1 Introduction

1.1 What Is Chemical Technology?

The field of *chemical technology* stands between:

- **classical chemistry**, which is the science concerned with the composition, behavior, and properties of matter and with the changes it undergoes during chemical reactions, and
- **chemical engineering**, which is the branch of engineering that deals with the application of chemistry, physics, life sciences, and mathematics to processes of converting raw materials or chemicals into more useful or valuable forms or to environmental processes and involves the design of large-scale processes and also of laboratory-scale plants. Modern chemical engineering is also concerned with the design and synthesis of new materials and is one of the major disciplines related to energy technology such as the development of efficient batteries and fuel cells, energy storage systems, and the use of solar energy and other renewables.

In the chemical industry, natural scientists (primarily chemists, but also biologists and physicists), engineers, and businessmen form a team, and the following questions may, for example, be important:

- What is the amount and purity of the product that the client would like to have?
- What apparatus are suitable to produce a certain chemical?
- How can the heat be provided for an endothermic reaction, and how can we efficiently cool a reactor in case of an exothermic reaction to get an optimal performance of the reactor as well as a safe operation without the danger of a thermal runaway?
- Is the process safe and economic?
- How can a current process be improved?
- What type of equipment is needed to separate a reaction mixture?
- Which catalyst is the best, and for how long is the catalyst still active and selective?
- Is the process environmentally benign?

Chemical technology should give answers to all these questions and relies mainly on knowledge of the following four key disciplines and on their application and integration:

(1) (Physical) **chemistry** with a focus on key reactions, kinetics, and catalysis;
(2) **Thermal and mechanical unit operations** to design processes like distillation, absorption, adsorption, extraction, pumping and compressing of liquids and gases, filtration, and so on;
(3) **Chemical reaction engineering**, that is, knowledge of how to measure kinetic data for industrially relevant conditions, of the influence of heat and mass transfer on chemical reactions, and of all aspects of reactor design and modeling;
(4) **General chemical technology**, that is, the pedigree of routes from raw materials such as crude oil, natural gas, coal, and biomass via intermediates to final products, but also environmental aspects and production costs.

This book covers all these disciplines: chemical aspects (Chapter 2), unit operations (Chapter 3), reaction engineering (Chapter 4), and general chemical technology (Chapter 5). In addition, 24 industrial processes are inspected (Table 1.1.1), covering the production of fuels and of various organic and inorganic chemicals, as well as environmental protection processes.

Chemical Technology: From Principles to Products, Second Edition. Andreas Jess and Peter Wasserscheid.

Table 1.1.1 Industrial chemical processes inspected in detail in Chapter 6.

Chemical product or process	Subchapters in Chapter 6
Syngas and products based on syngas	
Syngas and Hydrogen	6.2
Ammonia Synthesis	6.1
Fuels and Chemicals by Fischer–Tropsch Synthesis	6.11.1
Methanol Synthesis	6.11.2
Inorganic base chemicals	
Sulfuric Acid	6.3
Nitric Acid	6.4
Chlorine and Sodium Hydroxide	6.19.2
Electrolysis of Water	6.19.3
Refinery processes	
Liquid Fuels by Cracking of Heavy Oils	6.7
Clean Liquid Fuels by Hydrotreating	6.8
High-Octane Gasoline by Catalytic Reforming	6.9
Refinery Alkylation	6.10
Organic base chemicals	
Basic Chemicals by Steam Cracking	6.6
Ethylene and Propylene Oxide	6.12
Catalytic Oxidation of *o*-Xylene to Phthalic Acid Anhydride	6.13
Hydroformylation (Oxosynthesis)	6.14
Acetic Acid	6.15
Ethylene Oligomerization Processes for Linear 1-Alkene Production	6.16
Organic speciality chemicals and consumer goods	
Production of Fine Chemicals (Example Menthol)	6.17
Polyethene Production	6.20
Polytetrafluoroethylene (PTFE)	6.23
Production of Amino Acids by Fermentation	6.24
Metals and metal-based materials	
Coke and Steel	6.5
Electrometallurgy (Purification of Metals by Electrorefining)	6.19.4
Titanium Dioxide	6.21
Silicon	6.22
Environmental protection processes	
Automotive Emission Control	6.18.1
Selective Catalytic Reduction (SCR) of NO_x from Flue Gas from Power Plants	6.18.2

1.2 The Chemical Industry

The chemical industry, which can be briefly divided in industrial inorganic and organic chemistry, is a central part of the world economy and converts raw materials like coal, oil, natural gas, biomass, air, water, salts, minerals, and metals into many thousand products.

Important inorganic chemicals are base chemicals such as ammonia, nitric and sulfuric acid, sodium hydroxide, but also products of air separation (N_2, O_2, Ar) and other technical gases such as H_2, CO, CO_2, and Cl_2. Important final inorganic products are ceramics including cement, concrete, and glass, as well as base and precious metals.

Industrial organic chemicals range from base chemicals such as ethylene, propylene, and aromatics to final products like polymers, detergents, and fine chemicals. They are mainly produced from oil derivatives, such as from naphtha and liquefied petroleum gases (LPGs), but – predominantly in North America – also from natural gas liquids (NGLs) (above all ethane and propane). These two feedstocks represent the vast majority of petrochemical sources around the world; the estimated annual production rate of organic chemicals derived from oil and natural gas is 450 million tons (see footnote a of Table 1.2.8).

Since the beginning of the nineteenth century, coal-based organic chemicals are used by the chemical industry, particularly aromatic hydrocarbons such as benzene and naphthalene, generated as by-products of blast furnace coke production in coking plants. Their annual global production is about 20 million tons (Section 5.1.5.2), which is today quantitatively of minor importance for the industrial chemistry. Dedicated coal-to-petrochemical processes are exceptional and conducted mainly in two countries: about 6 million tons of fuels (gasoline, diesel oil, jet fuel) and 1 million tons of petrochemicals like ethylene and propylene (Du Plessis 2010) are annually produced in South Africa from coal-derived syngas by Fischer–Tropsch synthesis (Section 6.11), and China produces methanol from coal via syngas, 30 million tons in 2016, 10 million tons of which are converted to olefins (Litvinenko and Meyer 2018). Overall, 50 million tons of coal-based petrochemicals are globally produced, a small amount compared with 450 million tons based on oil and gas.

Compared with the oil, gas, and coal industries, which are equally reliant on chemical technology, the chemical industry is small. In 2016, 4 of the 10 (7 of the 30) largest companies by revenue were primarily oil and gas companies, and the biggest chemical company (BASF) was ranked only 126 (Table 1.2.1). Thus, the chemical industry, most notably with regard to organic chemicals, has a "free ride" in terms of energy and fuel consumption, which is still driven by the huge demand for fossil fuels for transportation, heating, and electricity. The following numbers elucidate this: in 2016, 4.4 billion tons of oil and not much less of natural gas and coal (3.2 and 3.7 billion tons of oil equivalent (toe)) were globally consumed, but the production of organic chemicals was "only" 0.5 billion tons (see footnote a of Table 1.2.8), i.e. 4% of oil, gas, and coal production (Lippert 2018).

The oil and gas business is still dominated by a small number of huge companies, each with annual revenues of typically more than US$ 100 billion such as Sinopec, China National Petroleum, Shell, Exxon Mobil, and BP (Table 1.2.1). However, the number of chemical companies (even excluding pharmaceuticals) is much larger; in 2016, 113 companies had sales of more than US$ 2 billion each (www.icis.com). The 10 largest chemical companies by sales and a geographic breakdown of world chemicals and pharmaceuticals sales are listed in Tables 1.2.2–1.2.4. Table 1.2.5 lists the top 10 pharmaceutical companies.

In recent years the role of the chemical industry in the European Union (EU) and also in North America has decreased in terms of share of global production of chemicals (Table 1.2.3); for example, the EU-28 share in 2006 was 28% compared with 15% in 2016. The respective numbers for North America are 24% (2006) and 16% (2016). To the contrary, the share of Asia (including China, but without Japan) has strongly increased between 2006 and 2016 from 24% to 52%. China's share alone has grown from 13% (2006) to 40% (2016).

The sales of the chemical industry in the EU and North America in terms of absolute numbers have almost not changed during the last 10 years and are in both regions at US$ 500 billion (Table 1.2.3), while the sales in Asia (including China but excluding Japan) jumped up from US$ 530 billion in 2006 to US$ 1930 billion in 2016. This is equivalent to an annual growth rate of 19% in China compared with the global average of 6% (see Table 1.2.3).

A geographic breakdown of the world consumption of chemicals and pharmaceuticals in 2016 as well as of export and import data is listed in Tables 1.2.6 and 1.2.7. Thirty five percentage of the chemicals and 50% of pharmaceuticals are consumed in highly industrialized (currently rich) countries (North America, Europe, Japan, and Australia), although these countries only have a share of 17% of the global population. Forty percentage of all chemicals and 30% of pharmaceuticals are consumed in China with 19% of population. Hence, the remaining population of 64% living in Asia outside of China and Japan, in Latin America, and in Africa consume only 25% of the world's chemicals and only 20% of the pharmaceuticals.

Net importers of chemicals and pharmaceuticals are Latin America, China, North America, Africa, and the rest of Asia. The only net exporter is Europe (see Table 1.2.7). Note that the consumption values have to be consistent with the export, import, and sales data by the correlation "consumption = sales − export + import": for 2016, the data for chemicals (excluding pharmaceuticals) in the EU-28 are €467 billion consumption (Table 1.2.6), €507 billion sales (Table 1.2.3), €426 billion export, and €386 billion import (Table 1.2.7), which fulfills the correlation (467 = 507 − 426 + 386).

Global production data of important base chemicals in about 2015 are listed in Table 1.2.8. *Note that throughout this book, the term ton refers to a metric ton equaling 1000 kg*. The structure of the chemical industry is characterized by a small number of inorganic base chemicals such as sulfuric acid, ammonia, and chlorine and also a small number of organic base chemicals such as ethylene, propylene, methanol, benzene, and *p*-xylene. These base chemicals are converted into intermediates like ethylene oxide, styrene, and vinyl chloride and finally into a huge number of consumer goods such as polymers.

Global mass flows in the chemical and petrochemical sector in 2013 are listed in Table 1.2.9 for chemicals based on fossil fuels. Important secondary reactants such as water (steam), O_2, and CO_2 are included, but inorganic chemicals and reactants like acids are here not considered, although H_2SO_4 (231 million tons in 2012) is also mainly produced from fossil fuels, e.g. from sulfur obtained as by-product of desulfurization of oil and natural gas.

In total, 0.68 billion tons of fossil feedstocks and 0.96 billion tons of secondary reactants are annually converted into 0.82 billion tons of chemicals such as nitrogenous fertilizers, polymers, solvents, explosives, and other chemical products. The same amounts (0.82 billion tons) of unwanted but unavoidable secondary products such as CO_2, H_2O, CH_4, HCl, and $CaCl_2$ are formed. The amount of CO_2 produced as secondary product is huge, 0.3 billion tons, but negligibly small compared with the global CO_2 emissions of 32 billion tons.

Table 1.2.1 The 30 largest companies by revenues in 2016.

Rank	Company	Primary industry[a)]	Revenue in billion US$	Employees in 1000	Country
1.	Walmart	General merchandisers	486	2300	USA
2.	State Grid	Utilities	316	926	China
3.	Sinopec Group	Petroleum refining	268	713	China
4.	China National Petroleum	Petroleum refining	263	1512	China
5.	Toyota	Motor vehicles and parts	255	364	Japan
6.	Volkswagen Group	Automotive	240	627	Germany
7.	Royal Dutch Shell	Petroleum refining	240	89	UK/NL
8.	Berkshire Hathaway	Conglomerate	224	368	USA
9.	Apple	Computers, electronics, entertainment	216	116	USA
10.	Exxon Mobil	Petroleum refining	205	73	USA
11.	McKesson	Healthcare	199	65	USA
12.	BP	Petroleum refining	187	75	UK
13.	UnitedHealth	Healthcare	185	230	USA
14.	CVS Health	Healthcare	177	204	USA
15.	Samsung Electronics	Electronics	174	325	South Korea
16.	Glencore	Mining, crude oil production	174	93	SW/NL
17.	Daimler	Automotive	169	282	Germany
18.	General Motors	Automotive	166	225	USA
19.	AT&T	Telecommunications	164	269	USA
20.	Exor	Diversified financials	155	303	Italy
21.	Ford Motor Company	Automotive	152	201	USA
22.	Bank of China	Financial services	148	462	China
23.	AmerisourceBergen	Pharmaceuticals	147	19	USA
24.	China Construction Engineering	Construction	145	264	China
25.	AXA	Financial services	144	98	France
26.	Amazon	Internet	136	341	USA
27.	Foxconn	Electronics	135	725	Taiwan
28.	China Construction Bank	Financial services	135	362	China
29.	Honda	Automotive	129	212	Japan
30.	Total	Oil and gas	128	102	France
126.	BASF	Chemical industry	64	115	Germany

a) Shares of revenues of the 30 largest companies grouped by segments: 25% oil and gas; 19% automotive; 14% electronics, Internet, and telecommunication; 12% healthcare; pharmaceuticals; 10% financial services; and 20% others.

Source: Data from UK, United Kingdom; NL, Netherlands; SW, Switzerland; http://en.wikipedia.org/wiki/List_of_companies_by_revenue (last accessed 22.03.2018).

Today, bulk chemicals are increasingly produced in Asia and in the Middle East and not anymore predominantly in Europe, Japan, and North America. With regard to value, the most important chemicals are fine chemicals and pharmaceuticals (see Table 1.2.10 for the example of Germany in 2016). These two chemical product segments had a share of 47%, whereas the role of organic and inorganic base chemicals is in Germany comparatively small (16% and 9%, respectively). Polymers and rubber account for 20%, and soaps, detergents, and cosmetics for 8%.

Global sales of the chemical and pharmaceutical industry (US$ 5.1 trillion in 2016; Table 1.2.11) are about the same as those of the oil and gas

Table 1.2.2 The 10 largest chemical companies by sales in 2010 and 2016 (excluding pharmaceuticals) ranked by sales in 2016.

Company	Country	Sales in 2010 in billion US$ (rank)	Sales in 2016 in billion US$ (rank)
BASF	Germany	73 (1)	61 (1)
Sinopec	China	31 (4)	48 (2)
Dow Chemical	United States	45 (2)	48 (3)
SABIC	Saudi Arabia	27 (7)	35 (4)
INEOS	United Kingdom	26 (10)	33 (5)
Mitsubishi Chemical	Japan	27 (8)	30 (6)
LyondellBasell	Netherlands	31 (5)	29 (7)
ExxonMobil Chemical	United States	41 (3)	26 (8)
DuPont	United States	26 (9)	25 (9)
Air Liquide	France	17 (15)	19 (10)

Source: Data from International Chemical Information Service, www.icis.com (last accessed 22.03.2018).

Table 1.2.3 Geographic breakdown of global sales of chemicals in 2006 and 2016 ranked by sales in 2016 (chemicals excluding pharmaceuticals).

Country/region	Sales (billion €)		Share of world sales (%)		Average growth rate (period 2006–2016) (%/a)
	2006	2016	2006	2016	
China	238	1331	13.2[a)]	39.6	18.8
NAFTA[b)]	435	528	24.1[a)]	15.7	2.0
EU-28[c)]	505	507	28.0	15.1	0
Rest of Asia (excluding China and Japan)	290	596	16.1	17.8	8.0
Japan	134	140	7.4	4.2	0.5
Latin America	91	127	5.1	3.8	3.5
Rest of Europe	69	90	3.8	2.7	2.8
Rest of the world	40	41	2.2	1.1	0
Total	1803	3360	100	100	6.4

a) The strong shift of the shares of different regions during the last two decades are underlined by the numbers in 2001: China 6% (40% in 2016), NAFTA 30% (16%), and Germany 7.5% (4.3%).
b) The United States, Canada, and Mexico.
c) EU-28: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, and the United Kingdom.

Source: Data from www.cefic.org (last accessed 22.03.2018).

industry (US$ 5.3 trillion) and the electrical and electronics industry (US$ 4.5 trillion). The sales of mechanical engineering, of the automotive industry, of e-commerce, and of metals and mining are in a range of US$ 1.4–3.1 trillion. Thus, the sales share of industries directly related to chemical engineering (chemical, pharmaceutical, and oil and gas industry) within these major industrial activities is quite large: 43% compared with 18% of electrical and electronics industry, 13% mechanical engineering, 11% automotive industry, 9% e-commerce, and 6% metals and mining. Note that the metallurgical industry also relies on chemistry and chemical engineering, but this is here not considered.

Table 1.2.4 Geographic breakdown of pharmaceuticals sales in 2016.

Country/region	Sales (billion €)	Share (%)
North America (United States and Canada)	277	21.4
EU-28	277	21.4
Rest of Europe	82	6.3
Japan	56	4.3
Australia/Oceania	8	0.6
North America, Europe, Japan, and Australia/Oceania	700	54.0
China	379	29.3
Rest of Asia (without China and Japan)	175	13.5
Latin America (including Mexico)	33	2.5
Africa	8	0.6
Asia (excluding China and Japan), Latin America, and Africa	216	16.7
Total	1295	100

Source: Data from www.vci.de (last accessed 23.03.2018).

Table 1.2.5 The 10 largest pharmaceutical companies by 2016 sales.

Company	Country	Sales in 2016 (billion US$)
Novartis	Switzerland	46
Pfizer	United States	45
Hoffmann-La Roche	Switzerland	40
Sanofi	France	38
MSD	United States	37
Johnson & Johnson	United States	31
GlaxoSmithKline	United Kingdom	30
AstraZeneca	United Kingdom	26
Gilead Sciences	United States	24
AbbVie	United States	20

Source: Data from http://de.wikipedia.org/wiki/Pharmaunternehmen (last accessed 22.03.2018).

Table 1.2.6 Geographic breakdown of consumption of chemicals and pharmaceuticals in 2016.

Region/country	Consumption of chemicals		Consumption of pharmaceuticals	
	Billion €	Share (%)	Billion €	Share (%)
North America (United States and Canada)	479	13.9	336	17.2
EU-28	467	13.6	217	17.1
Rest of Europe	109	3.2	53	4.2
Japan	121	3.5	76	6.0
Australia/Oceania	23	0.7	14	1.1
North America, Europe, Japan, Australia/Oceania	*1199*	*34.9*	*696*	*55.0*
China	1372	40.0	382	30.2
Asia without China and Japan	611	17.3	120	9.5
Latin America (including Mexico)	206	5.8	50	4.0
Africa	44	1.2	18	1.4
Asia (excluding China and Japan), Latin America, Africa	*861*	*24.3*	*188*	*14.9*
World	3432	100	1265	100

Italic emphasis indicates a group of regions.
Source: Data from www.vci.de (last accessed 23.03.2018).

1.3 The Changing Global Economic Map

The production of chemicals with regard to the geographic breakdown has changed tremendously in the last decades. In 2016, Asia (excluding Japan) has a share of 57% of the global sales of chemicals compared with Europe, North America, and Japan combined with 38% (Table 1.2.3). Ten years before (2006), these numbers were quite different with a 29% share of Asia (excluding Japan) and a 63% share of North America, Europe, and Japan.

A similar trend is valid for the distribution of the global gross domestic product (GDP), which is the commonly used measure for the economic performance of a country or a region: in 2017, North America, Japan, and the EU-28 have a combined share of 54% (compared with 68% in 2006), whereas China alone had a share of 15% in 2017 compared with only 5% in 2006. So we are living in a rapidly changing world, and it is therefore worthwhile to have a closer look on the changing economic map and the historical development of economic power in countries and regions of the world.

Table 1.3.1 shows the 15 largest countries with regard to GDP in current US dollars and in purchasing power parity (PPP). In 2017, these countries accounted for 75% of global GDP in current dollars. The United States is still the strongest economy in terms of current dollars, followed by China, Japan, Germany, the United Kingdom, India, and France. Western Europe has about the same economic power

Table 1.2.7 Geographic breakdown of world export, import, and net imports (= [import – export]/import) of chemicals and pharmaceuticals (ranked by net imports in 2016).

	Chemicals (billion €)			Pharmaceuticals (billion €)			Chemicals and pharmaceuticals (billion €)		
Region/country	**Export**	**Import**	**Net imports**	**Export**	**Import**	**Net imports**	**Export**	**Import**	**Net imports**
Latin America	31	82	+51	6	23	+17	37	105	+68
China	87	128	+41	18	21	+3	105	149	+44
United States, Canada	130	109	−21	55	114	+59	185	223	+38
Africa	17	34	+17	1	12	+10	18	46	+28
Asia (excluding China and Japan)	225	240	+15	37	41	+4	262	281	+19
Australia, Oceania	4	12	+8	3	9	+6	7	21	+14
Japan	52	33	−19	5	24	+20	57	57	+0.3
Rest of Europe	41	60	+21	74	45	−29	115	105	−10
EU-28	426	386	−40	315	255	−60	741	641	−100

Source: Data from www.vci.de (last accessed 23.03.2018).

in current dollars as the United States and even outplays (as also China does) the United States in terms of purchasing power (Table 1.3.1). The Western world (the United States, Canada, Western Europe, Australia) accounts for 50% of the global GDP (current dollars).

In 2014, China's economy surpassed the United States in terms of domestic purchasing power and will probably also do so in current dollar terms in the next decade. Nevertheless, China's GDP per capita (pc) (PPP) is still by a factor of 3.5 lower, which is due to the large population of China, 1368 million compared with the United States with 326 million in 2017.

The GDP of different regions is listed in Table 1.3.2. The Global North and East Asia (Table 1.3.2, no. 1–3) have a share of 82%, whereas all remainders, namely, Latin America, Africa (including The Middle East), and South Asia, only account for 18%.

Table 1.3.3 underlines that the economies of China and India – although the latter to a smaller extent – have strongly grown in the last decades.

This trend is also reflected by the regional distribution of the GDP during the last six decades (Table 1.3.4, Figure 1.3.1). Until 2000, the United States and the EU combined had always a share of around 60%, but since then this share is shrinking to today's value of 45%. This trend is valid for all OECD countries, but for China and India the trend is opposite: between 1960 and 2000, the combined share of their global GDP was only 5%, but then rises to today's value of 18%. Japan is a special case: at first, the share of the global GDP rose strongly from 3% in 1960 to a maximum of 15% in 2000, but thereafter dropped down to today's value of 6%.

The development of the GDP pc of selected countries and regions between 1960 and 2017 is shown in Figure 1.3.2 inflation adjusted in constant 2010 US dollars. Globally, the pc GDP has tripled from US$ 3700 (at constant 2010 values) pc in 1960 to US$ 10 600 pc in 2017. The increase in China and India is even more remarkable if we consider that the population of these two countries also strongly rose in that period (Figure 1.3.3). This trend is underpinned by the GDP growth rates: since 1980, China's growth rate is higher than 8%/a and for India not much less (Table 1.3.5). To the contrary, the rates in the United States, the EU, and in Japan are much lower and vary from almost 0 to not more than 4%/a.

The GDP per person adjusted for inflation and also for differences in purchasing power of selected countries (in contrast to Figure 1.3.2) are listed in Table 1.3.6 for the period of 1800–2000.

All these figures indicate that the prominence of the Western world, namely, of Europe and North America, will further shrink to a certain extent; vice versa, the role of Asian countries such as China and India will probably still rise in the decades to come.

It is beyond the scope of this book to speculate too much about the future global economic map, but the following brief historical review of the development of economic and political power and of the associated distribution of wealth and poverty over the last five centuries (or even more) might serve as inspiration for further thoughts of the readers.

Since ancient times, civilizations and empires have gone through cycles. Over time, their political and economic power has risen, has been stable for a period and then has fallen. In this context, Table 1.3.7

Table 1.2.8 World production of important organic and inorganic base chemicals around 2016.

Base chemicals	Production (Mt)	Year
Inorganic base chemicals		
Calcium oxide	350	2016
Sulfuric acid (100%)	231	2012
Ammonia	146	2016
Chlorine	65	2016
Nitric acid (HNO_3)	55	2014
Phosphoric acid (H_3PO_4)	43	2016
Organic base chemicals[a]		
Urea [$CO(NH_2)_2$]	164 (194; www.icis.com, February 2019)	2013 (2018)
Ethylene[b), c)]	134 (153)	2014 (2017)
Propylene[b), c)]	94 (102)	2015 (2017)
Ethanol (<1% synthetic ethanol)	80	2015
Methanol	86 (42 only in China based on coal)	2016
Isobutene and *n*-butenes	49	2010
Benzene[d)]	46	2015
Formaldehyde	41	2016
p-Xylene	38	2015
Ethylene oxide	21	2012
Methyl tertiary-butyl ether (MTBE)	15	2013
Toluene[e)]	12	2013
Acetic acid	12	2014
Butadiene	11	2014
Phenol	9	2012
Acetone	7	2016

a) About 500 Mt of organic base chemicals (excluding urea and biomass-based ethanol) are produced per year: according to Lippert (2018), 450 Mt of oil derivatives and NGLs are converted by steam cracking into 360 Mt of base chemicals like olefins and aromatics (assuming a cracker yield of 80%; Section 6.6). Eighty million tons organic chemicals (methanol, Fischer–Tropsch chemicals, etc.; Table 5.1.28) are produced from syngas based on natural gas (approximately 50 Mt) or coal gasification (30 Mt), 40 Mt olefins and aromatics may be estimated as refinery products (e.g. FCC process; Section 6.7.2), and 20 Mt of aromatics are by-products of coal coking (Section 5.1.5.2). So 90% of the organic base chemicals are produced from oil and gas and 10% from coal.

b) Two-thirds of ethylene and propylene are used for polyethylene (PE) and polypropylene (PP). According to Table 5.4.19, 64% are ethylene and 66% are propylene. This is in agreement with numbers given by Lippert (2018) for 2017: 59% of ethylene for PE and 68 of propylene for PP.

c) The production of petrochemicals still increases. In 2017, the production of ethylene reached 153 million tons (41% from naphtha, 38% from ethane, 9% propane, 5% butane, 3% gas oil, and 4% from other feedstocks such as coal). This corresponds to a growth rate of 5%/a in 2014–2017; the production of propylene in 2017 was 102 million tons, which corresponds to a growth rate of 6% (Lippert 2018).

d) 5 Mt are generated as by-product of coking plants (Section 5.1.5.2), 10% of total demand. Fifty percentage are produced in refineries by reforming of gasoline (and subsequent separation), 15% by hydrodealkylation or disproportionation of toluene, and 25% are by-products of steam cracking of oil products like naphtha (25%) (Levi and Cullen 2018). This underlines that oil and gas are far more important sources of petrochemicals than coal; an exception is naphthalene (1 Mt/a), derived mainly (90%) from coal tar.

e) Only counting the net output. Production of raw toluene (in Mt) in 2013 was 23.1, 7.7 by steam cracking of naphtha and 15.4 by gasoline reforming in refineries, but 11.6 are converted by hydrodealkylation or disproportionation into benzene and xylenes.

Source: Data from www.essentialchemicalindustry.org (last accessed 22.03.2018) value for toluene from Levi and Cullen (2018), value for methanol from Zhen and Wang (2015).

Table 1.2.9 Global mass flows in the chemical and petrochemical sector in 2013: from fossil fuel feedstocks to chemical products.

Fossil fuel feedstocks and secondary reactants	Mass flow (million tons/a)	Share (%)
Coal (only for syngas production)[a)]	55	3.4
Natural gas and natural gas liquids (NGLs)[b)]	199	12.2
Refinery sourced olefins and aromatics[c)]	163	10.0
Liquid oil products[d)]	260	15.9
Total fossil feedstocks	676	41.3
Secondary reactants[e)]	960	58.7
Total feedstocks/reactants	1636	100
Chemical products and secondary products		
Nitrogenous fertilizers	275	16.8
Thermoplastics	222	13.6
Fibers and elastomers	107	6.5
Solvents, additives and explosives	107	6.5
Other chemical products	109	6.7
Total primary products	820	50.1
Secondary products[f)]	816	49.9
Total products	1636	100

a) Only coal as feedstock for syngas production and subsequent conversion to ammonia and methanol not considering by-products (e.g. benzene and naphthalene) of coking plants.
b) 50% as feedstock for syngas (natural gas) and 50% as light feedstock (NGLs) for steam cracking.
c) By-products of refineries such as fluid catalytic cracking (olefins) or reforming of gasoline (aromatics).
d) Mainly liquid crude oil products such as naphtha used as feedstock for steam cracking to produce olefins (230 million tons), but also feedstocks for production of carbon black (about 19 million tons of oil products) and for syngas production (11 million tons liquid oil products).
e) Secondary reactants (million tons/a) are H_2O (274), O_2 (221), CO_2 (152), N_2 (142), H_3PO_4 (61), and others (110). For example, 90 million tons O_2 are needed for syngas from heavy oil or coal.
f) Secondary products (million tons/a) are CO_2 (287), H_2O (140), CH_4 (43), HCl (25), $CaCl_2$ (8), and other products (313). Note that CO_2 emissions related to the consumption of electricity, heat, etc., of the chemical industry are here not counted as "secondary product."

Source: Data from Levi and Cullen (2018).

depicts the shares of global GDP and population of Western Europe, the United States, China, and India during the last five centuries. Data on the GDP pc (inflation adjusted) from even 1 CE to 2008 are given in Tables 1.3.8 and 1.3.9.

Table 1.2.10 Important products (by value) of the German chemical industry (including pharmaceuticals) in 2016 (www.vci.de, last accessed 23.03.2018).

Products	Share of total production value (%)
Organic base chemicals	16
Inorganic base chemicals	9
Polymers and rubber	20
Fine and specialty chemicals	26
Pharmaceuticals	21
Soaps, detergents, and cosmetics	8

From 1500 until the end of the eighteenth century, China and India combined had a share both of global GDP and population of around 50% (Table 1.3.7); Western Europe and the United States combined had a share of the population of 14%, whereas the share in GDP already continuously increased from 15% (1500) to 23% (1800). So in 1500, the economic power per capita in the Western world and in India/China was very close, but by the end of the eighteenth century, the GDP pc in the Western world was already 80% higher compared with China and India, where the value remained static (Tables 1.3.7–1.3.9).

In the whole period from 1 CE to 1700, the GDP pc in all regions of the world only varied in a narrow range of 0.7 (Africa) to 1.6 (Europe) relative to the global average (Table 1.3.9). Thereafter the interregional spread strongly increased. Currently (values from 2008), the differences are much broader, ranging from 0.23 (Africa) to 4.1 (United States), hence a spread of 18 : 1. This strongly rising disparity with regard to economic power started in the second half of the eighteenth century by the onset of the Industrial Revolution in United Kingdom and subsequently in continental Europe and in the United States. This is also underlined by the strong change of determinants of growth (stock of machinery, years of education, and GDP per work hour) as listed in Table 1.3.10 for the examples of the United Kingdom and the United States for 1820–1998.

The Western empires, founded in the sixteenth and seventeenth centuries, further expanded in the next two centuries (Topic 1.3.1), partly due to the superiority of European technologies. This gave the West, among other things, a military advantage over the rest of the world. The technological progress combined with the morally condemnable imperialism had an enormous influence on the distribution of economic and political power in the nineteenth and twentieth

Table 1.2.11 Global sales of chemical and pharmaceutical industry (2016), oil and gas business (2015), electrical and electronics industry (2015), mechanical engineering (2016), automotive industry (2016), e-commerce (2017), and metals and mining (2016).

Industrial sector	Sales in trillion (10^{12}) (US$)	Share (%)
Chemical industry (excluding pharmaceuticals)	3.7[a)]	15
Pharmaceutical industry	1.4[a)]	6
Oil and gas industry	5.3[b)]	22
Subtotal (industries related to chemistry and chemical engineering)	10.4	43
Electrical and electronics industry[c)]	4.5[a)]	18
Mechanical engineering	3.1	13
Automotive manufacturers and suppliers	2.8[a),d)]	11
E-commerce	2.3	9
Metals and mining	1.4[e)]	6
Total	24.5	100

a) Values in € were converted in US$ by using the average exchange rate in 2016 of 0.9 €/$.
b) Estimation based on revenues of the 48 leading oil and gas companies (including State-owned enterprises) in 2015 (top 20 with a share of 80%: Saudi Aramco, Sinopec, China National Petroleum, PetroChina, Exxon Mobil, Royal Dutch Shell, Kuwait Petroleum, BP, Total, Lukoil, Eni, Valero Energy, Petrobras, Chevron, PDVSA, Pemex, National Iranian Oil Company, Gazprom, Petronas, China National Offshore Oil).
c) Shares within electrical and electronics industry by sector: 24% electronic components and systems, 12% automation, 11% communications technology, 10% information technology, 6% power engineering, 6% household appliances, 6% consumer electronics, 3% lighting, 2% medical engineering, and 20% others.
d) Estimation based on the revenues of major car manufacturers and suppliers: the revenues of the 17 leading car manufacturers (Toyota, VW, Daimler, GM, Ford, Honda, Fiat Chrysler, SAIC, Nissan, BMW, Hyundai, Peugeot-Citroen, Renault, Kia, Mazda, Suzuki, Mitsubishi) were US$ 1.87 trillion (2016). The revenues of the 100 leading suppliers (top 10: Bosch, Continental, Denso, Magna, ZF Friedrichshafen, Hyundai, Aisin, Bridgestone-Firestone, Michelin, Faurecia) were US$ 0.93 trillion in 2016 (top 10: US$ 0.34 billion = 37% of top 100). Hence, the sum is US$ 2.8 trillion. In 2017, 74 million passenger cars, 19 million light commercial vehicles, 4 million heavy trucks, and 0.4 million buses and coaches were globally produced.
e) Estimation based on revenues of the 46 leading metal and mining companies (top 10 with share of 43%: Glencore (Al, Ni, Cu, etc.), JX Holdings (various materials), ArcelorMittal (steel), Wesfarmers (various), Thyssenkrupp (steel), Citic (steel), POSCO (steel), Itochu (steel, nonferrous metals), Rio Tinto (iron ore, coal, TiO_2, Au, diamonds), and BHP Billiton (steel, Ag, Pb, Cu)). The top 15 steel companies had a revenue based on steel of US$ 0.27 trillion.

Source: Data for chemicals and pharmaceuticals from www.vci.de; oil/gas from https://en.wikipedia.org/wiki/List_of_largest_oil_and_gas_companies_by_revenue, electrical and electronic industry from www.zvei.org, other industrial sectors from www.statista.com (all last accessed 22.3.2018).

centuries (Table 1.3.7): in 1900, Western Europe and the United States had reached a share of 48% of GDP compared with China and India with 20%, although the shares of the global population were 21% (Europe, United States) and 40% (India, China). Hence, the Western world doubled its GDP share in the nineteenth century, and the share of India and China more than halved.

After WWII, the GDP share of Western Europe and the United States was still high, 52% in 1950, and low for China and India (9%), but since 1990 (Tables 1.3.3–1.3.9, Figure 1.3.1), the GDP and GDP shares of China and India are increasing, and those of Western countries are shrinking. The future will show whether and to what extent this trend will continue.

The remarkable achievements of mankind (despite the morally condemnable imperialism) over the last 200 years can be illustrated by the number and share of the global population living in extreme poverty: 94% in 1820, 90% in 1870, 76% in 1930, 60% in 1970, 37% in 1990, but "only" 10% in 2015. Since 1970, even the absolute number of extreme poor is shrinking (Figure 1.3.4): in 1820, there were 1.1 billion people in the world, of which the vast majority lived in extreme poverty. Over the next 150 years, the decline of the share of extreme poor people was not fast enough to offset the rapid rise of the world population, so both the number of non-poor *and* poor rose although the share of extreme poor continuously dropped. Since then, even the number of poor fell from the maximum

Table 1.3.1 The 15 largest countries and selected regions by gross domestic product (GDP) in 2017 ranked by GDP in current US dollars.

	GDP in 2017 (current US$)			GDP in 2017 (US$) based on purchasing power parity[a)]		
Country	**Trillion $**	**Share (%)**	**1000 $ pc**	**Trillion $**	**Share (%)**	**1000 $ pc**
United States	19.4	24.0	59.5	19.4	16.1	59.5
China	12.2	15.2	8.8	23.3	19.3	16.8
Japan	4.9	6.0	38.4	5.6	4.6	43.9
Germany	3.7	4.6	44.5	4.2	3.5	50.7
United Kingdom	2.6	3.3	39.7	2.9	2.4	43.9
India	2.6	3.2	1.9	9.5	7.9	7.1
France	2.6	3.2	38.5	2.9	2.4	42.8
Brazil	2.0	2.5	9.8	3.2	2.6	15.5
Italy	1.9	2.4	31.9	2.4	2.0	39.8
Canada	1.7	2.0	45.0	1.7	1.4	46.4
Russian Federation	1.6	2.0	10.7	3.7	3.1	25.5
South Korea	1.5	1.9	29.7	2.0	1.7	38.3
Australia	1.3	1.6	53.8	1.2	1.0	47.0
Spain	1.3	1.6	28.2	1.8	1.5	38.1
Mexico	1.2	1.4	8.9	2.3	1.9	18.1
World	80.7	100	10.7	120.8	100	16.2
Listed countries in total	60.5	75	—	86.1	71	—
Western Europe[b)]	18.4	22.8[b)]	34.7	21.2	17.5	40.2
Western world[c)]	40.7	50.4	—	43.5	36	—
OECD members	49.6	61.4	—	54.1	44.8	—

a) Purchasing power parity (PPP) is here – as usual – related to the purchasing power in the United States.
b) European Union (EU-28) including Norway, Switzerland, and Iceland. In 2000 (number needed in Table 1.3.4), the share was 27%. EU-28 only (2017): 17.3 trillion in current dollars and 20.3 trillion based on PPP.
c) The United States, Canada, Western Europe, and Australia.
Source: Data from www.data.worldbank.org (last accessed 7.09.2018).

Table 1.3.2 Gross domestic product (GDP) of different continents/regions in 2017 ranked by GDP in current US dollars.

		GDP in 2017 (current US$)	
	Continent/region	**Trillion (10^{12}) $**	**Share (%)**
1.	East Asia and Pacific	24.00	29.7
2.	Europe and Central Asia	21.44	26.6
3.	North America (United States, Canada)	21.05	26.1
4.	Latin America and Caribbean	5.95	7.4
5.	South Asia[a)]	3.29	4.1
6.	Middle East and North Africa	3.27	4.0
7.	Sub-Saharan Africa	1.65	2.0
	World	80.7	100

a) India, Pakistan, Bangladesh, Afghanistan, Bhutan, Nepal, and Sri Lanka.
Source: Data from www.data.worldbank.org (last accessed 7.09.2018).

Table 1.3.3 Development of the gross domestic product (GDP) of the United States, the European Union, Japan, South Korea, China, and India between 1960 and 2017 in trillion US$ (inflation adjusted, constant 2010 US dollars).

	GDP in trillion (10^{12}) US$ (constant 2010 $)						
Year	**1960**	**1970**	**1980**	**1990**	**2000**	**2010**	**2017**
United States	3.1	4.8	6.5	9.1	12.7	15.0	17.3[a)]
European Union (EU-28)	4.1	6.8	9.3	11.8	14.8	17.0	18.8
United States and EU combined	7.2	11.6	15.8	20.9	27.5	32.0	36.1
Japan	0.8	2.0	3.0	4.7	5.4	5.7	6.2[a)]
South Korea	0.02	0.06	0.14	0.36	0.71	1.1	1.3[a)]
China	0.13	0.19	0.34	0.83	2.2	6.10	10.2[a)]
India	0.14	0.20	0.27	0.47	0.80	1.7	2.6[a)]
China and India combined	0.26	0.39	0.61	1.30	3.0	7.8	12.8
Rest of world	3.0	5.2	8.5	11.0	14.1	20.6	25.1

a) The values for 2017 given in Table 1.3.2 differ from those of Table 1.3.1, as the numbers in the former case are chained to the value of the US dollars of the year 2010.
Source: Data from: www.data.worldbank.org (last accessed 7.09.2018).

Table 1.3.4 Share of global GDP of the United States, European Union, Japan, South Korea, China, and India between 1960 and 2017 (GDP in current US dollars).

	Shares of global GDP (current US$) (%)						
Year	**1960**	**1970**	**1980**	**1990**	**2000**	**2010**	**2017**
United States	39.8	36.4	25.6	26.5	30.6	22.7	24.0
European Union (EU-28)	26.3	28.9	34.5	33.5	26.5	25.8	21.4
United States and EU combined	*66.1*	*65.3*	*60.1*	*60.0*	*57.1*	*48.5*	*45.4*
Japan	3.2	7.2	9.9	13.9	14.6	8.6	6.0
South Korea	0.3	0.3	0.6	1.2	1.7	1.7	1.9
China	4.4	3.1	1.7	1.6	3.6	9.2	15.2
India	2.7	2.1	1.6	1.4	1.4	2.5	3.2
China and India combined	*7.0*	*5.2*	*3.4*	*3.0*	*5.0*	*11.8*	*18.4*
Rest of world	*23.6*	*22.3*	*26.6*	*23.1*	*23.3*	*31.2*	*30.1*
OECD members	78.4	80.9	78.5	82.9	81.6	67.6	61.4

Italic emphasis indicates the sum of US and EU.
Source: Data from www.data.worldbank.org (last accessed 8.09.2018).

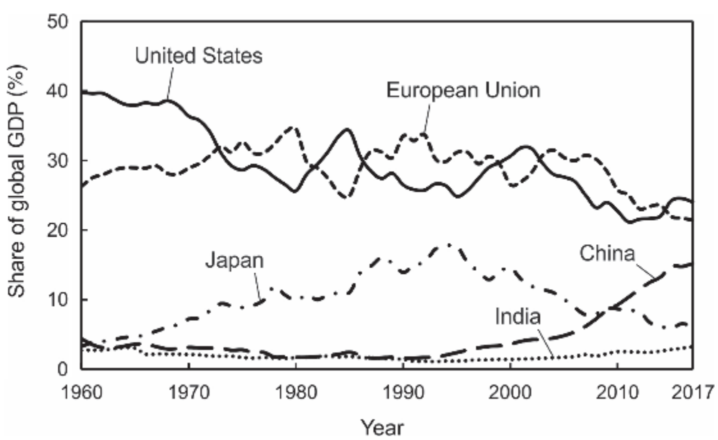

Figure 1.3.1 Share of global GDP of the United States, the European Union, Japan, China, and India between 1960 and 2017 (GDP in current US dollars). Source: Data from www.data.worldbank.org (last accessed 8.09.2018).

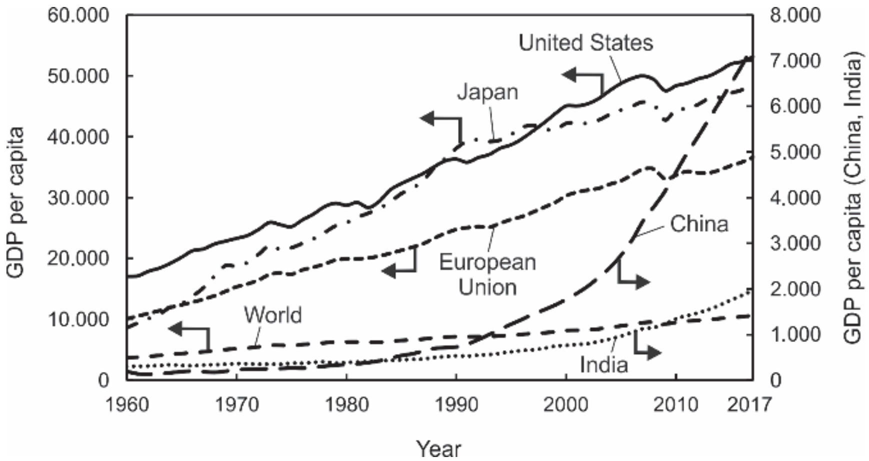

Figure 1.3.2 GDP *per capita* in selected countries and regions (1960–2017) (constant 2010 US dollars; www.data.worldbank.org, last accessed 9.10.2018). Values for 2017 slightly differ from Table 1.3.1. Here, the GDP value is inflation adjusted in constant 2010 dollars; numbers in Table 1.3.1 refer to 2017 value.

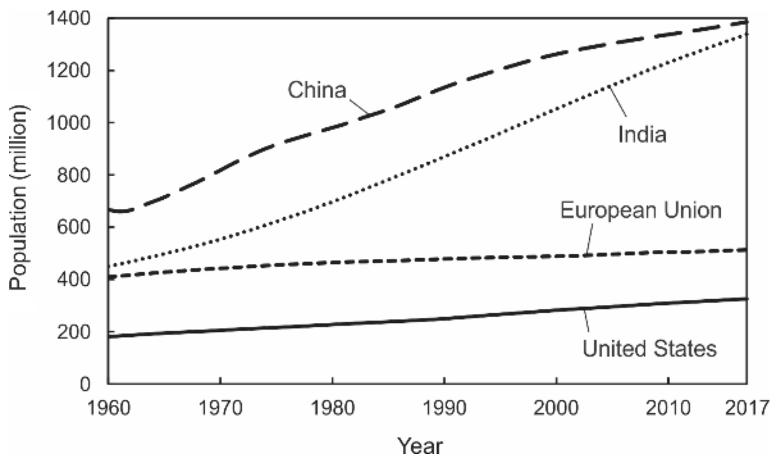

Figure 1.3.3 Development of the population of the United States, the European Union, China, and India between 1960 and 2017. Source: Data from: www.data.worldbank.org (last accessed 12.09.2018).

Table 1.3.5 Average annual growth rate of the GDP of selected countries and regions between 1970 and 2017 ranked by decreasing value in 2010–2017.

	Average annual growth rates of GDP (%/a)				
Year	**1970–1979**	**1980–1989**	**1990–1999**	**2000–2009**	**2010–2017**
China	7.4	9.7	10.0	10.4	7.9
India	2.9	5.7	5.8	6.9	7.3
United States	3.5	3.1	3.2	1.8	2.2
EU-28	3.6	2.3	2.2	1.6	1.5
Japan	4.3	4.3	1.5	0.5	1.5
World	4.2	3.0	2.7	2.8	3.9

Source: Data from www.data.worldbank.org (last accessed 29.12.2018).

Table 1.3.6 GDP per person adjusted for inflation and differences in purchasing power (fixed 2011 prices) in selected countries between 1800 and 2000.

	GDP pc in US$ 1000 (PPP, inflation adjusted)				
Year	**1800**	**1850**	**1900**	**1950**	**2000**
United States	2.1	3.1	7.0	15.0	49.4
Germany	1.6	2.2	4.6	6.9	40.4
Japan	1.1	1.1	1.8	2.5	35.8
China	1.0	1.0	0.9	0.5	9.5
India	1.0	1.1	1.2	0.9	4.4

Source: Data from www.gapminder.org (last accessed 25.10.2018).

of 2.2 billion in 1970 to 0.7 billion in 2015, which is still too much.

The huge improvement of the global material living conditions – at least on average – in the last two centuries can be also well illustrated by the following numbers:

- Between 1820 and today, the global average GDP pc (inflation adjusted) increased by a factor of more than 10 (Tables 1.3.8 and 1.3.9) compared with the relatively small increase of only 40% within almost the two former millennia between 1 and 1820 CE.

Table 1.3.7 Western Europe, the United States, China, and India: shares of global GDP and of population in the last five centuries (estimations of GDP until 1950 from Ferguson (2012); for 2000/2017 see Tables 1.3.1 and 1.3.4; estimation of population shares until 1900 from www.visualizingeconomics.com, accessed 25.10.2018).

Year	1500	1600	1700	1800	1900	1950	2000	2017
	Shares of global GDP (%, estimations until 1950)							
Western Europe	15	17	19	21	32	25	27	23
United States	—	—	—	2	16	27	31	24
China	25	29	23	31	12	5	4	15
India	24	23	25	17	8	4	1	3
Western Europe and United States	15	17	19	23	48	52	57	47
China and India combined	49	52	48	48	20	9	5	18
Rest of world	36	31	33	29	32	39	36	35
	Shares of global population[a] (%, estimations until 1900)							
Western Europe and United States[b]	13	13	14	14	17	—	—	11
China and India combined	48	52	51	55	41	—	—	36
Rest of world	39	35	35	31	42	—	—	54[c]
	Ratio of share of GDP to share of population (rounded values)							
Western Europe and United States	1.2	1.3	1.4	1.6	2.8	—	—	4.3
China and India combined	1.0	1.0	0.9	0.9	0.5	—	—	0.5
Interregional spread: ratio of GDP pc in Western Europe and the United States and GDP pc in China and India								
	1.2 : 1	1.3 : 1	1.6 : 1	1.8 : 1	6 : 1	—	—	9 : 1
Global GDP in total (purchasing power parity, inflation adjusted) relative to 1500								
	1	1.3	1.5	2.8	11	21	205 (2008)	

a) Global population (in billion): 0.46 (1500), 0.55 (1600), 0.60 (1700), 0.99 (1800), 1.65 (1900), 2.6 (1950), and 7.5 (2017).
b) US population (excluding Native Americans until 1900) in million: 0.05 (1650), 0.25 (1700), 5.3 (1800), 76 (1900), and 326 in 2017 (https://en.wikipedia.org/wiki/demographic_history_of_the_United_States, accessed 8.11.2018). The numbers of Native Americans living in the area of the United States given by Ubelaker (1988) based on tribe-to-tribe estimates are 1.6 million in 1600, 1.2 in 1700 (83% of total US population), 0.9 in 1800 (15%), 0.5 in 1900 (0.6%), and 1.1 in 1970 (0.5%). In the census 2000, 2.9 million people reported American Indian or Alaska Native alone, and 2.3 million reported Native in combination with other races (5.2 million in total, 1.6% of US population). It is difficult to determine how many natives lived in the area of the United States before Columbus. Most estimates range from 1 to 12 million (Lord 1997); the numbers given by Maddison (2005) and Ubelaker (1988) are 2.3 (including Canada) and 1.7 million, respectively; comparison with the number of only 0.5 million Natives in 1900 underlines that the Indian population of North (and also Latin) America suffered a catastrophic collapse between 1492 until 1900.
c) Rising share of rest of world in 1900–2017 is mainly the result of Africa's fast-growing population: share of 7% in 1900 (120 million), 9% in 1950 (230 million), and 17% in 2017 (1.3 billion).

Source: Data from https://en.wikipedia.org/wiki/List_of_regions_by_past_GDP_(PPP), accessed 7.11.2018. In 1500, global GDP was US$ 250 billion (in 1990 international dollars) compared with 2008 with 51 000 billion.

- In 1820, the GDP pc (in 1990 US dollars) was only about US$ 1200 in both Europe and the United States (Table 1.3.8); this is the value reached in India, a country considered as poor, in 1990. In 1900, the GDP pc (still in 1990 dollars) has increased in Europe and the United States to 2900 and 4100, respectively; this is comparable with the actual value in India (3000) in 2008.
- These historical developments and improvements of the GDP pc can also be illustrated very well taking Germany as a currently rich country as example, as depicted in Table 1.3.11 for the period 1700–1995. In addition to Germany's GDP pc, countries are named where the respective historical value of Germany was reached in 2017. In 1850, the GDP pc in Germany was not higher than today in Kenya, in 1913 comparable with Guatemala today, and even in 1960 not higher than today in Costa Rica.

Closely linked to this remarkable improvement in global mean material living conditions in the last two centuries are improvements with regard to health (life expectancy) and education (literacy rate):

- The global average life expectancy was only 29 years in 1820, increased to 48 years until 1950, and rose further to today's value of 72 years (2016), ranging today from around 50 years in still poor

Table 1.3.8 GDP per capita (inflation adjusted in 1990 international dollars) from year 1 CE until 2008 CE in selected countries and regions according to Angus Maddison from the University of Groningen, Netherlands (http://www.ggdc.net/maddison/oriindex.htm, accessed 7.11.2018; see also Maddison (2005)).

	GDP pc in US$ 1000 (inflation adjusted in 1990 US$)									
Year	**1**	**1000**	**1500**	**1600**	**1700**	**1820**	**1900**	**1950**	**1990**	**2008**
Western Europe	0.58	0.43	0.77	0.89	0.99	1.19	2.89	4.57	15.91	21.67
United States	0.40				0.53	1.26	4.09	9.56	23.20	31.18
Australia	0.40					0.52	4.01	7.41	15.91	25.30
Former USSR	0.40		0.50	0.55	0.61	0.69	1.24	2.84	6.89	7.90
Japan	0.40	0.43	0.50	0.52	0.57	0.67	1.18	1.92	18.79	22.82
China	0.45	0.47	0.60				0.55	0.45	1.87	6.73
India	0.45		0.55			0.53	0.60	0.62	1.31	2.98
Asia (total)	0.46	0.47	0.57			0.58	0.64	0.72	2.78	5.61
Latin America	0.40		0.42	0.44	0.53	0.69	1.11	2.51	5.07	6.97
Africa (total)	0.40	0.42					0.60	0.89	1.42	1.78
World	0.47	0.45	0.57	0.60	0.62	0.67	1.26	2.11	5.15	7.61
World relative to year 1 CE	1	0.96	1.21	1.28	1.32	1.43	2.68	4.49	10.96	16.19

Table 1.3.9 GDP per capita relative to global average between 1 CE and 2008.

	GDP pc relative to global average (in inspected year)									
Year	**1**	**1000**	**1500**	**1600**	**1700**	**1820**	**1900**	**1950**	**1990**	**2008**
Western Europe	1.23	0.96	1.35	1.48	1.60	1.78	2.29	2.17	3.09	2.85
United States	0.85	0.89	0.70	0.67	0.85	1.88	3.25	4.53	4.50	4.10
Australia	0.85	0.89	0.70	0.67	0.65	0.78	3.18	3.51	3.09	3.32
Former USSR	0.85	0.89	0.88	0.92	0.98	1.03	0.98	1.35	1.34	1.04
Japan	0.85	0.96	0.88	0.87	0.92	1.00	0.94	0.91	3.65	3.00
China	0.96	1.04	1.05	1.00	0.97	0.90	0.44	0.21	0.36	0.88
India	0.96	1.00	0.96	0.92	0.89	0.79	0.48	0.29	0.25	0.39
Asia (total)	0.98	1.04	1.00	0.95	0.92	0.87	0.51	0.34	0.54	0.74
Latin America	0.86	0.88	0.74	0.73	0.86	1.04	0.88	1.19	0.98	0.92
Africa (total)	0.85	0.93	0.74	0.70	0.68	0.63	0.48	0.42	0.28	0.23
Interregional spread	1.4 : 1	1.2 : 1	1.9 : 1	2.2 : 1	2.5 : 1	3 : 1	7 : 1	22 : 1	16 : 1	18 : 1

Source: See Table 1.3.8.

African countries such as Sierra Leone (52 years) and Nigeria (53 years) to 84 years in Japan (www.ourworldindata.org; www.worldbank.org, last accessed 9.10.2018). The historical development and improvement of life expectancy in a currently rich country is depicted in Table 1.3.12 for the example of Germany for the period of 1875 until 1990. In addition, countries are named where the respective historical value of Germany was reached in 2016. Until about 1900, the life expectancy in Germany was lower than in any country today, in 1925 not higher than today in Burundi, in 1950 comparable with Kenya today, and even in 1980 not higher than today in Paraguay.

- The global literacy rate strongly increased during the last two centuries: 12% in 1800, 21% in 1900, 36% in 1950, 56% in 1970, and 85% in 2014. Today, all countries outside Africa with the exception of Afghanistan (32% in 2011) have rates above 50% (www.ourworldindata.org/literacy, last accessed 9.10.2018). African countries with a rate below 50% only mentioned for completeness are Niger (15% in 2012), Chad (22% 2016), Sierra Leone (32% 2011), Benin (33% 2012), Mali (33% 2015), Burkina Faso (35% 2014), Gambia (42% 2013), Senegal (43% 2013), Cote d'Ivoire (44% 2014), and Guinea-Bissau (46% 2014).

Table 1.3.10 Determinants of growth in the United Kingdom and the United States in the period 1820–1998.

Year	United Kingdom	United States	United Kingdom	United States
	Machinery and equipment pc (1990 US$)		Years of education per person employed	
1820	92	87	2	1.8
1870	334	489	4.4	3.9
1913	878	2 749	8.8	7.9
1950	2 122	6 110	10.6	11.3
1973	6 203	10 762	11.7	14.6
1998	11 953	25 153	15.1	19.5
Change 1998/1820 (%)	+13 000	+29 900	+760	+1 080
	Hours worked per head of population		GDP per work hour (1990 US$)	
1820	1 153	968	1.5	1.3
1870	1 251	1 084	2.6	2.3
1913	1 181	1 036	4.3	5.1
1950	904	756	7.9	12.7
1973	750	704	16.0	23.7
1998	657	791	27.5	34.6
Change 1998/1820 (%)	−43	−18	+1 830	+2 660

Source: Data from http://www.ggdc.net/maddison/oriindex.htm (last accessed 7.11.2018); see also Maddison (2005).

Topic 1.3.1 The European Colonial Period

The European colonial period or imperialism began at the end of the fifteenth century with the *age of discoveries* led by the Portuguese and Spanish exploration of the Americas and the coasts of Africa, India, and East Asia. In the seventeenth century, England, France, and the Dutch Republic also established overseas empires. In 1500, the future imperial powers of Europe accounted for only 10% of the global land surface and at most 16% of its population (Ferguson 2012). By 1800, so just at the beginning of Industrial Revolution, Europeans already controlled 35% of the globe (https://en.wikipedia.org/wiki/colonialism; last accessed 11.09.2018). During the Industrial Revolution, the Western world obtained the technological and thus also the military superiority over the rest of the world by inventions such as the steam engine (1769), steam locomotive (1829), automobile with internal combustion engine (1885), and airplane (1903), just to name a few (see Section 5.1.7.2). At the onset of WWI (1914), 11 Western empires – Austria, Belgium, France, Germany, Italy, Netherlands, Portugal, Spain, Russia, the United Kingdom, and the United States – controlled 60% of the global territory and 80% of the population (Ferguson 2012).

To elucidate the extent of the morally condemnable European imperialism, only 10 countries, representing 5% of the global land area, have never been colonized by Europeans, namely, Afghanistan, Bhutan, Iran, Japan, Mongolia, Nepal, North and South Korea (temporary ruled by Japan and China), Thailand, and Turkey, although some of these countries were temporarily at least in the European sphere of influence. Even if we count Ethiopia, only occupied by Italy for a short period (1936–1941), and China, where only coastal areas were temporary controlled by Europeans, the total never colonized land area is only 12%.

It should be mentioned that besides a superior technology and its ruthless use, other factors also had a strong influence on the development of the economic and political power of the Western world since 1500 and of a civilization in general. According to Ferguson (2012) these (debatable) additional five factors are as follows:

- Competition by decentralization of political and economic life created the launch pad for capitalism.
- The production and purchase of consumer goods played a central economic role; without this consumer society, the Industrial Revolution would have been unsustainable.
- Property rights, protecting private owners and peacefully resolving disputes between them, formed the basis for the most stable form of representative government.
- Medicine improved health and life expectancy in Western societies and later in their colonies.
- The work ethic, a moral framework such as Protestant Christianity in the United States, Northern Europe, and parts of Western Europe, provided the glue for a dynamic, successful, and otherwise unstable society.

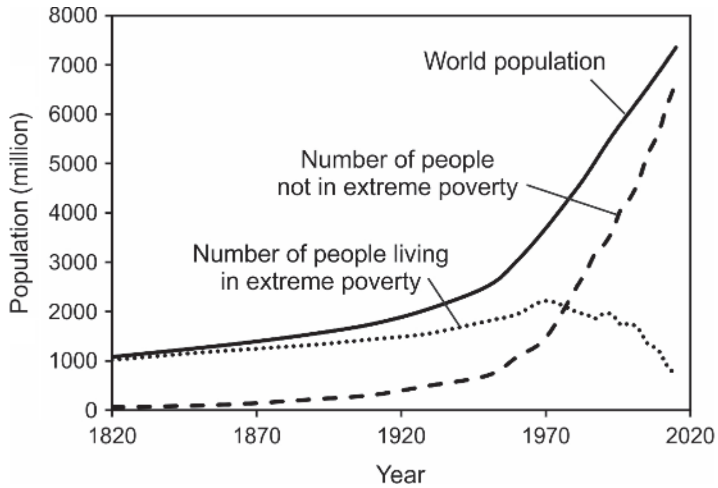

Figure 1.3.4 World population living in extreme poverty over the last 200 years (1820–2015). Extreme poverty is defined as living with less than 1.9 US$/day in 2011 purchasing power parity. Source: Data (and further details): www.ourworldindata.org/extreme-poverty (last accessed 08.10.2018).

Table 1.3.11 Historical development of GDP per capita (pc) in Germany 1700 until 1995 and country where the respective value of Germany was reached in 2017 (values in purchasing power parity, PPP, in 2011 international dollars).

Year	GDP pc in Germany (rounded values in 2011 US$ PPP)	Country where Germany's GDP pc (in the indicated year) was reached in 2017
1700	1 900	Zimbabwe
1850	2 900	Kenya
1870	3 700	Zambia
1913	7 400	Guatemala
1929	8 200	Jamaica
1937	9 500	Namibia
1960	15 600	Costa Rica
1973	24 200	Greece
1995	34 600	Spain

Source: Data from https://data.worldbank.org (last accessed 9.11.2018).

Table 1.3.12 Historical development of life expectancy in Germany 1875 until 1990 and country where the respective value of Germany was reached in 2016 (historical values of Germany: https://ourworldindata.org/life-expectancy; values of 2016: https://data.worldbank.org, accessed 9.11.2018).

Year	Life expectancy in Germany (years)	Country where Germany's life expectancy (in the indicated year) was reached in 2016
1875	38	None (Sierra Leone had the lowest value of 52 years in 2016)
1895	42	
1925	57	Burundi, Guinea-Bissau
1950	67	Kenya, Senegal, Guyana
1960	70	Nepal, Iraq
1980	73	Guatemala, Paraguay
1990	75	Thailand, Malaysia, Peru, Venezuela

More interesting aspects and details of human progress in the past are outlined, for example, by Hans Rosling (2018) and Steven Pinker (2018).

BUT on the other side of the coin of the growing average global prosperity, hopefully – as in the past decades – combined with a further drop in the number of extreme poor people, are environmental problems such as climate change, pollution of air, soil, and water, destruction of nature, and declining reserves and resources of raw materials such as of some metals and of easily exploitable (cheap) fossil fuels (see Sections 5.1, 5.2, and 5.4).

In addition, the human population is likely to keep growing until 2100, reaching an estimated 10 billion by 2050 and 11 billion by 2100. This is by all means a huge challenge with regard to a sufficient supply of humanity with food, clean water, and much less CO_2 generating energy sources (wind, solar, etc.) for electricity, heat, and transport.

To face these serious challenges with success, we should look with optimism into the future and not in the belief of an approaching apocalypse. "Enlightened environmentalism" is needed and not "misanthropic environmentalism," as Steven Pinker (2018) pointedly put it: "Problems are solvable. That does not mean that they will solve themselves, but it does mean that we can solve them if we sustain the benevolent forces of modernity that have allowed us to solve problems so far, including societal prosperity, wisely regulated markets, international governance, and investments in science and technology."

In any event, clever chemical technologies will be an important part of the solution to these challenges, and the development of sustainable chemical technologies is more important than ever to enable a positive development of mankind on our planet.