1 INTRODUCTORY REMARKS

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1.1 WHY PRODUCE SYNTHETIC NATURAL GAS?

The answer to this question [which may also explain why one should read a book on synthetic natural gas (SNG) production] changes with time.

During the years from 1950 to the early 1980s, SNG production was an important topic, mainly in the United States, in the United Kingdom, and in Germany. The interest was caused by a couple of reasons. In these countries, a relative abundance of coal and the expected shortage of natural gas triggered several industrial initiatives, partly funded by public authorities, to develop processes from coal to SNG. Due to the oil crisis during the 1970s, the use of domestic coal rather than the import of oil became a second motivation. A third motivation is the possibility to make domestic (low quality) energy reserves available de-centrally as an energy carrier for which the distribution infrastructure already exists and that allows for both clean and efficient use by consumers.

These boundary conditions lead in 1984 to the start-up of the 1.5 GW$_{\text{SNG}}$ plant in Great Plains which is run by the Dakota Gas Company and converts lignite into SNG and many other products. This plant stayed the only commercial SNG production for nearly 30 years because, with the drop of the oil price in the mid1980s, the exploration of natural gas in the North Sea, and the gas pipelines between Russia and Europe, the interest in SNG from coal ceased.

Especially in the United States, the interest came back in the years after the turn of the millennium, now triggered by the again rising oil price and the meanwhile established use of CO$_2$ (which is an inherent by-product of coal to SNG plants) for...
enhanced oil recovery (EOR). Back then, a dozen coal to SNG projects were started, including EOR. Now, due to the rapidly increasing exploitation of the shale gas and the connected possibility for a significant reduction of CO₂ emission, all the projects in the United States have been stopped.

However, all the mentioned motivations for SNG production, that is, shortage of domestic natural gas, use of domestic coal reserves which are far away from the highly populated areas, and the possibility for clean and efficient combustion, still prevail in China. Therefore, China is now by far the most important market for the production of SNG from coal. Three large plants have started operation, and further plants are planned or under construction.

In Europe, several aspects triggered a reconsideration of SNG production about 15 years ago. Due to its cleaner combustion and inherently lower CO₂ emission, using natural gas in transportation (e.g., for CNG cars) is supported in many countries and has even been economically beneficial for the past few years due to the lower gas price. With the aim of the European Commission to replace up to 20% of European fuel consumption by biofuel, replacing natural gas partly with bio-methane becomes necessary. So far, bio-methane is mostly produced by up-grading biogas from anaerobic digestion. However, due to the limited amount of substrate, this pathway cannot be increased much more and other sources of bio-methane are sought.

Additionally, many European countries wish to use their domestic biomass resources for energy production in order to decrease CO₂ emissions and the import of energy. A major part of the biomass is ligno-cellulosic (mostly wood) and mainly used for heating, for example, in wood pellet heating. As the heat demand is generally decreasing due to better building insulation, the conversion of wood to high value forms of energy, that is, electricity and fuels, is of increasing interest. Like in the case of coal, conversion to fuels requires (so far) gasification as the first step. As shown by process simulations and the first demonstration plants, the conversion of wood to SNG can reach significantly higher efficiencies than conversion to liquid fuels.

Very recently, a third aspect began to gain greater importance, especially in Central Europe. Due to the increasing integration of stochastic renewable sources like photovoltaics and wind energy into electricity generation, the demand for balancing the electricity supply and the demand over spatial and temporal distances is increasing. For the future, even the seasonal storage of electricity may be necessary. Here, the production of SNG can play an important role. While the gasification of solid feedstocks is a more or less continuous process, the further conversion to electricity or SNG can be flexibly adjusted to the balancing needs of the electricity grid within so-called polygeneration schemes.

Moreover, in times where the electricity production from renewables exceeds the actual demand in the electricity grid (a situation that today occasionally is observed in Central Europe and is expected to be more common in future), producing SNG could utilize the excess electricity instead of curtailing photovoltaics or wind turbines. In so-called power to gas applications, hydrogen is produced from excess electricity by electrolysis of water and then converted to SNG by methanation of
carbon oxides. As a source of carbon oxides, biogas, producer gas from (biomass) gasification, flue gas from industry, or even CO\textsubscript{2} from the atmosphere can be considered, opening a pathway to produce SNG without solid feedstock that can be stored or transported over long distances within the existing natural gas infrastructure.

1.2 OVERVIEW

This book aims at a suitable overview over the different pathways to produce SNG (Figure 1.1).

The first four chapters cover the main process steps during conversion of coal and dry biomass to SNG: gasification, gas cleaning, methanation, and gas upgrading. The main technology options will be highlighted and the impact of a technology choice for downstream processes and the complete process chain. In these chapters, especially in the chapter on methanation reactors, the state of the art coal to SNG processes are discussed in detail.

The following chapters describe a number of novel processes for the production of SNG with their specific combination of process steps as well as the boundary conditions for which the respective process was developed. These processes comprise those which are already in operation (e.g., the 20 MW\textsubscript{SNG} bio-SNG production in Gothenburg, Sweden, or the 6 MW\textsubscript{SNG} power to gas plant in Werlte, Germany) and processes which are still under development.

The gasification chapter covers the thermodynamics of gasification and presents both coal and biomass gasification technologies.

![Diagram of SNG production pathways](image_url)  
**FIGURE 1.1** The different pathways to produce SNG.
The *gas cleaning* chapter discusses the impurities to be expected in gasification-derived producer gas, explains the state of the art gas cleaning technologies, and focuses on the innovative gas cleaning steps which are developed for hot gas cleaning.

The chapter on *methanation reactors* presents the chemical reactions proceeding inside the reactors, their thermodynamic limitation and their reaction mechanisms. Further, an overview of the different reactor types with their advantages and challenges is given covering coal to SNG, biomass to SNG and power to gas processes. The last section of this chapter focuses on the modeling and simulation of methanation reactors, including the necessary experiments to determine reaction kinetics and to generate data for model validation.

The chapter on *gas-upgrading* discusses technologies for gas drying, CO₂ and hydrogen removal based on adsorption, absorption, and membranes and includes a techno-economic comparison.

The chapter on the *GoBiGas project* (“Gothenburg Bio Gas”) presents the boundary conditions and technologies applied in the 20 MW SNG wood to SNG plant in Gothenburg, Sweden, which was commissioned in 2014.

The next chapter explains the development of the *power to gas* process at the Zentrum für solare Wasserstoffenerzeugung (ZSW), including the 6 MW SNG plant in Werlte, Germany.

The chapter on *fluidised bed methanation* describes the process development at the Paul Scherrer Institut aiming at a flexible technology for efficiently converting wood to SNG and for hydrogen conversion within power to gas applications.

The following chapter presents the technologies developed at the Energy Center of the Netherlands (ECN) for efficient SNG production from wood, especially their allothermal gasification technology (MILENA) and their broad experience with gas cleaning.

The chapter on *hydrothermal gasification* discusses the unique technology allowing for the simultaneous catalytic gasification and methanation of wet biomass under super-critical conditions.

The chapter on *agnion’s small scale SNG concept* focuses on two novel technologies that allow for significant process simplification, especially in small scale bio-SNG plants: the pressurized heatpipe reformer and the polytropic fixed bed methanation.

The last chapter offers a view on the research for even more simplified SNG processes, that is, for methanation steps that allow for *integrated desulfurization and methanation*.

The author of these lines wishes to express his gratitude, especially to the contributors of this book and to the persons at the publisher for their excellent work, but also to all colleagues, scientific collaborators, partners, friends and scientists in the community for many fruitful and interesting discussions. All of you bring the field forward and made this book possible.