Bernard Durand

PETROLEUM, NATURAL GAS AND COAL

Nature, formation mechanisms, future prospects in the energy transition

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Contents

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Preface

We love fossil fuels. We really do. Otherwise, would we spend between 300 and 700 billion dollars each year to find new oil and gas fields, and enhance the capacity to extract what they contain? Would we protest loudly each time the government considers to raise taxes on gasoline or domestic fuel oil? Would countries have sent armies to conquer or protect coal mines, then oilfields, a number of times in the course of recent history? Would Hitler have invaded Russia if it were not for the Caucasian oil fields, and would Japan have bombed Pearl Harbor if it were not to get rid of the US marine and secure a naval route to the Indonesian oil fields?

Actually, we love fossil fuels so much that it is acceptable to say that we are addicted to them. We can plea to have good reasons to do so, though: their use gave us all the pleasures we could dream of. Through fossil fuels, we have acquired the freedom to move fast, on the Earth, on the sea or in the air. We got heat in the winter and cool air in the summer. We got electricity (70% of the world production comes from coal, gas and oil), which in turn gave us all the domestic comfort, and the plants that manufacture all that we can find in a store.

Fossil fuels also tremendously increased our food production, through the N-fertilizers made from gas, and the agricultural machinery running on oil. Do you know that when you eat a kilogram of beef, you kind of eat a kilogram of fossil fuels, that were used to grow the cereals eaten by the cattle?

They gave us organic chemistry then plastics, steel and cement, and thus all the buildings that have appeared in the 20th century, but also clothes (all synthetic fibers are oil and gas derivatives), shoes, windows and toys, coffee machines and carpets, beds and fridges, TV screens and chairs, skis and shampoo, forks and planes, coffee cups and dishwashers, and of course smartphones and modern communications.

They have also made possible to install everywhere water distribution systems and sewage, that, together with the increase of food security, have played a major role - far greater than curative medicine - in tripling our life expectancy between 1800 and 2000.

Actually, fossil fuels gave us everything we see in the modern world. Suppress them, and we lose computers thus money, transportation thus food – and all the other goods – in the cities, and the productivity of work, that is merely empowering each of us with machinery that multiplies our mechanical power by hundreds or thousands.

The list is not finished: because they allowed a tremendous increase in the productivity of work, fossil fuels also gave us long studies, vacations and retirement, they enabled to put 80% of the population in cities (because we do not need so many people in the fields, where they have been replaced by tractors, pesticides and fertilizers), and they have allowed globalization – because of boats, trucks and planes – and modern financial markets (that require computers and electricity).

And all this, nature has given it to us for free. What, fossil fuels would be free? Indeed, they are. Just as no one has ever paid a single cent for wind to exist, no one has ever paid a single cent for oil – or gas, or coal – to exist. This precious resource has been formed by Mother Nature without the help of any human, with remnants of ancient life, for hundreds of millions of years. Actually, when the process of oil formation began, there were not that many humans around to give a helping hand!

The price of oil, today, is only money paid by some humans to other humans: those that have worked to extract it from the environment, those that have been lucky enough to sit on the oilfield, and all those that transport it or trade it. But not a single cent ever went to Nature, that manufactured it.

And it is precisely because it is so much easier to extract energy from the environment – and store it, and transport it, and use it whenever you want – when it is coal, oil or gas than when it is wood, wind or the run of water that humanity has moved from a 100% renewable civilization to the present state. It made energy much more available, both in the physical and in the economic sense.

We have not become addicted to fossil fuels just because we are total idiots. We have done so because these energies can be used whenever we want and not just when the sun shines or the wind blows, or just where there are forest and mountains (for water mills then hydroelectricity). They have enabled to use energy elsewhere than where it is harnessed. Wood can be stored but not easily moved around and try to store running water or wind!

So, if these fuels have made easy for all, what is the point of bothering about the future? Every coin has two faces, and these energies have alas two disadvantages: they are subject to depletion, and they cause climate change. Depletion is easy to understand for a non-renewable resource. It's the application of "you cannot eat your cake and have it". Once you have extracted and burnt a resource that takes several ten million to several hundred million years to renew, you have less.

Mathematics allows to demonstrate that when you draw from a stock that has been given once and for all, all you can get is a yearly production that starts at zero (which has been the case in the remote past), will eventually fall to zero, and go through an absolute maximum in between, named the peak. This is not limited to oil or gas, though: it is valid for any metal ore, or phosphates, or potash. The only question, so to say, is when the peak might occur (and should we trigger it for environmental reasons or wait for it to happen for other reasons), at what level, and with what consequences. The oil production of the North Sea peaked in 2000, and the world production of conventional oil (everything except tar sands and shale oil) peaked in 2006, so this is no virtual process!

And once you have burnt a fossil fuel, mostly made of carbon because it's ancient life, you have created carbon dioxide, because combustion is a particular form of oxidation. And, because any oxide is a stable molecule, carbon dioxide cannot be removed fast from the atmosphere, and accumulates in the air, trapping more infrared close to the ground and causing global warming. This process has been identified almost two centuries ago by Joseph Fourier, it's solid science!

What is also solid science being that, when it went from the last ice age to today, the planet warmed by only 5 degrees (Celsius). So, a global warming of a couple degrees in a century is likely to trigger war everywhere, because our sedentary species will be unable to adapt to such a rapid and massive change in the conditions that have prevailed for millennia and framed the civilizations everywhere.

So, what is at the heart of our modern world is at the root of a Faustian pact: with oil and its friends, we can have the land of plenty today, but once we are totally dependent on it, at some point we will have less, and on top of that we'll pay a high price in terms of global environmental issues.

Bernard Durand has not the ambition to suggest an easy way out in this situation. But he has one, for sure!

From the beginning of this foreword, I have used the words oil, gas, coal, and "fossil fuels" without defining them. Easy, you will think? Well… Did you know that part of what is counted with oil comes from gas fields, and vice versa? That nobody knows exactly how much oil we can extract from the ground, because there is no centralized information on the topic?

That oil production is counted in barrels, which is a unit of volume, and not in kWh or joules, so that nobody knows exactly what is the energy content of what is extracted? That the proven reserves of the Middle East countries were worth 360 billion barrels in 1980, and 810 at end 2016, with 280 billion barrels extracted – or "produced" – in between, and no major discoveries in that time interval?

So, before trying to answer the questions "how long can we extract enough fossil fuels from the earth's crust to sustain our present way of life, and "how can we do with less", because we will have to do so one day, Bernard just wants to enable the reader to understand what we are talking about: What are fossil fuels exactly, and what are they made of? How were they formed in the Earth crust? How do oil and gas companies know that there are hydrocarbons under the ground somewhere? Is there a common way to define reserves, production, and consumption, or everyone has his own way to provide a figure? When the issue is crucial, how do we know what we know, or why can't we know what we would like to know? My dear reader friend, do not imagine a single second that you can avoid to go through the pain of learning, because the mighty people "know all this, and take it into account when framing their decisions". I have discussed with 5 or 6 governments in France since 2003, and dozens of members of parliament in my country. Trust me: when it comes to technical topics – and energy is a lot of technique – they know nothing more than the ordinary citizen.

So, Bernard has a tremendous ambition: he is still dreaming that, if he has enough readers, it might enhance the knowledge of enough voters and enough decision makers to change a little something to the future. My dear reader friend, I hope you will enjoy understanding better what are those fossil fuels that have made possible all your present living conditions, and I wish the best success to Bernard and to this book.

Jean-Marc Jancovici

Foreword

"As long as the weather is fine, the man does not predict the storm"
Niccolo Machiavelli

For more than a century now, carbonaceous fossil fuels (petroleum, gas and coal) have provided the bulk of the flow of energy that gives life to industrial societies.

In these societies, therefore, a strong link existed between the increase in their consumption of fossil fuels and their material and human development. But, perhaps by virtue of the adage "don't look a gift horse in the mouth", their public opinions and most of their decision-makers did not have a clear conscience of this link, and still do not seem to really perceive it. Even now, carbonaceous fossil fuels are the forgotten ones of the debate on the energy, which invades the public sphere and the media. Indeed, this debate mainly deals with electricity, renewable against nuclear energy.

This period of recklessness will not last very long: Questions of the professional circles on the future availability of carbonaceous fossil fuels are beginning to reach the opinion. The latter also seems to better realize their importance, that of oil in particular, in everyday life. It is also more and more concerned about the climate change caused by the greenhouse gas emissions resulting from their use.

Undoubtedly, the industrial countries will be, are already, facing a major and even existential problem: that of the passage of human societies based on the massive use of fossil fuels to societies that have learned to do without. This will be, by necessity, the real engine of the energy transition that we are talking about so much now! For it is the future availability of fossil fuels that will give the tempo of this transition, not the development of other sources of energy, so difficult is the way they still have to do to replace fossil fuels!

Only a few technical developments on the methods used by industry to find, extract and process fossil fuels can be found in this book. There will also be no detailed statistics of their production and consumption, nor a treatise on economics. Its objective is to provide non-specialists, first and foremost those preoccupied, or concerned in their activity, by energy transition and climate protection, with basic knowledge enabling them to better understand the nature of fossil fuels, their importance in the economies of the industrialized countries, and why their future availability will play an essential role in the future economic and social transformations in these countries.

It comprises two parts, which can be read widely independently of one another:

- The first part has a pedagogical purpose: in a few pages and avoiding too technical developments, it is a question of presenting an inventory of the variety of fossil fuels and of understanding the physicochemical principles that govern their formation and that of their deposits in the earth's crust.
- The second part is more speculative: on as quantitative bases as possible, we discuss major current issues: What are the remaining reserves of fossil fuels? When precisely during this century can we foresee the decline of their productions? What consequences will this decline have for industrial societies? What is and will be their role in climate change? What risks does their use entail for public health?

On the road is specified what are categories of fossil fuels such as oil and gas known as shale oil and shale gas, oil shales and tar sands, lignite and coal, conventional and unconventional oil and gas... which are too often the subject of passionate debates without that their exact nature is well understood.

I would like to thank most warmly for the help they have given me in the writing of this book, by providing me with essential documents or attentive criticism: Pierre Alba, Denis Babusiaux, Pierre-René Bauquis, Art Berman, Dorothy Bjorøy, François-Marie Bréon, Patrick Brocorens, Xavier Chavanne, Hubert Flocard, Marcel Descamps, David Fridley, Jean-Marc Jancovici, Jean Laherrère, Claude Laffont, Michel Lepetit, Jean-Marie Martin-Amouroux, Luis Martinez, Euan Mearns, Nicolas Meilhan, Matt Mushalik, Christian Ngô, Hervé Nifenecker, Christian Ravenne, Olivier Rech, Alexandre Rojey, David Rutledge, Jacques Treiner and Roland Vially. Without them, this work would have been impossible.

I am specially indebted to Jean Laherrère, whose outstanding work on the subject was a source of inspiration, and who also provided me with invaluable graphs and data.

But of course, the interpretations and conclusions of this book are of my own.

Introduction The importance of fossil fuels for industrial societies

Living organisms cannot exist and develop without the energy provided by their food. Similarly, human societies cannot exist and develop without the energy they take from natural sources, which is called primary energy.

The quantity of primary energy, which these societies require, is closely connected with the nature and quantity of the material objects, which they produce. In fact, these material objects can be produced only by transforming raw materials, and no transformation of matter is possible without energy.

More than 80% of the world's primary energy currently comes from fossil fuels. That is to say the dependence on these of human societies, and especially the industrial societies, which are the most consuming of them!

Global consumption of fossil fuels has grown dramatically since the mid-19th century: per capita of the planet, it was then multiplied by about 30 (Figure 1). But in the meantime, the world's population has been multiplied by just over 6. The world's consumption of fossil fuels has thus been multiplied by about 200!

This growth took place in three successive waves: first coal, then oil, and then natural gas.

It is observed on Figure 1 that as a whole, periods of exponential growth of primary energy per capita alternate with periods of moderate growth. Moreover, since 2013

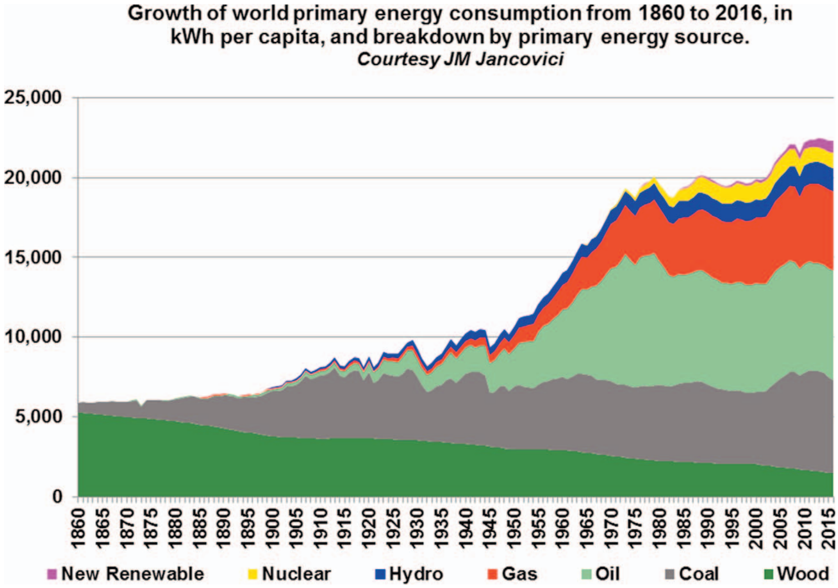

Figure 1 *Evolution of world consumption of different sources of primary energy from 1860 to 2016, in kWh per capita. Fossil fuels, oil, coal and natural gas, by order of decreasing importance, account globally for just over 80% of this consumption in 2016. "New Renewable" refers to so-called renewable energies, other than firewood and hydroelectricity. The kilowatt hour (kWh) is an energy unit worth 3.6 million joules (MJ). It is customary to use it to measure quantities of electrical energy, but nothing prevents it from being used for other energies. The joule (J) is the energy unit of the International System of Units (SI), but it is a very small unit: to raise the temperature of one liter of water from 0 °C to 100 °C, approximately 418,500 joules (418,5 kJ) of heat are required. More figuratively, it takes a mechanical energy of 1 joule to raise by one meter a small apple (with a mass of 101.94 grams).*

the total primary energy per capita is declining, this being mostly due to a decline of coal consumption in China.

The most consuming countries are of course the industrialized countries, of which China is now a part. The proportions of the different fossil fuels used vary widely from country to country (Figure 2), between 50 and 100% of their primary energy consumption, excluding firewood.

Of all these major consuming countries, France, with roughly 50% of its primary energy consumption, excluding firewood, uses the least fossil fuels in its energy mix[1]. This is due to the importance of its nuclear power production. Saudi Arabia uses them most, 100%.

[1] The energy mix of a country is the set of energy sources it uses, detailed by percentage of each source in total consumption.

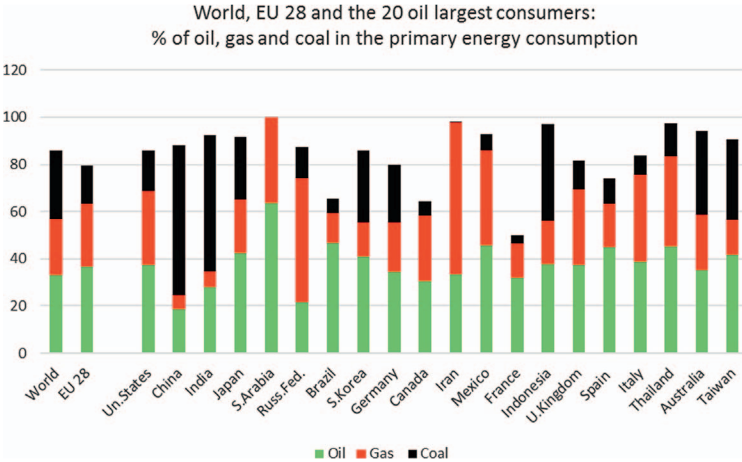

Figure 2 *Proportions of fossil fuels in percentage of the primary energy consumption of the world, of EU 28 and of the 20 most oil-consuming countries, ranked from left to right by decreasing importance of their oil consumption. These data come from the British Petroleum Statistical Review 2016, which does not take into account traditional biomass (firewood...). Taking this into account would reduce the world average share from 86% to about 81%, the most frequently cited value, but would not change much for the highly industrialized countries, which are relatively non-wood consumers.*

Still excluding firewood, the world average was 86% in 2015. For the United States, the proportion was also 86%, for China 88.2% and for India 92.5%. For the EU28, despite its efforts to develop recourse to other sources, it was still 80%, and for Germany, although champion of renewable energies, also 80%.

Now, there is a strong correlation between growth in primary energy consumption and economic growth (Figure 3). Fossil fuels, which provide the bulk of primary energy in all industrialized countries, have been and continue to be the main engines of their economic development.

This growth in the per capita primary energy supply of the planet has brought about tremendous changes in the organization and lifestyles of human societies, first of all in the countries which gave birth to the Industrial Revolution, initially fuelled by coal, because of the considerable increase in labor productivity thus permitted. This has led to major social advances (material abundance, health, education, hours of work, reduction of social inequalities, etc.), as well as serious conflicts and human tragedies, and great inequalities in the development of Countries according to their unequal access to fossil energy.

This growth has also been accompanied by a sharp increase in the world population, driven by medical advances and increased agricultural yields, firstly in industrialized countries, then in many of those which are not or not yet. Most of the men currently living are somehow the children of fossil carbon energies.

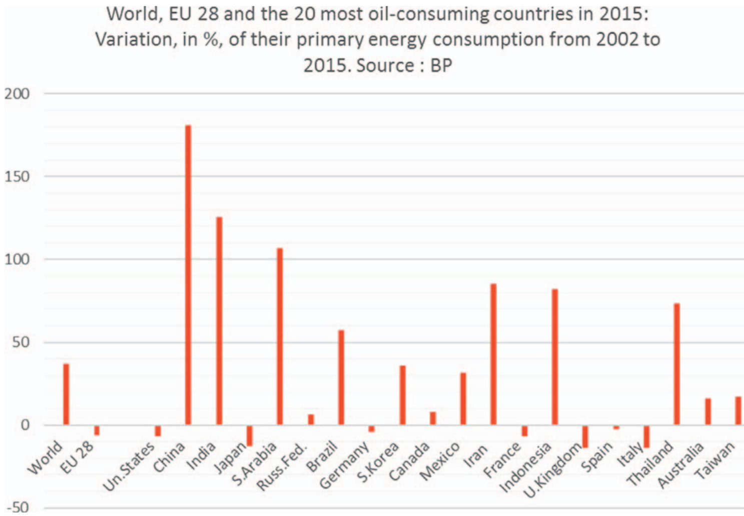

Figure 3 *Change in the primary energy consumption of the 20 most oil consuming countries during the period 2002–2015, ranked from left to right by decreasing importance of their oil consumption. The countries with strong economic growth are those whose primary energy consumption has increased significantly, with the most spectacular growth being China. In negative values are those who have experienced a decrease in this consumption: they are also those who have experienced a decline or a stagnation of their economy during this period. Source: British Petroleum Statistical Review 2016.*

But the global consumption of fossil carbon energy has now become such that its growth seems very difficult to maintain during this century, first for oil and natural gas: when looking at Figure 1, it should be noted that after a nearly exponential increase, the rate of consumption has a tendency to decrease with time. Greenhouse gas emissions and the nuisance caused by their use are also of concern to those who care about climate and public health.

An energy transition, the transformation of human societies that have based their development essentially on fossil fuels into societies capable of doing without them, is therefore inevitable. However, other known primary energy sources, nuclear energy and "renewable energies" are currently only marginally replacing them on a global scale. Without doubt, therefore, the future availability of fossil fuels will give the tempo of this transition. Yet, very surprisingly, they have barely been mentioned in the debates on the Energy Transition in France.

It would seem, therefore, that in France and probably in other industrialized countries too, economists, politicians, media and even teachers and non-specialist scientists, influencing public opinion, have not yet taken the real measure of the situation.

Obviously, in order to understand the problems involved, a good knowledge of what fossil fuels are really about and their future production possibilities is necessary. The purpose of this book is to provide the reader with the basics of such knowledge.

Its first part consists of a description of the variety of fossil fuels, of the principles of their formation, and of the physical mechanisms of the formation of their deposits, i.e. their economically exploitable accumulations. This description, although not very technical, may seem austere to a non-scientific reader. Its reading is nevertheless useful for those who want to acquire the basic vocabulary and an overall vision. In its second part, quantitative benchmarks are given, particularly on their remaining reserves and production forecasts over the course of this century, and then the relationship between fossil fuel consumption and climate and the risks of their use for human health.

Explanations of categories of fossil fuels, such as conventional and unconventional petroleum and gas, shale oil and shale gas, oil (bituminous) shales and tar sands, or lignite, the exact nature of which often does not seem to be well understood, are also given.

The accumulations of fossil fuels, despite their wide variety, all originate from the incorporation into some sediments of significant amounts of biologic debris and biologic substances, the whole of which constitutes the so-called kerogen. These debris and substances are the remains of organisms that have lived in the sedimentation environment or on neighboring land. Kerogen is then transformed during geological times by physicochemical mechanisms linked to the progressive burial of the sediments that contain it, giving birth to fossil fuels and their deposits.

This organic origin was fully recognized for coals as early as the middle of the 19th century, when the debris of plants from which they were mostly formed could be commonly identified under the microscope. On the other hand, it was not until the 1960s for natural oils and gases, because they did not contain a visible marker of their origin, even under a microscope. The methods of investigation had still been insufficient to carry a unanimous conviction. Decisive observations were then made. They have been fully confirmed over the last 50 years by the practice of oil and gas exploration.

A difficulty in understanding the subject is inherent in geological studies: time scales are far superior to those governing human life. The formation of fossil fuel deposits is an incredibly slow phenomenon on a human scale. It takes place in immense natural physicochemical reactors, sedimentary basins.

This very low formation rate makes it impossible to carry out laboratory experiments in order to faithfully reproduce the mechanisms. It was thanks to an intense observation, measurement and modeling work that we could really understand them.

Computer simulation models of the formation of oil and gas deposits in sedimentary basins during geological time have now become commonly used by oil companies to guide exploration. Some go a long way in the details and are of a complexity that has nothing to envy to that of the climate models that currently hold the spotlight. The most powerful computers available on the market have been used since the 1980s to exploit these models.

First part

Nature and variety of fossil fuels, physicochemical principles of their formation and that of their deposits in the earth's crust

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