revolution. The short-lived utopia-like Lowell System was formed, as a direct response to the poor working conditions in Britain. However, by 1850, especially following the Irish Potato Famine, the system had been replaced by poor immigrant labour.

The industrialisation of the watch industry started 1854 also in Waltham, Massachusetts, at the Waltham Watch Company, with the development of machine tools, tools, gauges and assembling methods adapted to the micro precision required for watches.

Japan

In 1871 a group of Japanese politicians known as the Iwakura Mission toured Europe and the USA to learn western ways. The result was a deliberate state led industrialisation policy to prevent Japan from falling behind. The Bank of Japan, founded in 1877, used taxes to fund model steel and textile factories. Education was expanded and Japanese students were sent to study in the west.

Second Industrial Revolution and later evolution

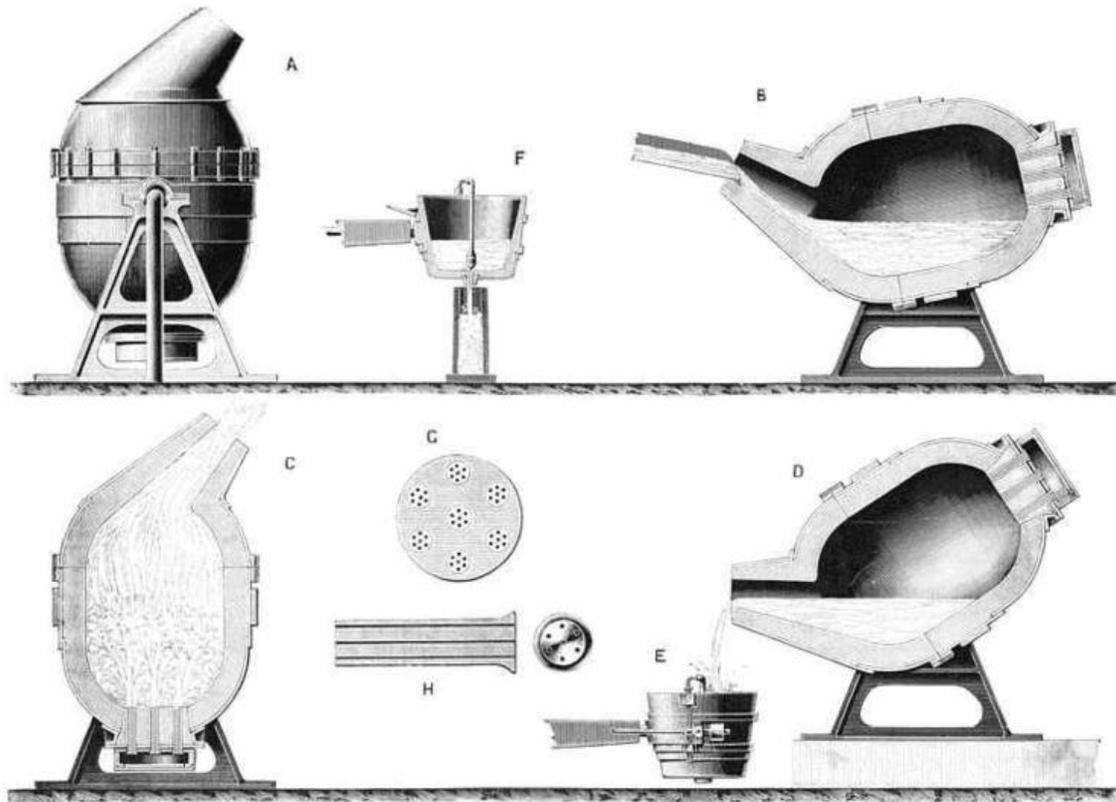


FIG. 43. THE FIRST FORM OF BESSEMER MOVEABLE CONVERTER AND LADLE

Bessemer converter

The insatiable demand of the railways for more durable rail led to the development of the means to cheaply mass-produce steel. Steel is often cited as the first of several new areas for industrial mass-production, which are said to characterise a "Second Industrial Revolution", beginning around 1850, although a method for mass manufacture of steel was not invented until the 1860s, when Sir Henry Bessemer invented a new furnace which could make wrought iron and steel in large quantities. However, it only became widely available in the 1870s. This second Industrial Revolution gradually grew to include the chemical industries, petroleum refining and distribution, electrical industries, and, in the 20th century, the automotive industries, and was marked by a transition of technological leadership from Britain to the United States and Germany.

The introduction of hydroelectric power generation in the Alps enabled the rapid industrialisation of coal-deprived northern Italy, beginning in the 1890s. The increasing availability of economical petroleum products also reduced the importance of coal and further widened the potential for industrialisation.

Marshall McLuhan analysed the social and cultural impact of the electric age. While the previous age of mechanisation had spread the idea of splitting every process into a sequence, this was ended by the introduction of the instant speed of electricity that brought simultaneity. This imposed the cultural shift from the approach of focusing on "specialised segments of attention" (adopting one particular perspective), to the idea of "instant sensory awareness of the whole", an attention to the "total field", a "sense of the whole pattern". It made evident and prevalent the sense of "form and function as a unity", an "integral idea of structure and configuration". This had major impact in the disciplines of painting (with cubism), physics, poetry, communication and educational theory.

By the 1890s, industrialisation in these areas had created the first giant industrial corporations with burgeoning global interests, as companies like U.S. Steel, General Electric, and Bayer AG joined the railroad companies on the world's stock markets.

Intellectual paradigms and criticism

Capitalism

The advent of the Age of Enlightenment provided an intellectual framework which welcomed the practical application of the growing body of scientific knowledge—a factor evidenced in the systematic development of the steam engine, guided by scientific analysis, and the development of the political and sociological analyses, culminating in Adam Smith's *The Wealth of Nations*. One of the main arguments for capitalism, presented for example in the book *The Improving State of the World*, is that industrialisation increases wealth for all, as evidenced by raised life expectancy, reduced working hours, and no work for children and the elderly.

Socialism

Socialism emerged as a critique of capitalism. Marxism began essentially as a reaction to the Industrial Revolution. According to Karl Marx, industrialisation polarised society into the bourgeoisie (those who own the means of production, the factories and the land) and the much larger proletariat (the working class who actually perform the labour necessary to extract something valuable from the means of production). He saw the industrialisation process as the logical dialectical progression of feudal economic modes, necessary for the full development of capitalism, which he saw as in itself a necessary precursor to the development of socialism and eventually communism.

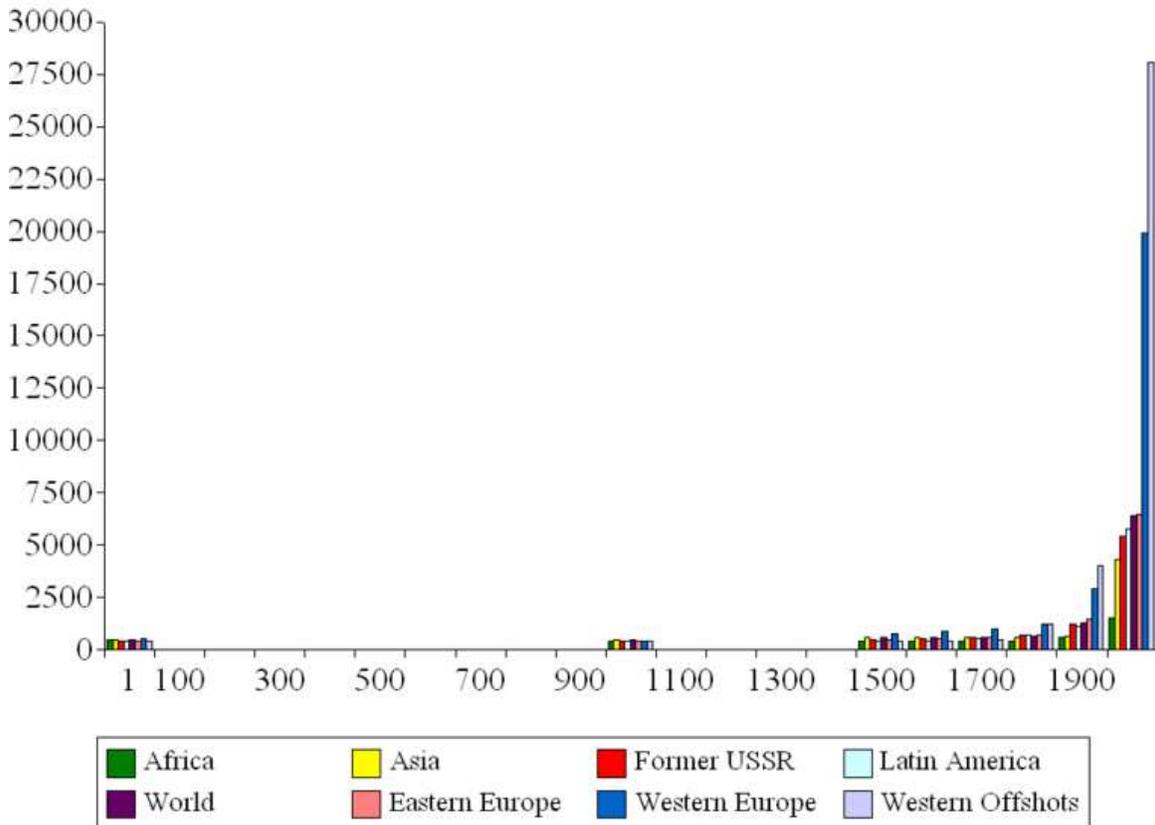
Romanticism

During the Industrial Revolution an intellectual and artistic hostility towards the new industrialisation developed. This was known as the Romantic movement. Its major exponents in English included the artist and poet William Blake and poets William Wordsworth, Samuel Taylor Coleridge, John Keats, Lord Byron and Percy Bysshe Shelley. The movement stressed the importance of "nature" in art and language, in

contrast to "monstrous" machines and factories; the "Dark satanic mills" of Blake's poem "And did those feet in ancient time". Mary Shelley's novel *Frankenstein* reflected concerns that scientific progress might be two-edged.

Causes

World GDP/capita 1-2003 A.D.



Regional GDP per capita changed very little for most of human history before the Industrial Revolution. (The empty areas mean no data, not very low levels. There is data for the years 1, 1000, 1500, 1600, 1700, 1820, 1900, and 2003)

The causes of the Industrial Revolution were complicated and remain a topic for debate, with some historians believing the Revolution was an outgrowth of social and institutional changes brought by the end of feudalism in Britain after the English Civil War in the 17th century. As national border controls became more effective, the spread of disease was lessened, thereby preventing the epidemics common in previous times. The percentage of children who lived past infancy rose significantly, leading to a larger workforce. The Enclosure movement and the British Agricultural Revolution made food production more efficient and less labour-intensive, forcing the surplus population who could no longer find employment in agriculture into cottage industry, for example weaving, and in the longer term into the cities and the newly developed factories. The

colonial expansion of the 17th century with the accompanying development of international trade, creation of financial markets and accumulation of capital are also cited as factors, as is the scientific revolution of the 17th century.

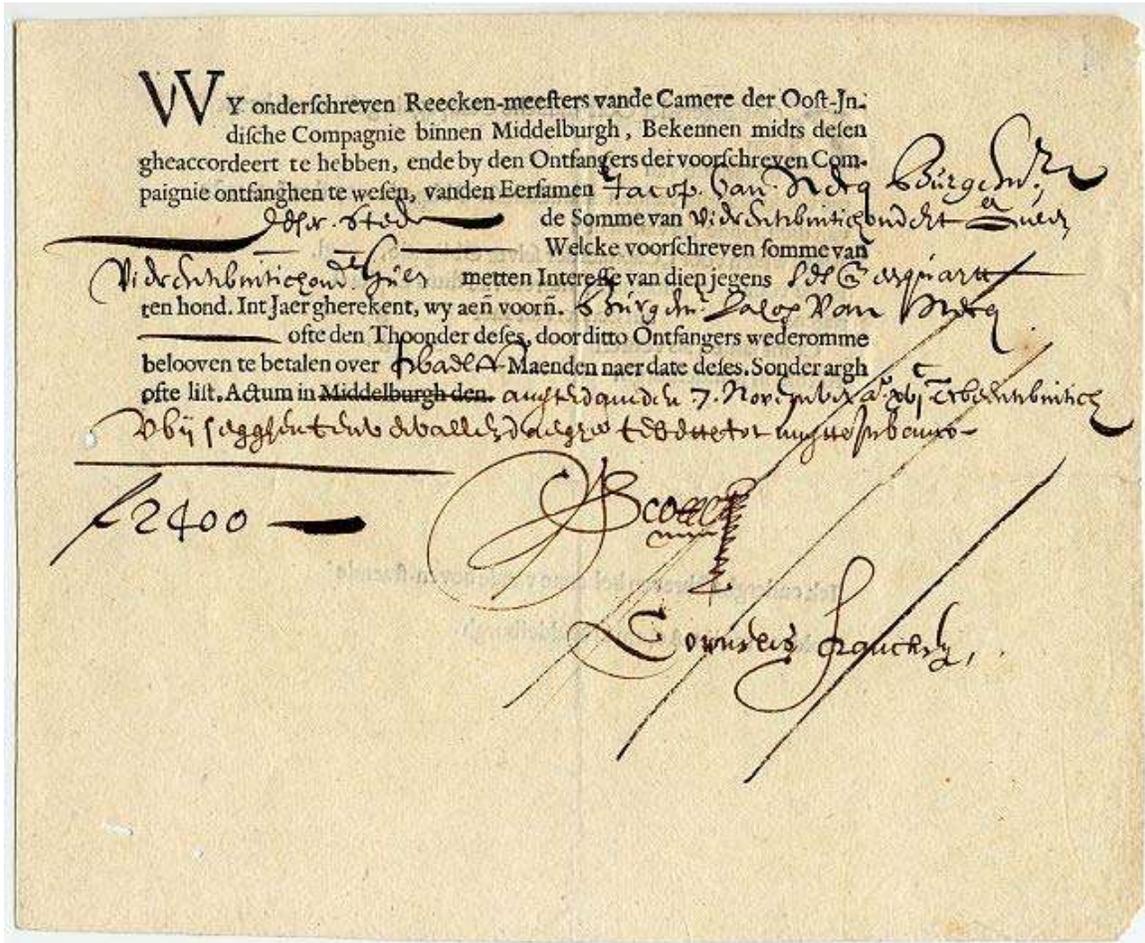
Until the 1980s, it was universally believed by academic historians that technological innovation was the heart of the Industrial Revolution and the key enabling technology was the invention and improvement of the steam engine. However, recent research into the Marketing Era has challenged the traditional, supply-oriented interpretation of the Industrial Revolution.

Lewis Mumford has proposed that the Industrial Revolution had its origins in the Early Middle Ages, much earlier than most estimates. He explains that the model for standardised mass production was the printing press and that "the archetypal model for the industrial era was the clock". He also cites the monastic emphasis on order and time-keeping, as well as the fact that medieval cities had at their centre a church with bell ringing at regular intervals as being necessary precursors to a greater synchronisation necessary for later, more physical, manifestations such as the steam engine.

The presence of a large domestic market should also be considered an important driver of the Industrial Revolution, particularly explaining why it occurred in Britain. In other nations, such as France, markets were split up by local regions, which often imposed tolls and tariffs on goods traded amongst them. Internal tariffs were abolished by Henry VIII of England, they survived in Russia till 1753, 1789 in France and 1839 in Spain.

Governments' grant of limited monopolies to inventors under a developing patent system (the Statute of Monopolies 1623) is considered an influential factor. The effects of patents, both good and ill, on the development of industrialisation are clearly illustrated in the history of the steam engine, the key enabling technology. In return for publicly revealing the workings of an invention the patent system rewarded inventors such as James Watt by allowing them to monopolise the production of the first steam engines, thereby rewarding inventors and increasing the pace of technological development. However monopolies bring with them their own inefficiencies which may counterbalance, or even overbalance, the beneficial effects of publicising ingenuity and rewarding inventors. Watt's monopoly may have prevented other inventors, such as Richard Trevithick, William Murdoch or Jonathan Hornblower, from introducing improved steam engines, thereby retarding the industrial revolution by about 16 years.

Causes for occurrence in Europe



A 1623 Dutch East India Company bond.

European 17th century colonial expansion, international trade, and creation of financial markets produced a new legal and financial environment, one which supported and enabled 18th century industrial growth.

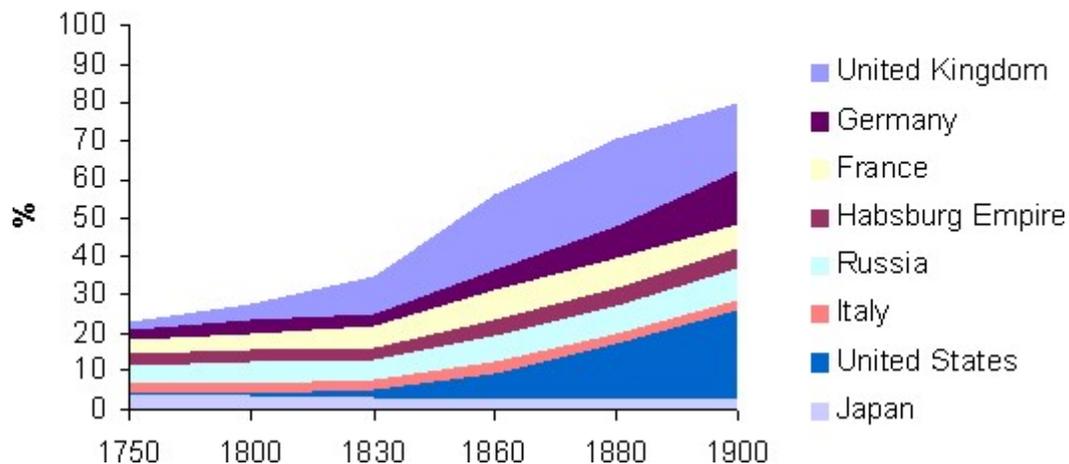
One question of active interest to historians is why the industrial revolution occurred in Europe and not in other parts of the world in the 18th century, particularly China, India, and the Middle East, or at other times like in Classical Antiquity or the Middle Ages. Numerous factors have been suggested, including education, technological changes, "modern" government, "modern" work attitudes, ecology, and culture. The Age of Enlightenment not only meant a larger educated population but also more modern views on work. However, most historians contest the assertion that Europe and China were roughly equal because modern estimates of per capita income on Western Europe in the late 18th century are of roughly 1,500 dollars in purchasing power parity (and Britain had a per capita income of nearly 2,000 dollars) whereas China, by comparison, had only 450 dollars.

Some historians such as David Landes and Max Weber credit the different belief systems in China and Europe with dictating where the revolution occurred. The religion and beliefs of Europe were largely products of Judaeo-Christianity, and Greek thought. Conversely, Chinese society was founded on men like Confucius, Mencius, Han Feizi (Legalism), Lao Tzu (Taoism), and Buddha (Buddhism). Whereas the Europeans believed that the universe was governed by rational and eternal laws, the East believed that the universe was in constant flux and, for Buddhists and Taoists, not capable of being rationally understood. Other factors include the considerable distance of China's coal deposits, though large, from its cities as well as the then unnavigable Yellow River that connects these deposits to the sea.

Regarding India, the Marxist historian Rajani Palme Dutt said: "The capital to finance the Industrial Revolution in India instead went into financing the Industrial Revolution in England." In contrast to China, India was split up into many competing kingdoms, with the three major ones being the Marathas, Sikhs and the Mughals. In addition, the economy was highly dependent on two sectors—agriculture of subsistence and cotton, and there appears to have been little technical innovation. It is believed that the vast amounts of wealth were largely stored away in palace treasuries by totalitarian monarchs prior to the British take over. Absolutist dynasties in China, India, and the Middle East failed to encourage manufacturing and exports, and expressed little interest in the well-being of their subjects.

Causes for occurrence in Britain

Relative Share of World Manufacturing Output, 1750-1900



As the Industrial Revolution developed British manufactured output surged ahead of other economies. After the Industrial Revolution, it was overtaken later by the United States.

The debate about the start of the Industrial Revolution also concerns the massive lead that Great Britain had over other countries. Some have stressed the importance of natural or financial resources that Britain received from its many overseas colonies or that profits from the British slave trade between Africa and the Caribbean helped fuel industrial investment. It has been pointed out, however, that slave trade and West Indian plantations provided only 5% of the British national income during the years of the Industrial Revolution. Even though slavery accounted for minimal economic profits in Britain during the Industrial Revolution, Caribbean-based demand accounted for 12% of England's industrial output.

Alternatively, the greater liberalisation of trade from a large merchant base may have allowed Britain to produce and use emerging scientific and technological developments more effectively than countries with stronger monarchies, particularly China and Russia. Britain emerged from the Napoleonic Wars as the only European nation not ravaged by financial plunder and economic collapse, and possessing the only merchant fleet of any useful size (European merchant fleets having been destroyed during the war by the Royal Navy). Britain's extensive exporting cottage industries also ensured markets were already available for many early forms of manufactured goods. The conflict resulted in most British warfare being conducted overseas, reducing the devastating effects of territorial conquest that affected much of Europe. This was further aided by Britain's geographical position—an island separated from the rest of mainland Europe.

Another theory is that Britain was able to succeed in the Industrial Revolution due to the availability of key resources it possessed. It had a dense population for its small geographical size. Enclosure of common land and the related agricultural revolution made a supply of this labour readily available. There was also a local coincidence of natural resources in the North of England, the English Midlands, South Wales and the Scottish Lowlands. Local supplies of coal, iron, lead, copper, tin, limestone and water power, resulted in excellent conditions for the development and expansion of industry. Also, the damp, mild weather conditions of the North West of England provided ideal conditions for the spinning of cotton, providing a natural starting point for the birth of the textiles industry.

The stable political situation in Britain from around 1688, and British society's greater receptiveness to change (compared with other European countries) can also be said to be factors favouring the Industrial Revolution. In large part due to the Enclosure movement, the peasantry was destroyed as a significant source of resistance to industrialisation, and the landed upper classes developed commercial interests that made them pioneers in removing obstacles to the growth of capitalism. (This point is also made in Hilaire Belloc's *The Servile State*.)

Britain's population grew 280% 1550-1820, while the rest of Western Europe grew 50-80%. 70% of European urbanisation happened in Britain 1750-1800. By 1800, only the Netherlands was more urbanised than Britain. This was only possible because coal, coke, imported cotton, brick and slate had replaced wood, charcoal, flax, peat and thatch. The latter compete with land grown to feed people while mined materials do not. Yet more

land would be freed when chemical fertilisers replaced manure and horse's work was mechanised. A workhorse needs 3 to 5 acres (1.21 to 2.02 ha) for fodder while even early steam engines produced 4 times more mechanical energy.

In 1700 5/6 of coal mined worldwide was in Britain while the Netherlands had none; so despite having Europe's best transport, most urbanised, well paid, literate people and lowest taxes, it failed to industrialise. In the 18th century it was the only European country whose cities and population shrank. Without coal, Britain would have run out of suitable river sites for mills by the 1830s.

Protestant work ethic

Another theory is that the British advance was due to the presence of an entrepreneurial class which believed in progress, technology and hard work. The existence of this class is often linked to the Protestant work ethic and the particular status of the Baptists and the dissenting Protestant sects, such as the Quakers and Presbyterians that had flourished with the English Civil War. Reinforcement of confidence in the rule of law, which followed establishment of the prototype of constitutional monarchy in Britain in the Glorious Revolution of 1688, and the emergence of a stable financial market there based on the management of the national debt by the Bank of England, contributed to the capacity for, and interest in, private financial investment in industrial ventures.

Dissenters found themselves barred or discouraged from almost all public offices, as well as education at England's only two universities at the time (although dissenters were still free to study at Scotland's four universities). When the restoration of the monarchy took place and membership in the official Anglican Church became mandatory due to the Test Act, they thereupon became active in banking, manufacturing and education. The Unitarians, in particular, were very involved in education, by running Dissenting Academies, where, in contrast to the universities of Oxford and Cambridge and schools such as Eton and Harrow, much attention was given to mathematics and the sciences—areas of scholarship vital to the development of manufacturing technologies.

Historians sometimes consider this social factor to be extremely important, along with the nature of the national economies involved. While members of these sects were excluded from certain circles of the government, they were considered fellow Protestants, to a limited extent, by many in the middle class, such as traditional financiers or other businessmen. Given this relative tolerance and the supply of capital, the natural outlet for the more enterprising members of these sects would be to seek new opportunities in the technologies created in the wake of the scientific revolution of the 17th century.

This theory does not explain how the second country to be industrialised-Belgium, was Catholic.

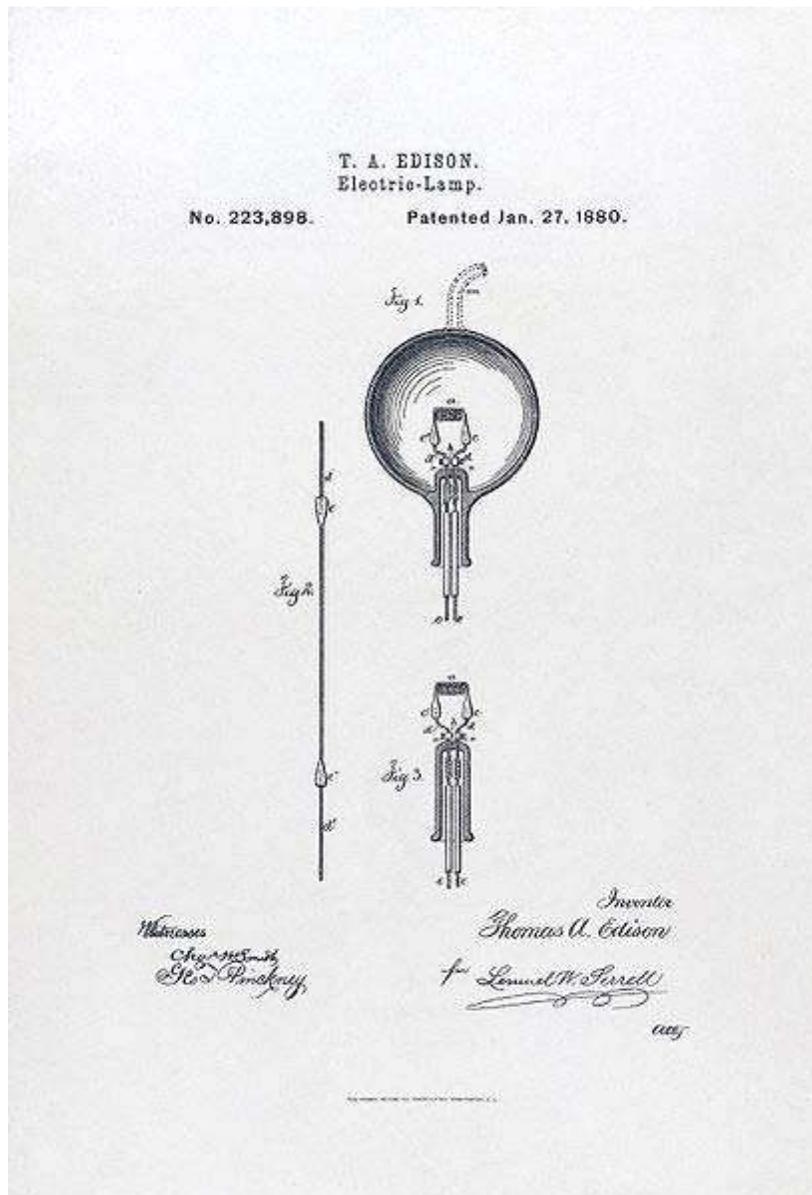
Name history

The earliest use of the term "Industrial Revolution" yet located seems to be a letter of 6 July 1799 by French envoy Louis-Guillaume Otto, announcing that the process had started in his country. In his 1976 book *Keywords: A Vocabulary of Culture and Society*, Raymond Williams states in the entry for "Industry": "The idea of a new social order based on major industrial change was clear in Southey and Owen, between 1811 and 1818, and was implicit as early as Blake in the early 1790s and Wordsworth at the turn of the century." The term *Industrial Revolution* applied to technological change was becoming more common by the late 1830s, as in Louis-Auguste Blanqui's description in 1837 of *la révolution industrielle*. Friedrich Engels in *The Condition of the Working Class in England in 1844* spoke of "an industrial revolution, a revolution which at the same time changed the whole of civil society". Credit for popularising the term may be given to Arnold Toynbee, whose lectures given in 1881 gave a detailed account of it.

WWT

Chapter- 4

Second Industrial Revolution



U.S. Patent#223898: Electric-Lamp. Issued January 27, 1880

The **Second Industrial Revolution**, also known as the **Technological Revolution**, was a phase of the larger Industrial Revolution corresponding to the latter half of the 19th century and the first decade and a half of the 20th, until World War I. It is considered to have begun with Bessemer steel in the 1860s and culminated in mass production and the production line.

The Second Industrial Revolution saw rapid industrial development in Western Europe (Britain, Germany, France, the Low Countries, Denmark), the United States (Northeast and Great Lakes) and, after 1870, in Japan. It followed on from the First Industrial Revolution that began in Britain in the late 18th century that then spread throughout Western Europe and North America.

The concept was introduced by Patrick Geddes, *Cities in Evolution* (1915), but David Landes's use of the term in a 1966 essay and in 'The Unbound Prometheus' (1972) standardized scholarly definitions of the term, which was most intensely promoted by American historian Alfred Chandler (1918–2007). However some continue to express reservations about its use.

Landes (2003) stresses the importance of new technologies, especially electricity, the internal combustion engine, new materials and substances, including alloys and chemicals, and communication technologies such as the telegraph and radio. While the first was centered on iron, and steam technologies and textile production, the second revolved around steel, railroads, electricity, and chemicals.

Vaclav Smill called the period 1867-1914 "The Age of Synergy" during which most of the great innovations were developed. Unlike the First Industrial Revolution, the inventions and innovations were science based.

Industry

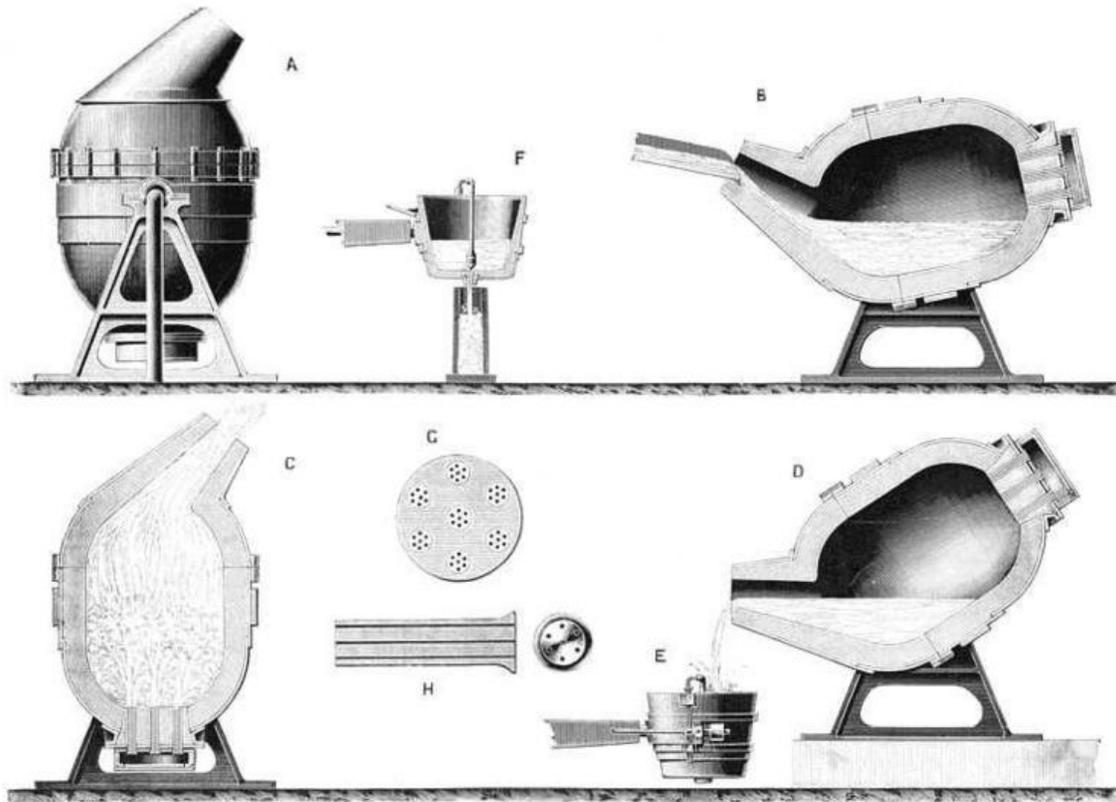


FIG. 43. THE FIRST FORM OF BESSEMER MOVEABLE CONVERTER AND LADLE

A diagram of the Bessemer converter. Air blown through holes in the converter bottom creates a violent reaction in the molten pig iron that oxidizes the excess carbon, converting the iron to steel.

The Bessemer process was the first inexpensive industrial process for the mass-production of steel from molten pig iron. Its inventor Sir Henry Bessemer, revolutionized steel manufacture by decreasing its cost, increased the scale and speed of production of this vital raw material, and decreased the labor requirements for steel-making. The Bessemer process was soon followed by the Siemens-Martin and the open hearth processes, the former allowing recycling of scrap iron and steel and the latter being the leading steel making process in early 20th century.

The concept of interchangeable parts had been implemented in the early 19th century by inventors including Honoré Blanc, Henry Maudslay, John Hall, and Simeon North. Interchangeable parts in firearms had been developed by the armories at Springfield and Harper's Ferry by the mid 19th century and mechanics familiar with *armory practice* introduced the concept to other industries, mainly in New England. The system relied on machine tools, jigs for guiding the tools and fixtures for properly holding the work and

gauge blocks for checking the fit of parts. This method eventually became known as the *American system of manufacturing*. Application of the *American system* to the sewing machine and reaper industries in the 1880s resulted in substantial increases in productivity. The *American system* was applied in the bicycle industry almost from the beginning. A later concept developed during the period was scientific management or Taylorism developed by Frederick Winslow Taylor and others. Scientific management initially concentrated on reducing the steps taken in performing work such as bricklaying or shoveling by using analysis such as time and motion studies, but the concepts evolved into fields such as industrial engineering manufacturing engineering and business management that helped to completely restructure the operations of factories, and later, entire segments of the economy.

The use of wood for making paper freed paper makers from using cotton and linen rags, which had been the limiting factor in paper production since the invention of the printing press (ca. 1440). Finding a more abundant source of pulp became particularly important after a machine was invented for continuous paper making (Ptd. 1799). The first wood pulp (ca. 1840) was made by grinding wood, but the 1880s chemical processes were in use, becoming dominant by 1900.

The petroleum industry, both production and refining, began during the 2nd I.R., with its primary product being kerosene for lamps and heaters.

Electrification allowed the final major developments in manufacturing methods of the Second Industrial Revolution, namely the assembly line and mass production. The importance of machine tools to mass production is shown by the fact that production of the Ford Model T used 32,000 machine tools, most of which were powered by electricity. Henry Ford is quoted as saying that mass production would not have been possible without electricity because it allowed placement of machine tools and other equipment in the order of the work flow.

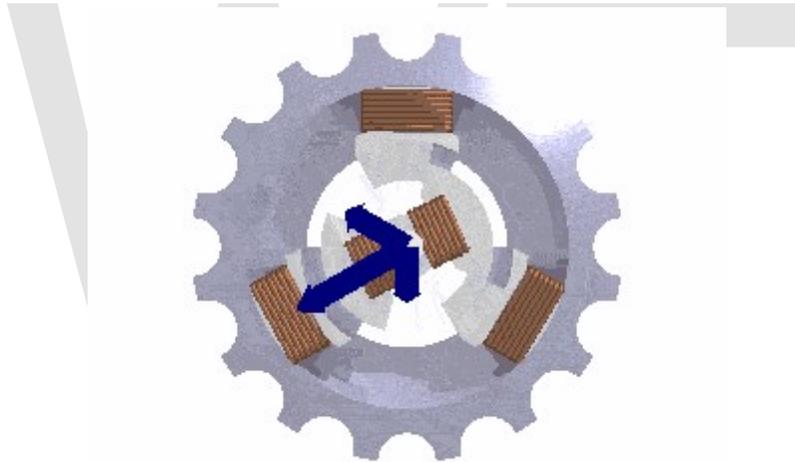
Electrification also allowed the inexpensive production of electro-chemicals, a few of the more important ones being: aluminum, chlorine, sodium hydroxide and magnesium.

Railroads overtook canals as the main transport infrastructure. The building of railroads accelerated after the introduction of inexpensive steel rails, which lasted considerably longer than the 10 year life of wrought iron rails. Railroads lowered the cost of shipping to 0.875 cents/ton-mile from 24.5 cents/ton-mile by wagon. This increased the population of many towns. Improved roads such as the Macadam pioneered by John Loudon McAdam, were developed in the first Industrial Revolution, but the road network was greatly expanded during the second Industrial Revolution with hard surfaced roads being built around the time of the bicycle craze of the 1890s.

Iron had been used in ship building for a relatively short time before the development of inexpensive steel, after which steel quickly displaced iron.

The gasoline powered automobile was patented by Karl Benz in 1886, although others had independently built cars around that time. Henry Ford built his first car in 1896 and worked as a pioneer in the industry, with others who would eventually form their own companies, until the founding of Ford Motor Company in 1903. Ford and others at the company struggled with ways to scale up production in keeping with Henry Ford's vision of a car designed and manufactured on a scale so as to be affordable by the average worker. The solution that Ford Motor developed was a completely redesigned factory with special purpose machine tools that were systematically positioned in the work sequence. All unnecessary human motions were eliminated by placing all work and tools within easy reach, and where practical on conveyors, forming the assembly line, the complete process being called mass production. This was the first time in history when a large, complex product consisting of 5000 parts had been produced on a scale of hundreds of thousands per year. The savings from mass production methods allowed the price of the Model T to decline from \$780 in 1910 to \$360 in 1916.

Technology



Three-phase rotating magnetic field of an AC motor. The three poles are each connected to a separate wire. Each wire carries current 120 degrees apart in phase. Arrows show the resulting magnetic force vectors. Three phase current is used in commerce and industry.

By the middle of the 19th century there was a scientific understanding of chemistry and a fundamental understanding of thermodynamics and by the last quarter of the century both of these sciences were near their present day basic form. Thermodynamic principles were used in the development of physical chemistry. Understanding chemistry and thermodynamics greatly aided the development of basic inorganic chemical manufacturing and the aniline dye industries.

Another beneficiary of chemistry was steel making with development of the Gilchrist-Thomas process (or *basic Bessemer process*) which involved lining the converter with limestone or dolomite to remove phosphorus, an impurity in most iron ores. Chemistry also benefited metallurgy by identifying and developing processes for purifying various

elements such as chromium, molybdenum, titanium, vanadium and nickel which could be used for making alloys with special properties, especially with steel. Vanadium steel, for example, is strong and fatigue resistant, and was used in half the automotive steel. Other important alloys are used in high temperatures, such as steam turbine blades, and stainless steels for corrosion resistance.

One of the most important developments of chemistry was the Haber process for producing ammonia (ca. 1913); however, the process did not become widespread until the W.W.2 era. Today world food supply is critically dependent on inexpensive nitrogen fertilizers produced by the Haber-Bosch process.

The Corliss steam engine (1849) was a significant improvement in efficiency, and later steam engines were designed with multiple expansions (stages) which resulted in even greater efficiency. The steam turbine was developed by Charles Parsons in 1884. Unlike steam engines the turbine produced rotary power rather than reciprocating power that required a crank and heavy flywheel. The large number of stages of the turbine allowed for high efficiency and reduced size by 90%. The turbine's first application was in shipping followed by electric generation in 1903.

The first widely used internal combustion engine was the Otto type (1876). From the 1880s until electrification it was successful in small shops because small steam engines were inefficient and required too much operator attention. The Otto engine soon began being used to power automobiles, and remains as today's common gasoline engine.

The diesel engine was designed by Rudolf Diesel in 1897 using thermodynamic principles with the specific intention of being highly efficient. It took a number of years to perfect and to catch on, but found application in shipping before powering locomotives. It remains the world's most efficient prime mover.

One of the most important scientific advancements in all of history was the unification of light, electricity and magnetism through Maxwell's electromagnetic theory. A scientific understanding of electricity was necessary for the development of efficient electric dynamos, generators, motors and transformers. Heinrich Hertz's 1887 experiments confirmed and explored the phenomenon of electromagnetic waves that had been predicted by Maxwell. This would lead to the development of radio before the end of the 2nd I.R., but radio was mainly used in shipping until the early 1920s when commercial broadcasts began. Radio as we know it depended on the development of the vacuum tube (thermionic valve) (ca. 1906-08) which allowed amplification. The vacuum tube was essential for most electronics until the transistor became available in the 1950s.

Electrification was called the "most the most important engineering achievement of the 20th century" by the National Academy of Engineering. In 1881, Sir Joseph Swan, inventor of the incandescent light bulb, supplied about 1,200 Swan incandescent lamps to the Savoy Theatre in the City of Westminster, London, which was the first theatre, and the first public building in the world, to be lit entirely by electricity. Electricity was used for street lighting in the early 1880s. Electric lighting in factories greatly improved

working conditions, getting rid of the heat and pollution caused by gas lighting and reducing the fire hazard to the extent that costs of the electricity to power lights was often offset by the reduction in fire insurance premiums. Frank J. Sprague developed the first successful DC motor in 1886 which he successfully adapted to power street railways and by 1889 there were 110 electric railways either in operation and using his equipment or in planning. The electric street railway became a major infrastructure before 1920. AC motors were developed by Nikola Tesla (Westinghouse) and others in the 1890s and soon began to be used in the electrification of industry. Household electrification did not become common until the 1920s, and then only in cities.

Telegraph lines were installed along rail lines initially for communicating with trains, but later becoming a communications network. The first commercial electrical telegraph was co-developed by Charles Wheatstone and William Fothergill Cooke, and was first successfully demonstrated on 25 July 1837 between Euston railway station and Camden Town in London. The first lasting transatlantic telegraph cable was laid by Isambard Kingdom Brunel's ship the *SS Great Eastern* in 1866. By the 1890s there was an international telegraph network connecting major cities worldwide, which greatly facilitated international commerce, travel and diplomacy.

The telephone was patented in 1876; and like the early telegraph, it was used mainly to speed business transactions.

Socioeconomic impacts

The period from 1870 to 1890 saw the greatest increase in economic growth in such a short period as ever in history. Living standards improved significantly in the newly industrialized countries as the prices of goods fell dramatically due to the increases in productivity. This caused unemployment and great upheavals in commerce and industry, with many laborers being displaced by machines and many factories, ships and other forms of fixed capital becoming obsolete in a very short time span.

“The economic changes that have occurred during the last quarter of a century -or during the present generation of living men- have unquestionably been more important and more varied than during any period of the world’s history”.

Crop failures no longer resulted in starvation in areas served by railroads and inland waterways.

By 1870 the work done by steam engines exceeded that done by all inanimate sources: water, wind, animal and human power. Horses and mules remained important in agriculture until the development of the tractor near the end of the second Industrial Revolution.

The improvements in steam engine efficiencies, like triple expansion, allowed ships to carry much more freight than coal, resulting in greatly increased volumes of international trade. Higher steam engine efficiency caused the number of steam engines to increase

several fold, leading to an actual increase in coal usage, the phenomenon being called the Jevons paradox.

By 1890 there was an international telegraph network through which orders could be placed by merchants in England or the U.S. to suppliers in India and China for goods to be transported in efficient new steamships. This, plus the opening of the Suez Canal, led to the decline of the great warehousing districts in London and elsewhere, and also the elimination of any middlemen.

The tremendous growth in productivity, transportation networks, industrial production and agricultural output lowered the prices of almost all goods. This led to many business failures and periods that were called *depressions* that occurred as the world economy actually grew.

The factory system centralized production in a separate building funded and directed by specialists (as opposed to work at home). The division of labor made both unskilled and skilled labor more productive, and led to a rapid growth of population in industrial centers. Like the first industrial revolution, the second supported population growth and saw most governments (not including Britain) protect their national economies with tariffs. The wide-ranging social impact of both revolutions included the remaking of the working class as new technologies appeared; the creation of a larger, increasingly professional, middle class; the decline of child labor; and the dramatic growth of a consumer-based, material culture.

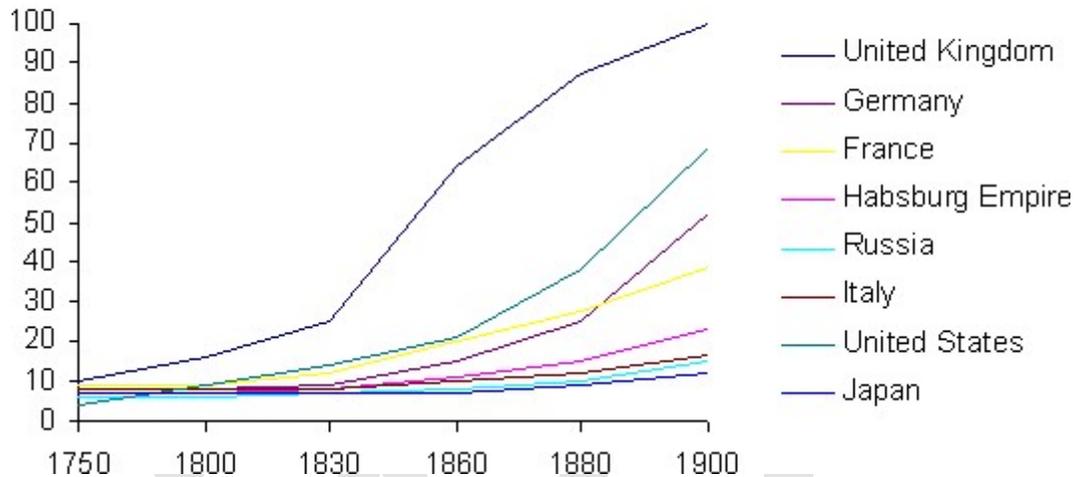
By 1900, the leaders in industrial production were the U.S. with 24% of the world total, followed by Britain (19%), Germany (13%), Russia (9%) and France (7%). Europe together accounted for 62%.

The great inventions and innovations of the Second Industrial Revolution are part of our modern life. They continued to be drivers of the economy until after W.W. 2. Only a few major innovations occurred in the post war era, some of which are: computers, semiconductors, the fiber optic network and the Internet, cellular telephones, combustion turbines (jet engines) and the Green Revolution. Although commercial aviation existed before W.W.2, it became a major industry after the war.

Britain

Relative Levels of Industrialization, 1750-1900

(U.K. in 1900 = 100)



New products and services were introduced which greatly increased international trade. Improvements in steam engine design and the wide availability of cheap steel meant that slow, sailing ships were replaced with faster steamship, which could handle more trade with smaller crews. The chemical industries also moved to the forefront. Britain invested less in technological research than the U.S. and Germany, which caught up.

Michael Faraday discovered electromagnetic induction, and his inventions of electromagnetic rotary devices formed the foundation of electric motor technology. In 1880, pioneer of electric light Sir Joseph Swan began installing light bulbs in homes and landmarks in England, with the Savoy in London electrically lit in 1881. The Bessemer process was the first inexpensive industrial process for the mass-production of steel from molten pig iron. The process named after its inventor Sir Henry Bessemer, revolutionized steel manufacture by decreasing its cost, from £40 per long ton to £6-7 per long ton during its introduction, along with greatly increasing the scale and speed of production of this vital raw material. The process also decreased the labor requirements for steel-making. After the introduction of the Bessemer process, steel and wrought iron became similarly priced, and most manufacturers turned to steel. The availability of cheap steel allowed large bridges to be built and enabled the construction of railroads, skyscrapers, and large ships. Other important steel products—also made using the open hearth process—were steel cable, steel rod and sheet steel which enabled large, high-pressure boilers and high-tensile strength steel for machinery which enabled much more powerful engines, gears and axles than were possible previously. With large amounts of steel it became possible to build much more powerful guns and carriages, tanks, armored fighting vehicles and naval ships. Industrial steel also made possible the building of giant turbines and generators thus making the harnessing of water and steam power possible. The steam turbine invented by Sir Charles Parsons in 1884, has almost completely replaced the reciprocating piston steam engine primarily because of its greater thermal

efficiency and higher power-to-weight ratio. As the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator – about 80% of all electricity generation in the world is by use of steam turbines. The introduction of the large scale steel production process perfected by Henry Bessemer, paved the way to mass industrialization as observed in the 19th-20th centuries. The introduction of the large scale steel production process perfected by Henry Bessemer, paved the way to mass industrialization as observed in the 19th-20th centuries.

The development of more intricate and efficient machines along with mass production techniques (after 1910) greatly expanded output and lowered production costs. As a result, production often exceeded domestic demand. Among the new conditions, more markedly evident in Britain, the forerunner of Europe's industrial states, were the long-term effects of the severe Long Depression of 1873-1896, which had followed fifteen years of great economic instability. Businesses in practically every industry suffered from lengthy periods of low — and falling — profit rates and price deflation after 1873.

Belgium

Belgium provided an ideal model for showing the value of the railways for speeding the Second Industrial Revolution. After 1830, when it broke away from the Netherlands and became a new nation, it decided to stimulate industry. It planned and funded a simple cross-shaped system that connected the major cities, ports and mining areas, and linked to neighboring countries. Belgium thus became the railway center of the region. The system was very soundly built along British lines, so that profits were low but the infrastructure necessary for rapid industrial growth was put in place.

United States

The U.S. had its highest economic growth during the Second Industrial Revolution. The Gilded Age in America was based on heavy industry such as factories, railroads and coal mining. The iconic event was the opening of the First Transcontinental Railroad in 1869, providing six-day service between the East Coast and San Francisco.

During the Gilded Age, American manufacturing production passed Britain and took world leadership. Railroad mileage tripled between 1860 and 1880, and tripled again by 1920, opening new areas to commercial farming, creating a truly national marketplace and inspiring a boom in coal mining and steel production. The voracious appetite for capital of the great trunk railroads facilitated the consolidation of the nation's financial market in Wall Street. By 1900, the process of economic concentration had extended into most branches of industry—a few large corporations, called "trusts", dominated in steel, oil, sugar, meatpacking, and the manufacture of agriculture machinery. Other major components of this infrastructure were the new methods for fabricating steel, especially the Bessemer process. The first billion-dollar corporation was United States Steel, formed by financier J. P. Morgan in 1901, who purchased and consolidated steel firms built by Andrew Carnegie and others.

Increased mechanization of industry is a major mark of the Gilded Age's search for cheaper ways to create more product. Frederick Winslow Taylor observed that worker efficiency could be improved through the use of machines to make fewer motions in less time. His redesign increased the speed of factory machines and the productivity of factories while undercutting the need for skilled labor. This mechanization made some factories an assemblage of unskilled laborers performing simple and repetitive tasks under the direction of skilled foremen and engineers. Machine shops grew rapidly, and they comprised highly skilled workers and engineers. Both the number of unskilled and skilled workers increased, as their wage rates grew. Engineering colleges were established to feed the enormous demand for expertise. Railroads invented complex bureaucratic systems, using middle managers, and set up explicit career tracks. They hired young men at age 18-21 and promoted them internally until a man reached the status of locomotive engineer, conductor or station agent at age 40 or so. Career tracks were invented for skilled blue collar jobs and for white collar managers, starting in railroads and expanding into finance, manufacturing and trade. Together with rapid growth of small business, a new middle class was rapidly growing, especially in northern cities.

The United States became a world leader in applied technology. From 1860 to 1890, 500,000 patents were issued for new inventions—over ten times the number issued in the previous seventy years. George Westinghouse invented air brakes for trains (making them both safer and faster). Westinghouse aided Nikola Tesla in developing alternating current long distance transmission networks. Theodore Vail established the American Telephone & Telegraph Company. Thomas A. Edison invented a remarkable number of electrical devices, as well as the integrated power plant capable of lighting multiple buildings simultaneously; he founded General Electric corporation. Oil became an important resource, beginning with the Pennsylvania oil fields. Kerosene replaced whale oil and candles for lighting. John D. Rockefeller founded Standard Oil Company to consolidate the oil industry—which mostly produced kerosene before the automobile created a demand for gasoline in the 20th century.

At the end of the century, workers experienced the "second industrial revolution," which involved mass production, scientific management, and the rapid development of managerial skills. The new technology was hard for young people to handle, leading to a sharp drop (1890–1930) in the demand for workers under age 16. This resulted in a dramatic expansion of the high school system.

Influential figures

Andrew Carnegie, John D. Rockefeller, and "Commodore" Cornelius Vanderbilt were among the most influential industrialists during the Gilded Age. Carnegie (1835–1919) was born into a poor Scottish family and came to Pittsburgh as a teenager. In 1870, Carnegie erected his first blast furnace and by 1890 dominated the fast-growing steel industry. He preached the "Gospel of Wealth," saying the rich had a moral duty to engage in large-scale philanthropy. Carnegie did give away his fortune, creating many institutions such as the Carnegie Institute of Technology (now part of Carnegie Mellon University) to upgrade craftsmen into trained engineers and scientists. Carnegie built

hundreds of public libraries and several major research centers and foundations. Rockefeller built Standard Oil into a national monopoly, then retired from the oil business in 1897 and devoted the next 40 years of his life to giving away his fortune using systematic philanthropy, especially to upgrade education, medicine and race relations. Cornelius Vanderbilt started out as a sailor in New York harbor, then took part in the transportation revolution, from steamboats to railroads. He brought the corporation from its infancy to maturity as the organization of choice for big business.

Germany

The German Empire came to rival Britain as Europe's primary industrial nation during this period. Since Germany industrialized later, it was able to model its factories after those of Britain, thus making more efficient use of its capital and avoiding legacy methods in its leap to the envelope of technology. Germany invested more heavily than the British in research, especially in the chemistry, motors and electricity. The German cartel system (known as *Konzerne*), being significantly concentrated, was able to make more efficient use of capital. Germany was not weighted down with an expensive worldwide empire that needed defense. Following Germany's annexation of Alsace-Lorraine in 1871, it absorbed parts of what had been France's industrial base.

By 1900 the German chemical industry dominated the world market for synthetic dyes. The three major firms BASF, Bayer and Hoechst produced several hundred different dyes, along with the five smaller firms. In 1913 these eight firms produced almost 90 percent of the world supply of dyestuffs and sold about 80 percent of their production abroad. The three major firms had also integrated upstream into the production of essential raw materials and they began to expand into other areas of chemistry such as pharmaceuticals, photographic film, agricultural chemicals and electrochemicals. Top-level decision-making was in the hands of professional salaried managers; leading Chandler to call the German dye companies "the world's first truly managerial industrial enterprises". There were many spinoffs from research—such as the pharmaceutical industry, which emerged from chemical research.

Alternative uses

There have been other times that have been called "second industrial revolution". Industrial revolutions may be renumbered by taking earlier developments, such as the rise of medieval technology in the 12th century, or of ancient Chinese technology during the Tang Dynasty, or of ancient Roman technology, as first. "Second industrial revolution" has been used in the popular press and by technologists or industrialists to refer to the changes following the spread of new technology after World War I. Excitement and debate over the dangers and benefits of the Atomic Age were more intense and lasting than those over the Space age but both were predicted to lead to another industrial revolution. At the start of the 21st century the term "second industrial revolution" has been used to describe the anticipated effects of hypothetical molecular nanotechnology systems upon society. In this more recent scenario, the nanofactory would render the

majority of today's modern manufacturing processes obsolete, transforming all facets of the modern economy.

WWT

Chapter- 5

Technology during World War I



The machine gun was one of the decisive technologies during World War I. *Picture: British Vickers machine gun crew on the Western Front.*

Technology during World War I reflected a trend toward industrialism and the application of mass production methods to weapons and to the technology of warfare in general. This trend began fifty years prior to World War I during the U.S. Civil War, and continued through many smaller conflicts in which new weapons were tested.

August 1914 marked the end of a relatively peaceful century in Europe with unprecedented invention and new science. The 19th-century vision of a peaceful future fed by ever-increasing prosperity through technology was largely shattered by the war's and, after the technological escalation during World War II, it was apparent that whatever the gains in prosperity and comfort due to technology applied to civilian uses, these

benefits would always be under the shadow of the horrors of technology applied to warfare.

The earlier years of the First World War can be characterized as a clash of 20th-century technology with 19th-century warfare in the form of ineffectual battles with huge numbers of casualties on both sides. It was not until the final year of the war that the major armies made effective steps in revolutionizing matters of command and control and tactics to adapt to the modern battlefield, and started to harness the myriad new technologies to effective military purposes. Tactical reorganizations (such as shifting the focus of command from the 100+ man company to the 10+ man squad) went hand-in-hand with armored cars, the first submachine guns, and automatic rifles that could be carried and used by one man.

Trench warfare

The new metallurgical and chemical industries, and many innovative mechanical inventions, had created new firepower that made defense almost invincible and attack almost impossible. These innovations included bolt-action infantry rifles, rifled artillery and hydraulic recoil mechanisms, zigzag trenches and machine guns, and their application had the effect of making it difficult or nearly impossible to cross defended ground. The hand grenade, already in existence —though crude—developed rapidly as an aid to attacking trenches. Probably the most important was the introduction of high explosive shells, which dramatically increased the lethality of artillery over the 19th-century equivalents.

Trench warfare led to the development of the concrete pill box, a hardened blockhouse that could be used to deliver machine gun fire. They could be placed across a battlefield with interlocking fields of fire.

Because attacking an entrenched enemy was so difficult, tunneling underneath enemy lines became one of the major efforts during the war. Once enemy positions were undermined, huge amounts of explosives would be planted and detonated as part of the preparation for an overland charge. Sensitive listening devices that could detect the sounds of digging were a crucial method of defense against these underground incursions. The British proved especially adept at these tactics, thanks to the skill of their tunnel-digging "sappers" and the sophistication of their listening devices.

Artillery



7.7 cm FK 16 developed and used by Germany in WWI

Of all the types of weapons in existence in 1914, artillery underwent the most revolutionary and scientific advances. At the beginning of the war, artillery was often sited in the front line to fire over open sights at enemy infantry. During the war, the following improvements were made:

- the first "box barrage" in history was fired at Neuve Chapelle in 1915; this was the use of a three- or four-sided curtain of shell-fire to prevent the movement of enemy infantry
- the wire-cutting No. 106 fuze was developed, specifically designed to explode on contact with barbed wire, or the ground before the shell buried itself in mud, and equally effective as an anti-personnel weapon
- the first anti-aircraft guns were designed out of necessity
- indirect counter-battery fire was developed for the first time in history
- flash spotting and sound ranging were invented, for the location and eventual destruction of enemy batteries
- the creeping barrage was perfected
- factors such as weather, air temperature, and barrel wear could for the first time be accurately measured and taken into account when firing indirectly
- forward observers were used to direct artillery positioned out of direct line of sight from the targets, and sophisticated communications and fire plans were developed

The majority of casualties inflicted during the war were the result of artillery fire.

Poison gas



Australian infantry with gas masks, Ypres, 1917.

At the beginning of the war, Germany had the most advanced chemical industry in the world, accounting for more than 80% of the world's dye and chemical production. Although the use of poison gas had been banned in the Hague Conventions of 1899 and 1907, Germany turned to this industry for what it hoped would be a decisive weapon to break the deadlock of trench warfare. Chlorine gas was first used on the battlefield in April 1915 at the Second Battle of Ypres in Belgium. The unknown gas appeared to be a simple smoke screen, used to hide attacking soldiers, and Allied troops were ordered to the front trenches to repel the expected attack. The gas had a devastating effect, killing

many defenders. Later, mustard gas, phosgene and other gases were used. Britain and France soon followed suit with their own gas weapons. The first defenses against gas were makeshift, mainly rags soaked in water or urine. Later, relatively effective gas masks were developed, and these greatly reduced the effectiveness of gas as a weapon. Although it sometimes resulted in brief tactical advantages and probably caused over 1,000,000 casualties, gas seemed to have had no significant effect on the course of the war.

Command and control

In the early days of the war, generals tried to direct tactics from headquarters many miles from the front, with messages being carried back and forth by couriers on motorcycles. It was soon realized that more immediate methods of communication were needed.

Radio sets of the period were too heavy to carry into battle, and phone lines laid were quickly broken. Runners, flashing lights, and mirrors were often used instead; dogs were also used, though they were only used occasionally as troops tended to adopt them as pets and men would volunteer to go as runners in the dog's place. There were also aircraft (called "contact patrols") that could carry messages between headquarters and forward positions, sometimes dropping their messages without landing.

The new long-range artillery developed just before the war now had to fire at positions it could not see. Typical tactics were to pound the enemy front lines and then stop to let infantry move forward, hoping that the enemy line was broken, though it rarely was. The lifting and then the creeping barrage were developed to keep artillery fire landing directly in front of the infantry "as it advanced". Communications being impossible, the danger was that the barrage would move too fast — losing the protection — or too slowly — holding up the advance.

There were also countermeasures to these artillery tactics: by aiming a counter barrage directly behind an enemy's creeping barrage, one could target the infantry that was following the creeping barrage. Microphones (Sound ranging) were used to triangulate the position of enemy guns and engage in counter-battery fire. Muzzle flashes of guns could also be spotted and used to target enemy artillery.

Railways



German ammunition train wrecked by shell fire, c. 1918.

Railways dominated in this war as in no other. Through railways, men and material could be moved to the front at an unprecedented rate, but they were very vulnerable at the front itself. Thus, advancing armies could only move forward at the pace that they could build or rebuild a railway, e.g. the British advance across Sinai. Motorized transport did feature in World War I, but only rarely. After the railhead, troops moved on foot and guns were drawn by horses. The German strategy was known beforehand by the Allies simply because of the vast marshaling yards on the Belgian border that had no other purpose than to deliver the mobilized German army to its start point. The German mobilization plan was little more than a vast detailed railway timetable. Railways lacked the flexibility of motor transport and this lack of flexibility percolated through into the conduct of the war.

War of attrition

All countries involved in the war applied the full force of industrial mass-production to the manufacture of weapons and ammunition, especially artillery shells. Women on the home-front played a crucial role in this by working in munitions factories. This complete mobilization of a nation's resources, or "total war" meant that not only the armies, but also the economies of the warring nations were in competition.

For a time, in 1914-1915, some hoped that the war could be won through an attrition of materiel--that the enemy's supply of artillery shells could be exhausted in futile exchanges. But production was ramped up on both sides and hopes proved futile. In Britain the Shell Crisis of 1915 brought down the British government, and led to the building of HM Factory, Gretna, a huge munitions factory on the English-Scottish border.

The war of attrition then focused on another resource: human lives. In the battle of Verdun in particular, German Chief of Staff Erich Von Falkenhayn hoped to "bleed France white" through repeated attacks on this French city.

In the end, the war ended through a combination of attrition (of men and material), advances on the battlefield, and a breakdown of morale and productivity on the German home-front due to an effective naval blockade of her seaports.

Air warfare



Richthofen's all-red Fokker Dr1 425/17 shortly before his demise

The Fokker triplane belonging to Manfred von Richthofen (the "Red Baron")



"PKZ" military helicopter prototype, Ganz Company, Hungary (1917)

As with most other technologies, the aircraft underwent many improvements during World War I. Early war aircraft were not much different in design from the original Wright Flyer, which made its first flight over a decade earlier.

While early air spotters were unarmed, they soon began firing at each other with handheld weapons and even throwing spears. An arms race commenced, quickly leading to increasingly agile planes equipped with machine guns. A key innovation was the interrupter gear, a German invention that allowed a machine gun to be mounted behind the propeller so the pilot could fire directly ahead, along the plane's flight path.

As the stalemate developed on the ground, with both sides unable to advance even a few miles without a major battle and thousands of casualties, planes became greatly valued for their role gathering intelligence on enemy positions and bombing the enemy's supplies behind the trench lines. Large planes with a pilot and an observer were used to reconnoiter enemy positions and bomb their supply bases. Because they were large and slow, these planes made easy targets for enemy fighter planes. As a result, both sides used fighter aircraft to both attack the enemy's observer planes and protect their own.

Germany led the world in the design of Zeppelins, and used these airships to make occasional bombing raids on military targets, London and other British cities, without any great effect. Later in the war, Germany began attacking English cities with long range strategic bombers. As with the Zeppelin attacks, Germany's strategic bombing of England had limited tactical value, but it was demoralizing and showed the British they could not be completely immune from the effects of the war in their own country. It also forced the British air forces to maintain squadrons of fighters in England to defend against air attack, depriving the British Expeditionary Force of planes, equipment, and personnel badly needed on the Western front.

Manned observation balloons floating high above the trenches were used as stationary reconnaissance points on the front lines, reporting enemy troop positions and directing artillery fire. Balloons commonly had a crew of two, each equipped with parachutes: upon an enemy air attack on the flammable balloon, the crew would jump to safety. At the time, parachutes were too heavy to be used by pilots in aircraft, and smaller versions would not be developed until the end of the war. (In the British case, there arose concerns that they might undermine morale, effectively encouraging cowardice.) Recognized for their value as observer platforms, observation balloons were important targets of enemy aircraft. To defend against air attack, they were heavily protected by large concentrations of anti-aircraft guns and patrolled by friendly aircraft.

By inhibiting the enemy's ability to move in secrecy, aerial reconnaissance over the front can be blamed to some degree for the stalemate of trench warfare.

Tanks

Although the concept of the tank had been suggested as early as the 1890s, few authorities showed interest in them until the trench stalemate of World War I caused serious contemplation of unending war and ever escalating casualties. In Britain, a Landships Committee was formed, and teamed with the Inventions Committee, set out to develop a practical weapon.

Based on the caterpillar track (first invented in 1770 and perfected in the early 1900s) and the four-stroke gasoline powered Internal combustion engine (refined in the 1870s), early tanks were fitted with Maxim type guns or Lewis guns, armor plating, and their caterpillar tracks were configured to allow crossing of an 8-foot-wide (2.4 m) trench.

Early tanks were unreliable, breaking down often. Though they first terrified the Germans, their use in 1917 engagements provided more opportunities for development than actual battle successes. It was also realized that new tactics had to be developed to make best use of this weapon. In particular, planners learned that tanks needed infantry support and massed formations to be effective. Once tanks could be fielded in the hundreds, such as they were at the Battle of Cambrai in November 1917, they began to show their potential. Still, reliability was the achilles heel of tanks throughout the remainder of the war. In the Battle of Amiens, a major Entente counteroffensive near the end of the war, British forces went to field with 534 tanks. After several days, only a few were still in commission, those that suffered mechanical difficulties outnumbering those disabled by enemy fire.

Regardless of their effects on World War I, tank technology and mechanized warfare had been launched and grew increasingly sophisticated in the years following the war. By World War II, the tank had evolved to a fearsome weapon which made the trench obsolete, just as the trench and the machine gun had made horse-mounted cavalry obsolete.

Naval Warfare

The years leading up to the war saw the use of improved metallurgical and mechanical techniques to produce larger ships with larger guns and, in reaction, more armor. The launching of HMS Dreadnought (1906) revolutionized battleship construction, leaving many ships obsolete before they were completed. Consequently, at the start of the war, many navies comprised newer ships and obsolete older ones. The advantage was in long-range gunnery, and naval battles took place at far greater distances than before. The Battle of Jutland (1916) was the only full-scale battle between fleets in the war.

Having the largest surface fleet, the United Kingdom sought to press its advantage. British ships blockaded German ports, hunted down German and Austro-Hungarian ships wherever they might be on the high seas, and supported actions against German colonies. The German surface fleet was largely kept in the North Sea. This situation pushed Germany, in particular, to direct its resources to a new form of naval power: submarines.

Submarines

World War I was the first conflict in which submarines were a serious weapon of war. In the years shortly before the war, the relatively sophisticated propulsion system of diesel power while surfaced and battery power while submerged was introduced.

The United Kingdom relied heavily on imports to feed its population and supply its war industry, and the German navy hoped to blockade and starve Britain using U-boats to attack merchant ships in unrestricted submarine warfare. This struggle between German submarines and British counter measures became known as the First Battle of the Atlantic. As German submarines became more numerous and effective, the British sought ways to protect their merchant ships. "Q-ships," attack vessels disguised as civilian ships, were one early strategy.

Consolidating merchant ships into convoys protected by one or more armed navy vessels was adopted later in the war. There was initially a great deal of debate about this approach, out of fear that it would just provide German U-boats with a wealth of convenient targets. Thanks to the development of active and passive sonar devices, coupled with increasingly deadly anti-submarine weapons, the convoy system reduced British losses to U-boats to a small fraction of their former level. Lieutenant Otto Weddigen remarked of the first submarine attack of the Great War:

“ How much they feared our submarines and how wide was the agitation caused by good little U-9 is shown by the English reports that a whole flotilla of German submarines had attacked the cruisers and that this flotilla had approached under cover of the flag of Holland. These reports were absolutely untrue. U-9 was the only submarine on deck, and she flew the flag she still flies -- the German naval ensign. ”

Mobility

Between late 1914 and early 1918, the Western Front hardly moved. Ironically, the beginning of the end for Germany started with a huge German advance. In 1917, when Russia surrendered after the October Revolution, Germany was able to move many troops to the Western Front. Using new stormtrooper tactics developed by Oskar von Hutier, the Germans pushed forward some tens of kilometers from March to July 1918. These offensives showed that machine guns, barbed wire and trenches were not the only obstacle to mobile warfare.

In the Battle of Amiens of August 1918, the Entente forces began a counter attack that would be called the Hundred Days Offensive. The Australian and Canadian divisions that spearheaded the attack managed to advance 13 kilometers on the first day alone. These battles marked the end of trench warfare on the Western Front and a return to mobile warfare. The sort of unit that now began to emerge combined cyclist infantry and machine guns mounted on motor cycle sidecars. These motor machine gun units had originated in 1915.

The Hindenburg Line fell to the Allies and the Canal du Nord was crossed. In Berlin, Kaiser Wilhelm was told Germany had lost, and must now surrender. Advances

continued but political developments inside Germany compelled Germany to sign an Armistice on November 11, 1918.

The war was over, but a new mobility-driven form of warfare was beginning to emerge; one that would be mastered by the defeated Germans and deployed in 1939 as their blitzkrieg, or *lightning warfare*, embodying all they had learned in 1918.

Small Arms

The machine gun directly impacted the organization of the infantry in 1914, and, by the middle of 1917, put an end to the tactic of company sized waves. Platoons and squads of men became important; hand in hand with that organization was the use of light automatic weapons. The Lewis Gun was the first true light machine gun that could in theory be operated by one man, though in practice the bulky ammo pans required an entire section of men to keep the gun operating (Postwar research would show that its ingenious, but heavy and intricate, air cooling ducts were entirely unnecessary.). The Browning Automatic Rifle was adopted by the U.S. Army in 1918; adapters on cartridge belts allowed the BAR man to walk and fire the gun at the same time. Early sub-machine guns were also developed in this period. While in use, these guns would often overheat - which led to the development of several cooling methods.

Flame throwers

The Imperial German Army deployed flame throwers (*Flammenwerfer*) on the West Front attempting to flush out French or British soldiers from their trenches. Introduced in 1915, it was used with greatest effect during the Hoge battle of the Western Front on 30 July 1915. The German Army had two main types of flame throwers during the Great War: a small single person version called the Kleinflammenwerfer and a larger multiple person configuration called the Grossflammenwerfer. In the latter, one soldier carried the fuel tank while another aimed the nozzle. Both the large and small versions of the flame-thrower were of limited use because their short range left the operator(s) exposed to small arms fire.

Chapter- 6

Technology during World War II

Technology during World War II played a Crucial role in determining the outcome of the greatest war of all. Much of it had begun development during the interwar years of the 1920s and 1930s, some was developed in response to lessons learned during the war, and yet more was only beginning to be developed as the war ended. The massive research and development demands of the war had a great impact on the scientific community. Given the scope of the war and the rapid technological escalation which happened during the war, a vast array of technology was employed, as different nations and different units found themselves equipped with different levels of technology. Military technology developments spanned across all areas of industry.

Effects on Warfare

Almost all types of technology were utilized, although main areas of technology which saw major developments were:

- **Weaponry**; including ships, vehicles, aircraft, artillery, rocketry, small arms, and biological, chemical and atomic weapons.
- **Logistical support**; including vehicles necessary for transporting soldiers and supplies, such as trains, trucks, and aircraft.
- **Communications and intelligence**; including devices used for navigation, communication, remote sensing and espionage.
- **Medicine**; including surgical innovations, chemical medicines, and techniques
- **Industry**; including the technologies employed at factories and production/distribution centers.

This was perhaps the first war where military operations were aimed at the research efforts of the enemy e.g.

1. The exfiltration of Niels Bohr from German-occupied Denmark to Britain in 1943
2. The sabotage of Norwegian heavy water production
3. The bombing of Peenemunde

Military operations were also conducted in order to obtain intelligence on the enemy's technology e.g. the Bruneval Raid for German radar and Operation Most III for the German V-2.

Between the wars

After the Treaty of Versailles the Western democracies were satiated powers and expected a general peace. Their political environment was one where the aim was disarmament. (In Britain there was the Ten Year Rule.) Consequently they conducted very little military R & D. On the other hand, Germany and the Soviet Union were dissatisfied powers that for different reasons cooperated with each other on military R & D. The Soviets offered Weimar Germany facilities deep inside the USSR for building and testing arms and for military training, well away from Treaty inspectors' eyes. In return, the Soviets asked for access to German technical developments, and for assistance in creating a Red Army General Staff.

The first German officers went to the Soviet Union for these purposes in March, 1922. One month later, Junkers began building aircraft at Fili, outside Moscow, in violation of Versailles. The great artillery manufacturer Krupp was soon active in the south of the USSR, near Rostov-on-Don. In 1925, a flying school was established at Vivupal, near Lipetsk, to train the first pilots for the future Luftwaffe. Since 1926, the Reichswehr had been able to use a tank school at Kazan (codenamed Kama) and a chemical weapons facility in Samara Oblast (codenamed Tomka). In turn, the Red Army gained access to these training facilities, as well as military technology and theory from Weimar Germany.

In the late 1920s, Germany helped Soviet industry begin to modernize, and to assist in the establishment of tank production facilities at the Leningrad Bolshevik Factory and the Kharkov Locomotive Factory. This cooperation would break down when Hitler rose to power in 1933. The failure of the World Disarmament Conference marked the beginnings of the arms race leading to war.

In France the lesson of World War I was translated into the Maginot Line which was supposed to hold a line at the border with Germany. The Maginot Line did achieve its political objective of ensuring that any German invasion had to go through Belgium ensuring that France would have Britain as a military ally. France had more, and much better, tanks than Germany as of the outbreak of their hostilities in 1940. As in World War I, the French generals expected that armour would mostly serve to help infantry break the static trench lines and storm machine gun nests. They thus spread the armour among their infantry divisions, ignoring the new German doctrine of blitzkrieg based on the fast movement using concentrated armour attacks, against which there was no effective defense but mobile anti-tank guns - infantry Antitank rifles not being effective against medium and heavy tanks.

Air power was a major concern of Germany and Britain between the wars. Trade in aircraft engines continued, with Britain selling hundreds of its best to German firms - which used them in a first generation of aircraft, and then improved on them much for use in German aircraft.

Weaponry

Military weapons technology experienced rapid advances during World War II, and over six years there was a disorientating rate of change in combat in everything from aircraft to small arms. Indeed the war began with most armies utilizing technology that had changed little from World War I, and in some cases, had remained unchanged since the 19th century. For instance cavalry, trenches, and World War I-era battleships were normal in 1940, however within only six years, armies around the world had developed jet aircraft, ballistic missiles, and even atomic weapons in the case of the United States.

The best jet fighters at the end of the war easily outflown any of the leading aircraft of 1939, such as the Spitfire Mark I. The early war bombers that caused such carnage would almost all have been shot down in 1945, many with two shots, by radar-aimed, proximity fuse-detonated anti-aircraft fire, just as the 1941 "invincible fighter", the Zero, had by 1944 become the "turkey" of the "Marianas Turkey Shoot". The best late-war tanks, such as the Soviet JS-3 heavy tank or the German Panther medium tank, handily outclassed the best tanks of 1939 such as Panzer IIIs. In the navy the battleship, long seen as the dominant element of sea power, was displaced by the greater range and striking power of the aircraft carrier. The chaotic importance of amphibious landings stimulated the Western Allies to develop the Higgins boat, a primary troop landing craft; the DUKW, a six-wheel-drive amphibious truck, amphibious tanks to enable beach landing attacks and Landing Ship, Tanks to land tanks on beaches. Increased organization and coordination of amphibious assaults coupled with the resources necessary to sustain them caused the complexity of planning to increase by orders of magnitude, thus requiring formal systematization giving rise to what has become the modern management methodology of project management by which almost all modern engineering, construction and software developments are organized.

Aircraft

In the Western European Theatre of World War II, air power became crucial throughout the war, both in tactical and strategic operations (respectively, battlefield and long-range). Superior German aircraft, aided by ongoing introduction of design and technology innovations, allowed the German armies to overrun Western Europe with great speed in 1940, largely assisted by lack of Allied aircraft, which in any case lagged in design and technical development during the slump in research investment after the Great Depression. Since the end of World War I, the French Air Force had been badly neglected, as military leaders preferred to spend money on ground armies and static fortifications to fight another World War I-style war. As a result, by 1940, the French Air Force had only 1562 planes and was together with 1070 RAF planes facing 5,638 Luftwaffe fighters and fighter-bombers. Most French airfields were located in north-east France, and were quickly overrun in the early stages of the campaign. The Royal Air Force of the United Kingdom possessed some very advanced fighter planes, such as Spitfires and Hurricanes, but these were not useful for attacking ground troops on a battlefield, and the small number of planes dispatched to France with the British Expeditionary Force were destroyed fairly quickly. Subsequently, the Luftwaffe was able

to achieve air superiority over France in 1940, giving the German military an immense advantage in terms of reconnaissance and intelligence.

German aircraft rapidly achieved air superiority over France in early 1940, allowing the Luftwaffe to begin a campaign of strategic bombing against British cities. With France out of the war, German bomber planes based near the English Channel were able to launch raids on London and other cities during the Blitz, with varying degrees of success.

After World War I, the concept of massed aerial bombing—"The bomber will always get through"—had become very popular with politicians and military leaders seeking an alternative to the carnage of trench warfare, and as a result, the air forces of Britain, France, and Germany had developed fleets of bomber planes to enable this (France's bomber wing was severely neglected, whilst Germany's bombers were developed in secret as they were explicitly forbidden by the Treaty of Versailles).

The bombing of Shanghai by the Imperial Japanese Navy on January 28, 1932 and August 1937 and the bombings during the Spanish Civil War (1936–1939), had demonstrated the power of strategic bombing, and so air forces in Europe and the United States came to view bomber aircraft as extremely powerful weapons which, in theory, could bomb an enemy nation into submission on their own. As a result, the fear of bombers triggered major developments in aircraft technology.

Nazi Germany had put only one large, long-range strategic bomber (the Heinkel He 177 Greif, with many delays and problems) into production, while the America Bomber concept resulted only in prototypes. The Spanish Civil War had proved that tactical dive-bombing using Stukas was a very efficient way of destroying enemy troops concentrations, and so resources and money had been devoted to the development of smaller bomber craft. As a result, the Luftwaffe was forced to attack London in 1940 with heavily overloaded Heinkel and Dornier medium bombers, and even with the unsuitable Junkers Ju 87. These bombers were painfully slow—German engineers had been unable to develop sufficiently large piston aircraft engines (those that were produced tended to explode through extreme overheating), and so the bombers used for the Battle of Britain were woefully undersized. As German bombers had not been designed for long-range strategic missions, they lacked sufficient defenses. The Messerschmitt Bf 109 fighter escorts had not been equipped to carry enough fuel to guard the bombers on both the outbound and return journeys, and the longer range Bf 110s could be out-manoeuvred by the short range British fighters. (A bizarre feature of the war was how long it took to conceive of the Drop tank.) The air defense was well organized and equipped with effective radar that survived the bombing. As a result, German bombers were shot down in large numbers, and were unable to inflict enough damage on cities and military-industrial targets to force Britain out of the war in 1940 or to prepare for the planned invasion.

British long-range bomber planes such as the Short Stirling had been designed before 1939 for strategic flights and given a large armament, but their technology still suffered from numerous flaws. The smaller and shorter ranged Bristol Blenheim, the RAF's most-

used bomber, was defended by only one hydraulically operated machine-gun turret, and whilst this appeared sufficient, it was soon revealed that the turret was a pathetic defence against squadrons of German fighter planes. American bomber planes such as the B-17 Flying Fortress had been built before the war as the only adequate long-range bombers in the world, designed to patrol the long American coastlines. Defended by as many as six machine-gun turrets providing 360° cover, the B-17s were still vulnerable without fighter protection even when used in large formations.

Despite the abilities of Allied bombers, though, Germany was not quickly crippled by Allied air raids. At the start of the war the vast majority of bombs fell miles from their targets, as poor navigation technology ensured that Allied airmen frequently could not find their targets at night. The bombs used by the Allies were very high-tech devices, and mass production meant that the precision bombs were often made sloppily and so failed to explode. German industrial production actually rose continuously from 1940 to 1945, despite the best efforts of the Allied air forces to cripple industry.

Significantly, the bomber offensive kept the revolutionary Type XXI U-Boat from entering service during the war. Moreover, Allied air raids had a serious propaganda impact on the German government, all prompting Germany to begin serious development on air defence technology—in the form of fighter planes.

The jet aircraft age began during the war with the development of the Heinkel He 178, the first true turbojet. Late in the war the Germans brought in the first operational Jet fighter, the Messerschmitt Me 262. However, despite their technological edge, German jets were overwhelmed by Allied air superiority, frequently being destroyed on or near the airstrip. Other jet aircraft, such as the British Gloster Meteor, which flew missions but never saw combat, did not significantly distinguish themselves from top-line piston-driven aircraft.

Aircraft saw rapid and broad development during the war to meet the demands of aerial combat and address lessons learned from combat experience. From the open cockpit airplane to the sleek jet fighter, many different types were employed, often designed for very specific missions.

During the war the Germans produced various Glide bomb weapons, which were the first smart bombs; the V-1 flying bomb, which was the first cruise missile weapon; and the V-2 rocket, the first ballistic missile weapon. The last of these was the first step into the space age as its trajectory took it through the stratosphere, higher and faster than any aircraft. This later led to the development of the Intercontinental ballistic missile (ICBM). Wernher Von Braun led the V-2 development team and later emigrated to the United States where he contributed to the development of the Saturn V rocket, which took men to the moon in 1969.

Theoretical foundation

The laboratory of Ludwig Prandtl at Göttingen was the main center of theoretical and mathematical aerodynamics and fluid dynamics research from soon after 1904 to the end of World War II. Prandtl coined the term boundary layer and founded modern (mathematical) aerodynamics. The laboratory lost its dominance when the researchers were dispersed after the war.

Vehicles

The Treaty of Versailles had imposed severe restrictions upon Germany constructing vehicles for military purposes, and so throughout the 1920s and 1930s, German arms manufacturers and the Wehrmacht had begun secretly developing tanks. As these vehicles were produced in secret, their technical specifications and battlefield potentials were largely unknown to the European Allies until the war actually began. When German troops invaded the Benelux nations and France in May 1940, German weapons technology proved to be immeasurably superior to that of the Allies.

The French Army suffered from serious technical deficiencies with its tanks. In 1918, the Renault FT-17 tanks of France had been the most advanced in the world, although small, capable of far outperforming their slow and clumsy British, German, or American counterparts. However, this superiority resulted in tank development stagnating after World War I. By 1939, French tanks were virtually unchanged from 1918. French and British Generals believed that a future war with Germany would be fought under very similar conditions as those of 1914–1918. Both invested in thickly-armoured, heavily-armed vehicles designed to cross shell damaged ground and trenches under fire. At the same time the British also developed faster but lightly armoured Cruiser tanks to range behind the enemy lines.

In contrast, the Wehrmacht invested in fast, light tanks designed to overtake infantry. These vehicles would vastly outperform British and French tanks in mechanized battles. German tanks followed the design of France's 1918 Renault versions—a moderately-armoured hull with a rotating turret on top mounting a cannon. This gave every German tank the potential to engage other armoured vehicles. In contrast, around 35% of French tanks were simply equipped with machine guns (again designed for trench warfare), meaning that when French and German met in battle, a third of the French assault vehicles would not be able to engage enemy tanks, their machine-gun fire only ricocheting off German armour plates. Only a handful of French tanks had radios, and these often broke as the tank lurched over uneven ground. German tanks were, on the contrary, all equipped with radios, allowing them to communicate with one another throughout battles, whilst French tank commanders could rarely contact other vehicles.

The Matilda Mk I tanks of the British Army were also designed for infantry support and were protected by thick armour. This was ideal for trench warfare, but made the tanks painfully slow in open battles. Their light cannons and machine-guns were usually unable to inflict serious damage on German vehicles. The exposed caterpillar tracks were easily

broken by gunfire, and the Matilda tanks had a tendency to incinerate their crews if hit, as the petrol tanks were located on the top of the hull. By contrast the Infantry tank Matilda II fielded in lesser numbers was largely invulnerable to German gunfire and its gun was able to punch through the German tanks. However French and British tanks were at a disadvantage compared to the air supported German armoured assaults, and a lack of armoured support contributed significantly to the rapid Allied collapse in 1940.

World War II marked the first full-scale war where mechanization played a significant role. Most nations did not begin the war equipped for this. Even the vaunted German Panzer forces relied heavily on non-motorised support and flank units in large operations. While Germany recognized and demonstrated the value of concentrated use of mechanized forces, they never had these units in enough quantity to supplant traditional units. However, the British also saw the value in mechanization. For them it was a way to enhance an otherwise limited manpower reserve. America as well sought to create a mechanized army. For the United States, it was not so much a matter of limited troops, but instead a strong industrial base that could afford such equipment on a great scale.

The most visible vehicles of the war were the tanks, forming the armored spearhead of mechanized warfare. Their impressive firepower and armor made them the premier fighting machine of ground warfare. However, even more important to a fighting mechanized army were the large number of trucks and lighter vehicles that kept the army moving.

Ships

Naval warfare changed dramatically during World War II, with the ascent of the aircraft carrier to the premier vessel of the fleet, and the impact of increasingly capable submarines on the course of the war. The development of new ships during the war was somewhat limited due to the protracted time period needed for production, but important developments were often retrofitted to older vessels. Advanced German submarine types came into service too late and after nearly all the experienced crews had been lost.

The German U-boats were used primarily for stopping/destroying the resources from the United States and Canada coming across the Atlantic. Submarines were critical in the Pacific Ocean as well as in the Atlantic Ocean. Japanese defenses against Allied submarines were ineffective. Much of the merchant fleet of the Empire of Japan, needed to supply its scattered forces and bring supplies such as petroleum and food back to the Japanese Archipelago, was sunk. This kept them from training adequate replacements for their lost aircrews and even forced the navy to be based near its oil supply. Among the warships sunk by submarines was the war's largest aircraft carrier, the *Shinano*.

The most important shipboard advances were in the field of anti-submarine warfare. Driven by the desperate necessity of keeping Britain supplied, technologies for the detection and destruction of submarines was advanced at high priority. The use of ASDIC (SONAR) became widespread and so did the installation of shipboard and airborne radar.

Weapons

The actual weapons; the guns, mortars, artillery, bombs, and other devices, were as diverse as the participants and objectives. A bewildering array were developed during the war to meet specific needs that arose, but many traced their development to prior to World War II. and were aimed with the aid of radar and airplanes. Torpedoes began to use magnetic detonators; compass directed, programmed and even acoustic guidance systems; and improved propulsion. Fire-control systems continued to develop for ships' guns and came into use for torpedoes and anti-aircraft fire. Human torpedoes and the Hedgehog (weapon) were also developed.

- Armour weapons: The Tank destroyer, Specialist Tanks for Combat engineering including mine clearing Flail tanks, Flame tank, and amphibious designs
- Aircraft: Glide bombs - the first "smart bombs", such as the Fritz X anti-shipping missile, had wire or radio remote control; the world's first jet fighter (Messerschmitt 262) and jet bomber (Arado 234), the world's first operational military helicopters (Flettner Fl 282), the world's first rocket-powered fighter (Messerschmitt 163)
- Missiles: The Pulse jet powered V-1 flying bomb was the world's first cruise missile, Rockets progressed enormously: V-2 rocket, Katyusha rocket artillery and air launched rockets.
- V1,V2 V3 autopilot bombs
- HEAT, and HESH anti-armour warheads.
- Proximity fuze for shells, bombs and rockets. This fuze is designed to detonate an explosive automatically when close enough to the target to destroy it, so a direct hit is not required and time/place of closest approach does not need to be estimated. Magnetic torpedoes and mines also had a sort of proximity fuse.
- Guided weapons (by radio or trailing wires): glide bombs, crawling bombs, rockets.
- Self-guiding weapons: torpedoes (sound seeking, compass guided and looping), V1 missile (compass and timer guided)
- Aiming devices for bombs, torpedoes, artillery and machine guns, using special purpose mechanical and electronic analog and (perhaps) digital "computers". The mechanical analog Norden bomb sight is a well known example.
- Napalm was developed, but did not see wide use until the Korean War
- Plastic explosives like Nobel 808, Hexoplast 75, Compositions C and C2

Small arms development

New production methods for weapons such as stamping, riveting, and welding came into being to produce the number of arms needed. While this had been tried before, during World War I, it had resulted in quite possibly the worst firearm ever adopted by any military for use: the French Chauchat light machine gun. Design and production methods had advanced enough to manufacture weapons of reasonable reliability such as the PPSH-41, PPS-42, Sten, MP 40, M3 *Grease Gun*, Gewehr 43, Thompson submachine gun and the M1 Garand rifle. Other Weapons commonly found During World War II include the

American, Browning Automatic Rifle (BAR), M1 Carbine Rifle, as well as the Colt M1911; The Japanese Type 100 submachine gun, the Type 99 machine gun, and the Arisaka bolt action rifle all were significant weapons used during the war.

World War II saw the birth of the reliable semi-automatic rifle, such as the American M1 Garand and, more importantly, that of the first real assault rifles. The Germans essentially created and pioneered the idea of an "assault rifle" or *sturmgewehr*, coining the name for the species in the process. Earlier renditions that hinted at this idea were that of the employment of the Browning Automatic Rifle and 1916 Fedorov Avtomat in a *walking fire* tactic in which men would advance on the enemy position showering it with a hail of lead. The Germans first developed the FG 42 for its paratroopers in the assault and later the Sturmgewehr 44 (StG 44), the world's first true assault rifle. The FG 42 would probably hold this place but for its use of a full powered rifle cartridge making it hard to control by an unskilled operator.

Developments in machine gun technology culminated in the Maschinengewehr 42 (MG42) which was of an advanced design unmatched at the time. It spurred post-war development on both sides of the upcoming Cold War and is still used by some armies to this day including the German Bundeswehr's MG 3. The Heckler & Koch G3, and many other Heckler & Koch designs, came from its system of operation. The United States military meshed the operating system of the FG 42 with the belt feed system of the MG42 to create the M60 machine gun used in the Vietnam War.

Despite being overshadowed by self-loading/automatic rifles and sub-machine guns, bolt-action rifles remained the mainstay infantry weapon of many nations during World War II. When the United States entered World War II, there were not enough M1 Garand rifles available to American forces which forced the US to start producing more M1903 rifles in order to act as a "stop gap" measure until sufficient quantities of M1 Garands were produced.

During the conflict, many new models of bolt-action rifles were produced as a result of lessons learned from the First World War with the designs of a number of bolt-action infantry rifles being modified in order to speed up production as well as to make the rifles more compact and easier to handle. Examples of bolt-action rifles that were used during World War II include the German Mauser Kar98k, the British Lee-Enfield No.4, and the Springfield M1903A3. During the course of World War II, bolt-action rifles and carbines were modified even further to meet new forms of warfare the armies of certain nations faced e.g. urban warfare and jungle warfare. Examples include the Soviet Mosin-Nagant M1944 carbine, which were developed by the Soviets as a result of the Red Army's experiences with urban warfare e.g. the Battle of Stalingrad, and the British Lee-Enfield No.5 carbine, that were developed for British and Commonwealth forces fighting the Japanese in South-East Asia and the Pacific.

When World War II ended in 1945, the small arms that were used in the conflict still saw action in the hands of the armed forces of various nations and guerrilla movements during and after the Cold War era. Nations like the Soviet Union and the United States provided

many surplus, World War II-era small arms to a number of nations and political movements during the Cold War era as a pretext to providing more modern infantry weapons. Besides seeing conflict long after World War II ended, the small arms of World War II are now considered collector's items with many civilian firearm owners and collectors around the world due to their historical nature, low cost (due to many of these firearms now appearing on the firearms market in large numbers over the past decade), and their durability.

The atomic bomb

The massive research and development demands of the war included the Manhattan Project, the effort to quickly develop an atomic bomb, or nuclear fission warhead. It was perhaps the most profound military development of the war, and had a great impact on the scientific community, among other things creating a network of national laboratories in the United States.

Development was completed too late for use in the European Theater of World War II. Its invention meant that a single bomber aircraft could carry a weapon sufficiently powerful to devastate entire cities, making conventional warfare against a nation with an arsenal of them suicidal.

The strategic importance of the bomb, and its even more powerful fusion-based successors, did not become fully apparent until the United States lost its monopoly on the weapon in the post-war era. The Soviet Union developed and tested their first nuclear weapon in 1949, based partially on information obtained from Soviet espionage in the United States. The competition between the two superpowers would lead to the Cold War. The strategic implications of such a massively destructive weapon still reverberate in the 21st century.

There was also a German project to develop an atomic weapon. This failed for a variety of reasons, most notably German Antisemitism. The first tier of continental high energy physicists (Einstein, Bohr, Fermi, and Oppenheimer) who did much of their early study and research in Germany, were either Jewish or, in the case of Enrico Fermi, married to a Jew. Oppenheimer, who was an American Jew, was also a Socialist by conviction, and associated with the Communist Party. When they left Germany, the only significant atomic physicist left in Germany was Heisenberg, who dragged his feet on the project. He made some faulty calculations suggesting that the Germans would need significantly more heavy water than was necessary. The project was then doomed due to insufficient resources.

The Empire of Japan was also developing an Atomic Bomb, however, it floundered due to lack of resources despite gaining interest from the government.

Electronics, communications and intelligence



German Enigma encryption machine

Electronics rose to prominence quickly in World War II. While prior to the war few electronic devices were seen as important pieces of equipment, by the middle of the war such instruments as radar and ASDIC (sonar) had proven their value. Additionally, equipment designed for communications and the interception of those communications was becoming critical.

Digital electronics, particularly, were also given a massive boost by war-related research. The pressing need for numerous time-critical calculations for various projects like code-

breaking and ballistics tables accentuated the need for the development of electronic computer technology. The semi-secret ENIAC and the super-secret Colossus demonstrated that systems using thousands of valves (vacuum tubes) could be reliable enough to be useful, paving the way for the post-war development of stored program computers.

The United Kingdom and the United States were the leaders in electronics. The US center for basic radar development was the Massachusetts Institute of Technology Radiation Laboratory. The British developed the cavity magnetron which gave a high power source of microwaves suitable for radar, and which is now used in microwave ovens.

Electronic and optical countermeasures such as jamming and radar absorbing material were developed.

While the war stimulated many technologies, such as radio and radar development, it slowed down related yet non-critical fields such as television and radio.

Industrial technology

While the development of new equipment was rapid, it was also important to be able to produce these tools and get them to the troops in appropriate quantity. Those nations that were able to maximize their industrial capacity and mobilize it for the war effort were most successful at equipping their troops in a timely way with adequate material. An outstanding German innovation was the Jerrycan which carries by its name a tribute to its success.

One of the biggest developments was the ability to produce synthetic rubber. Natural rubber was mainly harvested in the South Pacific, and the Allies were cut off from a large quantity of it due to Japanese expansion. Thus the development of synthetic rubber allowed for the Allied war machine to continue growing, giving the US a significant technical edge as World War II continued.

For the Germans it was the development of alternative fuels as in hydrogen peroxide - which would be a forerunner to the development of fuel-cell technology and synthetic fuel technology.

New medicines

One of the most dramatic single medical advances was probably the wide spread use of penicillin to treat wounds and bacterial diseases.