# The oil-based technology and economy: Prospects for the future

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## Introduction

This paper outlines the technological and economic characteristics of a singular era in the history of the Earth where cheap oil has given affluence to a minority of its population, namely those who have the technology and capital to exploit the oil reserves developed in the second half of the 20th century.

The world economy's technological infrastructures are in all respects based on abundant supplies of cheap, so-called conventional oil.[1] Therefore, for the stability of the world economy it is of decisive importance to avoid an unforeseen gap between demand for and supply of cheap conventional oil. If demand continues to grow, such a gap may occur long before the world's oil resources are used up.

The question is not whether or not the world is running out of oil. The question is for how long an increasing demand for cheap, conventional oil can in practice be met under the actual circumstances regarding the world endowment of oil reserves, the amounts already used, present and future discovery trends, the recovery techniques made available, and the predominant economic and geo-political regimes, which control investment and production policies in the different regions.

As shown by the demand and production scenario displayed in figure 1, it is likely that continued growth in demand and production for another 10-20 years will result in a sudden and steep decline in the supply of cheap, conventional oil.

Demand growth means that the functioning of cities, intercity and international transport, agricultural production and many industries becomes increasingly dependent on oil-based technologies. Thus, the more motorways, parking lots and airports are built, the more oil-powered vehicles and aircraft are fed into the traffic veins, and the more agricultural production world-wide becomes dependent on oil-powered machinery, the quicker we reach the point where most of all these oil-engines suddenly come to their final standstill – without any alternative technologies ready to replace them.

On the other hand, demand reduction before the oil-engines come to a standstill implies that many of these engines are replaced by other technologies even though oil is still in abundant supply at low costs. If the affluent societies within the next decades accomplish a technological transition away from oil-engines, oil will remain in abundant supply at low costs for a long time – to the benefit of poor, developing countries, which need more time for the transition.

Moreover, the mitigation of unfortunate changes in the global climate requires a substantial reduction in fossil fuel consumption. Therefore, although non-conventional oil from tar sands and oil shale is available – at higher prices – in abundant amounts, these resources should only to a limited extent replace conventional oil.

In this situation there are no business-as-usual solutions. Radical technological transformations of our energy supply and demand infrastructures are needed. Apparently, few architects and urban planners have considered the full consequences that this transformation will have for the future development of our cities.

## The cheap oil era

The second half of the 20th century bears no resemblance to any earlier period in the history of the Earth. Never before did its population grow from two to six billion. Never before was it a regular experience for millions of people to watch from above the myriads of motorcars and trucks circulating on motorways around a city when their plane approached the destination of their holiday or business trip. Never before were so many new urban areas, roads, motorways and airports built. Never before did agricultural and industrial production and international trade grow exponentially to the levels of the present economy. And never before did man have the power to exhaust the fish stocks in the seas and to change the climate.

Obviously, this explosive economic growth, which in all respects has changed the world, was based on abundant supplies of cheap fossil fuels: coal, mainly for electric power generation, oil and gas for the heating of buildings, and petrol and diesel for the millions of internal combustion engines in cars, trucks, buses, aeroplanes, tractors, ferries, cargo ships and fishing boats. Had oil not been found in abundant amounts in the 1950s and 1960s, the basic infrastructures of the industrialized societies – the physical structures and transportation networks of the cities, the industrial production networks, the mechanized agricultural production, etc. – would not have been as they are today. Also, the migration of millions of people from rural areas to the megapolises in the Third World was conditioned by oil for the transportation of food and other basic necessities to these huge, overcrowded habitats.

Although there are, naturally, limits to growth on a finite planet, the predominant economic growth theories of this singular historic era are based on the axiom that economic growth will not be constrained by limitations in the supply of the fossil fuel resources upon which the economy is based, in particular the supply of oil. It is recognized that continued growth in the global oil demand will result in accelerated depletion of conventional oil reserves. But economists assume that the market will ensure the smooth transition to non-conventional resources (oil sands and oil shale, conversion of natural gas (gas-to-liquids)) and other chemical energy carriers (natural gas, hydrogen) without major unfortunate consequences either for the affluent or for the poor societies. Thus, in its *World Energy Outlook 1998* the International Energy Agency (IEA) does "not foresee any shortage of liquid fuels before 2020, as reserves of non-conventional oil are ample, should the production of conventional oil turn down."

However, considering the fact that our present economy in all respects depends on the physical power and mobility provided by petrol and diesel engines and that hundreds of millions of people have no immediate alternative to oil for heating their houses, it is hazardous to rely on the validity of an axiom for which there is no empirical evidence. In this singular historic period of transition from growth to decline in conventional oil reserves, the particular geological, economic, demographic and political circumstances which determine the supply of liquid fuels must be scrutinized (fig. 1).

In its *World Energy Outlook 2002* the IEA forecasts an increase in oil demand from 26 billion barrels in 2000 to 44 billion barrels in 2030, of which only 8 percent will be covered by non-conventional oil. This means that the global economy becomes increasingly dependent on continued supplies of cheap, conventional oil – while at the same time the reserves of this cheap, conventional oil are depleted at such a rate that a steep decline in production is likely to occur if not years before, then shortly after 2030. Under these circumstances it is questionable whether liquid fuel production from non-conventional sources can be brought on-stream quickly enough to make up for the decline in conventional oil production.

**The graphs show the results of an oil depletion scenario computation for**

- **a global endowment of conventional reserves of 1900 Gb (Gigabarrels = billion barrels) of which about 900 Gb had been produced by the year 2000 and about 150 Gb are yet to be found,**
- **a production of non-conventional oil and natural gas liquids (NGL) of 475 Gb from 2000 to 2030, and**
- **a demand growth of 1.6 percent per year until 2030.**

**Although the production of conventional oil from existing reserves in most regions is declining, the decline in total production is offset by production from new conventional reserves and increased production of non-conventional oil and NGL.**

**This scenario is possible but catastrophic: The demand is covered until 2020 but then a sudden steep decline in the production occurs. To avoid such a development, demand must be reduced.**

**The results are not very sensitive to changes in the assumptions made. A 20 percent increase in conventional oil reserves postpones the sharp peak by less than five years.**

**Fig. 1:** Oil demand and production, 2000-2075.

Regarding demography, wealth distribution and oil demand, the IEA assumes that a global economy in which the inequalities between the affluent minority and the poor majority are perpetuated can be sustained. Today the 1.1 billion people living in the affluent OECD countries consume 16 billion barrels of oil per year whereas the 4.9 billion living in poorer countries

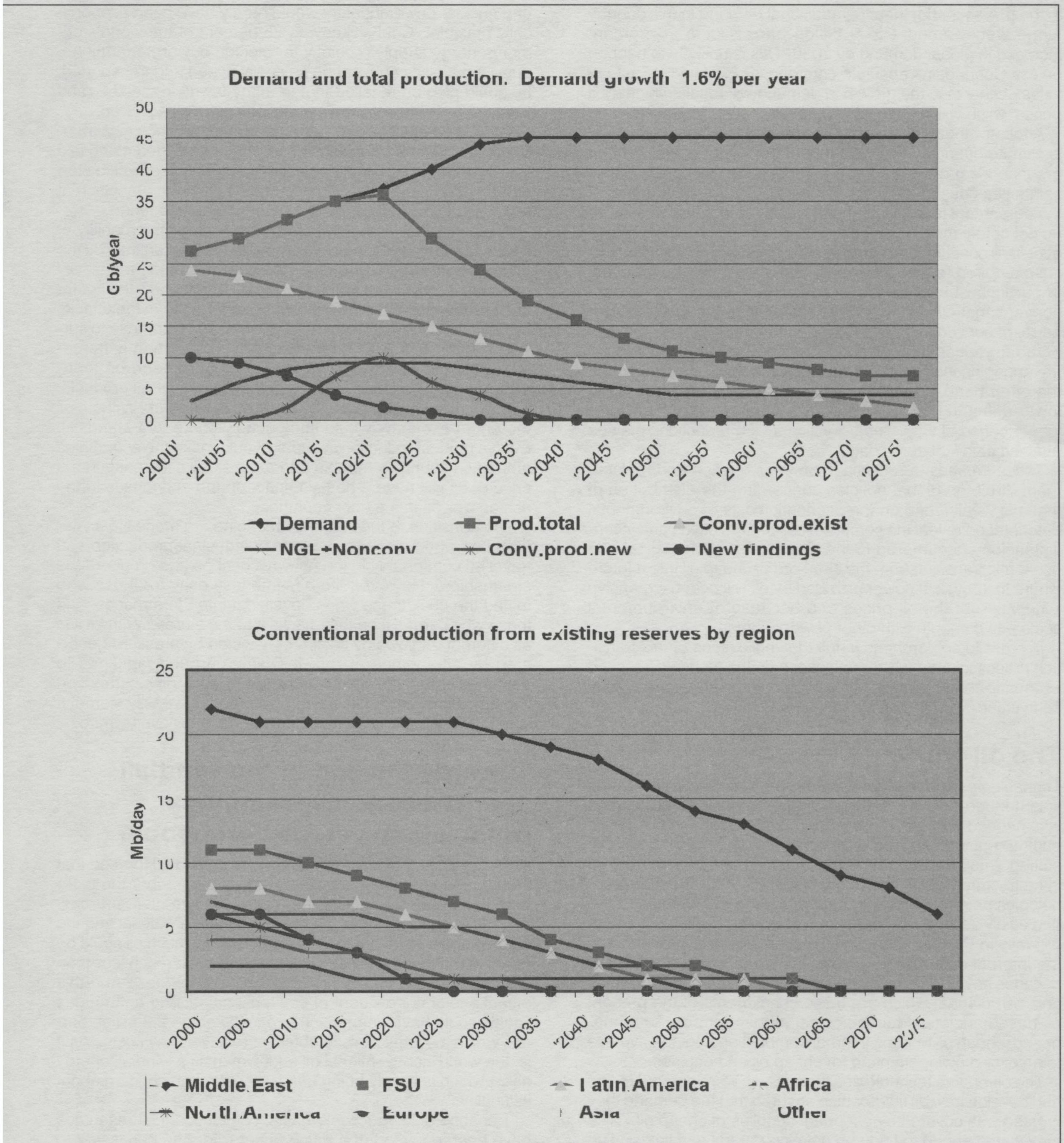


**Fig. 1** (cont'd).

consume 10 billion barrels. In other words, the per capita consumption is 7 times higher in the OECD countries than in the rest of the world. In the IEA scenario, this ratio will be only modestly reduced in the coming decades, the average per capita consumption being 5.7 times higher in the OECD countries than in the rest of the world by 2030.

Thus, as long as oil consumption is an indicator of material wealth, the assertion that there will be no oil shortage in the next decades implies that poor peoples remain poor. Should, for instance, the economy of China continue to grow so that the Chinese per capita demand for oil grows to just 50 percent of the OECD level by 2030, instead of the 17 percent assumed in the IEA scenario, then the additional demand in this country alone would amount to 9 billion barrels or a 20 percent increase in global demand by 2030. This is unlikely to happen unless China gains absolute control over the Middle East oilfields. Otherwise the growth in demand will result in higher oil prices which will in turn reduce growth.

Another fundamental issue concerning the global economy is climate change. The rationale of the Kyoto Agreement on greenhouse gas reductions is to reduce the risks of economic calamities caused by climate change. Therefore, the aim of the agreement is to initiate the transition to technologies which do not or to a much lesser extent depend on fossil fuels. However, if oil consumption continues to grow, $CO_2$ emission reductions required to prevent climate change cannot be achieved, in particular because the $CO_2$ emission per barrel of non-conventional oil is significantly higher than the emission per barrel of conventional oil. Consequently, unless they are prepared to reduce their oil consumption, the Kyoto signatories are engaging their countries in a futile, expensive exercise. On the other hand, if they do reduce their oil consumption, the lower demand may keep the price of oil relatively low for a longer period of time. Thus significant $CO_2$ reductions may be attained at low or zero costs.

These immediate reflections on the depletion and replacement of oil, on global policies concerning the distribution of material wealth, and on the economic costs of environmental deterioration reveal the complexities, contradictions and inconsistencies encountered in the process of technological and economic transition from the short era of cheap oil into a future where the physical power provided by oil will be too expensive – because of the oil prices and because of environmental costs – to compete with other power sources.

In order to comprehend in full the implications of this transition process, some further reflections on the technological and economic characteristics of the system to be transformed may be in place.

## The oil-world

Technologies and natural resources are complementary. Coal was needed to fuel the steam engine and the steam engine was needed to mine and transport coal. Coal and the steam engine replaced watermills, windmills, horse-drawn coaches, sailing ships and human labor, thus creating the industrial infrastructures which in turn enabled man to develop the technologies needed to exploit another natural resource: oil. Yet, had easily accessible, cheap oil not become available from the oil wells in Pennsylvania and Texas in the late 19th century, the internal combustion engine would not within a couple of decades have been developed to propel the cars, trucks, ships and aeroplanes, which are basic constituents of the present oil-based societies' technological infrastructure. As it happened, cheap oil and the internal combustion engine gave rise to an ever growing demand for cheap oil and engines.

The oil-engine technologies themselves were needed to find and develop new oil fields which ensured that the demand they created was covered by abundant supplies of cheap oil. Also they were needed to find and develop natural gas fields. The world-wide oil prospecting, the drilling, the pumping, and the transport of oil and gas from the wells could not have taken place without the oil-engines which propelled the aeroplanes, helicopters, the on-site equipment, the trucks, and the cranes for the laying of pipelines. Also, the construction of huge dam walls for hydropower stations in remote areas could not have been accomplished without oil-engines. Moreover, without oil-engine propelled aeroplanes the first nuclear bombs would have remained destructive only to those who made them, and without the production of nuclear warheads the development of a nuclear power industry would hardly have been economically feasible. Coal still covers 25 percent of the world's primary energy supply – chiefly for electric power generation – but without oil it could not be so easily mined and transported. It should also be recalled that in many towns in the U.S. and Europe the first electric power stations were oil-powered.

Thus, the transition to oil had many more technological ramifications than the transition to coal which preceded it and laid the grounds for it. Ample power from oil-engines, which start at the push of a button, has become available at any place at any time at very low costs. It is Prometheus unbound.

World War II was the first great war in which the mobility of troops, armory and bombs was provided almost entirely by the oil-fueled internal combustion engine: in trucks, jeeps, armored cars, tanks, warships and, most prominently, the fighter and bomber planes. However, while suffering from the attacks by oil-driven war machines Europe's civilians were able to survive without oil. Agriculture was still predominantly horse-powered and the supply of food did not depend on long-distance transportation of feedstock and agricultural products. Today, half a century later, the situation is different. Without oil the entire economy would immediately come to a standstill. Even a modest reduction in supply would make the economies of the rich countries tremble and a substantial increase in the price of oil will have a heavy impact on the economies in the rich as well as in the poor countries.

The transition to the coal-steam engine era made life easier for those who enjoyed the goods of industrial production and travelled comfortably in the railway coaches and on board the steamships. However, life became less easy for those who mined the coal, those who shovelled it into the furnaces, and those who carried it on their backs into the stores. With oil it is all different. It flows by itself – or assisted by pressure generated by oil-engines – from the wells through pipelines to refineries or tankers which, propelled by oil-engines, transport it to any destination. It is easily distributed and easily stored. It is readily available as petrol, diesel and fuel-oil everywhere.

## Towards the end of the windfall energy economy – empirical pragmatism versus cornucopia

At the beginning of the 19th century no one could foresee that the coal-based industrialization was to bring about the technologies needed to utilize the then unknown oil resources. And in the second half of the century, when the Diesel and the Otto engine was invented, no one knew how much oil could be found to run these engines. It could have been much less than the approximately 1.7 trillion barrels found so far. And this planet's total endowment of conventional oil and natural gas liquids could have been much in excess of the 2.3 trillion barrels which it seems likely to obtain at relatively low costs. As it is, the world's conventional oil endowment is a windfall energy asset which is hastily being used without much concern about its finality.

Because of low recovery costs, conventional oil resources have been depleted at a much faster rate than necessary to provide the goods and services obtained. Had the oil price been substantially higher, more energy efficient technologies would have been developed and less wasteful, local production would have had competitive advantages against goods produced far away. Cars would have run more kilometers per liter and buildings would have been designed to sustain a comfortable indoor climate at lower oil or gas expense; railways would have been modernized instead of closed down; energy saving recycling would have played a bigger role in industries; and less feedstock and food would have travelled thousands of miles before being consumed.

Thus, in the short era of cheap oil all the techniques and technological infrastructures upon which the functioning of present societies is based have been designed so as to balance investment and maintenance costs against low costs of oil consumption. When oil prices rise, this balance shifts in favor of other techniques and infrastructures, meaning that not just some but practically all techniques and infrastructures must be renewed and restructured. The question is whether this transition will take place smoothly as oil prices rise slowly, allowing the market economy to accommodate to the new conditions. Or whether more abrupt oil price upswings will cause a self-perpetuating economic recession which inhibits technological renewal and restructuring.

The literature on oil resources, reserves and depletion is divided into two, sharply contrasted but hitherto unnamed schools of forecasting:

- those belonging to the one school could be called *the historical pragmatists*;
- those belonging to the other *the theoretical resource economists.*

● Historical pragmatists claim that no economic theory can give a credible answer to questions about oil depletion, simply because there is no empirical evidence upon which the assessment of the validity of economic theorems concerning this singular era in the history of economic development can be based. Therefore, attempts to answer questions about the depletion of conventional oil must be based on specific analyses of the actual circumstances, based on the best available data on conventional oil reserves; present and potential future production capacities in the different oil provinces; and alternative demand forecasts, resulting from different assumptions as to future technological, social and economic development. The geophysicist and social development analyst M. King Hubbert (1903-1989), who in the 1950s predicted that conventional oil production in the U.S. would peak in the mid-1970s – a prediction which turned out to be correct – is one of the most prominent representatives of this line of thought.

In 1976 Dr Hubbert concluded his paper "Exponential growth as a transient phenomenon in human history"[2] with the following observations:

> *"It appears therefore that one of the foremost problems confronting humanity today is how to make the transition from the precarious state that we are now in to this optimum future state by a least catastrophic progression. Our principal impediments at present are neither lack of energy or material resources nor of essential physical and biological knowledge. Our principal constraints are cultural. During the last two centuries we have known nothing but exponential growth and in parallel we have evolved what amounts to an exponential-growth culture, a culture so heavily dependent upon the continuance of exponential growth for its stability that it is incapable of reckoning with problems of nongrowth.*
>
> *Since the problems confronting us are not intrinsically insoluble, it behooves us, while there is yet time, to begin a serious examination of the nature of our cultural constraints and of the cultural adjustments necessary to permit us to deal effectively with the problems rapidly arising. Provided this can be done before unmanageable crises arise, there is promise that we could be on the threshold of achieving one of the greatest intellectual and cultural advances in human history."*

Twelve years later, in 1988, Dr Hubbert said in an interview:

> *"Our window of opportunity is slowly closing ... at the same time, it probably requires a spiral of adversity. In other words, things have to get worse before they can get better. The most important thing is to get a clear picture of the situation we're in, and the outlook for the future – exhaustion of oil and gas, that kind of thing – and an appraisal of where we are and what the time scale is. And the time scale is not centuries, it is decades."*

Since then exponential growth has now continued for another 15 years and the world economy has year by year become more and more dependent on oil and natural gas. At the same time, prominent oil and gas geologists have presented quite a "*clear picture of the situation we're in*" and assessed *"what the time scale is."* On the basis of increasingly detailed mappings of the Earth's geological formations and meticulous recordings of the findings of new oil and gas fields and the development in reserves, they have recorded the history of the exploration and discovery of oil and gas reserves and the subsequent depletion of these reserves. Naturally, these recordings do not provide accurate data on the development in reserves and production – the ultimate yield from any particular oil field can only be assessed to a certain degree of accuracy and in many cases production potential forecasts depend on assumptions regarding future investments in oil rigs, recovery techniques, pipelines, refineries, etc. However, they constitute the only empirical evidence for the appraisal of the prospects for the future.

● The theoretical resource economists, with Morris A. Adelman as a prominent representative, repudiate the depletion warnings issued by the historical pragmatists, which they refer to as Neo-Malthusian pessimism. Peter J. McCabe of the U.S. Geological Survey presents a distinction between what he finds to be unwarranted "empty-barrel-pessimism" and cornucopia,[3] the core argument against the pessimistic outlook being that reserves are not fixed but determined by *"the mix of knowledge, technology and investment that sustains the process of exploration and production sufficiently to meet short- and medium-term demand expectations. Reserves depend on the interaction of this process, government policies and, finally, the price people are willing to pay for oil products. Since we cannot know future technology or prices, we cannot quantify future reserves. This should not be a concern, since it is these processes that are important. Ultimately, as Adelman commented, 'oil resources are unknown, unknowable and unimportant'."*[4]

The technological development aspect of this theory is expressed in the frequently cited saying that "the stone age did not end because of lack of stones. Likewise, the oil age will not end because of lack of oil." History shows that technologies come and go. As conventional oil becomes too expensive or more convenient fuels and technologies become available, it will be replaced by non-conventional oil, other liquid fuels, electric power or whatever new technologies may turn up.

However, few would miss the difference between on the one hand the shift, taking place over hundreds of years, from axes and spearheads made of stone to the more effective ones made out of bronze, and, on the other, the transition to be accomplished over a few decades of an eight billion people world economy based on cheap-oil technologies to an economy based on other, not yet developed technologies.

Yet, the Stone Age may offer an analogy to modern times. Flint stone well suited for tool-making was mined from underground veins. As the miners did not know the extension of the veins of relatively easily mined, good quality flint stone, one could imagine that they kept producing the stones at low costs in increasing quantities until one day they suddenly, without warning, came to the end of the veins. Unprepared, because no price increases had signalled that the growth in the cheap-flint-stone economy was coming to an end, the tribe faced a sudden economic recession as it took time and big investments to open other, less easily accessible veins. Likewise, cheap conventional oil may cover a rising demand for another decade or two before a sudden decline in production occurs. As Peter J. McCabe states: *"... in the long run the supply of fossil fuel is finite, and prices inevitably will rise unless alternate energy sources substitute for fossil energy supplies; however, there appears to be little reason to suspect that long-term price trends will rise significantly over the next few decades."*[3] The question is whether under these circumstances the transition to an economy based on other technologies and fuels will begin early enough to be accomplished smoothly.

## The future for the city

Can the city change so as to accommodate its functions to a future where oil and natural gas is expensive and in short supply and the consumption of non-conventional oil and coal is strictly rationed in order to mitigate the greenhouse effect? Not a hundred years but 20 or 30 years from now. Or will it deteriorate with heaps of rusting cars around it?

Buildings have been designed to sustain a comfortable indoor climate by means of heating and/or cooling systems driven by cheap fossil fuels. When these fuels become expensive and in short supply, how will a comfortable indoor climate be sustained? The vehicles in the streets and on the parking lots are powered by oil-engines. What will replace them? Food and goods are transported to the city on trucks powered by oil-engines. What other means of transport will replace the trucks?

There are no simple answers to these questions. Fuel cells converting hydrogen to electric power can replace the oil-engine but the hydrogen must be produced on the basis of renewable energy sources or nuclear power. Thus hydrogen production for vehicles, aeroplanes, ships and agricultural machinery will compete with buildings and industries for electric power from renewable energy sources and nuclear power plants.

Even if the nuclear power industry is revived – a revival likely to be opposed in many countries – it will take several decades and be very costly to build enough nuclear power stations to replace a substantial amount of the present fossil fuel consumption. To build renewable energy installations with such capacities that they can replace a substantial part of the present fossil fuel consumption will be economic madness, partly because of the storage and regulation systems required in a system where continually fluctuating inputs from solar installations and windmills play a major role.

Therefore, end-use energy consumption – in buildings, vehicles, industries, etc. – which is presently covered by fossil fuels cannot be covered by renewable energy sources and, if accepted, nuclear power. End-use consumption must be greatly reduced.

To reconstruct the city, built in the period where end-use energy consumption was no major concern, so that it can function at greatly reduced end-use energy consumption is an enormous challenge to architects, urban planners, engineers, economists, and – not least – the city's inhabitants and their politicians.

To postpone the initiation of the reconstruction is to neglect not only the foreseeable shortage in the supply of cheap conventional oil but also the probable consequences of the greenhouse effect. The consequence is likely to be deterioration and impoverishment of the urban environment.

## Notes

1. The notion "conventional oil" has been introduced by oil economists and oil geologists to denote crude oil which at low costs can be extracted from onshore wells and offshore wells at moderate depths, as distinct from oil from deepwater wells (at ocean depths more than 500 meters), oil extracted from tar sands, oil shale, etc.
2. Presented before the World Wildlife Fund, Fourth International Congress, "The Fragile Earth," San Francisco, 1976.
3. Peter J. McCabe, "Energy resources – Cornucopia or empty barrel?" *AAPG Bulletin,* vol. 82, no.11 (November 1998).
4. John Mitchell et al., *The New Economy of Oil. Impacts on Business, Geopolitics and Society* (London, Earthscan, 2001), pp. 46-47.