In a way, everything is technology: not only man’s most strenuous endeavours but also his patient and monotonous efforts to make a mark on the external world; not only the rapid changes we are a little too ready to label revolutions (gunpowder, long-distance navigation, the printing-press, windmills and watermills, the first machines) but also the slow improvements in processes and tools, and those innumerable actions which may have no immediate innovating significance but which are the fruit of accumulated knowledge: the sailor rigging his boat, the miner digging a gallery, the peasant behind the plough or the smith at the anvil. ‘What I call technology,’ Marcel Mauss used to say, ‘is a traditional action made effective’; in other words one which implies the action of one man or generation upon another, a kind of training which has been going on since the beginning of time.

Technology ultimately covers as wide a field as history and has, of necessity, history’s slowness and ambiguities. Technology is explained by history and in turn explains history; but the correlation is in neither case fully satisfactory. In the realm of technology, co-extensive with the whole of history, there is no single onward movement, but many actions and reactions, many changes of gear. It is not a linear process. The mistake of Lefebvre des Noëttes, still in many ways an admirable writer, was to reduce the history of technology to a simple-minded materialism. It just will not do to say that the horse-collar, which replaced the yoke-harness from about the ninth century, thus increasing the traction-power of horses, ‘progressively reduced man’s slavery’. This particular over-simplification was criticized by Marc Bloch. Nor did the centre-line rudder, which originated in the northern seas in the twelfth century, pave the way for, and then ensure, the success of the great maritime discoveries. And Lynn White must have had his tongue in his cheek when he advanced his theory about spectacles for reading – namely that when they came into general use in the fifteenth century they assisted the intellectual advance of the Renaissance by increasing the numbers of readers. There were of course a number of other
factors present — the printing-press, for instance (or to answer White in the same coin, the spread of domestic lighting: imagine the hours gained for reading and writing!). Most important of all, one should investigate the motives behind the new passion for reading and knowledge — what economists would call the level of desired demand. After all, a desperate search for ancient manuscripts was already going on in Petrarch’s time, well before many people were wearing spectacles.

In other words, one must always take account of history, or perhaps one should say society, in the broad sense; technology is never the only factor in the discussion. To say society is to speak of a history that is slow, mute and complicated; a memory that obstinately repeats known solutions, to avoid the difficulty and danger of imagining something else. Every invention that presents itself has to wait for years or even centuries before being introduced into real life. First comes the *inventio*, then, very much later, the application (*usurpatio*), society having attained the required degree of receptivity. The scythe is a good example. *Schnitter Tod*, death armed with a scythe, became an obsessive image following the epidemics that decimated the West in the fourteenth century. But the scythe was used exclusively to cut grass in meadows at that time. It was rarely the harvester’s implement. The ears of corn were cut at varying heights, with a sickle. The straw was left standing for the flocks to eat, while leaves and branches from the forest served as their litter. In spite of the enormous urban growth, in spite of Europe’s becoming a cereal-growing area (the *Vergetreidung* of German historians), the use of the scythe to harvest grain did not become general before the beginning of the nineteenth century. Only then did the need for greater speed and a certain permissible degree of grain-wastage ensure the scythe’s widespread predominance.

Hundreds of other examples show the same process. The steam engine, for example, was invented a long time before it launched the industrial revolution — or should one say before being launched by it? The history of inventions, taken by itself, is therefore a misleading hall of mirrors. A splendid sentence by Henri Pirenne neatly sums up the question: ‘America [when the Vikings reached it] was lost as soon as it was discovered, because Europe did not yet need it.’

In other words, there are times when technology represents the possible, which for various reasons — economic, social or psychological — men are not yet capable of achieving or fully utilizing; and other times when it is the ceiling which materially and technically blocks their efforts. In the latter case, when one day the ceiling can resist the pressure no longer, the technical breakthrough becomes the point of departure for a rapid acceleration. However, the force that overcomes the obstacle is never a simple *internal* development of technology or science, or at any rate not before the nineteenth century.
The key problem: sources of energy

Between the fifteenth and eighteenth centuries, man had at his disposal his own strength and that of his domestic animals; he also had the wind, running water, wood, charcoal and coal – varied but still only modest sources of energy. With the benefit of hindsight, we know that progress could only have been made by concentrating on coal, and particularly in using it systematically, in the form of coke, in iron metallurgy. Coal was in fact used in Europe from the eleventh and twelfth centuries, and in China, according to writings of the time, from the fourth millennium before the Christian era. But men took a very long time to realize that coal was anything more than a supplementary fuel. The discovery of coke itself did not immediately result in its use.
The human engine

Man, using his muscles alone, is not a very powerful engine. His strength measured in horse-power (seventy-five kg to a height of one metre in one second) is derisory: between three and four hundredths of one horsepower against twenty-seven to fifty-seven hundredths for a cart horse. In 1739, Forest de Belidor maintained that seven men were required to do the haulage work of one horse. Other measurements in 1800 suggested that one man could ‘till from 0.3 to 0.4 hectares, turn 0.4 hectares of meadow, harvest 0.2 hectares with a sickle, or thresh about 100 litres of grain in a day’ – not a particularly impressive record.

However, in the time of Louis XIII, a man’s daily wage was not one-seventh but one-half of what one paid for a horse: eight sols to sixteen sols. The tariff rightly over-estimated human labour because this not-very-powerful engine always had great flexibility. Man had many tools at his disposal, some of them dating from the distant past: hammers, axes, saws, tongs and spades; he also possessed rudimentary engines which he worked with his own strength: trepans, capstans, pulleys, cranes, jacks, levers, pedals, cranks and lathes. G. Haudricourt has suggested the appropriate term ‘human engines’ for the last three, which had come to the West from either India or China. The most complex human engine of all was the loom, which reduced everything to simple actions: the alternate movement of the feet worked the pedals, raising half the threads of the warp and then the other, while the hands threw the shuttle carrying the thread of the woof.

Man in himself therefore contains many possibilities; he combines skill and flexibility. A porter in Paris (according to an account dating from 1782) lifted on his back ‘loads that would kill a horse’. P.G. Poinsot, in L’Ami des cultivateurs (1806), gives advice which is flabbergasting in view of its late date:

It would be most desirable if all the land could be tilled with a spade. The labour would certainly be much more profitable than with the plough and this implement is preferred in several cantons of France where great practice in handling it shortens the operation considerably, since one single man can turn over 487 [square] metres of earth at a depth of 65 centimetres in a fortnight, and such tilling is enough by itself, while tilling by plough must be repeated four times before heavy soil can be sown; furthermore the earth is never so well turned over nor crumbled up as with a spade. . . . It is clearly bad economy to till with a plough if a man has not a sizeable domain to cultivate, and this is the principal reason why almost all the small farmers are ruined. . . . Furthermore it has been proved that harvests from lands thus cultivated are triple those of the others. The spade used to cultivate the land must be at least double the length and strength of that used for gardens, which does not stand up to the efforts required to lift up compact earth and break it up sufficiently.
Nor was this purely theoretical. Day labourers in the countryside often cultivated their plots with pick-axes, if not with spades. This, as they said in the eighteenth century, was farming ‘by hand’ or ‘arm-labouring’. It would be interesting to calculate what would have been the result if this absurd Chinese-type tillage had been the rule instead of the exception. Would Western towns have been able to subsist in such conditions? Could they even have been created? And what would have happened to the livestock?

The lone man working with bare hands is a recurring figure in China in modern times. A traveller notes (1793): not only is human labour there ‘the least costly, but it is not spared at all, as long as it is sure of being put to good use’ - a qualification we need not believe. The Chinese labourer dug with a pick-axe, drew the plough in the place of the buffalo, distributed water, worked ‘chain pumps’, husked grain with handmills (‘this is the occupation of countless inhabitants’), carried travellers, lifted enormous burdens, transported weights balanced on a long wooden lever resting on his shoulders, turned the millstone at paper mills and hauled boats, whereas ‘in many other countries horses are used for this’. The highest lock on the Grand Canal from the Yang-tse-Kiang to Peking - called ‘Tien Fi Cha, which means the Queen and the Mistress of the Sky’ - was not worked by opening and closing the gates. The boats were hauled from one level to another by capstans and ‘many cables and ropes pulled from both sides of the canal by 400 or 500 men, or even by a larger number, according to the weight and size of the boat’. Was Father de Magaillans, who stresses the difficulty and danger of the operation, therefore right (1678) to hold up as an
example the Chinese custom of accomplishing ‘all sorts of mechanical work with many fewer instruments than we use’? Gemelli Careri, some ten years later (1695) was also amazed at the speed of the chair-carriers who went trotting along as fast as ‘little Tartary horses’. A Jesuit father at Peking in 1657 produced a fire-engine capable of throwing ‘water to a height of a hundred palms’ by manpower and wind. Yet even in India the noria and the sugar and oil mills were turned by teams of animals. Another extreme example could be found in Japan in the nineteenth century: there is a picture by Hokusai that shows the almost incredible sight of sugar cane being milled solely by manpower. The Jesuit fathers were still explaining matters in 1777:

The question of the utility of machines and working animals is not so easy to decide, at least for a country where the land is barely sufficient to feed its inhabitants. What use would machines and working animals be there? – to turn part of the inhabitants into philosophers [sic], that is to say into men doing absolutely nothing for society and making it bear the burden of their needs, their well-being, and what is even worse their comical and ridiculous ideas. When our country folk [the writer is a Chinese Jesuit] find themselves either supernumerary or unemployed in a few cantons, they decide to go away and work in Tartary, in the newly-conquered countries where our agriculture is making progress.

How reasonable it sounds. It is moreover true that at that time Chinese agriculture was being extensively developed. However, it is also true that agricultural progress was incapable of keeping pace with, let alone overtaking, demographic progress.

Human labour was widely used in Black Africa and India, as the reader will hardly need reminding. When Aurangzeb made his journey to Kashmir, the camels had to be unloaded at the first slopes of the Himalayas; they were relieved by 15,000 to 20,000 porters, some forced to serve, others ‘attracted by the alluring pay of ten crowns per hundred pounds in weight’. This might be regarded as wasteful – or on the other hand as a saving and an economy. At the house of correction in Bicêtre (1788), water used to be drawn from the wells by twelve horses, ‘but tough and powerful prisoners have since been employed at this work, a wise and most advantageous economy’. And this is the moralist Sébastien Mercier talking! Similarly black slaves could be seen even later than this, replacing horses in the towns of Brazil, pulling heavily laden carts.

The precondition for progress was probably a reasonable balance between human labour and other sources of power. The advantage was illusory when man competed with machines inordinately, as in the ancient world and China, where mechanization was ultimately blocked by cheap labour. There were slaves in Greece and Rome, and too many highly efficient coolies in China. In fact there is never any progress unless a higher value is set on human labour. When man has a certain cost price as a source of energy, then it is necessary to think about aiding him or, better still, replacing him.
Detail of the silver mine of Kutna Hora, about 1490. The baskets of ore were hauled to the surface by a windlass worked by two men. The same mine possessed giant windlasses worked by horses. But these were still only elementary means. Fifty years later, in the time of Agricola, huge hydraulic wheels were being used for lifting.

(Vienna, Aus dem Bildarchiv d. Ost. Nationalbibliothek.)
Animal power

Man was relieved by domestic animals early on, though the luxury was very unfairly distributed over the world. The history of these ‘engines’ will be clearer if we distinguish between Old and New Worlds from the beginning.

In America, the situation was comparatively straightforward. Llamas, ‘the sheep of the Andes’, were the only important heritage from the Amerindians. They were fairly poor carriers but unique in being able to adapt to the rarefied air of the high Cordillera. All the other animals (except for vicuñas and turkeys) came from Europe: oxen, sheep, goats, horses, dogs and poultry. The most important for economic life were mules, which gradually became indispensable as carriers – except in North America, certain areas of colonial Brazil, and in the Argentine pampas where wooden carts with high wheels, drawn by teams of oxen, remained the general rule until the twentieth century.

Elsewhere, caravans of mules with their noisy bells covered immense distances. In New Spain in 1808, Alexander von Humboldt noted their importance for the transport of merchandise and maize flour, indispensable to life in every town, above all the rich capital, Mexico City. The same was true of Brazil, where Auguste de Saint-Hilaire was an observant witness some twelve years later. This traffic, with its compulsory stops and fixed routes, required mule ‘stations’ – as at Porto da Estrella, at the foot of the Serra do Mar near Rio de Janeiro. The owners of the convoys, the Brazilian tropeiros, financed cotton production and later coffee. They were the pioneers of an early form of capitalism.

In the vast kingdom of Peru, in 1776, 500,000 mules were employed for trading along the coast or through the Andes and for drawing coaches in Lima. The kingdom imported about 50,000 of them a year from the Argentine pampas in the south. There they roved in the wild, watched over at a distance, and were driven northwards by peones on horseback in enormous herds of several thousand animals as far as Tucuman and Salta, where they were brutally broken in. They finally arrived in either Peru or Brazil, and would often end up at the enormous fair of Sorocaba, in São Paulo province. This production and trade reminded Marcel Bataillon of the automobile industry today and ‘its internal market in a continent open to motorization’.

The commerce gave primitive Argentina the chance to share in the silver of Peru and the gold of Brazil. Add the 500,000 mules in Peru to possibly the same number in Brazil and those in New Spain and elsewhere – Caracas, Santa Fé de Bogota, central America – and we have anything up to two million beasts, of burden or for saddle (rarely for hauling). Say one animal to every five or ten inhabitants; that represents an enormous ‘mechanization’ effort in the service of precious metals, sugar or maize. There was nothing comparable anywhere else in the world, with the exception of Europe. But even there, Spain only counted 250,000 mules for 10 million inhabitants (or almost the whole population of...
Iberian America) in 1797. Even if more accurate research were to modify the statistics for America, the disproportion would still be considerable.

Other European domestic animals also proliferated in the New World, particularly oxen and horses. Yoked oxen drew the heavy cart of the pampas and the carro de boi, with solid wheels and creaking wooden axle, typical of colonial Brazil. They also formed wild herds. This was the case in the Rio São Francisco Valley in Brazil, where a ‘leather civilization’ is reminiscent of similar scenes in the Argentine pampas and the Rio Grande do Sul, with orgies of eating meat roasted over an open fire.

Despite their superabundance, here as everywhere else in the world horses represented a sort of violent and virile aristocracy, that of the masters and the peones leading the herds of animals. The most astounding horsemen in the world, the gauchos, were already riding the pampas at the end of the eighteenth century. But a horse cost practically nothing – two reals: for there was no shortage of horseflesh. An ox did not even have a market price; it belonged to whoever caught it with a lasso or bola. A mule, however, sold for up to nine pesos in Salta. As a black slave in Buenos Aires was often worth 200 pesos, the New World had it seems both raised the price of man – and placed the whole animal kingdom in his power.

In the Old World, by contrast with the New, very old and complicated patterns had been inherited from ancient times.
Yet nothing could have been more logical – or so it seems *a posteriori* at least – than the spread of camels and dromedaries to all the empty parts of the Old World, that interminable chain of hot and cold desert lands running uninterrupted from the Atlantic Sahara to the Gobi desert. The hot deserts were the domain of dromedaries, animals susceptible to the cold and also unadapted to mountainous country. The cold deserts and mountains were the domain of camels, the division between them being on either side of Anatolia and Iran. As a traveller put it (1694): ‘Providence has made two types of camel, one for hot countries, the other for cold.’

But this providential division was in fact the result of a long process. Dromedaries only arrived in the Sahara at about the beginning of the Christian era and did not appear there in strength until the Arab conquests of the seventh and eighth centuries, and then the arrival of the ‘great nomads’ during the eleventh and twelfth centuries. Camels colonized the West between the eleventh and the sixteenth centuries, with the Turkish advances into Asia Minor and the Balkans. Of course camels and dromedaries could both be found outside their respective regions. Dromedaries crossed Iran and went as far as India where they sold at high prices, like horses. They penetrated south of the Sahara to the borders of Black Africa where canoes and carriers took over from them. At one time they even pushed as far northwards as Merovingian Gaul, while in the east, camels penetrated the Balkans: although their presence there was intermittent, they were still crossing the Balkans until the nineteenth century. In 1529 they brought supplies to the Turkish army under the walls of Vienna. Northern China, at the other end of the Old World, was likewise affected by the camel invasion. A traveller near Peking (1775) noticed alongside the rickshaws a camel ‘carrying sheep’ on its back.

In the camel, Islam possessed a near-monopoly in a powerful pack-animal which could be used for local transport, tilling the land and working norias (though donkeys had long been used for these purposes in the Mediterranean region) as well as for long-distance caravan connections with the Sahara, the Near East, and central Asia – a network of communications to be attributed to a resourceful ancient capitalism. Dromedaries and camels carried fairly heavy loads – 700 pounds for less powerful animals, quite often 800 (around Erzerum, for example), and 1000 to 1500 between Tabriz and Istanbul, according to a document of 1708. The pounds concerned must have been the so-called light pounds (under 500 grams) and the average load would have been roughly 4 or 5 present-day quintals. A caravan of 6000 camels could carry 2400 to 3000 tons, or the load of 4 to 6 reasonable-sized sailing ships of that period. For Islam, which thus controlled – over a long period – the bulk of inland communications in the Old World, the camel was the crucial element in commercial supremacy.

As for oxen (together with buffaloes and zebus) they spread throughout the Old World halted only by the Siberian forest in the north, where reindeer (wild
or domestic) predominated; and in the south by the African tropical forest, home of the tsetse fly.

In India they were sometimes not put to work at all; some, however, were harnessed to ploughs, pulled gilded carriages, turned mills or were ridden by soldiers and nobles; enormous convoys of up to ten thousand animals under the command of caravaneers of the curious Mouris caste would even be used to transport corn and rice. In case of attack, men and women defended themselves with volleys of arrows. When two caravans crossed on the narrow north Indian roads flanked by trees and walls, one line would wait for the other to pass by to avoid confusion. Other travellers might be blocked for two or three days, unable to move forward or backwards because of the animals. These Indian oxen were ill-fed and never stabled. Buffaloes in China, which were much rarer, worked very little, but were hardly fed at all, and had to fend for themselves. They were rather wild and easily frightened by travellers.

A common sight, particularly in Europe, was a pair of yoked oxen; even today, in places like Galicia in Spain, they can still be seen drawing wooden carts with solid wheels. Oxen could also be harnessed like horses: this was done by the Japanese and Chinese, who used the yoke harness, and sometimes by north Europeans who used the collar-harness. Oxen have immense possibilities as draught animals. Alonso de Herrera, a Spanish agriculturalist whose book appeared in 1513, advocated harnessing oxen and was not in favour of mules: mules were faster but oxen tilled more deeply and economically. In France, on the contrary, Charles Estienne and Jean Liebaut sang the praises of the horse: ‘Three of the best oxen of the Bourbonnais or the Forez cannot do as much as one good horse of France [i.e. the Ile-de-France] or the Beauce’, they wrote in 1564. François Quesnay took up the old discussion in 1758. In his time, capitalist agriculture using horses was driving out traditional agriculture which primarily employed oxen. All things considered, however (the horse is quicker and its working day longer, but it eats more and depreciates in value much more in old age than the ox destined for the butcher’s shop), the ox costs 30% more than its rival for an equal amount of work. A unit used to measure land in Poland in the seventeenth century corresponded to the surface that could be worked by one horse or a pair of oxen.

The horse has a long history. There were horses in France in the Neolithic Age, as is proved by the vast ossuary discovered at Solutré near Mâcon which covers more than a hectare. There were horses in Egypt in the eighteenth century BC and they crossed the Sahara in the Roman period. Did they perhaps originate in the regions surrounding the gates of Dzungaria, in the very heart of Asia? In any case they became so well distributed over Europe that by the sixteenth and seventeenth centuries AD, wild horses, or rather horses that had returned to a wild state, were to be found in the forests and thickets of north-west Germany, the Swiss mountains, Alsace and the Vosges. A cartographer, Daniel Spekle, mentions these wild horses in 1576 ‘in the forests of the Vosges, reproducing
themselves, feeding themselves in all seasons. In winter, they shelter beneath rocks... Extremely wild, they are very sure-footed on the narrow, slippery rocks."

So the horse had long been known in Europe. This centuries-old familiarity helped to bring about the gradual improvement in harnessing (the horse-collars in the West in the ninth century, soon to be followed by saddles, stirrups, bits, reins, harness, tandem teams, shoes). In the Roman period horses were badly harnessed (the yoke harness throttled them) and they could only draw a relatively light load: in terms of work they were not worth more than four slaves. In the twelfth century, their performance suddenly improved, like an engine increased to four or five times its power, as a result of the invention of the horse-collars. Until then they had been animals of war; thereafter they played a very large part in harrowing, tilling and transport. This important transformation was one of a series of changes which included demographic expansion, the spread of the heavy plough, the propagation of triennial rotation in the north, and increased crop yields— all factors in the rise of northern Europe.

However, horses remained very unevenly distributed. There were relatively few in China: ‘We have scarcely seen them,’ said Father de Las Cortes (1626),
in the Kingdom of Chanchinfu, and those we have seen are very small animals with short legs; they do not shoe them and do not use spurs. The saddles and bits are not as ours. [The Chinese were still using wooden saddles and ordinary ropes instead of reins in the eighteenth century.] We have seen a few more in the Kingdoms of Fuchinsu and Canton, but never in large numbers. I have been told that there are many horses in the mountains who have returned to wild life, and that it is the practice to capture them and break them in. As for mules, they were few in number and conspicuously ‘small’, according to another traveller, although they were sold at a higher price than horses ‘because they are easier to feed and they do not tire so easily’. If a traveller wanted to travel on horseback in China he would have been well advised to choose a good horse to start off with, since he would not have been able to change it; relay-points were reserved solely for the emperor’s use. The sensible choice remained the sedan chair—light, quick and comfortable, with eight men taking it in turns to carry it. As for the transport of baggage and merchandise, which was very well organized—they could be left at a goods office and would be found in the corresponding office on reaching one’s destination—this was often effected by porters or by one-wheeled carts pushed by one or two men, less frequently by pack-mules or donkeys.

True, the Emperor of China was described as ‘the most powerful prince in the world in cavalry’ and Magaillans in 1668 gives some apparently precise figures: 389,000 horses for the army, 175,000 for the staging-posts reserved for the Emperor’s service throughout the Empire. Even so, in 1690, when an expedition was launched against the khan of the Eluths, all privately owned horses in Peking, even those of the mandarins, were requisitioned for the army. One may wonder, however, whether all the Emperor’s subjects put together owned many more horses than their sovereign. Indeed, with a few exceptions (like the little horses of Szechwan) China’s horses were supplied from outside her frontiers, at the special fairs held on the frontiers of Mongolia and Manchuria: the fairs of Ka Yüan or Kuang Min; after 1467, the fairs of Fu Shun. According to an early eighteenth-century source, the Emperor bought about 7000 horses a year at the fairs, while ‘the lords, and civilian and military mandarins’ and the rest of the population bought in all only ‘twice or three times this number’. In other words a maximum of 28,000 horses a year was bought in the north: quite a low figure.

Horses were even rarer in India and Black Africa. Moroccan horses were indeed objects of great luxury, bartered for gold dust, ivory and slaves in the Sudan: twelve slaves for one horse at the beginning of the sixteenth century, and still as many as five later on. Fleets loaded with horses bought in Persia sailed for the Indies from Hormuz. A horse at Goa sold for as much as 500 pardoes or 1000 of the Great Mogul’s rupees, whereas a young slave at the same period was worth between 20 and 25 pardoes.

How did these expensive horses live with neither barley nor hay?
For food [wrote Tavernier in 1664] the horses are given a species of large pea that is crushed between two small millstones and then left to soak because its hardness makes its digestion very lengthy. These peas are given to the horses morning and evening; they are made to swallow two pounds of rough black sugar, crushed with the same amount of flour, and a pound of butter in small balls which are pushed down their throats; after which their mouths are carefully washed out because they have an aversion to this food. In the daytime they are only given certain herbs from the fields which are pulled up by the root and which are also carefully washed so that no earth or sand remains.48

In Japan, where carriages were normally harnessed to oxen (from Korea), horses were primarily nobles’ mounts.

In Muslim countries, horses were the aristocracy of the animal world. They constituted Islam’s great military weapon almost from the beginning, certainly after its first great successes. Giovanni Botero recognized the superiority of the Wallachian, Polish, Hungarian and Turkish cavalry in 1590: ‘If they have broken your lines you cannot escape them by fleeing, and if you have succeeded in scattering them you cannot catch them, for they are as swift as hawks and can either swoop down on you or vanish in a moment.’49 And they were plentiful: a traveller (1694) saw caravans of 1000 horses in Persia.50 From a military point of view, the Ottoman Empire in 1585 consisted of 40,000 horses in Asia and 100,000 in Europe; according to an ambassador, hostile Persia had 80,000.51 These were formidable reserves. In fact Asia won the race to produce war-horses - witness the vast numbers of them assembled at Scutari and then shipped to Istanbul.12

Théophile Gautier in nineteenth-century Istanbul marvelled at the sight of so many thoroughbreds from Nedj, Hedjaz and Kurdistan. He also described the ‘Turkish cabs’ or arabas stationed opposite the landing stage in Scutari. These were ‘gilded and painted carriages’, covered ‘with cloth fitted over a frame’ and harnessed to ‘black buffaloes or silver-grey oxen’.53 In fact in the nineteenth century horses were still reserved for soldiers, the rich, and nobles. In Istanbul horses might certainly turn the mills; and small horses, their feet shod in solid iron soles, provided transport in the Western Balkans. But they were menials, and it was not to horses like these that a traveller was referring when he said as recently as 1881 that a horse was worth 40 or 50 ducats at Mazagan in Morocco, while a black slave of eighteen years fetched sixteen ducats and a child seven.54 Horses did not finally replace oxen and camels for tilling in Asia Minor until after the First World War, in about 1920.

To its cost, Europe was slow to develop its own resources when faced with this world of horsemen. After the battle of Poitiers (732) it had to increase its numbers of horses and horsemen to protect itself and survive: the great charger the armed horseman rode in battle, the palfrey which carried him in times of peace, and his valet’s common nag. This period witnessed a war effort on the
part of both Islam and Christendom, with tensions and occasional respites. The Swiss victory over Charles the Bold’s cavalry, for example, marked a return in the West to infantry, pikemen and later to arquebusiers. The Spanish tercio in the sixteenth century was the most effective development of the foot-soldier. Similarly the janissary inaugurated the reign of the unmounted soldier on the Turkish side. However, the Turkish cavalry, the Sipahis, continued to fight alongside the janissaries and long remained incomparably superior to Western cavalry.

Good horses sold for high prices in Europe. When Cosimo de Medici was reinstalled at Florence in 1531 and created a guard of two thousand horsemen, the ostentatious magnificence ruined him. In 1580, the Spanish cavalry briskly achieved an easy conquest of Portugal, but immediately afterwards the Duke of Alva was complaining of a lack of horses and carriages. The same shortage occurred in the following century, for example during the war of Catalonia (1640–59), and throughout Louis xiv’s reign, when the French depended on the 20,000 or 30,000 horses they could rely on buying abroad during an average year. The stud farms established in France by Louis xiv, which made systematic

Eighteenth-century Manchuria: wild horses are caught by lasso as in the Argentine pampas. This was to supply the Emperor with cavalry - there was practically no horse-breeding in China. Musée Guimet, Paris. (Photo by the museum.)
purchases of stallions from Friesia, Holland, Denmark and the Barbary coast, 55 did not eliminate the need to buy foreign horses throughout the eighteenth century. 56

The best horses were bred in Naples and Andalusia: the large Neapolitan breed and the Spanish jennets. But it was impossible to buy one at any price without the gracious consent of the King of Naples or the King of Spain. Of course smuggling was rife on both sides; the passador de cavalls on the Catalan frontier was even risking the thunderbolts of the Inquisition, which had been entrusted with this unwonted supervision. In any case it took a very rich man, like the Marquis of Mantua, to have his own agents engaged in prospecting markets in Castile and as far afield as Turkey and North Africa in order to buy thoroughbred horses, pedigree dogs and falcons. 57 The Grand Duke of Tuscany, whose galleys (the Order of Saint-Stephen, founded in 1562) pirated the Mediterranean, often helped out Barbary privateers in return for gifts of good horses. 58 When relations with North Africa became easier in the seventeenth century, Barbary horses were shipped to Marseilles and sold at the Beauce fair.s Attempts were made to breed thoroughbreds from imported Arab horses, first in England in Henry VIII's reign, then in France in Louis XIV's and in Germany, where stud farms increased in the eighteenth century. 59 Buffon explained that 'it is from them [the Arab horses] that, either directly or indirectly, the best horses in the world are bred'. Breeds therefore gradually improved in the West; and numbers also increased. At the beginning of the eighteenth century, the Austrian cavalry which made possible Prince Eugène's successes against the Turks were in part the result of this progress.

Concurrently with the breeding of cavalry horses for Western armies, came the increased use of the draught-horse, which was indispensable for military transports and for hauling artillery. In 1580, the Duke of Alva's invading army made rapid progress through Portugal thanks to the requisition of many carts and carriages. 60 Almost a century earlier, Charles VIII's army had already surprised the Italian population when its pieces of field artillery passed quickly by, drawn not by oxen but by large horses 'clipped in the French style without tail or ears'. 61 A manual of Louis XIII's day 62 listed everything needed to mobilize a troop of 20,000 men equipped with artillery. It included among other things an enormous number of horses for the transport of cooking utensils, luggage and creakery belonging to the various officers, the field blacksmith's tools, the carpenter's, the surgeon's chests, but above all for the transport of pieces of artillery and their ammunition. The largest required at least twenty-five horses to carry the piece itself, plus at least a dozen for powder and shot.

Such were the duties of the large horses from the north which were increasingly exported southwards. Milan bought them from German merchants from the beginning of the sixteenth century; France from the Jewish dealers of Metz; they were in great demand in Languedoc. Clearly defined breeding areas developed in France - Brittany, Normandy (Guibray fair), the Limousin and the Jura.
We do not know whether the price of horses showed a relative fall in the eighteenth century. Whatever the case, Europe was equipped and even overburdened with horses. In England, horse thieves and receivers formed a social category of their own at the beginning of the nineteenth century. In France, just before the Revolution, Lavoisier calculated that there were 3 million oxen and 1,780,000 horses, including 1,560,000 engaged in agriculture (960,000 in regions where only horses were used, 600,000 where work was also done by oxen). And France at that time had 25 million inhabitants. If proportions were constant, Europe would have had 14 million horses and 24 million oxen at its disposal—an important contribution to the continent’s power supply.

Mules were also used in Europe; in Spanish agriculture, in Languedoc and elsewhere, Quiqueran de Beaujou mentions mules in Provence ‘whose price is often higher than that of horses’. A historian has deduced the tempo of economic life in Provence in the seventeenth century from the number of mules and muleteers and their movements. Since carriages could only cross the Alps at certain points, like the Brenner pass, the other paths were left exclusively to mule transport. These animals were even described as ‘large transports’ at Susa and all the other mule stations in the Alps. French Poitou should be noted among the important regions where asses and mules were reared. Every town depended on its horses for its daily provisioning, its internal communications, coaches and hired carriages. In about 1789, there were some 21,000 horses in Paris. And the supply had constantly to be renewed. Convoys of horses, known as ‘horse-trains’, were always arriving in the city. They consisted of files of ten to twelve animals, each attached to the tail of the one in front, with a blanket on its back and shafts along each side. They were assembled in the district of Saint-Victor or on the Montagne Saint-Geneviève, and for many years there was a horse market in the rue Saint-Honoré.

Except for Sundays when boats took sightseers to Sèvres or Saint-Cloud (not always safely), the Seine was scarcely used for public transport, which moreover was almost non-existent. The vehicle for someone in a hurry was a hired carriage. At the end of the century two thousand seedy cabs plied for trade in the town; they were drawn by broken-down horses and driven by foul-mouthed coachmen who had to pay out twenty sous a day for ‘the right to drive on the highway’. Congestion was notorious and we have many descriptions of it. ‘When the cabs are empty,’ said a Parisian, ‘they are fairly docile; around midday they are more difficult, in the evening they are unmanageable.’ And they were unobtainable at rush hours, for example at dinner time (for such it was) around two o’clock in the afternoon. ‘You open the door of the cab, someone else does the same on the other side; he gets in, you get in. It is then necessary to go to the commissioner [of police] for him to decide who shall have it.’ At such times a gilded carriage might be seen blocked by a cab crawling slowly along in front of it, at a slow and measured pace, ‘all broken down, covered with burnt leather and with planks in place of glass’.
25 HORSE-BREEDING AREAS IN FRANCE IN THE EIGHTEENTH CENTURY

Note 1. the horse-breeding regions; 2. the approximate boundaries of the north-east region, the country of open fields, triennial crop rotation, with large supplies of oats and where horses were the animals most used for ploughing. These were distinct zones, but there were areas of overlap (Normandy, the Jura, Alsace, etc.). Outside north-east France, teams of oxen were used for ploughing, if one excepts a few places where they were replaced by mules (Provence, part of Languedoc and Dauphiné).
The real responsibility for such congestion lay with Old Paris, that network of narrow streets often lined with sordid houses into which the population was crowded — particularly as Louis XIV had opposed further development of the city (by the ordinance of 1672). Paris had not changed since the days of Louis XI. There had never been any catastrophe to wipe out the old city, as happened in London in 1666 or in Lisbon with the earthquake of 1755. The idea that some such disaster might not have been altogether a bad thing seems to have crossed the mind of Sébastien Mercier when he writes that the destruction of Paris is sooner or later 'inevitable', and mentions Lisbon as a huge ugly town where 'three minutes sufficed to destroy what would have taken human effort much longer ... And the city arose from its ashes mighty and magnificent'.

Carriages had more room for manoeuvre on the road from Paris to Versailles and back; they were drawn by horses that were nothing but skin and bone, but urged recklessly on 'all dripping with sweat'; these cabs were known as the enragés. 'Versailles is the land of horses.' They showed 'the same differences as exist amongst the inhabitants of the town: some are fat, well fed, well trained ... others ... with drooping neck and withers, only drawing carriages of court valets or provincials.'

The scene would have been the same in St Petersburg and London, where we have only to follow day by day Samuel Pepys' drives and excursions in hired coaches in Charles II's reign. Later he treated himself to the luxury of a private carriage.

It is difficult to imagine what these problems of transport meant, for goods as much as people. Every town was full of stables. The shoewing smith was a person of substance, his establishment being rather like the present-day garage. Nor should the provision of oats, barley, hay and straw be forgotten. In Paris 'anyone who does not like the smell of new-mown hay,' wrote Sébastien Mercier in 1788, 'does not know the pleasantest of perfumes; anyone who likes this smell should go in the direction of the Porte d'Enfer [it is still there today, south of the Place Denfert-Rochereau] twice a week. There he will find long lines of carts overloaded with hay: they ... are awaiting purchasers ... suppliers to houses which keep horses and carriages are there, examining the quality of the produce; all of a sudden they pull out a fistful of hay, feel it, smell it, and chew it; they are cup-bearers for the horses of Madame la Marquise.' But the Seine remained the great supply route. The fire that broke out on 28 April 1718, setting light to the arches of the Petit Pont and burning houses on it and neighbouring dwellings, started on a boat loaded with hay. In London hay was bought at a market just outside Whitechapel bar. At the Perlachplatz market in Augsburg in the sixteenth century, October saw peasants offering piles of hay side by side with supplies of wood and game, and in Nuremberg pedlars with wheelbarrows sold the straw needed for the stables of the town.
Wind engines and water engines

The West experienced its first mechanical revolution in the eleventh, twelfth and thirteenth centuries. Not so much a revolution, perhaps, as a whole series of slow changes brought about by the increased numbers of wind- and watermills. The power from these ‘primary engines’ was probably not very great – from two to five horse-power from a water-wheel, sometimes five, at most ten, from the sails of a windmill. But they represented a considerable increase of power in

A curious representation, quite late in date (1430), of a horizontal water-wheel. But this mill was in Bohemia, where the horizontal system was maintained for many years (cf. the illustration of the French Bible, *infra*, Vol. III, chapter 5, where the wheel is already shown as vertical). [Document in the author’s collection.]
an economy where power supplies were poor. And they undoubtedly played a part in Europe’s first age of growth.

Watermills were both older and of much greater importance than windmills. They did not depend on the irregularities of the wind, but on water which is on the whole less capricious. They were more widespread because they had been in existence for a long time, and also on account of the large number of streams and rivers, dams, diversions and aqueducts which could turn a wheel fitted with blades or paddles. The force of the current was used by ‘boat-mills’ on the Seine in Paris, the Garonne at Toulouse, etc. Nor should power from the tides be forgotten; it was harnessed, both in Islam and the West, even in places where the tides were slight. In 1533 a French traveller to the lagoon at Venice was full of admiration for the only watermill he could have seen on the island of Murano, moved ‘by water from the sea on a wheel when the sea swells and subsides’.

The first watermill was horizontal, a sort of rudimentary turbine: it is
sometimes called the Greek mill (because it appeared in ancient Greece) or the Scandinavian mill (because it was used in Scandinavia for a long time). It might just as well be described as Chinese or Corsican, or Brazilian, or Japanese, or as coming from the Faroe Islands or central Asia, because water-wheels turned horizontally there until variously the eighteenth or twentieth centuries, developing a small amount of power able to move millstones slowly. It is no surprise to find these primitive wheels in Bohemia in the fifteenth century or in Rumania in about 1850. This type of mill, with vanes, even functioned up to about 1920 near Berchtesgaden.

It was a stroke of genius to move the wheel to the vertical position, which Roman engineers did in the first century BC. The energy was transmitted by gear wheels to a horizontal plane for the purpose of turning the millstone – which turned five times faster than the propelling wheel, thanks to the use of gears. These first engines were not always rudimentary. Archaeologists have discovered impressive Roman installations in Barbegal near Arles: an aqueduct over ten kilometres long in which the water was ‘forced along’ culminated in a series of eighteen wheels – a set of early engines.

Nevertheless, the appearance of this Roman equipment was both late and limited to a few points in the Empire and was used solely to grind corn. Whereas the twelfth- and thirteenth-century revolution that increased the number of water-wheels also extended their use to other purposes. The Cistercians built them in association with their iron-works in France, England and Denmark. Centuries went by until the day when no village in Europe, from the Atlantic to Muscovy, was without a miller and a wheel turning with the current, except where a piping system brought water from higher up.

The uses of the water-wheel had become manifold; it worked pounding devices for crushing minerals, heavy tilt hammers used in iron-forging, enormous beaters used by cloth fullers, bellows at iron-works; also pumps, grindstones, tanning mills and paper mills, which were the last to appear. We should also mention the mechanical saws that appeared in the thirteenth century – as shown in a sketch made about 1235 by that strange ‘engineer’ Villard de Honnecourt. With the extraordinary development of mining in the fifteenth century, the best mills worked for the mines: treadmills powering winches with a reversible action to raise buckets of ore, machines to ventilate galleries or to pump water by norias, bucket chains or even by lift-and-force pumps, and controls operating levers that could set in motion mechanisms which were already complicated and which were to remain unchanged until and after the eighteenth century. These impressive mechanisms with wheels sometimes up to ten metres in diameter are shown in the magnificent plates in De re metallica by Georg Agricola (Basle 1556) which summed up earlier work and brought it up to date.

For mechanical saws, fullers’ beaters, tilt hammers and bellows, the problem had been the transformation of a circular movement into an alternating movement: this was made possible by the use of the camshaft. A whole book could
be written (and indeed one was) on the necessary gear mechanisms. The astonishing thing, to our eyes, is that such complicated solutions should have been possible using wood as the only construction material. These mechanical marvels were not, I hasten to say, everyday sights in the past. When Barthélemy Joly crossed the Jura and arrived at Geneva in 1603 he noticed mills in the Neyrolles valley at the outlet of the lake of Silan handling ‘pine and fir wood which is thrown from the top of the precipitous mountains to the bottom; they have a pleasing device by which several movements from bottom to top and in the opposite direction [these were made by the saw] proceed from a single wheel turned by water, the wood moving forward of its own accord ... and another tree following in its place with as much method as if it were done by men’s hands’. It is obvious that this was indeed an unusual sight, worthy of inclusion in a traveller’s tale.

Mills had, however, become universally used machines, so that water power, from rivers, whether exploited to the full or not, was absolutely necessary. The ‘industrial’ towns (and what town at that time was not?) adapted themselves to the courses of rivers, moving near them, controlling the running water and taking on a Venetian appearance, at least along three or four distinctive streets. Troyes was typical; Bar-le-Duc still has its Rue des Tanneurs on an offshoot of the river; Châlons, the cloth centre, used the Marne (over which there is a bridge called the Cinq Moulins – the Five Mills); Rheims the Vesle; Colmar the Ill; Toulouse the Garonne, where a fleet of ‘floating mills’, that is boats with wheels turned by the current, existed very early on and long remained in use; and Prague was built round several loops of the Moldau. The Pegnitz made it possible for the many wheels of Nuremberg to turn inside the city walls and in the nearby countryside (180 were still operating in 1900). In and around Paris, about twenty windmills afforded extra power, but even if there had been enough wind to turn their sails every day of the year, they could have supplied no more than a twentieth of the flour consumed by Paris bakers. There were 1200 watermills (mostly reserved for grinding grain) along the banks of the Seine, the Oise, the Marne and smaller rivers like the Yvette or the Bièvre (where the royal manufacture of the Gobelins was set up in 1667). Smaller rivers, flowing from a nearby source, had the advantage that they rarely froze in winter.

Was the takeover of the mills by the towns a second-stage development? In a thesis yet to be published, Robert Philippe has shown how in the preceding phase, the first mills were built on sites dictated by the flow of water to be used, in the countryside, near villages, where the source of energy thus became established and remained for centuries. The mill, whose primary function was to grind grain, was thus the essential tool of the manorial economy. The lord of the manor bought the millstones, and provided wood and stone; the peasants contributed their labour. The manorial economy consisted of a series of basic units, capable of self-sufficiency. But the exchange economy, which concentrated and distributed commodities, operated on behalf of the towns and led to the
towns: it eventually imposed its own system on the preceding pattern and created a new series of mills, corresponding to its many requirements.75

The mill thus becomes a sort of standard measure of the energy supply in pre-industrial Europe. When the Westphalian doctor Kämpfer landed in 1690 on an insignificant island in the Gulf of Siam, he wrote of the river, to give some idea of its flow, that it was abundant enough to turn three windmills.76 Towards the end of the eighteenth century there were, according to records for Galicia (which had come under Austrian rule), 5243 watermills (and only 12 windmills) in an area of 2000 square leagues and for a population of 2 million. This looks an enormous figure at first sight, but then the Domesday Book of 1086 records 5624 mills serving a mere 3000 settlements south of the Severn and the Trent,77 and one has only to look out for the innumerable little wheels visible in so many paintings, drawings and town plans to understand how widespread they had become. If the ratio of watermills to population was the same elsewhere as in

(Photo Jean Roubier.)
Poland, there would have been 60,000 in France and not far off 500,000 to 600,000 in Europe on the eve of the industrial revolution.

In a meticulous article, to my mind as brilliant as Marc Bloch’s classic article on the watermill, Lazlo Makkai confirms these estimates: ‘500,000 to 600,000 mills, the equivalent of one and a half million to three million horse-power’. His calculations are based on the number of leases; the dimensions of the wheels (two or three metres diameter) and the numbers of paddles or blades they had (about twenty on average); the number of wheels per mill (1-2 or more); a comparison between the mills of East and West Europe (roughly the same, at least as far as flour mills are concerned); and the almost constant ratio of mills to population: on average from actual records, 1 to 29. Since the number of mills or the size of the wheels increased with the population, the supply of mill-power more or less doubled between the twelfth and the eighteenth century. As a rule, every village had its mill. Where there was not enough running water, on the Hungarian plains for instance, mills were operated by horses or even manual labour.79

Windmills appeared very much later than water-wheels. They were previously thought to have originated in China; more probably they came from the highlands of Iran or from Tibet.

Mills were probably operating in Iran from the seventh century AD and certainly by the ninth century. They were moved by vertical sails fitted to a wheel turning horizontally. The momentum from the wheel was transmitted to a central axis and set in motion a millstone to grind grain. Nothing was simpler: there was no need to adjust the direction of the wheel since it was always situated in the path of the wind. It had another advantage; no gear-wheel was required to transmit the energy to the millstone. The problem in the case of a grain mill was always to power a horizontal millstone, the mola versatilis, which crushed the grain on a stationary millstone placed beneath it. The Muslims were said to have spread these mills to China and the Mediterranean. Tarragona, at the northern limit of Muslim Spain, possessed windmills in the tenth century. But we do not know how they turned.80

The great event in the West – as opposed to China where mills turned horizontally for centuries – was the transformation of the windmill into a wheel fitted vertically, as had happened to watermills. Engineers say that the modification was a stroke of genius and that power was greatly increased. It was this new style of mill, a creation in itself, that spread in Christendom.

The statues of Arles record its presence in the twelfth century. It was in England and Flanders by the same period, and the whole of France welcomed it in the thirteenth century. There were already windmills in Poland and Muscovy in the fourteenth century; they had come via Germany. A point of detail: the Crusaders did not, as has been said, find windmills in Syria; they took them there.81 Timelags were numerous, but in general northern Europe was more advanced than southern. For example, the windmill arrived late in certain regions
of Spain, notably La Mancha, so much so that according to one historian Don Quixote's alarm was quite natural: the great monsters were new to him. The same did not apply in Italy; in 1319, in Dante's *Inferno*, Satan stretches out his enormous arms *come un molin che il vento gira*.

Windmills were more expensive to maintain than other mills and costlier for the same amount of work, notably flour-milling. But they had other uses. The major role of the *Wipmolen* in the Netherlands in the fifteenth century (and still more after 1600) was to drive the bucket chains that drained water from the soil and poured it into canals. So the mill became one of the instruments used in the patient reclamation of the Low Countries' soil; mills were located behind the dykes built up against the sea and along the lakes formed on the sites of over-exploited peatbogs. Another reason why Holland was the homeland of windmills was its situation in the centre of a great area of permanent westerly winds from the Atlantic to the Baltic.

Originally the whole mill pivoted on itself to align its sails in the direction of the wind, like the Brittany mills, called by the distinctive name of *chandeliers*. The whole mill was mounted on a central mast and a directing bar or 'tail-pole' enabled the body to pivot. It was best if the sails were situated as high as possible above ground level to catch the strongest wind, so the machinery of gear-wheels and millstones was placed at the top of the building (hence the need for sackleists). One small detail is worthy of note: the axis of the sails was never strictly horizontal, the tilt being regulated by trial and error. We can understand these simple machines from plans (like that of Ramelli, 1588) and mills still in existence - how they transmitted momentum, their braking systems, the possibility of substituting two lateral pairs of millstones for the single central pair, and so on.

It is scarcely more complicated to explain the working of a *Wipmolen*, which took its driving power from the top of the mill and retransmitted it to the base and the bucket chain that acted as a pump. The momentum was transmitted by a shaft through a hollow central mast. This gave rise to certain difficulties when *Wipmolen* were, as the opportunity offered, converted for the purpose of milling grain, but they were not insurmountable.

Quite soon, certainly in the sixteenth century, thanks to Dutch engineers, tower mills became widespread: their sails were adjusted at the top of the building, the only movable part. The difficulty with these mills, sometimes called 'smock mills' (because from a distance they looked like a peasant clad in his smock), was to facilitate the movement of the 'cap' on the fixed part of the mill by the use of wooden runners or various types of rollers. Inside, the problems to be solved remained the same: to adjust, control and stop the movement of the sails, to organize the slow descent from the mill-hopper of the grain, which passed through the upper turning part of the millstone by the ‘mouth’; the basic problem was to convert the momentum from the vertical plane of the sails to the horizontal plane of the millstones by gear-wheels.
Wooden machines and gears: this enormous tread-mill was a cage operated by three men standing inside. (Lichtbildstelle, Deutsches Museum, Munich.)
A windmill, with special sails turning round a vertical axis: they do not therefore have to be realigned to catch the wind. The transmission of the movement is in this case the opposite of that in a watermill: the initial horizontal movement is transmitted to a vertical bucket chain which is hauling up water (this mill was a draining-machine developed in 1652 in the English fens). In Dutch mills, there was a double transformation of the momentum: it began as horizontal, with the movement of the sails, became vertical through the transmission of the main shaft, then horizontal again for the pump. Drawing by W. Blith, from *The English Improver improved*, 1652. (Photothèque A. Colin.)

More generally the great advance was the discovery that a single engine, a single wheel – whether wind- or watermill – could transmit its momentum to several implements: not to one millstone but to two or three; not to one saw but to a saw plus a tilt-hammer; not to one pile but to a whole series, as in a curious model (in the Tyrol) which ‘pounded’ corn instead of milling it (in this case the roughly crushed grain was used to make wholemeal bread which was more like biscuit than bread).
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Sails: the European fleets

It is not my intention here to discuss the question of sailing-rigs in general, only to convey some idea of the power that sails put at the service of man. The sail was in fact one of the most powerful engines at his disposal, as the European example convincingly demonstrates. In about 1600 Europe had some 600,000 to 700,000 tons of merchant shipping (a figure to be treated with the usual caution, and best regarded as an order of magnitude). According to reliable statistics established in France probably in 1786, the European fleet had by then reached 3,372,029 tons. Its volume had therefore possibly quintupled in two centuries. At an average of three voyages a year this would represent a trade of ten million tons, equivalent to that of a large port today.

These figures do not enable us to calculate the power of the wind engines that shifted such a volume with the same reliability we would have in the case of a fleet of steam-driven cargo boats. It is true that around 1840, when sailing ships and steam ships existed side by side, it was estimated that steam did the work of about five sailing ships for equal tonnage. The European fleet was therefore equivalent to 600,000 to 700,000 tons of steam-driven cargo boats, and we can hazard a figure of between 150,000 and 233,000 horse-power, according to whether the power needed to propel a nautical ton in about 1840 is estimated at a third or a quarter of one horse-power. The figure would have to be considerably increased if we included war-time fleets.

Wood, an everyday source of energy

Calculations of energy today leave out work by animals and to some extent manual work by men; and often they ignore wood and its derivatives as well. But wood, the first material to be in general use, was an important source of energy before the eighteenth century. Civilizations before the eighteenth century were civilizations of wood and charcoal, as those of the nineteenth were civilizations of coal.

Everything in the European scene points to it. Wood was much used in buildings, even stone ones; all overland and sea transport was made of wood, as were machines and tools, the metal parts always being kept to a minimum; looms and spinning wheels, wine-presses and pumps were made of wood, and most ploughing implements were wooden; the swing plough was made entirely of wood, the plough usually had a wooden ploughshare fitted with a thin iron blade. To our eyes nothing is more extraordinary than some of the complicated gear-wheels with their precision-fitting wooden pieces that can be seen, for example, in the Deutsches Museum, the museum of technology in Munich. Exhibits there even include several eighteenth-century clocks, made in the Black Forest, with works entirely of wood, as well as a rarer item, a round wooden watch.
The fact that wood was used everywhere carried enormous significance in the past. One of the reasons for Europe’s power lay in its being so plentifully endowed with forests. Against it, Islam was in the long run undermined by the poverty of its wood resources and their gradual exhaustion.88

Strictly speaking, we should here be concerned only with the wood directly transformed into power for heating houses and for industries using heat, iron furnaces, glass works, tile works and charcoal workshops, and salt mines, which often used firing processes. But, apart from the fact that supplies of wood available for burning were limited by the other uses of wood, these other uses exerted a major influence on the manufacture of all the implements producing energy.

The forest enabled man not only to warm and house himself but to build his furniture, tools, carriages and boats.

The type of wood he required varied. He used oak for houses; ten different woods, ranging from fir to oak or walnut, were used for galleys;89 elm was used for gun carriages. The result was enormous devastation. No transport was too long or too costly for the needs of the arsenals; every forest was affected. Planks and timber loaded in the Baltic and Holland were being imported to Lisbon and Seville in the sixteenth century; so were rather heavy but cheap ready-made boats which the Spaniards sent to America with no intention of bringing them back, leaving them to finish their career in the Caribbean or sometimes abandoning them to the ship-breakers as soon as they arrived. These were the lost boats, los navios al través.

Every fleet, in no matter what country, required for its construction the destruction of enormous expanses of forest. Ship-building in Colbert’s time exploited the forestry resources of the entire kingdom; timber was transported by every navigable route, even small waterways like the Adour or the Charente. Fir from the Vosges was floated along the Meurthe and then transported by road to Bar-le-Duc where the tree trunks were assembled into rafts on the Orne. Next the Saulx, Marne and finally the Seine were used.90 For the crucial supplies of masts for warships, France found itself excluded from the Baltic trade which primarily supplied England (via Riga and later St Petersburg). France did not think of exploiting the forests in the New World, particularly those of Canada (as the British did later).

The French navy was therefore obliged to use ‘assembly masts’ made of pieces of jointed wood ringed with iron, but they lacked flexibility and broke if overloaded with sail. Compared with the English, French ships could never show an extra turn of speed. We can judge better by looking at the time when the situation was momentarily reversed during the War of American Independence: the English had to resort to the inferior type of mast, for the League of Neutrals closed the Baltic to them, and the advantage passed to their opponents.91

This was not the only way in which forest reserves were wasted, nor even the most dangerous in the long run. The peasant, particularly in Europe, was
continually uprooting trees to extend his tillage. Common land was the enemy of the forest. The forest of Orléans measured 140,000 arpents in François I’s reign and only 70,000, it was said, a century later. The figures are not reliable, but certainly land clearance from the end of the Hundred Years War (which had favoured the invasion of field by forest) until Louis XIV’s reign reduced wooded expanses to their lowest limits, which correspond more or less to those of today.92 Everything conspired against the forest; in 1579 a hurricane destroyed fifty to sixty thousand trees in the forest of Bleu, which linked the Lyons massif with the woods of Gisors in the middle ages; peasants with ploughs moved quickly into the breach and the forest was never united again.93 Today the view of the land on an aeroplane journey from Warsaw to Cracow still shows the way in which the long fields thrust into the forest areas. If French forests were stabilized in the sixteenth and seventeenth centuries, was it the result of careful legislation (for example, the great ordinance of 1573 and Colbert’s measures); or was a balance naturally reached because the land that was still unexploited was too poor and not worth the effort?

Some historians, thinking primarily of the New World, have said that those who burned forests and set up cultivated zones in their place were much misled, since they were destroying one kind of wealth which already existed, in favour of another, yet to be created and not necessarily worth more. There is a clear fallacy in this argument: forest wealth only existed when incorporated into the economy through intermediaries – shepherds tending their flocks (not only the pigs at acorn time), woodcutters, charcoal-burners, carters: a whole community whose profession it was to exploit, to utilize and to destroy. The forest was worth nothing unless it was used.

Immense forest areas still remained outside the clutches of civilizations before the nineteenth century: there were the Scandinavian forests; the Finnish forests; the almost uninterrupted forest between Moscow and Archangel, crossed by a narrow network of roads; the Canadian forest; the Siberian forest linked by trappers to the markets of China and Europe; the tropical forests of the New World and the Indian Archipelago, where precious woods were pursued instead of furs: campeachy wood in present-day Honduras, pau brasil (‘brazil’, which gave a red dye and was cut down on the coasts of north-east Brazil), teak from the Deccan, sandalwood and rosewood elsewhere.

Wood was also used for cooking, for heating houses, and for all the industries that needed fire-power – for which demand was increasing with alarming speed even before the sixteenth century. A striking example is recorded near Dijon in 1315-17: to feed the six furnaces producing terracotta tiles, 423 woodcutters were employed in the forest of Lesayes and 334 drovers were needed to transport the wood.94 There were many eager takers for the forest wealth which was bitterly fought over – since its abundance was only apparent. A forest was not a fuel reserve in any sense comparable to the most modest coal-mine, even at this time. It took twenty or thirty years to grow again once it had been harvested.
During the Thirty Years War, the Swedes, who needed money, cut down vast areas of forest in Pomerania with the result that many regions were afterwards invaded by sand-dunes. When the fuel situation became difficult in France in the eighteenth century, it was said that a single forge used as much wood as a town the size of Châlons-sur-Marne. Enraged villagers complained of the forges and foundries which devoured the trees of the forests, not even leaving enough for the bakers’ ovens. In Wielicza in Poland, the heat-process for the saline water of the huge mine often had to be abandoned after 1724, and mining restricted to slabs of rock salt, because of the devastation of the surrounding forests.

Because of its bulk, wood for burning had indeed to be close at hand. It was ruinous to transport it more than thirty kilometres – unless, that is, it could float on its own by waterway or sea. Tree trunks thrown into the Doubs could travel all the way to Marseilles in the seventeenth century. ‘New’ wood arrived in Paris in boatloads and ‘floated’ wood began to arrive from Morvan along the Cure and Yonne after 1549. Twelve years later it was floating down the Marne and its tributaries from Lorraine and the Barrois. It took extraordinary skill to manoeuvre these floats, up to 250 feet long, under the arches of the bridges. Charcoal reached Paris in the sixteenth century by way of Sens from the forest of Othe; by the eighteenth century, it was arriving from all accessible forests,
sometimes in carts or on pack animals, usually by the rivers – the Yonne, the Seine, the Marne and the Loire – in boats ‘piled high, with hurdles along the sides of the boat to keep the charcoal in’.  

Great rafts of wood were coming down the Polish rivers to the Baltic from the fourteenth century onwards. The same sight, on an even more grandiose scale, was to be seen in distant China. Rafts of wood from Szechwan, the trunks tied together with a sort of ‘wicker rope’, were taken down to Peking. ‘The richer the merchant, the longer the rafts; some of them are half a league long.’

Wood was also transported over long distances by sea. There were the ‘black sailing ships’ that carried charcoal from Cape Corse to Genoa, and the boats from Istria and Quarnero that brought Venice its winter wood. The ships from Asia Minor that supplied Cyprus and Egypt sometimes towed tree trunks behind them. Even slender galleys were used to carry firewood to Egypt, where the fuel shortage was acute.

However, there were limits to this form of supply and most towns had to be content with what they could find close at hand. Thomas Platter, a citizen of Basle who finished his medical studies in 1595 at Montpellier, noted the absence of forests around the town.

The nearest is at the Saint-Paul glass works, a good three miles in the direction of Celleneuve. The firewood is brought from there in winter and sold by weight. One wonders where they would get it if the winter lasted a long time because they consume an enormous quantity of it in their fireplaces, while shivering beside them. Stoves are unknown in this region; unlike at home, the shortage of wood is so great that bakers fill their ovens with rosemary, kermes-oak and other bushes.

The shortage increased the farther south one went. Antonio de Guevara, the Spanish humanist, was right: fuel in Medina del Campo was more expensive than what was cooked in the pot. In Egypt the straw from the sugar cane was burned for want of anything better; in Corfu the residue from squeezed olives, made into bricks and immediately put to dry, was used as fuel.

To supply fuel on this huge scale required a vast transport organization, regular maintenance of the waterways used for floating, extensive commercial networks and the supervision of stocks – to which end governments increased the number of regulations and prohibitions. None the less wood became rarer every day, even in richly endowed countries. The problem was to utilize it better. But it would appear that no attempt was made to economize on fuel in either glass- or iron-works. As soon as the radius from which a wood-burning factory drew its supplies became too large and costs increased, the response was if anything to move the factory. Or else to reduce its activity. A blast furnace ‘built in Dolgyne in Wales in 1717’ was not fired until four years later when ‘enough charcoal had been accumulated for thirty-six and a half weeks’ work’. It only operated for an average of fifteen weeks a year, again because of lack of fuel. Furthermore, it was the general rule, in view of this constant shortage of supplies,
for ‘blast furnaces only to function one year in every two or three, or even one year in five, seven or ten’. According to calculations by one expert, an average iron-works where the furnace was working two years on and two years off, in the period before the eighteenth century, absorbed the production of 2000 hectares of forest. The pressures this produced were aggravated by the industrial progress of the eighteenth-century. ‘In the Vosges, trade in wood has become the trade of all the inhabitants: it is a case of who can fell more trees, and in a short time the forests will be completely destroyed.’ It was from this crisis – latent in England from the sixteenth century – that in the course of time the coal revolution emerged.

And, of course, there was also the pressure of prices. In his *Oeconomies Royales* Sully went so far as to say ‘that the price of all the commodities necessary for life would constantly increase and the growing scarcity of firewood would be the cause’. The rise in price accelerated in 1715 and ‘shot up with the last twenty years of the ancien régime’. In Burgundy ‘timber can no longer be found’ and ‘the poor do without fires’.

It is very difficult to present the matter statistically, but we do have at least three rough estimates at our disposal. In 1942, when France was reduced to heating with wood, the country is said to have used 18 million tons, about half of it in the form of firewood. In 1840, French consumption was of the order of 10 million tons in firewood and charcoal alone (not counting wood used for building). And in 1789, it was about 20 million tons. In Paris alone, on the eve of the Revolution, charcoal and firewood represented more than 2 million tons, that is 2 tons per head. That is a very high figure, but at this time Paris was receiving only insignificant quantities of coal – the figure for wood was 140 times that for coal. The difference between 1789 and 1840 is of course accounted for by the increasing use of coal. If France is reckoned to account for one-tenth of European consumption, Europe as a whole must have been burning 200 million tons of wood in 1789 and 100 million in 1840.

It is on the basis of this figure of 200 million tons that we must try to conduct the hazardous calculation of the value in horse-power of wood as a source of energy. Two tons of wood are equal to a ton of coal. If we assume that one horse-power hour represents the combustion of two kilograms of coal and that energy was used at the rate of about three thousand hours per year, the energy available will be in the order of 16 million horse-power. These calculations, which I have shown to specialists, only give a very approximate order of magnitude and the reduction to horse-power is both outmoded and risky. It should also be borne in mind that there was a very low return on the energy invested – about 30%, which brings us to 4 or 5 million horse-power. This figure is still comparatively high, given the scale of pre-industrial energy, but it is not to be ruled out of court: after all, more serious calculations than mine have shown that coal did not overtake wood in the economy of the United States until 1887!
Coal

Coal was not unknown to either China or Europe. In China it was used in Peking for domestic heating (and had been for four thousand years according to Father de Magaillans), for cooking food in the houses of the mandarins and those in high positions, and also by ‘blacksmiths, bakers, dyers and the like’. In Europe it was extracted in the eleventh and twelfth centuries - from the shallow basins in England, for example, in the Liège basin, in the Saar, and in the small coal basins of the Lyonnais, Forez and Anjou - for lime kilns, domestic heating and for some processes in the iron-works (not all, at least not until anthracite or coke were available, coke coming in at the end of the eighteenth century). However, well before that date coal was fulfilling the minor functions charcoal left it, in chaferies and splitting mills (where the iron was split up) and wire mills where the wire was drawn. And coal was transported over quite long distances.

The excise authorities in Marseilles in 1543 noted the arrival of ‘brocz’ of coal by the Rhône, probably from Alès. At the same period, a peasant mine at La Machine, near Decize, yielded barrels (they called them ‘fish’ or ‘loads’) of coal, which were taken up to the small port of La Loge on the Loire. From there they were sent on by boat to Moulins, Orléans and Tours. Admittedly these were all small-scale enterprises. So too was the coal-firing employed at the Saulnot salt mines, near Montbéliard, as early as the sixteenth century. When wood was short in Paris in the autumn of 1714, the import firm Galabin & Co. made public experiments in the city hall with ‘Scottish fuel’. They obtained a
licence to import this foreign fuel. The Ruhr itself had to wait until the first years of the eighteenth century before coal became really significant. Similarly, it was only at this time that coal from Anzin was exported beyond Dunkirk to Brest and La Rochelle: that coal from the Boulonnais mines was used in Artois and Flanders in brickworks, breweries, lime-kilns and blacksmiths’ forges, as well as for keeping sentries warm; and that coal from the mines of the Lyonnais could be brought more quickly, after 1750, along the recently constructed Givors Canal to Lyon itself. The major obstacle to the spread of coal was indeed transport, usually effected by carts or pack animals.

Within Europe there were only two achievements of any magnitude: in the Liège basin and in the Newcastle basin in England. Liège was already an ‘arsenal’, a metallurgical town, in the fifteenth century, and its coal was used to finish its products. Production tripled or quadrupled during the first half of the sixteenth century. Later its neutrality (Liège came under the authority of its bishop) helped it to prosper throughout the religious wars. The coal, which had already been extracted from deep galleries, was exported towards the North Sea and the Channel by the Meuse. Newcastle’s success was on an even greater scale. It was an integral part of the coal revolution that modernized England after 1600, enabling fuel to be used in a series of industries with large outputs: the manufacture of salt by evaporating sea water; the production of sheets of glass, bricks, and tiles; sugar refining; the treatment of alum, previously imported from the Mediterranean but now developed on the Yorkshire coast; not to mention the bakers’ ovens, breweries and the enormous amount of domestic heating that was to pollute London for centuries. Stimulated by rising consumption, production in Newcastle continually increased: 30,000 tons annually in 1563–4, 500,000 in 1638–9. Production around 1800 was probably in the neighbourhood of two million. The Tyne estuary was permanently filled with coal ships plying mainly between Newcastle and London. Their tonnage rose to 348,000 in 1786, at a rate of six round journeys a year. Part of this coal was exported; ‘sea coal’ travelled great distances, at least as far as Malta in the sixteenth century.

Very early on it was thought necessary to refine the coal before using it in iron production, just as wood was burnt in primitive earth-covered furnaces to produce charcoal. The method of producing coke was known in England in 1627. The first combustion of coal in Derbyshire dates from 1642. Almost immediately the brewers in the region began to use coke instead of straw and ordinary coal for drying and heating the malt. The new fuel was to give Derby beer the ‘paleness and sweetness which made its reputation’, ridding it of the unpleasant smell of ordinary coal. It duly became the leading beer in England.

But coke did not achieve immediate popularity in metallurgy. ‘[Coal] can, with fire, be purged of the bitumen and sulphur it contains,’ said an economist in 1754, ‘so that by losing two-thirds of its weight and very little of its volume it remains a combustible substance but cleared of those parts that give off the unpleasant smoke for which it is criticised.’ Nevertheless this ‘coal cinder’, as
A brass foundry in Thuringia belonging to the Nuremberg family of Pfinzing. In 1588 the fuel used was charcoal. The logs can be seen stacked in enormous piles.

the same eighteenth-century economist called it, only achieved its first metallurgical success around 1780. We will have to return to this apparently incomprehensible delay.\textsuperscript{119} It is a good example of social inertia in the face of anything new.

The case of China is even more conclusive in this respect. We have indicated that coal played a part in domestic heating there, possibly several millennia before Christ, and in iron metallurgy from the fifth century BC. In fact the firing of coal made the production and utilization of cast iron possible very early on. This tremendous precocity did not lead to the systematic utilization of coke during the extraordinary Chinese advance in the thirteenth century, although it was probably known then.\textsuperscript{120} Probably, not certainly. Otherwise, what an argument for our thesis: China, vigorous as it was in the thirteenth century, might have had the means to make the crucial breakthrough of the industrial revolution, and failed to do so! The achievement was left to England at the end of the eighteenth century - and England itself had taken some time to utilize what was
under its nose. Technology is only an instrument and man does not always know how to use it.

Concluding remarks

Let us return to Europe at the end of the eighteenth century to formulate two connected remarks: the first on the subject of energy resources as a whole, the second on the machinery available.

1. We can accurately classify available sources of energy in descending order of importance: first, animal traction; 14 million horses, 24 million oxen, each animal representing a quarter horse-power – that is roughly 10 million horse-power; next, wood, possibly equivalent to 4 or 5 million horse-power; then water-wheels, between 1.5 million and 3 million horse-power; then manpower (50 million workers), representing 900,000 horse-power; finally, sails, at most 233,000 horse-power, without counting the war fleet. This is obviously a far cry from the present-day energy supply, but that is not the point I wish to make. The interest of this incomplete calculation (in which, it should be pointed out, we have counted neither windmills, nor river boats, nor charcoal, nor even coal) is that it shows incontestably that the two principal sources of energy were draught-animals and wood combustion (windmills, which were not as numerous as watermills, cannot have represented more than a third or a quarter of the power of the water under control). If the mill was not more developed, it was partly for technical reasons (the widespread use of wood rather than metal) but chiefly because in the places where the mills were sited, there was no use for any greater energy supply, and at this time energy could not be transported. Lack of energy was the major handicap of ancien régime economies. The average watermill gave five times the yield of a hand mill operated by two men – and that was itself a revolution; but the first steam-driven mill would do five times the work of a watermill.\(^{121}\)

2. However, a preliminary stage was reached before the industrial revolution. The harnessing of horses, the flames from burning wood, rudimentary engines utilizing wind and river currents, plus an increased number of men at work, all provoked a certain amount of growth in Europe from the fifteenth to the eighteenth century, a slow increase in strength, power and practical understanding. Increasingly active progress in the 1730s and 1740s was built upon this gradual advance. There was thus an often imperceptible or unrecognized industrial pre-revolution in an accumulation of discoveries and technical advances, some of them spectacular, others almost invisible: various types of gear-wheels, jacks, articulated transmission belts, the ‘ingenious system of reciprocating movement’, the fly-wheel that regularized any momentum, rolling mills, more and more complicated machinery for the mines. And there were so many other innovations: looms for knitting and manufacturing ribbons, chemical processes. ‘It was during the second half of the eighteenth century that the first attempts
were made to adapt lathes, borers and drilling machines [tools which had long been known] to industrial use.’ It was the mechanization of weaving and spinning processes at the same time that launched the English economy. Nevertheless what was lacking before these imagined or realized machines could be fully employed was a surplus of easily mobilized – and that means easily transportable – energy. But the machinery existed and was constantly being perfected. It is revealing to see how European travellers unfailingly comment on the contrast between the primitive machinery in use in India and China, and the quality and refinement of its products. ‘One is amazed at the simplicity of the instruments used to make the finest silks in China,’ writes one visitor, and his words are echoed in almost identical terms by another writing about the famous cotton muslins of India.

With the coming of steam, the pace of the West increased as if by magic. But the magic can be explained: it had been prepared and made possible in advance. To paraphrase a historian (Pierre Léon), first came evolution (a slow rise) and then revolution (an acceleration): two connected movements.