

Martin Bertau · Heribert Offermanns
Ludolf Plass · Friedrich Schmidt
Hans-Jürgen Wernicke *Editors*

Methanol: The Basic Chemical and Energy Feedstock of the Future

Asinger's Vision Today

 Springer

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Based on "Methanol - Chemie- und Energierohstoff:
Die Mobilisation der Kohle" by Friedrich Asinger
published in 1986. Includes contributions by more than
40 experts from Industry and Academia.

 Springer

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Preface

The world population is increasing dramatically; fossil fuels are finite, and farmland as well as pastureland is limited or even declining. Therefore, the question of how to supply mankind not just with raw materials, fuels and energy, but also with food has been a topic of importance to the scientific community for a long time. The discussion has even intensified since “The Limits to Growth” was published by the Club of Rome, since climate conferences (Montreal 2005 etc.) have taken place, and especially since Germany’s nuclear power phase-out.

The pioneer of petrochemistry in research and teaching, Friedrich Asinger from RWTH in Aachen, Germany, very early drew attention on to the waste of fossil fuels and proposed alternative concepts to secure raw material supply for the chemical and energy industry. In his book, published in 1986, he recommended methanol as a suitable basic chemical that can be easily stored and used as fuel or a fuel additive, as well as a chemical or energy raw material. He worked on this book without any help. He searched for, found and selected (and commented on) every citation completely on his own. With his book’s subtitle “The Mobilisation of Coal” he indicated a medium-term solution—doing without oil and gas as fuels in the shortest possible timeframe. He also developed visions for a time after coal, oil and gas.

When all fossil fuel sources are exhausted, only CO₂ will be left (in the atmosphere and in the oceans) and—up to a point—Biomass.

Because Asinger’s book is out of print and has never been translated into English, and because the issue of methanol as a chemical and energy feedstock is—now more than ever—a “hot topic”, the time for a new book (in memory of Asinger, in a broad sense) has come.

Heribert Offermanns, a former student and assistant to Friedrich Asinger, took the initiative to gather a team of five editors—four of them with industrial experience and one who is professor at Freiberg University of Mining and Technology—with the aim of publishing a second revised edition that comprehensively documents the latest state of development in the field of methanol generation and usage. Also playing an active part in authoring this book, the editors succeeded in finding 46 well known experts from industry, academia and governmental research facilities as authors for the new edition.

The book is divided into a general and a more specific part. The general part begins with Asinger's vita, a short history of methanol and its present importance, as well as visions for the future beyond oil and gas: "Fossil Raw Materials—What Comes Next?" by Willi Keim, Aachen and "Technical Photosynthesis" by Franz X. Effenberger, Stuttgart. The extensive specific part, with contributions from the respective experts, provides information on the raw materials and their conditioning for methanol synthesis, as well as methanol synthesis itself. New topics include the physical and toxicological properties and issues of transport and storage. Methanol use as fuel and energy feedstock is addressed, as is its potential as an oil and gas substitute and as chemical feedstock. The book comprises eight chapters, and the number of literature citations exceeds 3,000. In particular, [Chap. 4](#) (dealing with methanol feedstock and its conditioning) and [Chap. 6](#) (methanol use) were substantially extended in comparison to the "old" Asinger. Of special value is access to the 1,400 references of the "Asinger" of 1986.

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From the Institute of Chemical Technology, Freiberg University of Mining and Technology, we wish to thank Valentin G. Greb and Ringo Heyde for skilled and sophisticated graphical illustrations. Particular thanks are also owed to Ramona Handrek, Sebastian Hippmann, Michael Kraft, Tom Lorenz, Gunter Martin, Carsten Pätzold, Lydia Reichelt, Martin Seifert and Eric Weingart for proofreading the manuscript and helpful discussions. Steffen Braun, Freiberg University of Mining and Technology, is thanked for installing and patiently maintaining electronic data exchange. Sincere thanks are due to Norbert Ringer, Clariant Produkte Deutschland GmbH, for reviewing the chapters related to methanol synthesis and synthesis gas generation. Wolfgang Hildebrand, a former Lurgi colleague, gave very helpful advice regarding syngas and methanol processes, and Sandra Schröder of Air Liquide Global E&C Solutions prepared many figures and schemes.

Last but not least, we wish to express our utmost thanks to our families for showing never-ending patience and understanding. Finishing this book took much more effort and time than originally scheduled, so thank you all very much!

Freiberg, Hanau, Kronberg, Rosenheim, Wolfratshausen in February 2014.

Martin Bertau
Heribert Offermanns
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About the Editors



Martin Bertau Chair of Chemical Technology at Freiberg University of Mining and Technology, received his Ph.D. in 1997 at the University of Freiburg. He then headed the biotechnology division of Rohner Ltd. (Dynamit-Nobel group) in Basel, Switzerland. In the year 2000, he moved to Dresden University of Technology, where he received his *venia legendi* as well as *facultas docendi* both for biochemistry and organic chemistry in 2005. Since 2006, he has been heading the Institute of Chemical Technology at Freiberg University of Mining and Technology. His key areas of activity comprise resource chemistry and white biotechnology with

the aim of developing integrated processes (zero-waste concept) for producing and recycling of chemistry raw materials such as strategic metals (rare earth metals, lithium, indium and others) and phosphorous, but also utilising CO₂ as well as lignocellulose for the production of base chemicals. For his work on the first industrial process for phosphate recycling, in 2012 he was awarded the resource efficiency prize of the German Federal Ministry of Economics and Technology.



Heribert Offermanns studied Chemistry at the RWTH Aachen, where he received his diploma in 1963. His doctoral degree was earned at the Institute of Technical Chemistry and Petrochemistry of the RWTH Aachen (under Prof. Dr. Friedrich Asinger) in 1966. He joined Degussa AG, Frankfurt in 1968 and served in various positions (R&D of organic chemistry, drug research, production of fumed silica and corporate technology in Germany, Belgium and the United States). From 1976 until retirement in 1999, he was for nearly 25 years a member of the Executive Board, where he was responsible for Central Functions (R&D, Chemical Engineering),

operational activities (Industrial Chemicals) and regions (United States, South America). Under his leadership, Degussa entered very successfully the field of biotechnology (mainly amino acids). He was a member of the council of the Johann-Wolfgang-Goethe-University, Frankfurt, a board member of the “Freunde und Förderer” of the university, and honorary professor. He served as a senator of the German Science Foundation (DFG). He also was member and later on president of the Chemical Industry Fund (*Fonds der Chemischen Industrie*) and for 13 years was a member of the board of the German Chemical Society. He was awarded Dr.-Ing. E.h. of RWTH Aachen, honorary member of the *Physikalischer Vereins* (Frankfurt) and of the *Wilhelm-Ostwald-Gesellschaft* (Großbothen), the *Carl-Duisberg-Plakette der GDCh*, the *Karl-Winnacker-Preis* of the *Marburger Universitätsbund*, and the *Bundesverdienstkreuz First Class*.



Ludolf Plass studied Mechanical Engineering at the Technical University in Darmstadt and graduated with a Ph.D. in chemical engineering from the University of Erlangen-Nuremberg. He has been employed with Lurgi GmbH for 40 years, among others in charge of the Lurgi Division for Coal and Power Technologies and the Company Lurgi Energy and Environmental Technologies GmbH. For several years, he has taken the function of chief technology officer of the Lurgi Group as executive vice president, responsible for Lurgi’s technological processes including R&D. In 2006, he took the

responsibility for product management and in 2008 for special projects. He served as chairman and board member of several Lurgi Affiliates and Joint Ventures in Germany, France, Italy, the United Kingdom, Spain, China, Australia and South Africa. He retired from Lurgi in 2009. He continued to work as senior advisor to the management board of Air Liquide E&C Solutions until the end of 2013. Aside from his work with Lurgi, he was a member of the Board of Directors of DECHEMA, and worked in several VDMA organisations/functions.

His present assignments include chairman of the advisory board of Schaefer Kalk, Diez, Lahn; chairman of the advisory board of Techno-Physik GmbH, Essen; member of the industry council Finatem Beteiligungs Gesellschaft Frankfurt, Main; Chairman of the advisory board of Ecoloop GmbH, Duisburg/Elbingerode/Harz; and chairman of the supervisory board of Christopherus Heim, Welzheim. In addition he is member of the advisory board of FMW Industrieanlagen GmbH, Kirchstetten (Austria).



Friedrich Schmidt was born in Beuthen, Germany (today Bytom, Poland), in 1943. He studied chemistry at the University of Hamburg, where he received his Ph.D. in 1973. Thereafter, he was an academic assistant at the University of Hamburg. In 1982, he was awarded the *venia legendi* on completion of his habilitation in physical chemistry at the University of Hamburg. From 1983 to 1986, he was Professor of Physical Chemistry at the University of Hamburg, Germany. From 1986 to 1992, he held various positions at the Munich-based Süd-Chemie, Germany; in 1993, he was appointed Director of Süd-Chemie Catalyst Development. He retired in 2002. He was a founding member and (from 2002 to 2006) chairman of the board of CONNECAT, the German Network of Catalysis.



Hans-Jürgen Wernicke studied Chemistry at the University of Kiel and received his Ph.D. in 1976 (supported by a grant from the German Chemical Industry Association). From 1976 to 1984, he was employed with Linde AG, Munich, where he was involved in engineering and construction of petrochemical plants, and assisted with the startup of a coal-to-liquids complex in South Africa. In 1985, he changed to Süd-Chemie AG, München, where he held various positions in the catalyst division, was active as project manager of zeolite catalysts, and assisted with the startup of a gas-to-liquids complex in South Africa. He was business unit manager of petrochemical catalysts and vice president of sales at Süd-Chemie Inc., USA. From 1996 to 2011, he was member of the Süd-Chemie executive board, and from 2007 to 2011 he was vice chairman of the executive board. Since 2007, he has been a member of the board of DECHEMA, which he headed from 2010 to 2012 as chairman. From 2008 to 2010, he was founding board member of the German Catalysis Society; from 1997 to 2011, he was a member of the board of trustees of the Chemical Industry Fund. He is a member of the board of curators of the Leibniz Institute for Catalysis, Rostock and of the Council of the University of Bayreuth.

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Abbreviations

AAGR	Average annual growth rate
ABB	Asea Brown Boveri, Zürich/CH
ACHEMA	Ausstellungstagung für chemisches Apparatewesen (Exhibition Congress on Chemical Engineering, Environmental Protection and Biotechnology)
ADH	Alcohol dehydrogenase
ADR	(European) Agreement concerning the International Carriage of Dangerous Goods by Road
ADN	(European) Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
AEE	Aminoethoxyethanol
AEL	Alkaline electrolysis
AFC	Alkaline fuel cell
AFI	Aluminophosphate-five (zeolite structure)
AGHR	Advanced gas heated reformer
AIDH	Aldehyde dehydrogenase
AIT	Automobile ignition temperature
ALPO	Aluminophosphate (zeolite)
ANG (plant)	American Natural Gas, now Dakota Gasification Comp. (plant)
AOX	Alcohol oxidase
ARC	Axial-radial converter
ASTM	American Society for Testing and Materials
ASU	Air separation unit
ATE	1. Approach to equilibrium 2. Acute toxicity equivalence
atm	pressure (1 atm = 1.01325 bar)
ATR	Autothermal reformer
B7	Diesel fuel containing 7 % Biodiesel
bar g	gauge pressure (absolute pressure minus atmospheric pressure)
BASF	Badische Anilin- & Soda-Fabrik SE, Ludwigshafen/D
bbl	barrel (used in petrochemical industry), equals approx. 0.159 m ³

BCG	Boston Consulting Group, Boston
BEL	Biological exposure limit
BET	Brunauer-Emmett-Teller (method to determine specific surfaces)
BEWAG	Berliner Städtische Elektrizitätswerke AG, (now part of Vattenfall Europe)
BFW	Boiler feed water
BGL	British Gas /Lurgi (gasifier)
bioliq [®]	Biomass-to-Liquids process of KTI, Karlsruhe
BMA	Blausäure aus Methan und Ammoniak (Hydrogen cyanide from methane and ammonia) process by DEGUSSA AG/D (now Evonik Industries AG/D)
BMFT	renamed to BMBF, Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
b.p.	Boiling point
BP	British Petroleum p.l.c/UK (today also referred to as “beyond petroleum”)
BPD	Barrels per day (1 barrel = 0.159 m ³)
BTL	Biomass-to-Liquids
BtM	Biomass-to-Methanol
BTU	British thermal unit (BTU or Btu), equal to about 1055 joules
BWR	Boiler water reactor
CAES	Compressed air energy storage
CAPEX	Capital expenditure
CC	Combined cycle
CCP	Clean coal power
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CD	Catalytic Distillation
cf or ft ³	cubic feet (1 cf = 0.0283 m ³)
CFB	Circulating fluid bed (gasifier)
CFD	Computational Fluid Dynamics
CHA	Chabasite
CHG	Compressed hydrogen gas
CHP	Combined heat and power
CI	Compression ignition (engine)
CLP (regulation)	Classification, Labelling and Packaging regulation in the European Union
CMD	Collext-mix-distribute (concept)
CMG	Conversion of methanol to gasoline (catalyst)
COD	Conversion of olefins to diesel
CPA	Conversion of paraffins to aromatics
CPO	Catalytic partial oxidation

CRG	Catalytic rich gas (process)
CRI	Carbon Recycling International Inc., La Jolla CA, USA
CTF	Covalent triazine framework
CTP	Coal-to-Propylene
CW	Cooling water
DEA	Diethanolamine
DGA	Diglycolamine
DHA	Dihydroxyacetone
DHAP	Dihydroxyacetone phosphate
DI	Direct injection (engine)
DICP	Dalian Institute of Chemical Physics, Dalian/China
DIPA	Diisopropyl amine
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre)
dm ³	cubic decimeter
DMC	Dimethyl carbonate
DME	Dimethyl ether
DMF	Dimethyl formamide
DMFC	Direct methanol fuel cell
DMM	Dimethoxy methane
DMS	Dimethyl sulphide
DMSO	Dimethyl sulphoxide
DMT	Dimethyl terephthalic acid
DMTO	(DICP technology for) Methanol-to-Olefins
DPT	Davy Process Technology, now Johnson Matthey Davy Technologies Ltd, London/UK
DRI	Direct Reduced Iron (process)
DVGW	Deutscher Verein des Gas- und Wasserfaches e.V. (German Technical and Scientific Association for Gas and Water)
ECU	Engine control unit
EEC	European Economic Community
EEG	Erneuerbare Energien Gesetz (German Renewable Energy Sources Act)
EDLC	Electrochemical double-layer capacitor
EF	Entrained flow (gasifier)
EFAL	Extra-framework aluminium (in zeolites)
EFOY	Fuel cell system of SFC Energy GmbH, Brunthal, Germany
EG	Ethylene glycol
EJ	ExaJoule (about 278 TWh)
EPC	Engineering, procurement and construction
FaldDH	Formaldehyde dehydrogenase
FAME	Fatty acid methyl ester
FAO	United Nations Food and Agricultural Organization

FB	Fluidised bed (gasifier)
FBP	1. Final boiling point 2. Fructose-1,6-bisphosphate
FCC	Fluid catalytic cracking
FCCT	Freudenberg FCCT SE & Co. KG, Weinheim/D (fuel cells)
FCV	Fuel cell vehicle
FDBD	Fixed bed dry bottom (gasifier)
FDH	Formate dehydrogenase
FICFB	Fast internal circulating fluid bed (gasifier)
FZJ	Forschungszentrum Jülich GmbH, Jülich/D
F6P	Fructose-6-phosphate
GAP	Glyceraldehyde-3-phosphate
GCR	Gas cooled reactor
GDL	Gas diffusion layer
GHR	Gas heated reformer
GHSV	Gas hourly space velocity (Vol/Vol × h)
GIAP	Joint Stock Company, Scientific Research Institute of Nitrogen Industry, Moscow
GJ	GigaJoule (= 277.8 kWh)
GSH	Glutathione
GSP	1. “Gaskombinat Schwarze Pumpe” (now VSG Industrie- park Schwarze Pumpe GmbH, Spreetal, D) 2. Siemens gasifier
Gt	Gigatonne
GTI	Gas Technology Institute, Des Plaines, IL, USA
Gtoe	Gigatonnes of oil equivalent
GTL	Gas-to-Liquids
GTP	Gas-to-Propylene
GTR	Gas-to-Chemical resources (technology)
$\Delta_R G^\circ$	Standard free energy of reaction
H4MPT	Tetrahydromethanopterin
HER	Heat exchange reformer
HGT	Heavy gasoline treatment
HHV	Higher heating value
HM	Hydrogen from Methanol (process of Caloric GmbH)
HIAT	Hydrogen and Informatics Institute of Applied Technologies GmbH, Schwerin/D
HP Steam	High pressure steam
HTAS	Haldor Topsoe A/S, Lyngby/DK
HTEL	High temperature electrolysis
HTER	see HER
HTS	High temperature shift
HTW	High temperature Winkler (gasifier)

HYSOLAR	Hydrogen from Solar Energy (project led by Deutsches Zentrum für Luft- & Raumfahrt e.V.)
ΔH , ΔH_R	Enthalpy of reaction
ΔH° , $\Delta_R H^\circ$, ΔH°_R	Standard enthalpy of reaction
$\Delta_v H$	Heat of evaporation
ICIS	Independent Chemical Information Service (a business unit of Reed Business Information)
ICT	Fraunhofer Institute for Chemical Technologies, Pfinztal/D
ICVT	Institute of Chemical Process Engineering, Stuttgart/D
IDGCC	Integrated drying gasification combined cycle
IEA	International Energy Agency, Paris/F
IGCC	Integrated gasification combined cycle
ILPM	Improved low pressure methanol (technology)
IMDG (code)	International Maritime Code for Dangerous Goods (issued by International Marine Organisation)
IMFC	Indirect methanol fuel cell
IRR	Internal rate of return
ISE	Fraunhofer Institute for Solar Energy Systems, Freiburg/D
JAMG	Jincheng Anthracite Mining Group
JFE	JFE (Japan Fe Engng.) Group, Tokyo/J (formerly NKK)
JM	Johnson Matthey PLC, London/UK
KBR	Kellogg Brown & Root Inc., Houston, Tx
KRW	Kellog-Rust-Westinghouse (gasifier)
L, l	Litre
LC ₅₀	Median lethal concentration
LD ₅₀	Median lethal dose
LDP	Low pressure difference (shape)
LEL	Lower explosion limit
LEP	Lower explosion point
LHSV	Liquid hourly space velocity (volume/volume \times hour)
LPDME	Liquid phase dimethyl ether synthesis (process)
LPG	Liquid petroleum gas, also: liquefied petroleum gas
LPM	Low pressure methanol (synthesis)
LPMEOH	Liquid phase methanol synthesis (process)
LPSteam	Low pressure steam
LTEL	Low temperature electrolysis
LTS	Low temperature shift
M15	Gasoline based blended fuel containing 15 % of methanol plus solubility enhancers
M85	Gasoline based blended fuel containing 85 % of methanol plus solubility enhancers
M100	Blended fuel consisting of \sim 90 % methanol and \sim 10 % hydrocarbons plus solubility enhancers
m ³ (STP)	cubic metre at standard temperature and pressure (273.15 K, 100 kPa)

MA	Methyl acetate
MAC	Maximum allowable concentration
MAN	Maschinenfabrik Augsburg Nürnberg
MARS	Metal ash recovery system
MCFC	Molten carbonate fuel cell
MDEA	Methyldiethanolamine
MDI	Methylene diphenyl diisocyanate
MEA	Monoethanolamine
MEK	Methylethylketone
MeOH	Methanol
MESG	Maximum experimental safe gap
METHAPU	Methanol Auxiliary Power Unit (project consortium, on-board fuel cells for cargo vessels)
MGC	Mitsubishi Gas Chemical Co., Tokyo/J
MHI	Mitsubishi Heavy Industries Ltd
MIE	Minimum ignition energy
MMA	Methylmethacrylate
MMBTU, MmBTU, mmBTU	Million British thermal units (BTU or Btu)
MMO	Methane monooxygenase
MOGD	Mobil-Olefin-to Gasoline/Diesel (process)
MOI	Mobil olefins interconversion (process)
MON	Motor octane number
MP Steam	Medium pressure steam
MPG	Multi Purpose Gasification or Gasifier
MPa	Megapascal (= 10 bar)
MRDC	Mobil Research & Development Corp., Paulsboro/US
MRF	Multistage radial flow (reactor)
Mt	Megatonne (1 million tonnes)
Mt/a	Million tonnes per year
mt	metric tonne
mtpd	metric tonnes per day
MTA	Methanol-to-Aromatics (process)
MTBE	Methyl tert-butyl ether
mt/d	metric tonnes per day
MTG	Methanol-to-Gasoline
MTHC	Methanol-to-Hydrocarbon (process)
MTI (fuel cells)	MTI Micro Inc., Albany, NY
MTO	Methanol-to-Olefins
MTP	Methanol-to-Propylene
MTS, MTSynfuel	Methanol-to-Synfuel
MTU	MTU Engines, Munich/D (Motoren- und Turbinen-Union)
MUG	Make up gas (methanol process)
MW _{th}	Megawatt (thermal)
MW _e	Megawatt (electrical)

MWM (test engine)	Motorenwerke Mannheim/D (now Caterpillar Energy Solutions GmbH)
NADP	Nicotinamide adenine dinucleotide phosphate
NBP	Net biomass production
NET	Net ecosystem production
NG	Natural gas
NKK	Nippon Kokan K.K. (now part of JFE Group)
Nm ³	standard cubic metre: m ³ at standard temperature and pressure (273.15 K, 100 kPa)
NMP	N-methyl pyrrolidone
NMR	Nuclear magnetic resonance
NPP	Net primary production
OBATE	On-board alcohol-to-ether (process)
OCP	Olefin cracking process
OCV	Open circuit cell voltage
OMB	Opposed multiple burner (technology)
OPEX	Operating expense
PAFC	Phosphoric acid fuel cell
PCC sm	(Exxon) Propylene catalytic cracking (technology)
PDH	Propane dehydrogenation
PDU	Process demonstration unit
PEMEL	Proton exchange membrane electrolysis
PEMFC	Polymer electrolyte membrane fuel cell
PERP (report)	Process evaluation/Research planning (reports by ChemSystems/Nexant Inc., White Plains/US)
PET	Polyethylene terephthalate
PF	Pulverised fuel
PG	Propylene glycol
PGM	Platinum group metal
PHA	Polyhydroxyalkanoate
PHES	Pumped hydro energy system
PISI	Port-injection spark ignition (engine)
PMMA	Polymethylmethacrylate
POM	Polyoxymethylene
POMDME	Polyoxymethylene-dimethyl ether
POX	Partial oxidation
PP	Polypropylene
ppm _v or ppmv	Volume parts per million
ppm _w or ppmw	Weight parts per million
ppb _v or ppbv	Volume parts per billion
ppb _w or ppbw	Weight parts per billion
PSA	Pressure swing adsorption
psi	pound per square inch (1 psi = 0.06895 bar)
psia	pound per square inch (absolute)
PV	Photovoltaic

PVA	Polyvinyl alcohol
RDF	Refuse-derived fuel
RE	Renewable energy
RID	Regulations for international carriage of dangerous goods by rail (issued by the International Rail Transport Committee (CIT), Bern/CH)
RITE	Research Institute of Innovative Technology for the Earth, Kyoto/J
RM	Regenerative (renewable) methanol
RMFC	Reformed methanol fuel cell
RON	Research octane numer
R/P	(static) Reserves-to-Production ratio (of fossil sources)
RuMP	Ribulose monophosphate
RWGS	Reverse water gas shift
RWTH	Rheinisch-Westfälische Technische Hochschule, Aachen
SAPO	Silico-alumino phosphate (zeolithe)
SBU	Secondary building unit (in zeolites)
S/C	Steam to carbon ratio
SCF, scf	Standard cubic foot (at 60 degrees Fahrenheit (15.6 degrees Celsius) and 1 atm or 101.325 kPa)
SCOT	Shell Claus Off-Gas Treatment (process)
SCP	Single cell protein
SCR	Steam raising converter
SECA	Special environmental control area
SFC	SFC Energy AG, Brunenthal/D (fuel cells)
SGS	Sour gas shift
SMR	Steam methane reformer/reforming
SN	Stoichiometric number
SNG	Synthetic natural gas
SOEC	Solid oxide electrolysis cell
SOFC	Solid oxide fuel cell
SRK	Soave–Redlich–Kwong (equation)
SSZ	zeolite with chabazite structure
STD	Syngas-to-Dimethyl ether
STP	Standard temperature (273.15 K) and pressure (100 kPa or 1 bar)
STS	Syngas-to-Fuel
STY	Space-time-yield
SVZ	(former) Sekundärrohstoff-Verwertungszentrum Schwarze Pumpe, Spremberg/D
SWS	Sour water stripper
t, tonne	metric tonne
TAME	tert-Amyl methylether
TBA	tert-Butyl alcohol
TEA	Triethanolamine

TCC	Tube cooled converter (Davy Process Technology)
TCE	Total capital employed
tcf	Trillion cubic feet
tcm	Trillion cubic metre
TDG	Transport of dangerous goods (regulations by UNECE)
TGT	Tail gas treatment
THF	Tetrahydrofurane
TIC	Total installed costs
TIGAS	Topsoe's integrated gasoline synthesis (Haldor Topsoe A/S, Lyngby/DK)
TON	turn-over-number (moles of substrate per mole of catalyst before being deactivated)
TOS	Time-on-stream
tpd	(metric) tonnes per day
TRBS	“Technische Regeln für Betriebssicherheit” (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin Federal Institute for Occupational Safety and Health, Dortmund/D)
TRGS	“Technische Regeln für Gefahrstoffe” (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin/Federal Institute for Occupational Safety and Health, Dortmund/D)
UCC	Union Carbide Corp., Danbury/US (affiliate of Dow Chemical)
UEL	Upper explosion limit
VAM	Vinyl acetate monomer
WCR	Water cooled reactor
WGS	Water gas shift
WHB	Waste heat boiler
WHSV	Weight hourly space velocity (weight/weight × hour)
W/m ²	Heat flux (Watt per m ²)
WTY	Weight-time-yield
XTL	x -to -liquids (x = fossil or biomass feeds)
Xu5P	Xylulose-5-phosphate
ZBT	Zentrum für BrennstoffzellenTechnik GmbH, Duisburg/D (fuel cells)
ZnTPPS	Zinc tetraphenylporphyrin tetrasulphonate
ZSM	Zeolite Socony Mobil (class of zeolites)
ZSW	Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) Baden-Württemberg, Stuttgart/D

Chapter 1

Introduction

1.1 From Raw Materials to Methanol, Chemicals and Fuels

Heribert Offermanns, Ludolf Plass and Martin Bertau

The planet Earth is a sphere with a limited surface of $5 \times 10^{13} \text{ m}^2$, of which 71 % is water and only 29 % is land. A total of 27.5 % of the landmass (i.e. 11 % of earth's surface) is used as arable acreage, 20.8 % as pasture and 9.4 % is used to grow timber. The remaining surface, which mainly is made up of deserts and mountains, is unused: 10.1 % is a frozen surface and 2.0 % is inland water. Meanwhile, the human population requires not less than 7 % of the land—a number that is constantly growing at the expense of the arable landmass. In fact, the usable area has been diminishing for years.

Carbon is the 13th most common element. It is found in nature in the form of diamonds and graphite and it is chemically bound as CO_2 , carbonate, natural gas, crude oil, coal, or biomass. However, carbon is highly unequally distributed in the earth's upper crust. Approximately 50,000,000 Gt (99.92 %) of carbon is fixed in the earth's crust, chiefly as carbonate rock. Only approximately 40,000 Gt

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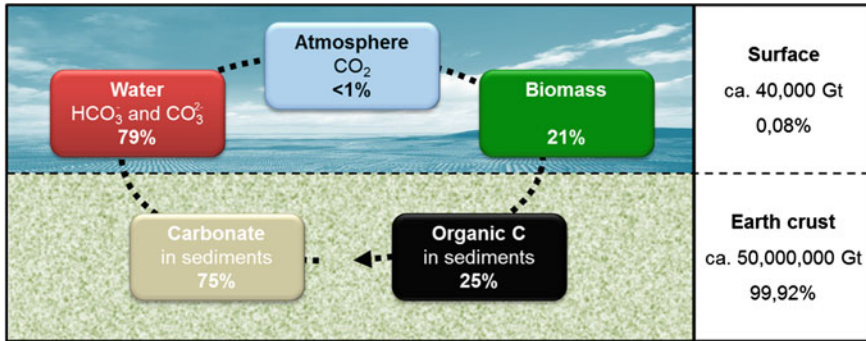


Fig. 1.1 Carbon distribution in the earth's crust. (Adapted from [3])

—a meager 0.08 %—is near the surface. The fact that 79 % of this latter amount is abundant as hydrogen carbonate and carbonate in water underscores the scarcity of economically exploitable carbon [1, 2]. Taking all this into account, one will inevitably come to the conclusion that the fraction of technically recoverable carbon is exceedingly rare but enriched in large-scale deposits (Fig. 1.1).

All natural carbon sources are exhaustible, but nature produces gargantuan amounts of renewable primary resources. By means of photosynthesis, plants produce carbohydrates from atmospheric CO_2 , sunlight and water. To a smaller extent, proteins and vegetable oils are also produced. The yearly production of biomass is estimated according to the U.S. Department of Energy (2005) to be approximately 150 Mt. Humans stand admiring this incredible performance while trying to understand how nature works. According to Primo Levi (see Fig. 1.2), the chemical leaf—technical photosynthesis—is the goal.

We use only small quantities of the long-existing and continuously accrued biomass (~ 4 %) for the production of food/fuel or as chemical or energy raw material. This usage (only 4 % human consumption) is not expected to substantially increase in the future.

Unlike the global population (currently 7 billion, estimated to be 9 billion in 2050), there will be no increase in the size of the earth. Therefore, every available acre of farmland should be prioritised for the production of food. However, there is a concerning downward trend in arable acreage because the growing population is consuming land for settling and concomitantly inappropriately using agricultural land. It should be common practice to use only the biomass that cannot serve as human nutrition as feedstock for energy and fuel, be it directly or indirectly.

Since the invention of fire, man has used biomass (wood) for heating. Wood used to play a considerable role in methanol production (wood alcohol), acetic acid (wood vinegar) and acetone. Also, hard coal and lignite have been (and are still) in use as feedstock for chemicals and energy. For instance, aromatics from tar distillation—a byproduct of coke production—served as raw materials for the production of dyes (I.G. Farben).