The process of genesis of the industrial system itself is extraordinarily complex and to date barely understood. Ever since observers in the 19th century became aware that they faced a novel phenomenon, many attempts to explain it have been presented. Today many contemporaries, even in the fields of history and economics, consider industrialisation as so natural that they see no need for explanation and are satisfied with empty formulae like 'modernisation' or 'economic development'. However, there are also remarkable approaches that take the problem seriously. (Baechler, Hall and Mann 1988; Hall 1985; Jones 1987; Landes 1998; Wrigley 1988).

In the first approach a series of elements can be cited that are inherent in the agrarian system, of which the specific convergence in Europe led to the birth of a new era in industrial transformation. These may be of varying importance and they may be weighted differently in each agrarian civilisation. They can be listed as follows:

- Creation of social cohesion through a web of relationships, at the centre of which lies the market and the production of goods.
- Institutional preconditions, in the sense that the agencies of political power are understood as service organs of society.
- Universality of private property, i.e. even soil and labour are for sale and traded on the market.
- Emancipation of (scientific) thought from institutional embeddedness, i.e. rupture of the stabilising power of tradition.
- Emancipation of nature-altering actions from social and political restrictions which enables increasing pragmatic subjugation and mastery of nature.
- Emancipation of economic action from cultural restrictions, i.e. establishment of the principle of profit maximisation as the driving motive of individuals and simultaneously as the imperative of the system.
- Rapid population growth, which requires an extension of the basis of subsistence.
- Political fragmentation, i.e. absence of a political power that would be capable of massively disrupting the autonomous economic processes.
- Cultural diversity and plurality in Europe, i.e. great and growing room for politically and institutionally independent communication.
- As a limiting condition: occurrence of easily accessible and easily transported fossil energy.

It is apparent that some of these factors were present in other historical and geographic situations, too, which leads to all sorts of speculation about an Industrial Revolution of the Middle Ages (Gimpel 1980) or the economic primacy of Asia (Frank 1998). Instead, one suspects that it was a specific, highly improbable and, therefore, unique convergence and combination of numerous factors that provided the impetus to industrial transformation in Europe.

No attempt will be made here to provide a comprehensive explanation, particularly since one must assume that the origin of the transformation process lay in a contingent constellation of individual factors that mutually supported each other and cannot be reduced to the prominence of a single factor. It is the goal of this study merely to draw attention to a set of components that have not been properly appreciated so far: natural and ecological foundations and, in particular, the energy system.

7. The Industrial System and Fossil Energy

European societies of the 18th century were still contained within the general pattern of agrarian civilisation, even though they had exploited the potential of the controlled solar energy system in exemplary fashion. Numerous elements of the technical, cultural, scientific and economic state of Europe in the 18th century had parallels in other agrarian civilisations, especially China and Japan. However, in Europe these phenomena stood in a particular combination, which resulted in such a unique dynamic that – seen retrospectively – they would virtually of necessity transcend the agrarian pattern during industrialisation. In this book it will be demonstrated that the occurrence and accessibility of fossil fuels were a limiting condition in this transformation process. Without coal, European societies of the 18th and 19th centuries would have remained agrarian societies, even if they had utilised the innovation potential fundamentally embodied in agrarian societies to a much greater extent.

This emphasis on ecological and economic conditions should not be understood as naturalistic reductionism. From an ecological and natural perspective, to achieve a specific economic effect two different elements are required:

i. A resource, a material or an energy carrier;

ii. A procedure for its utilisation in the widest sense, that is a technical instrument, a social need, a cultural acceptance, an economic structure or a political and institutional framework.

The difference appears trivial but it is necessary to be aware of its consequences in a historical context. Only the coincidence of resource and procedure creates an effect, and for this it is necessary that both elements are present. The mere existence of a resource, such as coal or oil, is inconsequential if it cannot be used. The existence of a demand or a procedure is also useless if the resource is lacking, for example, if it is exhausted. This particularly applies to agricultural societies in which numerous resources (and energy forms as well) have a qualitative character, i.e. they cannot be transformed into one another. The assumption that is valid in today's economy, that everything can be substituted for everything else, simply does not apply in the agrarian context.

For an explanation of the industrial transformation process a general differentiation between favouring and limiting factors is meaningful. A favouring factor takes an active part in structuring a field of events, and therefore has under all circumstances a modifying influence on overall structure. By contrast, the availability of fossil fuels like coal is a limiting condition within this web of factors, since the new industrial mode of production could not have developed without this component. On the other hand, the mere isolated existence of this factor obviously does not unfold the slightest dynamic in a different historical context. Coal existed before humans. It existed at the time of the Palaeolithic hunter-gatherer cultures and in the subsequent age of peasant societies. In numerous agrarian civilisations fossil fuels can be found and are even used sporadically, as in China, Mesopotamia and the Roman empire, but without triggering a revolution of the energy system. It was only in Europe during the modern period when a unique dynamic was constructed that coal suddenly gained its strategic importance. Only then did access to this resource hold the promise of overcoming the energy bottleneck of the agrarian solar energy system.

In the course of the Industrial Revolution all essential facets of life were affected and revolutionised, and this also applies to the energy system. For the first time in history, human beings switched systematically on a large scale to energy carriers that are not permanently renewed on the same scale. The energy basis and precondition for the Industrial Revolution was the use of fossil fuels. They, too, are the product of photosynthetic binding of solar energy – they were created during a period of the earth's history when more plant biomass was formed than was oxidised and lost in respiration. However, during the period when they are being consumed no fossilisation of plant substances worth mentioning is taking place. In contrast to the regenerating biomass, to wind and water energy, fossil fuels are a one-time-only bank of stored energy. In a historical timescale, these stocks cannot be reproduced. Currently about 10 billion tons of fossil fuels are consumed annually on a global basis. However, that is an amount that was stored in 500,000 years. Therefore, it can be said using an economic metaphor that the industrial system consumes not the energy income of the Earth but its accumulated wealth.

However, this wealth is quite large. There has been speculation for some time about how long the fossil energy age may last. The difficulty of this calculation lies in the fact that 'fossil fuels' are by no means homogeneous. It is not the consumption of a defined stock, as if capital of a given size is consumed – there are also qualitative problems. The carbon reserves of the earth's crust are huge but much of it is only available in low concentrations, contaminated with minerals and chemicals or difficult to access. The historical course can be imagined as follows: first easily accessible and high quality stocks are exploited and then gradually the remainder is used. This transition should be associated with rising 'costs' or increased investment of energy within a given technology. If one assumes that 'technical progress' in the sense of cost-neutral improvements of efficiency will take place, then this tendency is counteracted. However, future technological progress cannot be prognosticated and nobody knows future consumption figures, which will be influenced positively by increases in production and negatively by increases in productivity.

Precisely because of these qualitative aspects, an abrupt collapse of the fossil energy system can be ruled out. It can be assumed that costs will rise in the long term but this will place a premium on processes of adaptation: energy conservation, improved prospecting, and substitution. All this may mean that energy will become scarcer and more expensive so that behaviour that is associated with low energy usage will be rewarded. Overall, it will involve a continuous process of adaptation within which there will be crises but no dramatic end. Ecological problems in the narrow sense will probably result from the emission side rather than the resource side.

At the end of the 20th century, global coal reserves (the known stocks that can be mined with available technology) were estimated at more than 10^{12} t. The current use of coal lies at 4×10^9 tons annually. The reserves will last another 250 years at constant usage. If one looks at coal resources (the estimated total stock), which lie around 10^{13} t, the time frame is extended tenfold. Nobody knows what part of these resources can be mined at reasonable cost and it is also unknown how coal consumption will develop in the future.

Today the annual consumption of oil and gas is about double that of coal, while oil and gas reserves amount to only 5% of coal reserves. For this reason alone it may be expected that coal consumption will rise in the 21st century. Furthermore, it should be considered that the per capita level of energy use in the USA is about eight times the average level of the global population. If the desired 'development' of the Third World should come about, this would surely be linked to rising energy use, even if in the future increased efficiency in the sense of 'energy saving' may be anticipated. The fossil energy age will probably still have a duration of several centuries.

If the use of fossil fuels is represented graphically over long periods of time, the image of a spike on the time axis appears (Thirring 1958, 218; see also Cipolla 1962, 59). Up to the beginning of the Industrial Revolution consumption was virtually zero, a short, steep increase to a maximum occurred, which will then probably be followed by a somewhat flatter ascent and consumption will tend towards zero again over the next millennium. From a very long-term world history perspective the image of a short, at most thousand-year fossil fuel interlude emerges.

From this it becomes obvious at a glance why the Industrial Revolution is associated with a colossal acceleration of material consumption in the sense of 'economic growth'. Suddenly and very quickly much more energy became available than could have been provided by the agrarian solar energy system. Global consumption of fossil fuels has grown by a thousand fold since the beginning of the 19th century, which amounts to an annual growth rate of approximately 3.5%. Industrialisation depends in terms of energy on two closely linked processes: enormous reserves became available and their exploitation grew exponentially.

Humanity suddenly had fuel at its disposal on a scale that far exceeded what was available in regenerating biomass. This is unique in historical terms if not in the entire history of the earth. An agrarian society in a pioneer phase settling previously unused space could enter a similar situation of energy superabundance. Primeval forest in North America, for example, contained biomass formed over a period of 300 years. If this forest is clear cut, settlers can dispose over a yield that is three hundred fold the sustainable amount for this area. However, they are only able to cut down the primeval forest once, after which they are forced to turn to sustainable methods or move on. It is similar with agriculture. Short-term practices are conceivable that permit producing more plant nutrition than the soil will permanently yield, but the actual carrying capacity of the land will eventually come to bear with definite yield reductions.

The use of fossil fuels by industrial society is an expression of this kind of pioneer phase, but with the difference that it may last several centuries. This is rather long in biographical and historical dimensions. However, from a world history perspective it is not. Fundamentally no social structure can be built on the basis of a consumption of fossil fuels that could have a similar duration to agrarian society, or even to the agrarian civilisations that after all reached an age of 5,000 years. Industrial society, which relies on fossil energy, is ultimately only a transitional society: sooner or later a shift to the utilisation of other sources of energy will be necessary. This could be nuclear energy, which can use almost inexhaustible reserves of uranium in advanced fast-breeder technologies, with the possibility of a fusion reactor that would solve all energy problems. The other alternative would be a restriction to the use of solar energy again, which is

possible today with a completely different degree of efficiency than under the conditions of the agrarian mode of production. There is no doubt that far more people could be better fed with an industrial solar energy system than was the case with the agrarian solar energy system. But if we consider that about 750 million people lived in the world around 1750, and that there will be more than tenfold that number by the middle of the new century, there is understandable concern, in the face of expected environmental difficulties and threatening raw material scarcity, whether in terms of pure solar energy that number will ever be able to participate in the flow of material and energy to the extent customary today for the inhabitants of the core regions of the industrial system. However, it is not the task of this historical study to deal in detail with these difficult technical and economic problems.

An important characteristic of the fossil energy system was and is energy superabundance. Many characteristics of hunter-gatherer and agrarian societies are attributable to energy being in short supply and the need to be very economical with it. This was already a principle of organic evolution. The enormous abundance of energy in the industrial system led to the formation of behaviour that appears absurd from an energy point of view. While settlement structures and forms of space utilisation in solar energy societies were arranged according to the principle of a minimisation of transport, transport became almost free once the mineral oil economy prevailed. In the expansion of traffic systems, energy consumption plays virtually no further role. Transport infrastructures take a disproportionately large share in the formation of towns and regions with accessibility and speed at centre stage. Any attempt to establish a technically improved solar energy system faces the enormous problem that the result of energy superabundance has literally been poured in concrete in the meantime.

Another example of such an inversion is agriculture. As we have seen, the Neolithic revolution ushered in decisive technical improvements on the Pleistocene solar energy system. Preindustrial agriculture was a system designed to transform solar energy into forms that were useful to humanity. With the introduction of fossil energy the character of agriculture has fundamentally changed. Agriculture is no longer a part of the energy system, but only serves the material metabolism: it transforms carbon dioxide, water and minerals into nutrition for plants and animals, but requires an external source of energy. It stands to reason that this is only possible as long as fossil fuels are available.

The Industrial Revolution is a singular phenomenon in world history because of the nature of its energy base. The traditional agricultural system is not the ecological idyll it sometimes appears to be. Agriculture is fundamentally precarious in ecological terms because of its relatively short-term intervention into highly complex natural systems. Compared to the ten thousand year duration of the agrarian regime, the industrial system appears to some observers as a one time, short fling in which a treasure gathered over many millions of years is being squandered in a few centuries. This applies not only to fossil fuels but also to the concentrated occurrences of minerals that are exploited and diffused with its help, and to ecosystems and species that fall by the wayside. Perhaps a horrible hangover will follow this fling.

The temporally limited character of the fossil energy system may cast a shadow on the expectation of boundless material progress which has been built up in the course of its expansion into large parts of the world. However, this dark perspective is largely irrelevant in an explanation of the transformational dynamic that has held the preindustrial world in its grasp for the last two hundred years. Human beings do not live in an anticipated future but in the real present. Futuristic forecasts that cover long periods of time are therefore seen, by and large, to be of very little relevance. It is only possible to work with reserves if they are comprehensible, that is if they are relatively small. Within the agrarian system it was possible to make do in a 'sustainable' manner with available resources because their volume was transparent and overuse was readily noticeable. The enormous amounts of fossil fuel that suddenly became available burst the bounds of expectation. There is no human intuition for the use of such huge quantities – it comes more easily to consider them infinitely large.

To understand the processes that were and still are made possible by the energy transformation, the future dimension that has at bottom only prognostic but no empirical value may be ignored. Humans have experienced the growth phase that was fed by the new energy system as a permanent, almost natural process, more or less a matter of course . Often this is still so today. The energy transformation carried large areas of economic and mental reality along with it. Explosive change, growth and transformation have become the signature of the age. My purpose here is to understand better the historical origin of this process.

II

Forest and Wood in Preindustrial Germany

1. Natural Foundations

For any stage after the mastery of fire, it is meaningful to distinguish between energy flows that are mediated by the human metabolism and those forms of energy use that take place outside biological metabolism. In hunter-gatherer societies these different functions are not permanently assigned to a specific part of the habitat: hunting, collecting fruit and gathering fuel occur in principle in one and the same area; picking wild fruits is no different from collecting dry wood for the hearth.

By contrast, agrarian societies undertake a functional division of their economic territory. In central Europe it is generally tripartite: it consists of arable, pasture and forest, which are in turn associated with metabolic, mechanical and thermal energy respectively. This functional division becomes necessary when the occurrence of any of these is not enough to permit the simple appropriation of natural goods necessary for subsistence, and human beings must take care not to exhaust the productive capacity of nature. The transition from mere gathering to a reproductive economy is fluid. It does not occur evenly and simultaneously in all areas at once. Types of gathering or a pure 'harvest economy', in which the soil is not cultivated but care must be taken that fruit-bearing plants are not damaged and that natural seeding can take place, occurred for a considerable time next to intensive agriculture, which subjects the entire vegetative cycle from seeding to harvest to human control or 'colonisation'. However, the historical tendency was to draw ever more areas into the reproductive cycle. The forest finally became the last component of the agricultural biotope to be used 'sustainably' and managed actively.

After the last Ice Age, central and western Europe was not forested, but a steppe. In the post-glacial period, which began about 12,000 years ago, the forests advanced into the steppe. Climatically it was probably a little colder than today, so that hardy birch and pine were the pioneer plants. About 8,000 years ago average temperatures were about 2–3 °C higher than today; and 7,000 years ago, when the first Neolithic farmers arrived in central Europe, the land was