1
Various Aspects of the Energy and Raw Material Supply

fossil fuels natural gas, petroleum, coal have two functions:

1. energy source
2. raw material for chemical products

The availability and price structure of energy and raw materials have always determined the technological base and thus the expansion and development of industrial chemistry. However, the oil crisis was necessary before the general public once again became aware of this relationship and its importance for the world economy.

Coal, natural gas, and oil, formed with the help of solar energy during the course of millions of years, presently cover not only the energy, but also to a large extent chemical feedstock requirements.

There is no comparable branch of industry in which there is such a complete interplay between energy and raw materials as in the chemical industry. Every variation in supply has a double impact on the chemical industry, as it is one of the greatest consumers of energy. In addition to this, the non-renewable fossil products which are employed as raw materials are converted to a spectrum of synthetic substances which we encounter in everyday life.

The constantly increasing demand for raw materials and the limited reserves point out the importance of safeguarding future energy and raw material supplies.

long-range aims for securing industrial raw material and energy supply:

1. extending the period of use of fossil raw materials
2. replacing fossil raw materials in the energy sector

All short- and medium-term efforts will have to concentrate on the basic problem of how the flexibility of the raw material supply for the chemical industry on the one hand and the energy sector on the other can be increased with the available resources. In the long term, this double function of fossil fuels will be decoupled in order to maintain this attractive raw materials source for the chemical industry for as long as possible.

In order to better evaluate the present situation and understand the future consumption of primary energy sources and

Industrial Organic Chemistry 5th Edition. Hans-Jürgen Arpe

ISBN: 978-3-527-32002-8

raw materials, both aspects will be reviewed together with the individual energy sources.

1.1
Present and Predictable Energy Requirements

primary energy consumption (in 10^{12} kWh)

	1964	1974	1984	1994	2002
World	41.3	67.5	82.6	93.6	109.1
USA	12.5	15.4	19.5	24.0	26.9
W. Europe	7.9	10.7	11.6	13.2	16.6

During the last 40 years or so, world energy demand has almost tripled, and in 2002 it reached 109×10^{12} kWh, corresponding to the energy from 9.4×10^9 tonnes of oil (1 tonne oil $= 11620$ kWh $= 10 \times 10^6$ kcal $= 41.8 \times 10^6$ kJ). The average annual increase before 1974 was about 5%, which decreased in the late 1980s, as the data in the adjacent table illustrate. In the early 1990s, primary energy consumption hardly changed, due to the drop in energy demand caused by the economic recession following the radical changes in the former Eastern Bloc.

However, according to the latest prediction of the World Energy Council (WEC), global population will grow from the current 6 to 7.4×10^9 people by the year 2020, which, together with increasing living standards, will increase world energy demand to possibly 160×10^{12} kWh.

the OECD has 29 member states, which in Europe include Great Britain, Norway, and Germany

In 1989, the consumption of primary energy in the OECD (Organization for Economic Cooperation and Development) countries was distributed as follows:

31% for transport
34% for industrial use
35% for domestic use, agriculture, and other sectors

energy consumption of the chemical industry:

6% of total consumption, i.e., second largest industrial consumer

The chemical industry accounts for 6% of total energy consumption and thereby occupies second place on the energy consumption scale after the iron processing industry.

changes in primary energy distribution worldwide (in %):

	1964	1974	1984	1999
oil	41	48	42	36
coal	37	28	27	23
natural gas	15	18	19	22
nuclear energy	6	6	7	7
hydro/others	1	3	5	12

(others = renewable energy)

Between 1950 and 1999, the worldwide pattern of primary energy consumption changed drastically. Coal's share decreased from ca. 60% in 1950 to the values shown in the accompanying table. In China and some of the former Eastern Bloc countries, 40% of the energy used still comes from coal. Oil's share amounted to just 25% of world energy consumption in 1950, and reached a maximum of nearly 50% in the early 1970s. Today it has stabilized at just under 40%.

reasons for preferred use of oil and natural gas as energy source:

1. efficient recovery
2. versatile applicability
3. low transportation and distribution costs

The reasons for this energy source structure lie in the efficient and thus economic recovery of oil and natural gas and their versatile applicability as well as lower transportation and distribution costs.

In the following decades, the forecast calls for a slight de-crease in the relative amounts of energy from oil and natural gas, but a small increase for coal and nuclear energy. An eventual transition to carbon-free and inexhaustible energy sources is desirable, but this development will be influenced by many factors.

restructuring of energy consumption not possible in the short term

In any event, oil and natural gas will remain the main energy sources for decades to come, as technological reorientation will take a long time due to the complexity of the problem. The situation with regard to nuclear energy is uncertain. Considerable potential for development is present in the areas of fuel cells and photovoltaics.

oil remains main energy source for the near future

1.2
Availability of Individual Sources

1.2.1
Oil

oil reserves (in 10^{12} kWh):

	1986	1989	1998	2002
proven	1110	1480	1660	1660
total	4900	1620	2580	2580

proven reserves of “synthetic” oil from oil shale and oil sands (in 10^{12} kWh):

	1989	1992	1997	1998
proven	1550	1550	1059	977
total	13840	12360	5234	3907

kerogen is a waxy, polymeric substance found in sedimentary rock, which is converted to “synthetic” oil on heating to >500 °C or hydrogenation

oil consumption (in 10^9 t of oil):

	1988	1990	1998	2002
World	3.02	3.10	3.35	3.52
USA	0.78	0.78	0.83	0.90
W. Europe	0.59	0.60	0.67	0.76
Japan	0.22	0.25	0.25	0.25

n.a. = not available

New data shows that the proven and probable, i.e., supplementary, recoverable world oil reserves are higher than the roughly 520×10^9 t, or 6040×10^{12} kWh, estimated in recent years, owing to improved exploration and production technology. Of the proven reserves (2002), 65% are found in the Middle East, 9% in South America, 5% in North America, 2% in Western Europe, and the remainder in other regions. With about 24% of the proven oil reserves, Saudi Arabia has the greatest share, leading Iraq, Kuwait and other countries principally in the Near East. In 1996, the OPEC countries accounted for ca. 77 wt% of worldwide oil production. The countries with the largest shares of the total world production of 3.6×10^{12} t in 2002 were Saudi Arabia (12%), USA (9%), former Soviet Union (11%), and Iran (5%).

A further crude oil supply, which amounts to ten times the above-mentioned petroleum reserves, is found in oil shale, tar sand, and oil sand. This source, presumed to be on same order of magnitude as mineral oil only a few years ago, far surpasses it.

There is a great incentive for the exploitation of oil shale and oil sand. To this end, extraction and pyrolysis processes have been developed which, under favorable local conditions, are already economically feasible. Large commercial plants are being run in Canada, with a significant annual increase (for example, production in 1994 was 17% greater than in 1993), and the CIS. Although numerous pilot plants have been shut down, e.g., in the USA, new ones are planned in places such as Australia. In China, oil is extracted from kerogen-containing rock strata. An additional plant with a capacity of 0.12×10^6 t/a was in the last phase of construction in 1994.

aids to oil recovery:

recovered phase	recovery agent	oil recovered (in %)
primary	well-head pressure	10–20
secondary	water/gas flooding	→ 30
tertiary	chemical flooding (polymers, tensides)	→ 50

At current rates of consumption, proven crude oil reserves will last about 42 years as of 1998. If the additional supply from oil shale/oil sands is included, the supply will last for more than 100 years.

However, the following factors will probably help ensure an oil supply well beyond that point: better utilization of known deposits which at present are exploited only to about 30% with conventional technology, intensified exploration activity, recovery of difficult-to-obtain reserves, opening up of oil fields under the seabed, as well as a restructuring of energy and raw material consumption.

1.2.2
Natural Gas

natural gas reserves (in 10^{12} kWh):

	1985	1989	1998	2002
proven	944	1190	1425	1440
total	2260	3660	3492	n.a.

n.a. = not available

($1\ m^3$ natural gas = 9.23 kWh)

at the present rate of consumption the proven natural gas reserves will be exhausted in ca. 63 years (as of 1998)

The proven and probable world natural gas reserves are somewhat larger than the oil reserves, and are estimated (1998) at $374 \times 10^{12}\ m^3$, or 3492×10^{12} kWh. Proven reserves amount to 423×10^{12} kWh.

In 2002 these reserves were distributed among the regions former Soviet Union (35%), near East (36%), Africa (8%), and North America (5%). The remaining 15% is distributed among all other natural gas-producing countries.

Based on the natural gas output for 2002 (23.6×10^{12} kWh), the proven worldwide reserves should last for almost 62 years.

In 2002, North America and Europe, Eurasia were the largest producers, supplying 30 and 39%, respectively, of the natural gas worldwide.

rapid development in natural gas consumption possible by transport over long distances by means of:

1. pipelines
2. specially designed ships
3. transformation into methanol

Natural gas consumption has steadily increased during the last two decades. Up until now, natural gas could only be used where the corresponding industrial infrastructure was available or where the distance to the consumer could be bridged by means of pipelines. In the meantime, gas transportation over great distances from the source of supply to the most important consumption areas can be overcome by liquefaction of natural gas (LNG = liquefied natural gas) and transportation in specially built ships as is done for example in Japan, which supplies itself almost entirely by importing LNG. In the future, natural gas could possibly be transported by first converting it to methanol via synthesis gas, which, of course, means additional expenditure.

The dependence on imports, as with oil, in countries with little or no natural gas reserves is therefore resolvable. However, this situation will only fundamentally change when synthesis gas technology based on lignite and coal is established and developed. This will probably take place on a larger scale only in the distant future.

substitution of natural gas by synthetic natural gas (SNG) only in the distant future (cf. Section 2.1.2)

1.2.3
Coal

As far as the reserves are concerned, coal is not only the most widely spread but also the most important source of fossil energy. However, it must be kept in mind that the estimates of coal deposits are based on geological studies and do not take mining problems into account. The proven and probable world hard coal reserves are estimated to be 44835 × 10^{12} kWh (1999). The proven reserves amount to 3964 × 10^{12} kWh. Of this amount, ca. 38% is found in the USA, 5% in the former Soviet Union, 14% in the P. R. China, 7% in Western Europe, and 7% in Africa. In 2002, 3.5 × 10^{6} t of hard coal were produced worldwide, with 17 and 24% coming from China and the USA, respectively.

hard coal reserves (in 10^{12} kWh):

	1985	1989	1992	1999
proven	5600	4090	5860	3964
total	54500	58600	67800	44835

“hard coal” also includes tar coal and anthracite

brown coal reserves (in 10^{12} kWh):

	1985	1989	1992	1999
proven	1360	860	1110	578
total	5700	6800	n.a.	9442

n.a. = not available

In 1999, world reserves of brown coal were estimated at 6800 × 10^{12} kWh, of which 860 × 10^{12} kWh are proven reserves. By 1992, these proven reserves had increased by ca. 30%.

With the huge coal deposits available, the world’s energy requirements could be met for a long time to come. According to studies at several institutes, this could be for several thousand years at the current rate of growth.

nuclear fuels are fissile materials or materials that contain fissile substances, mainly uranium and plutonium in the form of metals or compounds

1.2.4
Nuclear Fuels

Given its state of development, nuclear energy could be a realistic solution to the energy supply problem of the next decades. Its economic viability has been proven, despite political moves to dispense with nuclear power.

Nuclear fuels offer an alternative to fossil fuels in important areas, particularly in the generation of electricity. Although fossil fuels have maintained their dominant position in electricity generation worldwide, different shares of nuclear

energy sources for electricity (in %):

	USA		Western Europe		World	
	1975	1987	1974	1998	1975	1999
natural gas/oil	76	13	36	21	35	26
coal		53	34	30	37	36
nuclear energy	9	17	6	35	5	17
hydro electric/ others	15	17	24	14	23	21

energy have developed in individual countries. In 2000, 433 nuclear reactors were in operation worldwide, and a further 38 were under construction. The largest numbers of reactors are found in the USA (104), France (59), and Japan (53).

The largest share of nuclear power in electricity generation is in France (76% in 1998).

uranium production (in 10^6 t):

	1991	1994	1998
world	41.9	31.6	35.0
Canada	8.2	9.6	10.9
Australia	3.8	2.2	4.9

Uranium reserves are large and distributed over extensive areas of the earth. Worldwide uranium production has decreased (see adjacent table), but with different trends from country to country. Canada has further strengthened its position as leading producer, followed by Australia, which has experienced pronounced growth. Uranium production in Western Europe has almost completely ceased, apart from a small amount in France.

energy content of uranium reserves (in 10^{12} kWh):

690	with conventional reactor technology
80000	by full utilization via breeders

When uranium is used in light-water reactors of conventional design, essentially only ^{235}U is consumed (up to 0.7% in natural uranium). The energy liberated in the form of radiation and fission products (e.g., α and β particles, neutrons) is transformed into heat, which is used, *e.g.*, to generate steam for driving turbines for generating electricity.

function of fast breeders (neutron capture):

$^{238}\text{U} \rightarrow {}^{239}\text{Pu}$

$^{232}\text{Th} \rightarrow {}^{233}\text{U}$

The fraction of fissile material can be increased by using fast breeder reactors, which operate by synthesizing fissionable ^{239}Pu from the nonfissionable nuclide ^{238}U (main constituent of natural uranium, abundance 99.3%) by means of neutron capture. ^{238}U is not fissionable using thermal neutrons. In the same way fissionable ^{233}U can be synthesized from ^{232}Th.

In 1995 France and Japan were the only countries in which fast breeder reactors were being operated and further developed.

The increasing energy demand can be met for at least the next 50 years using present reactor technology.

reactor generations:

- light-water reactors
- high-temperature reactors
- breeder reactors

advantage of high-temperature reactors:

high temperature range (900–1000 °C) process heat useful for strongly endothermic chemical reactions

The dominant reactor type today, and probably for the next 20 years, is the light-water reactor (boiling or pressurized water reactor) which operates at temperatures up to about 300 °C. High-temperature reactors with cooling-medium (helium) temperature up to nearly 1000 °C are already on the threshold of large-scale development. They have the advantage that they not only supply electricity but also process heat at higher temperatures (cf. Sections 2.1.1 and 2.2.2).

nuclear fusion, a thermonuclear reaction forming a new nucleus with release of energy.

Another major target in the area of nuclear energy is nuclear fusion, i.e., exploiting the energy from the combination of two atomic nuclei. This process, which is also the basis of energy generation in the sun, is being studied by various industrial nations. For example, in Germany the Stellarator nuclear fusion project was started in 2000.

An important prerequisite for the successful employment of nuclear energy is not only that safe and reliable nuclear power stations are erected, but also that the whole fuel cycle is completely closed. This begins with the supply of natural uranium, the availability of suitable enrichment units, and finishes with the disposal of radioactive fission products, including containment of highly radioactive waste from nuclear power stations, and recycling of unconsumed and newly bred nuclear fuels.

essential prerequisites for the use of nuclear energy:

1. reliable supply of nuclear energy
2. technically safe nuclear power stations
3. safe disposal of fission products and recycling of nuclear fuels (reprocessing)

Waste management and environmental protection will determine the rate at which the nuclear energy program can be realized.

1.3
Prospects for the Future Energy Supply

As seen in the foregoing sections, oil, natural gas, and coal will remain the most important primary energy sources for the long term. While there is currently little restriction on the availability of energy sources, in light of the importance of oil and natural gas as raw materials for the chemical industry, their use for energy should be decreased as soon as possible.

with the prevailing energy structure, oil and natural gas will be the first energy sources to be exhausted

competition between their energetic and chemical utilization compels structural change in the energy palette

The exploitation of oil shales and oil sands will not significantly affect the situation in the long term. The substitution of oil and natural gas by other energy sources is the most prudent solution to this dilemma. By these means, valuable fossil materials will be retained as far as possible for processing by the chemical industry.

In the medium term, utilization of nuclear energy has decisively contributed to decreasing fossil energy consumption. Solar energy offers an almost inexhaustible energy reserve and will only be referred to here with respect to its industrial potential. The energy which the sun annually supplies to the earth corresponds to thirty times the world's coal reserves. Based on a simple calculation, the world's present primary energy consumption could be covered by 0.005% of the energy supplied by the sun. Consequently, the development of solar energy technology including solar collectors and solar cell systems remains an important objective. At the same time, however, the energy storage and transportation problems must be solved.

possible substitution of fossil fuels by generation of energy from:

1. nuclear energy (medium term)
2. solar energy (long term)
3. geothermal energy (partial)
4. nuclear fusion energy (long term)

possible substitution of oil for energy generation by means of:

1. coal
2. nuclear energy
3. combination of coal and nuclear energy
4. hydrogen

The large-scale utilization of the so-called unlimited or renewable energies – solar energy, wind energy, water energy, geothermal energy, and nuclear fusion – will become important only in the distant future. Until that time, we will be dependent on optimal use of fossil raw materials, in particular oil. In the near future, nuclear energy and coal will play a dominant role in our energy supply, in order to stretch our oil reserves as far as possible. Nuclear energy will take over generation of electricity, while coal will be increasingly used as a substitute for petroleum products.

Before the energy supply becomes independent of fossil sources – undoubtedly not until the next century – there will possibly be an intermediate period in which a combination of nuclear energy and coal could be used. This combination could utilize nuclear process heat for coal gasification and thus lead to greater employment of synthesis gas products (cf. Section 2.1.1).

Along with the manufacture of synthesis gas via coal gasification, nuclear energy can possibly also be used for the manufacture of hydrogen from water by high-temperature steam electrolysis or chemical cyclic processes. The same is true of water electrolysis with solar energy, which is being studied widely in several countries. This could result in wide use of hydrogen as an energy source (hydrogen technology) and replacement of hydrogen manufacture from fossil materials (cf. Section 2.2.2).

long-term aim:
energy supply solely from renewable sources; raw material supply from fossil sources

This phase will lead to the situation in which energy will be won solely from renewable sources, and oil and coal will be employed only as raw materials.

1.4
Present and Anticipated Raw Material Situation

characteristic changes in the raw material base of the chemical industry:
feedstocks until 1950:

1. coal-gasification products (coking products, synthesis gas)
2. acetylene from calcium carbide

The present raw material situation of the chemical industry is characterized by a successful and virtually complete changeover from coal to petroleum technology.

The restructuring also applies to the conversion from the acetylene to the olefin base (cf. Sections 3.1 and 4.1).

1.4.1
Petrochemical Primary Products

feedstocks after 1950:

1. products from petroleum processing
2. natural gas
3. coal gasification products as well as acetylene from carbide and light hydrocarbons

The manufacture of carbon monoxide and hydrogen via gasification processes together with the manufacture of carbide (for welding and certain organic intermediates), benzene, and certain polynuclear aromatics are the only remaining processes of those employed in the 1950s for the preparation of basic organic chemicals from coal. However, these account for only a minor part of the primary petrochemical products; currently ca. 95% are based on oil or natural gas. Furthermore, there is no doubt that the expansion in production of feedstocks for the manufacture of organic secondary products was only possible as a result of the changeover to oil. This rapid expansion would not have been possible with coal due to inherent mining constraints. It can thus be appreciated that only partial substitution of oil by coal, resulting in limited broadening of the raw material base, will be possible in the future. The dependence of the chemical industry on oil will therefore be maintained.

expansion of organic primary chemicals was only possible due to conversion from coal to oil

return to coal for organic primary chemicals is not feasible in short and medium term

primary chemicals are petrochemical basis products for further reactions;
e.g., ethylene, propene, butadiene, BTX aromatics

primary chemicals production (10^6 t)

	1991	1993	1997	1999
USA	39.5	41.7	52.0	55.0
W. Europe	38.3	39.4	45.2	47.0
Japan	19.2	18.4	24.4	23.9

In Japan and Western Europe, naphtha (or crude gasoline) is by far the most important feedstock available to the chemical industry from the oil refineries. Decreasing availability of natural gas has also led to the increasing use of naphtha in the USA. Olefins such as ethylene, propene, butenes, and butadiene as well as the aromatics benzene, toluene, and xylene can be obtained by cracking naphtha. In 1997 about 660×10^6 t of naphtha were used as a petrochemical raw material worldwide. Of less importance are heavy fuel oil and refinery gas, which are employed together with natural gas for the manufacture of synthesis gas. The latter forms the basis for the manufacture of ammonia, methanol, acetic acid, and oxo products. The process technology largely determines the content and yield of the individual cuts.

feedstocks for olefins and aromatics:
Japan/WE: naphtha (crude gasoline)
USA: liquefied gas (C_2–C_4) and, increasingly, naphtha

feedstocks for synthesis gas ($CO + H_2$): methane and higher oil fractions

This technology has been increasingly developed since the oil crisis, so that today a complex refinery structure offers large quantities of valuable products. Thus, heavy fuel oil is partially converted to lower boiling products through thermal cracking processes such as visbreaking and coking processes. Furthermore, the residue from the atmospheric distillation can, following vacuum distillation, be converted by catalytic or hydro-cracking. This increases the yield of lighter products considerably, although it also increases the energy needed for processing. Energy saving therefore remains an essential task, both in basic processes and further processing of oil and its derivatives. In this regard, an important development is a new refinery at Leuna, developed by Elf Aquitane and Technip, in which “progressive distillation technology” is used. Improved exploitation of heat fluxes in crude oil distillation leads to staged heating for the lighter and heavier fractions in the lowest possible pressure ranges.

trend in demand for lighter mineral oil products necessitates more complex oil processing, e.g., of residual oils

restructuring of refineries by additional conversion plants such as:

1. thermocrackers
2. catalytic crackers
3. hydrocrackers

Table 1.1 Distribution of refinery products (in wt%)

	USA			Western Europe			Japan		
	1973	**1983**	**1993**	**1973**	**1985**	**1993**	**1973**	**1983**	**1993**
Refinery & liquefied gas	9	10	8	4	4	3	6	11	3
Motor gasoline, naphtha	44	49	47	24	26	29	21	24	20
Jet fuel	6	7	9	4	5	7	8	11	15
Light fuel oil, diesel oil	19	20	20	32	38	37	12	17	32
Heavy fuel oil	16	9	8	33	22	21	50	33	23
Bitumen, petroleum coke	6	5	8	3	5	3	3	4	7
Total refinery products (in 10^6 t)	825	730	690	730	527	577	260	220	179

markets 1973/93 for mineral oil products show characteristic drop in demand:

1. total of 16–31%
2. heavy fuel oil of 36–54%

The spectra of refinery products in the USA, Western Europe, and Japan are distinctly different due to the different market pressures, yet they all show the same trend toward a higher demand for lighter mineral oil fractions:

World refinery capacities (in 10 t/a)

1993	1996	1998	2002
3.7	3.8	4.0	4.2

World crude oil distillation capacities are listed in the adjacent table.

The aforementioned development toward lower boiling products from mineral oil was influenced by the fuel sector as well as by the chemical industry. Even though in principle all refinery products are usable for the manufacture of primary chemicals such as olefins and the BTX (benzene – toluene – xylene) aromatics, there is still a considerable difference in yield. Lowering the boiling point of the feedstock of a cracking process increases not only the yield of $C_2 – C_4$ olefins, but also alters the olefin mixture; in particular, it enhances the formation of the main product ethylene, by far the most important of the chemical building blocks (cf. adjacent table).

olefin yields from moderate-severity cracking (in wt%)

	ethane	naphtha	oil
ethylene	82	30	20
propene	2	17	14
C_4 olefins	3	11	9

remainder: fuel gas, gasoline from cracking, oil residue

Independent of the higher supply of refinery fractions preferred by the chemical industry through expanded processing technology, by and large the vital task of reducing and uncoupling the dual role of oil as a supplier of both energy and raw materials remains.

saving oil as an energy source is possible in several ways:

1. increased efficiency during conversion to energy
2. gradual substitution by coal or nuclear energy
3. gradual substitution as motor fuel by, e.g., methanol, ethanol

A first step toward saving oil could be to increase the efficiency of its conversion to electricity, heat, and motive power.

In the industrial sector, currently only 55% of the energy is actually used. Domestic and small consumers, who represent not only the largest but also the expanding consumption areas, use only 45%, while transport uses only 17%. The remainder is lost through conversion, transport, and waste heat.

The gradual replacement of oil in energy generation by coal and nuclear energy could have an even greater effect (cf. Section 1.3). This includes the partial or complete replacement of gasoline by methanol (cf. Section 2.3.1.2) or by ethanol, perhaps from a biological source (cf. Section 8.1.1).

future supplies of primary chemicals increasing due to countries with inexpensive raw material base, e.g., oil-producing countries

Over and above this, there are other aspects of the future of the primary raw chemical supply for the chemical industry. First among these is the geographic transfer of petrochemical production to the oil producing countries. Saudi Arabia has emerged in the last few years as a large-scale producer of primary chemicals and the most important olefins, in order inter alia to make use of the petroleum gas previously burned off. A number of nonindustrialized and newly industrialized nations have followed this example, so that in the future they will be able to supply not only their domestic requirements, but also the established production centers in the USA, Western Europe, and Japan.

typical production, e.g., in Saudi Arabia (starting in 1984):

- ethylene
- ethanol
- ethylene glycols
- dichloroethane
- vinyl chloride
- styrene

(starting in 1993, e.g., MTBE (0.86×10^6 t/a))

Thus, it can be expected that the capacity for production of primary chemicals in these newly industrialized countries will increase continuously. This is a challenge to the industrialized countries to increase their proportion of higher value products.

In 1999, the world production capacity for primary chemicals was about 211×10^6 t/a. Of this, about 29% was in the USA, 24% in Western Europe, 12% in Japan, and 6% in Germany.

1.4.2
Coal Conversion Products

The chemical industry uses appreciable amounts of coal only as a raw material for recovery of benzene, naphthalene, and other condensed aromatics.

coal as raw material:

currently up to 11% worldwide of the benzene-aromatics, but ca. 95% of the condensed aromatics, are based on coal gasification

Measured against the world demand, coal furnishes up to 11% of the requirements for benzene, and more than 95% of the requirements for polynuclear and heteroaromatics.

In addition, coal is the source for smaller amounts of acetylene and carbon monoxide, and is the raw material for technical carbon, i.e., carbon black and graphite.

substitution of oil by coal assumes further development of coal gasification and conversion processes extremely low coal costs required

The changing situation on the oil market brings up the question to what extent precursors and secondary products from petrochemical sources can be substituted by possible coal conversion products. In general, the organic primary chemicals produced from oil could be manufactured once again from coal using conventional technology. However, the prerequisite is an extremely low coal price compared to oil or natural gas. In Europe, and even in the USA with its relatively low coal costs, it is currently not economical to manufacture gasoline from coal.

coal, however, remains sole alternative to oil

Viewed on the longer term, however, coal is the only plausible alternative to petroleum for the raw material base. To fit the current petrochemical production structure and to enhance profitability, earlier proven technologies must be improved to increase the yield of higher valued products.

coal chemistry processes:

1. gasification
2. hydrogenation (hydrogenative extraction)
3. low-temperature carbonization
4. manufacture of acetylene (carbide)

Basically, the following methods are available for the manufacture of chemical precursors from coal:

1. Gasification of brown or hard coal to synthesis gas and its conversion into basic chemicals (cf. Section 2.1.1)
2. Hydrogenation or hydrogenative extraction of hard coal
3. Low-temperature carbonization of brown or hard coal
4. Reaction of coal with calcium carbonate to form calcium carbide, followed by its conversion to acetylene

The state of the art and possible future developments will be dealt with in detail in the following sections.

new process technologies coupling coal gasification with process heat under development

In the future, incentive for the gasification of coal, which requires a considerable amount of heat, could result from the availability of nuclear process heat.

The application of nuclear process heat in the chemical industry is aimed at directly utilizing the energy released from nuclear reactors for chemical reactions, rather than supplying it indirectly via electricity. This harnessing of nuclear process heat for chemical reactions is only possible under certain conditions. With the light-water reactors, temperatures up to about 300 °C are available, and application is essentially limited to the generation of process steam.

nuclear coal gasification results in up to 40% more gasification products

The development of high temperature reactors in which temperatures of 800–1000 °C are attained presents a different situation. It appears feasible that the primary nuclear process heat can be used directly for steam gasification or hydrogasification of coal, methane cracking, or even for hydrogen generation from water in chemical cyclic processes. The first-mentioned processes have the distinct advantage that coal and natural gas are employed solely as raw materials and not simultaneously as the energy source. By this means up to 40% more gasification products can be obtained.

In the long term the advent of nuclear coal gasification can make a decisive contribution to guaranteeing the energy supply. In these terms, the consumption of the chemical industry is minimal; however, in light of their processing possibilities, chemistry is compelled to take a deeper look at coal gasification products.

From the standpoint of the chemical industry, the dovetailing of energy and raw material needs offers the opportunity to develop high-temperature reactors attractive to both sectors. Since the development of the high-temperature reactors is not yet complete, this stage will not be reached for 10 to 20 years. Furthermore, coupling of the chemical section to the reactor will also involve considerable developmental work (cf. Section 2.1.1.1).

exploitation of nuclear coal gasification by chemical industry only makes sense in combination with power industry

technical breakthrough not expected before 2000, due to necessary development and testing periods

At the same time, this example illustrates the fact that the new technologies available at the turn of the century will be those which are currently being developed. This aspect must be taken into account in all plans relating to long-term energy and raw material supply.