Daniel Vallentin

Coal-to-Liquids (CtL):

Driving Forces and Barriers – Synergies and Conflicts from an Energy and Climate Policy Perspective

Including Country Studies on
the United States, China and Germany
and a Foreword by Peter Hennicke

ECOLOGICAL ENERGY POLICY - EEP

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Ecological Energy Policy (EEP) – Series Foreword

How can we initiate an ecological transformation process in the energy industry, a development toward increased use of renewable energies, more efficiency where the burning of fossil resources is still necessary, and the faster reduction of the gross energy consumption?

As evident as the necessity for changes of that kind may appear, it has only recently been brought to the attention of a broader international audience: The consequences of global warming, external costs, the finiteness of fossil resources, and the regional conglomeration of fossil sources bear problems for mankind on a scale that seemed utterly unthinkable before.

So the goal of the new series *Ecological Energy Policy (EEP)* is not about the – now widely accepted – necessity for a change, a transformation process, but it aims to discuss how such an alteration can be *implemented* in real-life economy and society.

Crucial for the papers to be published within EEP are the answers to questions such as:

- Which political, economical, technical, and cognitive *restrictions* oppose change, by which factors *(success conditions)* can those restrictions be overcome?
- Which *actors* can support change, which *constellations of actors* are necessary to induce alterations?
- Which *regulating pattern* is in favor of the implementation of a transformation process? How do the different *instruments* have to be formed, what is a reasonable policy mix to achieve the effects intended?

The new series EEP presents an attractive platform for the publication of monographs, anthologies, conference volumes, and studies.

The first volumes of the series are studies of outstanding quality which represent research that was conducted under the series' editor's supervision at the

Otto Suhr Institute for political science and in the master course Environmental Management at the Freie Universität Berlin.

May the series EEP contribute to a better understanding of the possibilities and constraints of the implementation of an ecological transformation process within the energy industry.

Prof. Dr. Danyel Reiche

The series' editor, Prof. Dr. Danyel Reiche, is Assistant Professor for Comparative Politics at the American University of Beirut (AUB), Lebanon.

For my Family

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served a desk for me during my stay in Beijing and helped me to find my way through this huge city.

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Preface

Due to an increasing and highly volatile oil price, alternative fuels for transportation are urgently needed to enhance energy security. This holds true even when energy efficiency has been given first priority for all sectors of transportation. Up to now, biofuels, hydrogen or electric vehicles have been introduced into niche markets, but will be fostered in the future as alternatives, which all have their pros and cons. Also in several countries with abundant coal resources, the commercialisation of coal-to-liquids (CtL) technologies which convert solid coal into liquid hydrocarbon fuels is advocated. The world's only large-scale CtL plants are currently operated in South Africa with a total capacity of 160,000 barrels per day, covering one third of the country's demand for transport fuels. However, other countries, especially China, the United States or Germany, show interest in expanding coal utilisation to the transport sector. Important Chinese and U.S. decision-makers as well as interest groups consider CtL as an option to cover significant shares of their domestic fuel supplies; especially coal-producing regions and pressure groups in both countries perceive CtL as an opportunity to extend their participation in the value-added chain of coal utilisation. Germany aims to benefit from its historically high technology expertise on the field of coal technologies by exporting CtL plant components to other countries. In the early 20th century, CtL processes were developed in Germany and firstly used during World War II by the Nazi regime.

The dissertation analyses driving forces and barriers for the diffusion of CtL technologies in the United States, China and Germany. It uses the so-called technological system approach as an analytical framework. The approach is based on a systemic conceptualisation of 'technology', assuming that processes of technological change and technology diffusion are not merely determined by 'hard' factors (e.g. costs, availability of energy resources) but their interactions with 'soft' factors, such as the policy framework or the constellation of stakeholders. Daniel Vallentin investigates the following research questions:

Which stakeholder-related, institutional, techno-economic and resources-related parameters can be identified as determinants of a possible diffusion of coal-to-liquids technologies in the U.S., China and Germany?

How do the identified determinants affect the market prospects of CtL technologies in these countries?

Which general conclusions with regard to driving forces and barriers for CtL diffusion can be derived from the investigated case studies?

The author has conducted more than 100 interviews with high-profile stakeholders from industry, politics or societal organisations to identify determinants of CtL R&D activities, pilots and diffusion in the selected countries. Section 2 describes the applied interview methodology. Section 3 gives an introduction to theories of technological change and technology diffusion and adapts the technological system approach to the specifics of large-scale energy technologies such as CtL. Section 4 investigates the technical and economic viability of CtL. This includes an analysis of the production costs of CtL – both with and without carbon capture and storage (CCS). Furthermore, the author quantifies the impact of different carbon prices on the economics of CtL. Section 5 presents an overview of the geographic distribution of global coal reserves and resources and describes the suitability of different coal qualities for CtL processes. Section 6 analyses driving forces for CtL diffusion in South Africa as former South African governments established a complex system of financial incentives to build the world's first coal-based synfuels industry.

The case studies on the U.S., China and Germany are at the heart of the presented dissertation and are studied in sections 7, 8 and 9. In a highly profound way, Daniel Vallentin examines technical and non-technical drivers and barriers for CtL diffusion in these potential key markets. Aiming at deriving general conclusions from the country analysis, section 10 compares the case studies and presents 17 theses to answer the third research question. Section 11 identifies needs for further research.

Besides the high dependence from oil imports, the priority of climate policy and its impact on national energy and technology policy is a possible decisive parameter for CtL diffusion in all case studies. Moreover, the availability of other alternative fuels or technologies for substituting petroleum-based fuels, such as electric vehicles or hydrogen-fuelled engine systems, plays an important role. In countries with progressive climate policy strategies, the high greenhouse gas (GHG) intensity of CtL is a major diffusion barrier. The well-to-tank (WTT) emissions of CtL are nine times as high as the WTT emissions of conventional diesel. Even in combination with carbon capture and storage (CCS), CtL remains more GHG intensive.

However, in China, which has not yet established binding CO_2 mitigation policies, the high specific water demand of CtL technologies constitutes the most important environmental constraint for CtL diffusion since most coal-producing provinces suffer from water scarcity. As water cooling causes the largest share of CtL's water demand, air cooling could significantly alleviate this problem. However, this would further increase the economic risk inherent to CtL diffusion. As large-scale CtL plants are highly capital-intensive, potential investors call for a high degree of investment security. This, however, is constrained by a highly volatile oil price which functions as the main benchmark for the commercialisation of alternative fuels. Therefore, most industrial stakeholders interviewed by the author consider governmental subsidies as a crucial precondition for CtL investments. As a consequence, characteristics of the national energy sectors (market-oriented vs. state-controlled), the policy framework and support by political decision-makers are major determinants of CtL diffusion.

The author argues that in the United States, energy security concerns are the most important stimulus for CtL activities. Due to that motivation, CtL is fostered by uncommon coalitions, such as the military, technology providers, trade unions, the coal industry and the aviation industry. Nonetheless, Daniel Vallentin concludes that CtL deployment in the U.S. is “hampered by a lack of political compatibility, as the growing importance of climate policy favours other fuel options and creates a high degree of economic uncertainty, which is in conflict with CtL's high investment costs”. As a consequence, stakeholders with high financial resources and expertise, such as the oil industry, are currently not interested in entering the market. Economic uncertainties due to climate policy targets are likely to increase in the future because of the new climate policy course of the Obama administration.

With regard to China, the author identifies the country's rapidly increasing demand for transportation fuels as major driver for CtL. This is particularly true as China is suffering from a growing dependence from crude oil imports. Large coal reserves and low capital and labour costs which improve the economic viability of CtL create positive conditions for CtL diffusion. However, the technology's deployment in China is strongly affected by water scarcity in coal-producing provinces where the water is needed for other purposes such as food production. Nonetheless, Daniel Vallentin concludes that "of the three countries investigated in this thesis, China indicates the most favourable market conditions for CtL, as the country combines economic advantages (lower CtL capital costs) with strong CtL investors (large state-owned companies) and a rather favourable CtL policy framework (low priority of CO_2 mitigation, CtL research, development and demonstration projects)".

For Germany, the world's largest lignite producer, the high feedstock flexibility of CtL technology and its capability to convert low-ranked coals into added value outside the electricity sector is of importance. Some German industrial stakeholders therefore consider CtL as a means of increasing the value of low-quality coal. Furthermore, German technology providers possess high technical expertise deriving from CtL research and development activities in the 1970s and 1980s. Nonetheless, current interest in CtL is mainly motivated by prospects for exporting CtL technologies in coal-producing countries, especially developing and transition countries. The author claims that "CtL is facing rather unfavourable market conditions in Germany". The technology's introduction is inhibited by high economic risks and would be "incompatible with German energy and climate policy goals".

The high greenhouse gas intensity of CtL reveals a clear conflict between strategies for enhancing "energy security" (less oil dependency) on the one hand and fighting global warming on the other hand. In order to overcome this conflict, political interventions, joint climate-friendly technology development and a global climate policy regime which integrates developing and transition countries such as China are needed. This is particularly important in order to guide the international cooperation and search for much more efficient transportation systems and alternative fuel options in a climate-compatible direction as the oil price is expected to increase further in the coming years and decades.

Focusing on a controversially debated alternative fuel pathway like CtL, this dissertation provides important scientific insights into the impact of fossil-based path-dependencies on the selection of new technologies. It offers an excellent and convincingly comprehensive empirical analysis of the driving forces and barriers for CtL diffusion – a technology which has been mostly investigated in purely economic or technical studies so far. As the selected countries are major consumers of energy and belong to the world's largest emitters of greenhouse gases, their strategies in substituting petroleum-based fuels are of utmost global relevance. Therefore, the dissertation makes an important contribution to the international debate on sustainable future energy and transportation systems. Daniel Vallentin presents an outstanding piece of scientific work which is highly recommended to the community of experts, planners, decision-makers and politicians in the field of climate and resource protection.

Prof. Peter Hennicke
Former President of the Wuppertal Institute for Climate, Environment and Energy

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List of Abbreviations

AAEO	Australian-American Energy Company
ACARP	Australian Coal Association Research Programme
AEO	Annual Energy Outlook
AEP	American Electric Power
AFL-CIO	American Federation of Labor and Congress of Industrial Organisations
AFS	Alternative Fuel Standard
AG	Aktiengesellschaft (Corporation)
AGA	American Gas Association
ANRTL	Alaska Natural Resources-to-Liquids
APEC	Asian-Pacific Economic Cooperation
ASFE	Alliance for Synthetic Fuels Europe
ATA	U.S. Air Transport Association
BBergG	Berggesetz
BBL	Barrel
BBL/Day	Barrels per Day
BCtL	Biomass-Coal-to-Liquids
BDEW	Bundesverband der Energie- und Wasserwirtschaft (German Federall Alliance of Energy and Water Utilities)
BECOP	Break-Even Crude Oil Price
BEE	German Renewable Energy Federation
BEWAG	Berliner Electricitäts-Werke AG (Berlin Power Utility)
BG	British Gas
BGR	German Federal Institute for Geosciences and Natural Resources
BMBF	German Federal Ministry of Education and Research
BMF	German Federal Ministry of Finance
BMFT	German Federal Ministry of Research and Technology
BMU	German Federal Ministry of Environment
BMVBS	German Federal Ministry of Transport
BMWi	German Federal Ministry of Economics
BP	British Petroleum
BRICC	Beijing Research Institute of Coal Chemistry
BT	Bundestag (German Parliament)
BtL	Biomass-to-Liquids
BTU	British Thermal Unit

C	Carbon
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAFE	Corporate Average Fuel Economy
CAN	Climate Action Network
CAS	Chinese Academy of Science
CATARC	China Automotive Technology & Research Centre
CCRI	China Coal Research Institute
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CDU	Christian Democratic Union of Germany
CEPCI	Chemical Engineering Plant Cost Index
CESDRRC	China Environment and Sustainable Development Reference and Research Centre
CFB	Circulating Fluidised-Bed Reactor
CH_4	Methane
CM	Curbe Mass
CMSL	Catalytic Multi-Stage Liquefaction
CNG	Compressed Natural Gas
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CO	Carbon Monoxide
Co	Cobalt
CO_2	Carbon Dioxide
CO_{2eq}	Carbon Dioxide Equivalent
CONUS	Contiguous United States
CRP	Conservation Research Programme
CSLF	Carbon Sequestration Leadership Forum
CtL	Coal-to-Liquids
CtLC	Coal-to-Liquids Coalition
CTSL	Catalytic Two-Stage Liquefaction Process
D	U.S. Democrat
DCL	Direct Coal Liquefaction
DICI	Direct Injection Compression Ignition
DEBRIV	German Federal Association of the Lignite Industry
DISI	Direct Injection Spark Ignition Engines
DME	Dimethylether
DOC	Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DSK	Deutsche Steinkohle AG

DTI	British Department of Trade and Industry
ECUST	East China University
EDS	Exxon Donor Solvent Process
E.g.	For Example; abbreviation of Latin ‘*exempli gratia*’
EGR	Enhanced Gas Recovery
EG_{sf}	Efficiency Gain Factor When Synfuel Displaces Conventional Hydrocarbon Fuel
EIA	U.S. Energy Information Administration
EnBW	Energie Baden-Württemberg
EOR	Enhanced Oil Recovery
EPA	U.S. Environmental Protection Agency
EPact	Energy Policy Act
EPRI	Electric Power Research Institute
ERI	Energy Research Institute
EU	European Union
EU ETS	EU Emission Trading Scheme
EWI	Institute of Energy Economics
FAA	Federal Aviation Administration
FAME	Fatty-Acid Methyl Esters
FC	Fuel Cells
FDP	Free Democratic Party of Germany
Fe	Iron
FFB	Fixed-Fluidised Bed Reactors
FoE	Friends of the Earth
FT Synthesis	Fischer-Tropsch Synthesis
FY	Fiscal Year
g	Gram
GCSFP	German-Chinese Sustainable Fuel Partnership
GDP	Gross Domestic Product
GE	General Electric
GESTCO	Geological Storage of CO_2 from Combustion of Fossil Fuel
GHG	Greenhouse Gas
GRE	Great River Energy
GS	Geologic Sequestration
GTI	Gas Technology Institute
GtL	Gas-to-Liquids
GVSt	German Hard Coal Alliance
H_2 or H	Hydrogen
HEW	Hamburgische Electricitäts-Werke (Hamburg Power

	Utility)
HFC	Hydroflourocarbons
HRI	Hydrocarbon Research Inc.
HTI	Hydrocarbon Technologies Inc.
HTIG	Headwaters’ Technology Innovation Group
HTFT	High-Temperature Fischer-Tropsch Synthesis
HTW	High-Temperature Winkler
HV_{hcd}	Volumetric Heating Value of the Concentival Hydrocarbon Fuel Displaced
IBLC	In Bond Landed Costs
iCET	Innovation Center for Energy and Transportation
ICL	Indirect Coal Liquefaction
i.d.	Inner Diameter
IDC	South African Industrial Development Corporation Ltd.
IEA	International Energy Agency
IEP	Innovations for Existing Plants
IGBCE	Mining, Chemical and Energy Industrial Union
IGCC	Integrated Gasification Combined Cycle
IL	Illinois
IN	Indiana
IPCC	International Panel on Climate Change
IPR	Intellectual Property Right
IT	Information Technology
JCU	James Cook University
Kg	Kilogram
Krw/AbfG	Kreislaufwirtschafts- und Abfallgesetz
KWI	Kaiser-Wilhelm Institute for Coal Research
KY	Kentucky
LAUBAG	Lausitzer Braunkohle AG (Lausitz Brown Coal Corp.)
LPG	Liquified Petroleum Gas
LTFT	Low-Temperature Fischer Tropsch Synthesis
M	Gross Mass
M^3	Cubic Metre
MD	Maryland
MIBRAG	Mitteldeutsche Braunkohlegesellschaft (Central German Brown Coal Company’)
MIT	Massachusetts Institute of Technology
MIWFT NRW	Ministry of Innovation and Research of North Rhine-Westphalia
MJ	Mega Joule

MJ_f	Mega Joule of Generated Fuel
MLP	Medium-to-Long-Term Plan for the Development of Science and Technology
MOST	Chinese Ministry of Science and Technology
MPV	Multi-Purpose Van
MRGHGRA	Midwestern Regional GHG Reduction Accord
Mt	Million Tons
MtG	Methanol-to-Gasoline Technology
MW	Megawatt
MW_{th}	Megawatt Thermal
MWME NRW	Ministry of Economics and Energy of North Rhine-Westphalia
MWR	Chinese Ministry of Water Resources
MWV	Association of the German Petroleum Industry
MY	Model Year
N	Nitrogen
N/A	Not Applicable
NAF	Northern Appalachia Fuel LLC
NAP II	National Allocation Plan
NCC	National Coal Council
NDRC	National Development and Reform Commission
NE	Nebraska
NETL	U.S. National Energy Technology Laboratory
NGL	Natural Gas Liquids
NGO	Non-Governmental Organisation
NG Storage	Natural Gas Storage
Ni	Nickel
NM	New Mexico
NMA	National Mining Association
NO_x	Nitrogen Oxide
N_2O	Nitrous Oxide
NOCs	China’s National Oil Companies
NRDC	National Resources Defense Council
NREL	National Renewable Energy Laboratory
NRW	North Rhine-Westphalia
NZEC	Near Zero Emissions Coal Technologies
O	Oxygen
O_2	Oxygen
OCR	Office of Coal Research
OK	Oklahoma

O&M Costs	Operation & Management Costs
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PA	Pennsylvania
PC_{sf}	Synfuel Production Costs
PDU	Process Development Unit
PFC	Perfluourocarbons
PISI	Port Injection Spark Ignition Engines
PJ	Peta Joule
PPM	Parts per Million
PPMV	Parts per Million by Volume
QP	Qatar Petroleum
R	U.S. Republican
R&D	Research and Development
RD&D	Research, Development and Demonstration
RFS	Renewable Fuel Standard
RGGI	Regional Greenhouse Gas Initiatives
RM_{hcd}	Refinery Margin for Conventional Hydrocarbon Fuel
R-P Ratio	Reserves-Production Ratio
Ru	Ruthenium
RAG	Ruhrkohle AG (Ruhr Coal Mining Company)
RWE	Rheinisch-Westfälisches Elektrizitätswerk AG (Rhenian Westfalian Power Utility)
S	Sulphur
SA	Deep Saline Aquifer
S.A. Ct.	South African Cent
S.A. DME	South African Department of Minerals and Energy
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act
SAS	Sasol Advanced Synthol
Sasol	South African Coal, Oil and Gas Corporation Ltd.
SCEC	Shanghai Clean Energy Research and Industry Promotion Centre
SCGP	Shell Coal Gasification Process
SEC	Shanghai Electric Group Corp.
SEPA	Chinese State Environmental Protection Agency
SF_6	Sulphur Hexafluoride
Siemens FG	Siemens Fuel Gasification
SMDS	Shell Middle Distillate Synthesis
SNEC	Sinopec Ningbo Engineering Company

SNG	Substitute Natural Gas
SO_2	Sulphur Dioxide
SPD	Social Democratic Party of Germany
SPDP	Slurry-Phase Distillate Process
SRC	Solvent Refined Coal
SSEB	Southern States Energy Board
S&T	Science and Technology
SUV	Sport Utility Vehicle
T/A	Tons per Year
T/D	Tons per Day
TFCS	Taxpayers for Common Sense
TPES	Total Primary Energy Supply
TTW	Tank-To-Wheels
TWh	Terawatt Hour
UBA	German Federal Environment Agency
UCI	Federal Underground Injection Control Programme
UMWA	United Mine Workers of America
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USFTF	Unconventional Strategic Fuels Task Force
V	Displacement
VA	Virginia
VCI	German Alliance of the Chemical Industry
VEAG	Vereinigte Energiewerke AG
VEBA Öl AG	Vereinigte Elektrizitäts- und Bergwerks Öl AG
VEW	Vereinigte Elektrizitätswerke Westfalen
WBGU	German Advisory Council on Global Change
WEC	World Energy Council
WCI	World Coal Institute
WGS	Water Gas Shift
WMPI	Waste Management and Processors Inc.
WTT	Well-To-Tank
WTW	Well-To-Wheels
W.Va.	West Virginia
ZAR	South African Rand
$	U.S. Dollar

1 Introduction

Some of the world's largest energy-consuming countries, such as the United States or China, possess vast domestic coal reserves, but limited oil reserves. Disregarding its negative climate impact, many political decision-makers consider an extension of coal utilisation as a way to alleviate energy security concerns. Currently, global coal utilisation is mainly limited to power generation. However, the transport sector is particularly dependent on crude oil, and technologies for the conversion of coal into liquid hydrocarbon fuels for the transportation sector are gaining relevance. These technologies are denoted as coal liquefaction or coal-to-liquids (CtL) technologies. There are direct and indirect coal liquefaction processes. Using high temperatures and pressures, direct coal liquefaction adds hydrogen to the organic structure of coal and, for this reason, can also be referred to as coal hydrogenation. Direct coal liquefaction was invented in Germany in the early 20th century and was first applied by the German national socialist regime during World War II to address crude oil shortages. In the post-war period, the United States, Japan and Germany made several attempts to demonstrate and commercialise the technology which, however, failed because of economic constraints. To date, only China seriously pursues the commercialisation of direct coal liquefaction. It plans to commission the world's first direct coal liquefaction demonstration plant (initial capacity: 20,000 barrels/day; bbl/day) in Inner Mongolia at the end of 2009 or in early 2010.

Most other potential CtL markets, such as the U.S. or Germany, focus on indirect coal liquefaction. Coal is transformed into a synthesis gas ('syngas') consisting of carbon monoxide, hydrogen and various impurities, such as sulphur compounds or CO_2. The syngas is then liquefied via Fischer-Tropsch synthesis. The latter generates a broad range of hydrocarbons, including high-quality synthetic diesel or jet fuels. Synthesis gas for Fischer-Tropsch conversion may also be produced from other types of feedstock, such as natural gas or biomass. These systems are referred to as gas-to-liquids (GtL) or biomass-to-liquids (BtL) technologies. There is a preference for indirect coal liquefaction by CtL project developers because this process is driven, among other factors, by the technology’s high maturity at commercial scales. For example, indirect coal liquefaction technology has been applied in South Africa for more than five decades, with coal-derived fuels covering about one third of the national liquid fuel supply. Globally, about 24 indirect coal liquefaction facilities and one hybrid plant, which combines direct and indirect coal conversion, are being planned. The total initial capacity of all planned indirect coal liquefaction plants adds up to 747,900 barrels per day, which is equivalent to approximately 72% of the total 2006 diesel and gasoline demand of Germany’s transport sector (BDEW 2008). In China, two additional indirect coal liquefaction demonstration plants, with daily capacities of 4,000 barrels, are already being constructed. Both plants will be put into operation in 2009 and are envisaged as pioneer plants for the commercialisation of indirect coal liquefaction in China.

Most available studies or reports on coal liquefaction focus on technical questions, aspects related to energy reserves and resources or economic issues. So far, political and stakeholder-related framework conditions for CtL investments have not been subjects of in-depth research. However, the international debate on CtL suggests that coal liquefaction is a highly politicised technology. The diffusion of coal liquefaction strongly depends on national and international political framework conditions and the balance among CtL advocates and opponents. This thesis seeks to investigate all these aspects. It is based on the hypothesis that technological change and technology diffusion are affected by a broad set of ‘hard’ parameters (techno-economic and resources-related aspects) *and* ‘soft’ parameters (political/institutional and stakeholder-related aspects). As the study is written in the field of Political Science, it emphasises the role of political and stakeholder-related aspects in CtL diffusion and aims to reveal interdependencies with ‘hard’ diffusion parameters. By doing so, the thesis contributes to an integration of Political Science into an interdisciplinary, technology-specific analytical framework.

The role of different diffusion parameters in processes of technological change is conceptualised in the technological system approach. This is an analytical framework which was developed by Thomas P. Hughes and Bo Carlsson. It is rooted in the theoretical school of innovation systems. The technological system approach is used as a framework for the investigation of the problem formulations listed below and implies an interdisciplinary and systemic understanding of technology. The thesis investigates three potential key markets for coal liquefaction. These are the case studies of the U.S., China and Germany. The selection of these countries is explained in more detail in section 2.2.

The research interest of this dissertation may be summarised in the following problem formulations:

1. Which stakeholder-related, institutional, techno-economic and resources-related parameters can be identified as determinants of a possible diffusion of coal liquefaction technologies in the U.S., China and Germany?
2. How do the identified determinants affect the market prospects of coal liquefaction in the selected countries?
3. Which general conclusions with regard to driving forces and barriers for CtL diffusion can be derived from the investigated case studies?

In order to answer these problem formulations, the following analytical steps need to be taken:

a) Development of an analytical framework which, based on theoretical assumptions and diffusion case studies, generates broad categories of different ‘hard’ and ‘soft’ diffusion parameters (section 3). These categories help to structure the case studies in a consistent and comparable way and identify country-specific driving forces or barriers for CtL commercialisation within each category.

b) Discussion of general techno-economic features of coal liquefaction technologies, as they strongly affect the positions of CtL stakeholders or the national setting of policies (section 4), e.g. technical principles of different conversion routes, their state of development or commercialisation, production costs and environmental performance.

c) Identification of interdependencies among the scope of global coal reserves, the availability of certain coal qualities and the deployment of coal liquefaction technologies (section 5). Most countries interested in CtL indicate limited domestic crude oil reserves and large coal reserves, which is why the given aspects decisively influenced the selection of case studies.

d) Analysis of driving forces for CtL diffusion in South Africa, as former South African governments established a complex system of financial incentives to build the world's first coal-based synfuels industry (section 6).

e) Analysis of driving forces and barriers for CtL diffusion in potential key markets, such as the United States (section 7), China (section 8) or Germany (section 9), in line with the analytical categories developed in section 3. Each country indicates an individual setting of more specific hard and soft parameters affecting the market prospects of CtL. The case studies emphasise 'soft' aspects, such as the constellation of CtL stakeholders and the national framework of technology, energy and climate policy.

f) Comparative discussion of the analysed case studies in order to draw general conclusions on important driving forces or barriers for CtL diffusion, most promising CtL markets and the technology's global prospects (section 10).

The investigation of the given problem formulations and listed analytical steps is based on archival research, including analysis of scientific studies, papers or legal documents, and a large number of stakeholder interviews. Section 2 presents more detailed information on the research design and applied research methods.