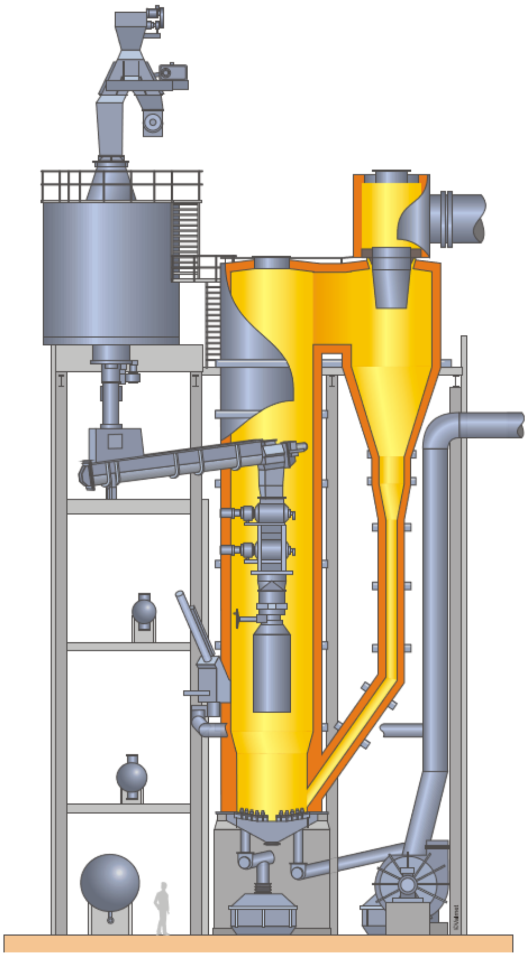
Lessons Learned about Thermal Biomass Gasification

IEA Bioenergy, Task 33
Thermal Gasification of Biomass and waste



IEA Bioenergy

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Lessons Learned about

Thermal Biomass Gasification

Report elaborated 2016-2018 under

IEA Bioenergy, Task 33 Thermal Gasification of Biomass and waste

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Cover: Valmet CFB Commercial Biomass Gasifier Serie 50-300MW [1]

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Abstract

This Report "Lessons learned about thermal biomass gasification" was elaborated by the IEA Bioenergy under Task 33 (Thermal Gasification).

The renewable resource of biomass (BM), the vision for a more CO_2 neutral energy supply and the high numbers of different value chain, as well the idea to overcome energy shortage were and are the main argument for that long-lasting research activities over decades in the field of thermal gasification for energy and material conversion.

This report shall show why there is a gap between implementation and the communicated success of this technology. What lessons shall we learn about the past activities and what can we do for future thermal gasification projects, that they will become successful.

At the beginning of this study, the authors assumed that problems with biomass gasification systems occur mainly at the technical level. It soon became apparent, however, that the plants built did not fail because of technical challenges, but often because of economic reasons.

For the central European forestry, smaller (<10 MW) plants are suitable, since usually no gigantic forest areas are present.

Optimal initial situations are offered, for example, by carpentries, which can generate added value with a connected heat network for process heat or district heating. Waste, that is produced and must be disposed anyway, can be recycled, electricity and heat can be sold or used by themselves.

If large plants (50-100MW and more) are to be built, it must be expected that this plant will have direct effect on the price of raw materials in the surrounding forestry. If e.g. a 100 MW plant is built in the border area of Switzerland, Germany and Austria, the biomass price will increase within a radius of about 200km, because the biomass material flow will be significantly changed.

If a complex plant, including heat and power output, is considered over its entire life cycle, it becomes clear that, in addition to long-term heat and power purchase agreements, the feedstock must also be secured in the long term. Only in this way long-term economic indicators can be reasonably calculated.

From a business point of view, direct competition with fossil technologies also makes no sense.

For example, a plant must always be supported with a "greenhouse gas subsidy" or a CO_2 bonus. This subsidy must, of course, be guaranteed for the entire lifetime of the plant.

This means that a large plant cannot be operated under free market conditions.

This can be different for large state (e.g. Scandinavian, Ukrainian or Canadian) forest owners. Large plants with various technologies are already being built there today.

Nevertheless, large combined heat and power (CHP) plants, which are to be operated separately from an industrial company, are hardly ever realised.

1 Introduction and Basic Information

1.1 MOTIVATION AND AUTHORS REMARKS

Decades of development of thermal biomass gasification is a long story of ups and downs, of failures and success. In the transition from researched know how into economic and ecological successfully operated plant is a long row of challenging, difficult and positive experiences. At least all of these steps are highly interesting and worth to consolidate. "Lessons Learned about Biomass Gasification" shall rise understanding of the chances.

12'735km diameter, just 25km atmosphere, surface temperatures form -89 to +58° Celsius on the surface. This is our earth.

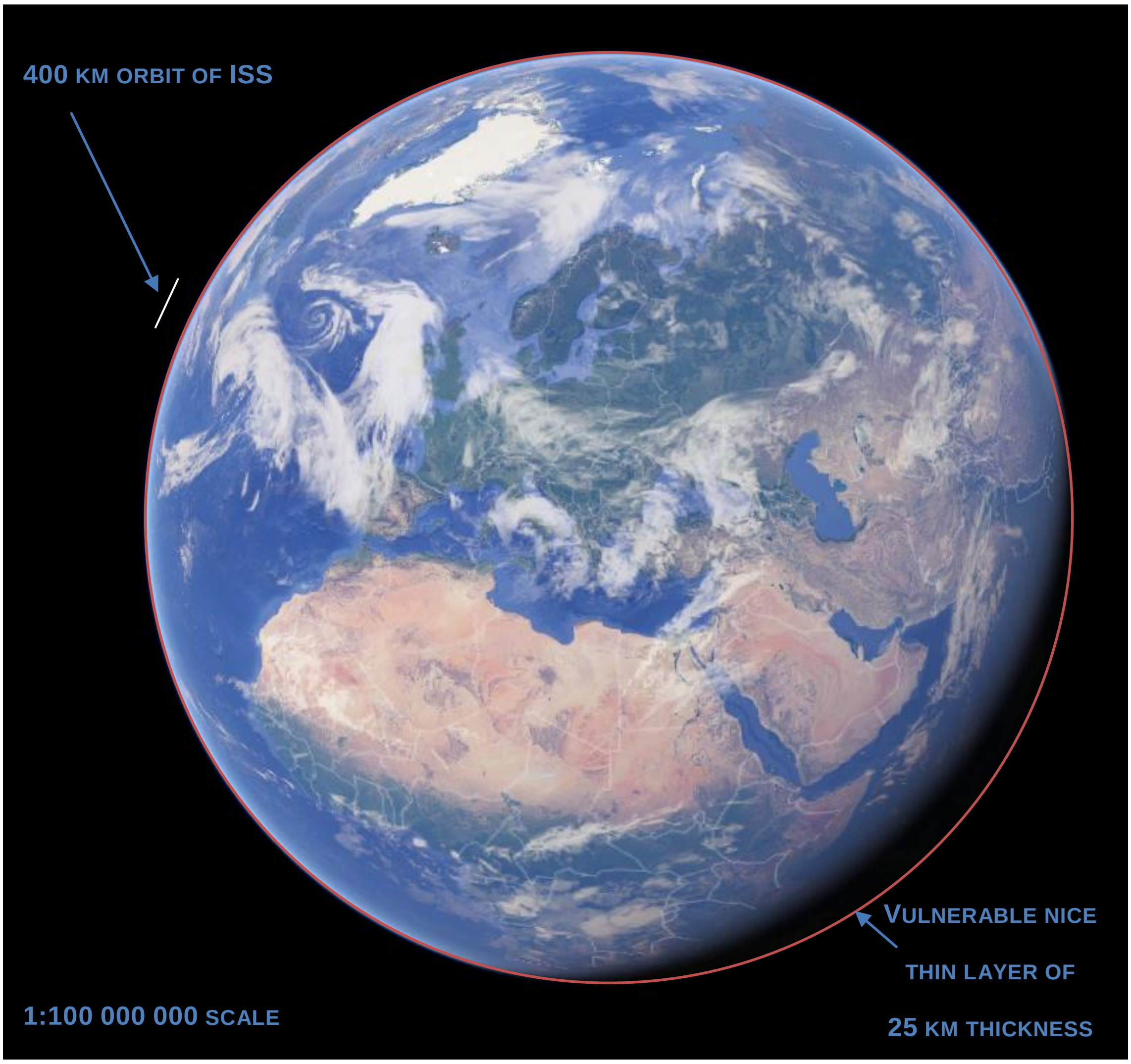

Figure 1: Our earth with the (nearly not paintable) atmosphere [2]

This picture from the earth and its atmosphere is the growing base of discussed biomass, it is the human home base. Why do we refer to that picture? We checked again the size of worldwide available biomass, we checked the different surfaces needed, checked also if it is real on google earth, where this biomass grows. Mentioned in relation to a proper scale we were so astonished how **thin this belt** of atmosphere is. It is the air we breathe and where the biomass is growing.

So please, we invite you to this exercise of understanding size! I have put a layer (orange) in exact scale with the thickness of 25 km. In relation to earth diameter of 12 735 km this atmospheric layer is just almost nothing and therefore very vulnerable!

Why we think to mention about? Very simple: We should mitigate CO_2 with biomass on the best possible sustainable, reliable and efficient way and with a technically approved value chain already today. And thermal gasification is a reasonable approved technology.

May some of the content of this report provoke oppositions. We try to give reflections on why there is a success for some projects and why there will be not so easy success for some larger projects, especially if we assume the market will regulate everything. Why changes happened it always has a reason. There is also a reason why certain tempting technologies in the past 100 years are in discussions and will not have a breakthrough. We see that in the renewables energy fields there are so many different opinions, information's and interests that it is not easy to get a feeling what is realistic, what is hyped and what is way out of reality. For that reason, we make also the frame up to history, to worlds available biomass and to different value chains. Technology must serve to human and society, not the contrary.

1.2 SCOPE AND AIM OF THIS REPORT

Background
The primary scope and focus of IEA Biomass Agreement Task 33, "Thermal Gasification of Biomass and waste", is to follow the developments in the area of chemical-thermal conversion technology of biomass and waste with the purpose of providing a comprehensive source of information on activities in this field from the participating countries. To disseminate this information, apart from in meetings and workshops arranged by the Task, a dedicated web site is free available for public also outside of this group (www.ieatask33.org).

Aim
Elaborating a tool and report for project developers, decisions makers and others in gasification interested persons. The aim is to show possible pathways to avoid failures and mistakes already experienced in the past and show for future projects how to lead them to successful operated thermal gasification units.

Scope
Output of this work shall be a "Report" addressed to project developers, decisions makers, researcher and others in gasification interested persons. The focus is clearly to commercial, early commercial plants and not to research, demonstration or Pilot Plant.

1.3 DISCUSSED BOUNDARIES

The discussed boundaries of this report are the value chains for woody fuel and waste from lignocellulosic biomass. It deals also from pilot plant as a reference but focusses on technical mature value chains and the commercially implementation to mitigate the CO_2 problem. We refer to all activities in within the IEA Bioenergy Task 33 as a conversion pathway "thermal gasification of biomass and waste". We do not investigate efficiency negative systems (e.g. plasma destruction for problematic waste) where more energy is put in as taken out. We clearly look to biomass in all forms as an input fuel with the aim to convert it for a market such as liquid or gaseous fuel, heat and power. We do not investigate conversion into chemicals or other non-energy containing product such as cellulose, plastic etc. We do not look in into municipal solid waste (MSW) from the technical point of view this is discussed in detail in a separate report. (see 1.3.2).

1.3.1 Value chains for biomass conversion with thermal gasification processes

The following diagram shows the various value chains for lignocellulosic feedstocks such as wood via gasification processes.

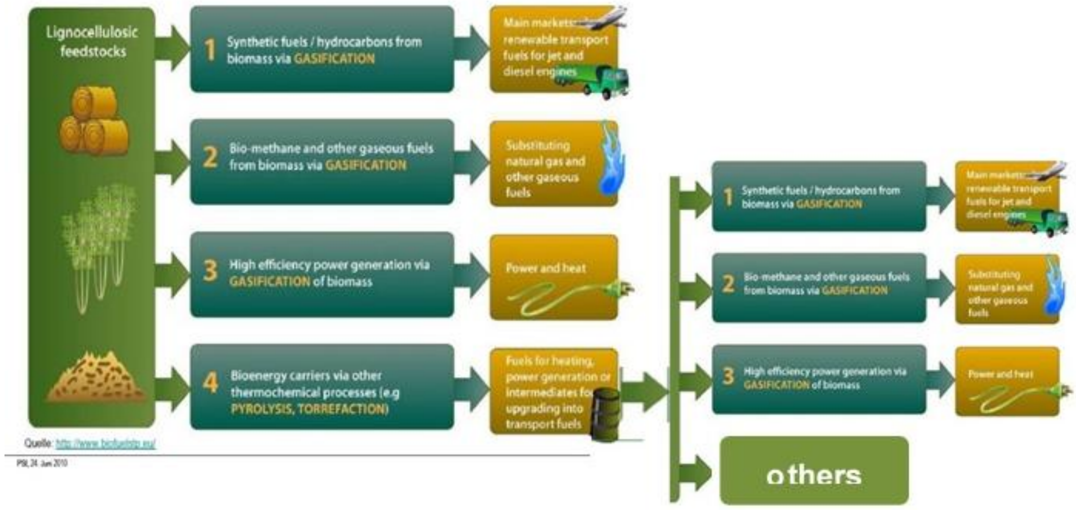

Figure 2: Value chains of thermal gasification and in different combination. [3]

1.3.2 Value chain for municipal solid waste conversion

For information about MSW conversion, see new report from 2018 under Bioenergy IEA Task 33 gasification of waste for energy carriers.

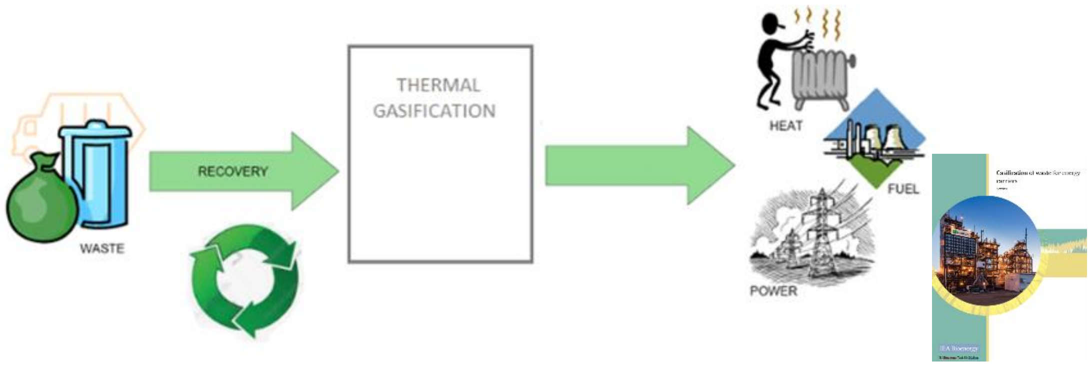

Figure 3: MSW Conversion [4]

2 History of thermal gasification

Thermal gasification is not a new technology, it has a long history for different applications. This chapter is a very important part to understand why biomass was, is and will be in future an important issue for human being. Since many centuries the thermal gasification has played an important role and will have an important place in present and in future, for biomass and fossil energy conversion as well.

2.1 PRE-INDUSTRIAL USE OF BIOMASS

Type of Biomass Conversion		Product	Used for	Negative points & impact	remark	Link
Combustion Open fire Agriculture fire clearing		Heat coal	Heating Cooking Forging Pottery Brick and tiles fabrication Soil improving	Smoke Efficiency Lung cancer	Still today for several billion of human most common	https://en.wikipedia.org/wiki/Combustion
Torrefraction		Charcoal (Köhlerei)	Heating Cooking Forging Metallurgy	Around towns deforestation (Accelerated Coal gasification for "town gas")	Clean burning of coal, hot burning, no smoke	https://en.wikipedia.org/wiki/Charcoal#Production_methods
Condensed wood gas (Pyrolysis)	 	Tar Pitch 	sealing protection chemical application medication Mummification (Egypt)	Toxic by products cancerogenic	For boat building Roofing Fuel	https://en.wikipedia.org/wiki/Tar https://en.wikipedia.org/wiki/Pitch_(resin)
Smoking = Low oxygen burning	 	Stabilized Food	Food storing	Strong smell cancerogenic	For thousands of year applicated	https://de.wikipedia.org/wiki/R%C3%A4uchern

Table 1: Pre-industrial use of biomass

Using the fire is one of the important steps of human development, away from "paradise" into the human formed world. Using all kind of converted and stabilized biomass is the first step of technology society. Before industrialization biomass was the most important energy carrier and wood the most reliable construction material for houses, boats, tools etc…

Also, since thousands of years we face the problem of human overpopulation, the overharvesting and a non-sustainable handling of biomass for energy use or construction material. Nice example therefore are the disappeared forests of the Adriatic islands and coast by the wood demanding old Greece society. Still today, many Adriatic Island are a dry stony desert, despite of the strong efforts and trials for reforestation.

2.2 GASIFICATION DEVELOPMENT ALONG INDUSTRIALIZATION

Gasification processes have been used since the beginning of industrialization in various sizes and fields of application. The following diagram shows a time line over the last two centuries.

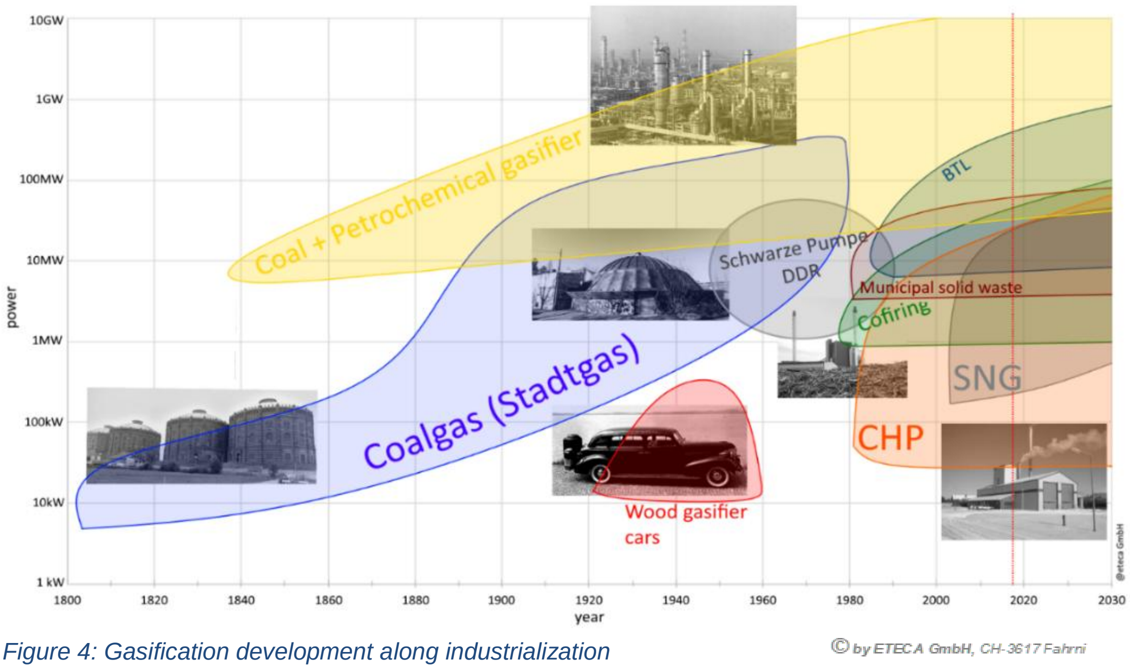

Figure 4: Gasification development along industrialization

Biomass to liquid (BTL) and synthetic natural gas (SNG) activities are mentioned to grow but today, the fact is that the progress is made over optimistic as shown in the figure. One million of wood gas driven car were in operation in the time of World War II. Those appeared and disappeared quickly. Strong research activities lasted till the eighties and are in the memories of today’s generations. The technology of wood gas cars is still very present and attracts many individuals in a positive way.

In contrary to the historical wood gas car, is in today’s collective memory almost not present, that almost every town in Europe had thermal gasification plant for “town gas production”. The ground and surroundings of this gasification plant had after closing to be cleaned from all kind of nasty chemicals and heavy metals (usually paid by the public).

Many of this town gas supplier where privately owned and the benefit disappeared in the private pockets. A typical phenomenon of free market: benefits must be guided to accumulate private wealth; business losses and restoration must be distributed to public tax payers. So, everybody is happy (or not?).

2.3 HISTORY OF COAL AND PETROCHEMICAL GASIFIER

In the petrochemical and coal gasification sector, the installed capacity exceeded the 1 GW limit around 1960. Currently, gasifier with a total capacity of approx. 300 GW are in operation worldwide.

<1GW	1960
70GW	2010[1] [5]
300GW	2018 (approximately)

The following diagram shows the cumulative power of fossil gasification plants in operation, under construction and planed worldwide.

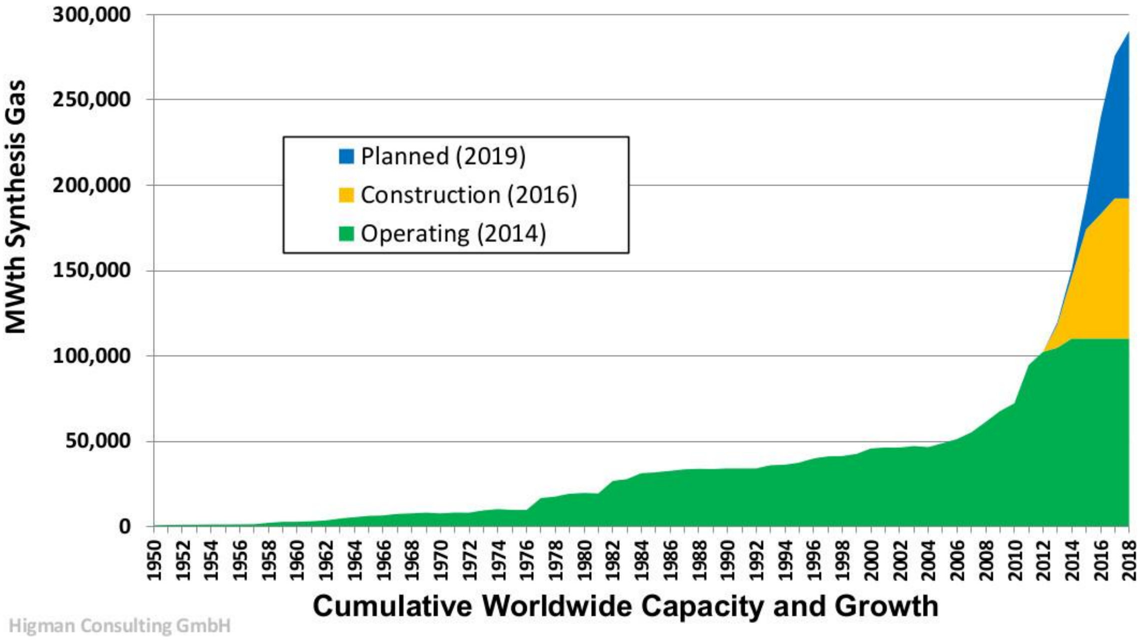

Figure 5: History of thermal Gasification worldwide (GSTC) [6]

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[1] The U.S. Department of Energy's (DOE 2010 Worldwide Gasification Database shows that the current gasification capacity has grown to 70'817 megawatts thermal (MW_{th}) of syngas output and 144 operating plants with a total of 412 gasifiers (NETL, National Energy Thechnology Laboratory 2010). In order to be consistent with prior databases only commercial operating plants with a capacity exceeding 100MW electric equivalent (MW_e) are included in the database. Cited of [5]

2.4 HISTORY OF THERMAL BM GASIFICATION OF THE LAST TWO DECADES

Approximative thousand small scale biomass gasification plants are in operation in 2018. Several larger units are planned and in operation worldwide. Further complex plants were built for pilot- and demonstration purposes only and have been shut down. Most of those activities gained high public attention. Documentation of this activities are available.

Under the IEA Bioenergy Task 33 the last status report 2016 and 2018 are available with nice and detailed information.

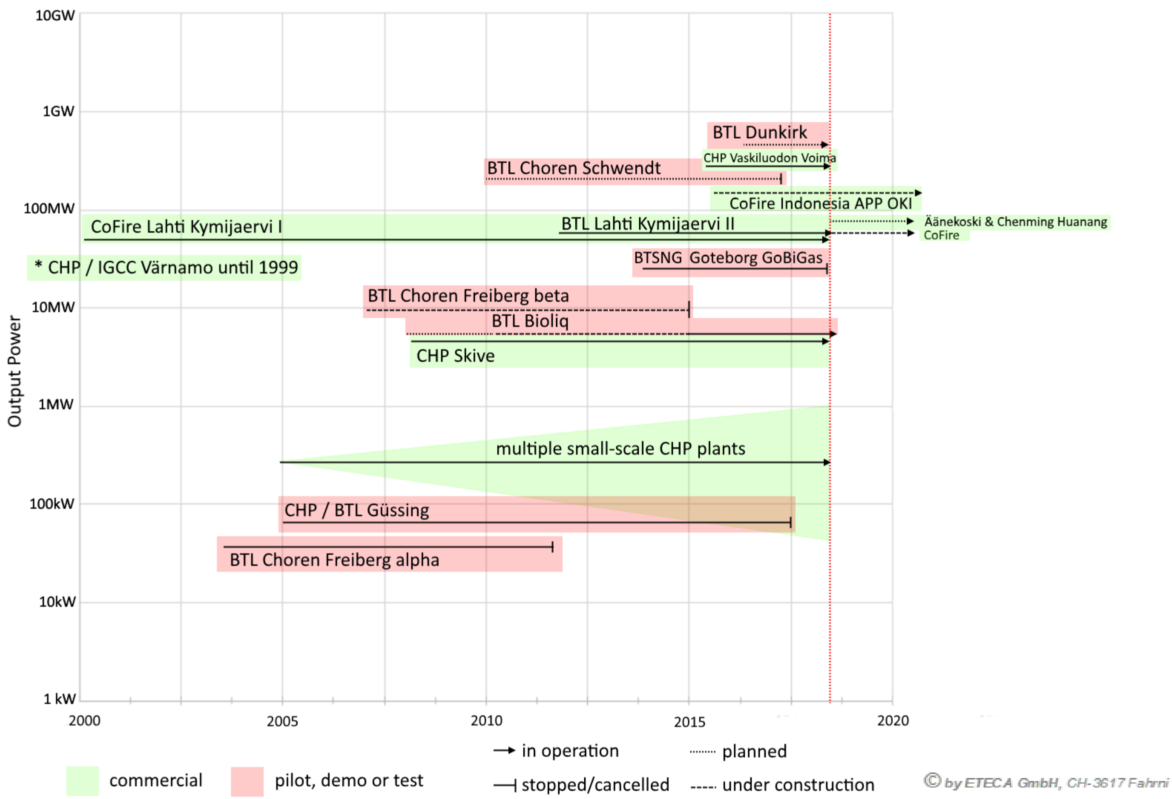


Figure 6: History of thermal biomass gasification in Europe

Status report see http://ieatask33.org/download.php?file=files/file/2016/Status_report.pdf [7]

2.5 HISTORY OF SMALL-SCALE GASIFICATION PROCESS

History of application for small scale gasification is quite interesting and can be grouped in the following steps:

	produces	aim	period	driver
Step 1	Fuel gas	fuel for transportation and stationery gas engines	1930-1950 1950-1980	War time 1 000 000 units fuel shortage (third world)
Step 2	Fuel gas and heat	CHP stationary	1973 - 1990	Oil crises
Step 3	Fuel gas and heat	CHP stationary	1990 - present	CO_2
Step 4	Fuel gas, heat and coal (by-product)	CHP stationary plus by-product	2010 - present	CO_2 + costs (1300 small-scale CHP units are in operation in 2018 in Europe)

Table 2: Historical steps of implementation

As a summary of historical conclusion of that table:

> Nobody would use a more complex process if simpler technology is available. Only believed shortage of energy, high prices and smaller CO_2 impacts are the driver of that small-scale gasification technology.

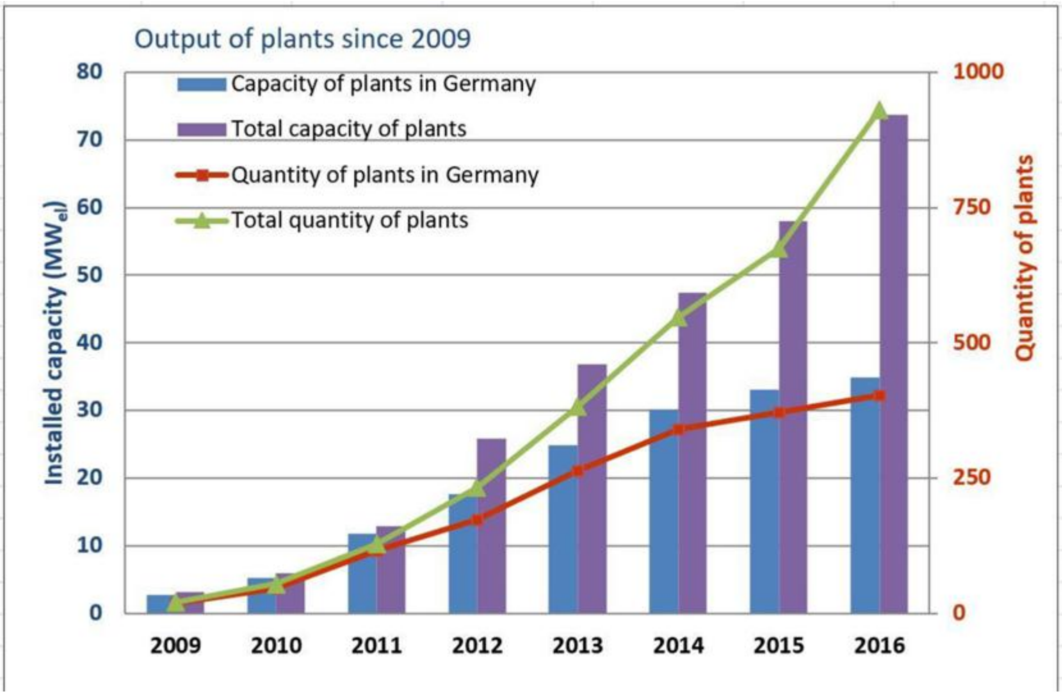


Figure 7: History of thermal small-scale gasification in the last decades. [8]

2.6 HISTORICAL VALUE CHAINS WITH THERMAL GASIFICATION

Find below a summary of historical implemented thermal gasification. The technically successfully applications build under industrial conditions, not necessarily economically, operated under normal conditions (not R&D) are underlaid with green colour.

	preindustrial	1900-2000	2001 - today
Coal to Gas	-	Yes	Yes
Coal to liquid	-	Yes	Yes
Crude oil to liquid	-	Few	Yes
CHP IGCC with NG/Coal	-	Yes	Yes
Small scale biomass CHP		No	Yes
Large scale biomass CHP	-	No	Yes
Co firing BM	-	Yes	Yes
MSW		No	Yes
BM to syngas	Yes, for smoking food	Yes, short time mobile application	Yes
BM to liquid	Yes, for tars and chemicals	No	No
Biomass CHP with IGCC	-	Demonstrated	No
BM to SNG	-	No	Demonstrated

Table 3: History of thermal gasification technically successfully applications

2.7 STATUS OF IMPLEMENTATION OF VALUE CHAINS AT PRESENT

To get an up-to-date overview of the implemented biomass gasification projects, the database on the IEA Task 33 website can be consulted.

The list below is only a rough summary.

Municipal waste gasifier CHP:
See report IEA TASK33 Report: gasification of waste for energy carriers 2018.

Biomass gasifier for process and district heat application
- Very large units in operation

Biomass gasifier CHP with gas engine:
- Small units largely implemented
- Large size >50 MW feedstock not implemented.

Biomass gasifier CHP with boiler and steam turbine
- 50 MW up to 300 MW commercially demonstrated and some in commercial operation

Biomass gasifier with Integrated Gasification Combined Cycle (**IGCC)**
- Demonstrated but not commercially implemented

Biomass gasifier for co-fire in combination of fossil power plant
- Successfully and in large units commercially implemented

Biomass gasifier BM to SNG
- Successfully demonstrated (GOBIGAS closed) but not commercially implemented

Biomass gasifier for BTL or BM to SNG
- Successfully demonstrated (Güssing, Choren, ENERKEM …) but not one in commercially implemented

2.8 HISTORY OF IEA BIOENERGY AGREEMENT AND IEA BIOENERGY TASK 33

Under the IEA Bioenergy Agreement activities for thermal gasification was a topic issue since 1979. The main driver of this activities was the oil crises of 1972. That means undersupply of fossil fuel. Especially, in the USA where many projects initiated. The orange lines in the graph below are leading through the thermal gasification activities for biomass.

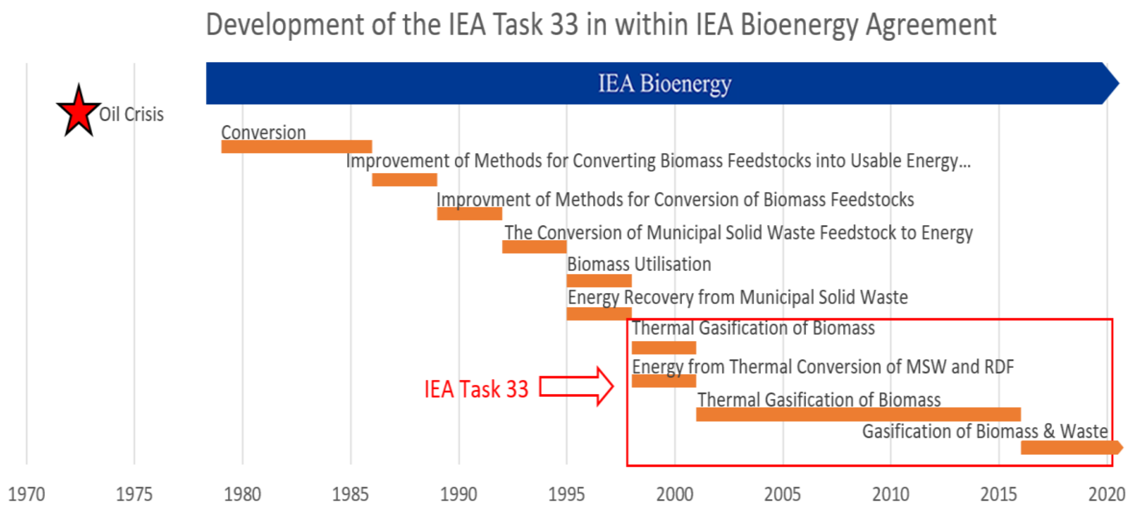


Figure 8: History of thermal gasification IEA Bioenergy activities in the last decades [9]

In within IEA Bioenergy 1979-2018 almost	40 years of follow up thermal gasification!
Task 33 since 1998	20 years!

Decades of development of thermal biomass gasification in within all these activities are well documented. Reports, research documents, workshops slides as well as summaries and conclusions are available under www.ieatask33.org. [10]

The status and country reports, and the database of the IEA Bioenergy TASK 33 shows clearly the large activities in thermal gasification in history as well as what are the facts of today's situation.

Status report see http://ieatask33.org/download.php?file=files/file/2016/Status_report.pdf [7]

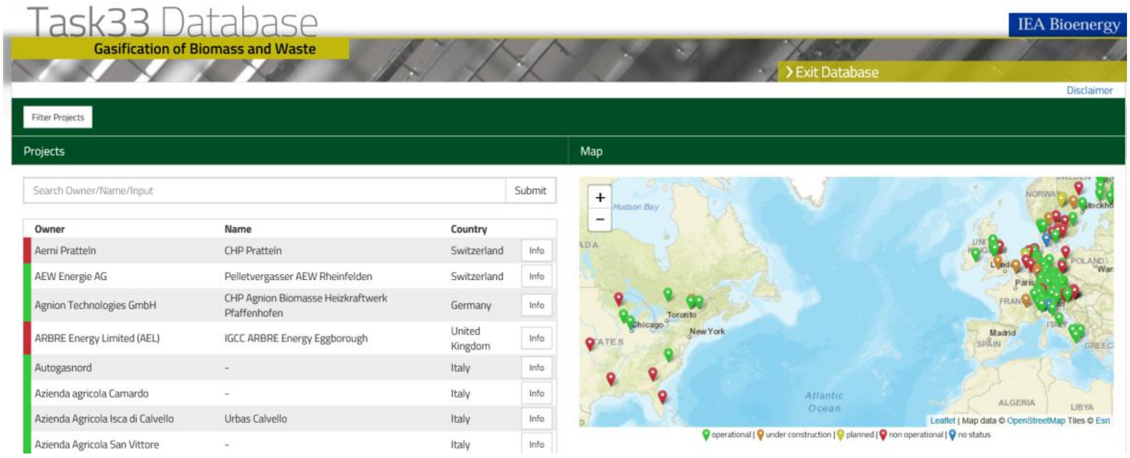


Figure 9: Excerpt of listing on the IEA-web-database (only member countries are listed) [10]

2.9 HISTORICAL DOCUMENTS OF EARLY 20TH CENTURY

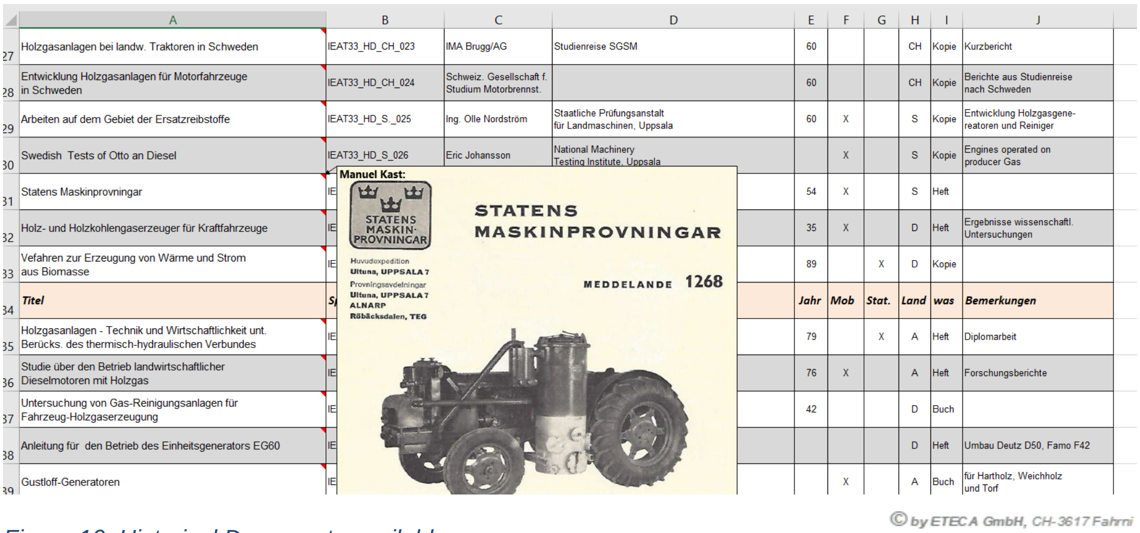


Figure 10: Historical Documents available

In within this IEA Bioenergy Task 33 projects "Lessons Learned" it is was possible to get access to different historical documents. In respect to get access to this document to all interested persons, these historical documents where scanned and the document are also available on the Task 33 website. Most documents still refer to small-scale gasification.

➔ see Annex 1: List of historical documents

2.10 HISTORICAL REMARKS OF 1998

Tom Reed (1998) offers the following insight as to his experience to date:

While a great deal of time and money has been spent on biomass gasification in the last two decades, there are very few truly commercial gasifiers, operating without government support or subsidies, day in, day out, generating useful gas from biomass. The typical project starts with new ideas, announcements at meetings, construction of the new gasifier. Then it is found that the gas contains 0.1-10% 'tars.' The rest of the time and money is spent trying to solve this problem. Most of the gasifier projects then quietly disappear. In some cases, the cost of cleaning up the experimental site exceeds the cost of the project! Thus 'tars' can be considered the Achilles heel of biomass gasification. (In the gasification of coal, a more mature technology, the 'tars' (benzene, toluene, xylene, coal tar) are useful fuels and chemicals. The oxygenated 'tars' from biomass have only minor use. With current Environmental and health concerns, we can no longer afford to relegate 'tars' to the nearest dump or stream. [11]

2.11 HISTORICAL REMARKS OF 2017

I believe that history shows that the killer for biomass gasification, that coal and petro coke don't face, is tars. Large biomass gasification projects that involve chemicals production or gas turbines have been too ambitious and challenging. The smaller genset CHP processes seem to be successful. Kevin Whitty Taskleader 33 2012-2018 [12]

Biomass Gasification remarks on the web from GSTC:

Biomass includes a wide range of materials, including energy crops such as switch grass and miscanthus, agricultural sources such as corn husks, wood pellets, lumbering and timbering wastes, yard wastes, construction and demolition waste, and biosolids (treated sewage sludge). Gasification can be used to convert biomass into syngas. Biomass gasification plants differ in several aspects from the large-scale gasification processes typically used in major industrial facilities such as power plants, refineries, and chemical plants.

Biomass usually contains a high percentage of moisture (along with carbohydrates and sugars). The presence of high levels of moisture in the biomass reduces the temperature inside the gasifier, which then reduces the efficiency of the gasifier. Therefore, many biomass gasification technologies require that the biomass be dried to reduce the moisture content prior to feeding into the gasifier.

Biomass can come in a range of sizes. In many biomass gasification systems, the biomass must be processed to a uniform size or shape to feed into the gasifier at a consistent rate and to ensure that as much of the biomass is gasified as possible. Most biomass gasification systems use air instead of oxygen for the gasification reactions (which is typically used in large-scale industrial and power gasification plants). Gasifiers that use oxygen require an air separation unit to provide the gaseous/liquid oxygen; this is usually not cost-effective at the smaller scales used in biomass gasification plants. Air-blown gasifiers use the oxygen in the air for the gasification reactions.

Benefits of Biomass Gasification:

- Converting what would otherwise be a waste product into high value products
- Reduced need for landfill space for disposal of solid wastes
- Decreased methane emissions from landfills
- Reduced risk of groundwater contamination from landfills
- Production of ethanol from non-food sources [13]

2.12 CONCLUSIONS AND LESSONS LEARNED

There is always a logical reason of implication in the history. Following visualization shows the development for heating applications. Obviously, humanity is always overharvesting till a negative impact forces to change technology.

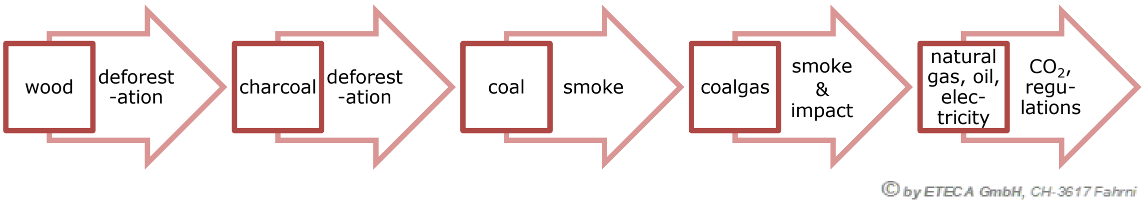


Figure 11: Reasons of implications in the history (example heating)

Legend to Figure 11:

 Chosen solution

 Resulting problem

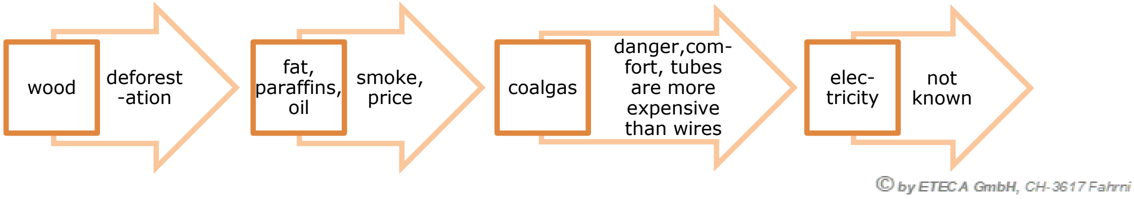


Figure 12: Reasons of implications in the history (example light)

Same game for the generation of light:

Legend to Figure 12:

 Chosen solution

 Resulting problem

So, driver for new technics are lack, harm, complexity, suffer or price. No one likes more complication, less comfort or higher costs. Political and economic power, convenience and inertia are inhibiting a change, even if an application could be replaced with an already available and better technology. Also, conspiracy theories (e.g. the oil lobby) and the possible implementation of a, maybe soon available, "one and only"-technology, is used as an excuse or reason why no change is possible now.

National, regional power games accelerate or prevent changes.
Large IGCC with gasifier are available and in operation, Coal to Gas (CTG) and Coal to Liquid (CTL) is common standard and worldwide in operation.

Thermal gasification is an established and available technology for fossil and biomass fuel and all those gasifiers, no matter if for biomass or fossil material, mitigates dramatically the today climate impact of fuel conversion.

3 Thermal gasification 2018 (at present)

3.1 THERMAL GASIFICATION WORLDWIDE

Worldwide gasification capacity is expected to grow significantly since 2018, with the primary growth occurring in Asia (primarily China, India, South Korea, and Mongolia)

The cumulated syngas output power of all gasification units is approx. 300 000 MW.

That means thermal gasification technology in general is worldwide commercially implemented. The technology is available, commercial supplier can deliver the equipment, investors support that technology widely. Project can easily be multiplied. There is a stable know how exchange and competition seems to work on that worldwide market place.

3.1.1 Thermal gasification operated worldwide, with fossil input fuel

The map shows the distribution of coal gasification plants. The high number proves that the gasification technology is available and can be used reliably. It is therefore likely that the gasification of biomass can also be successfully implemented.

Figure 13: Thermal fossil gasification worldwide (GSTC adapted) [14]

3.1.2 Thermal gasification operated worldwide, with biomass input fuel

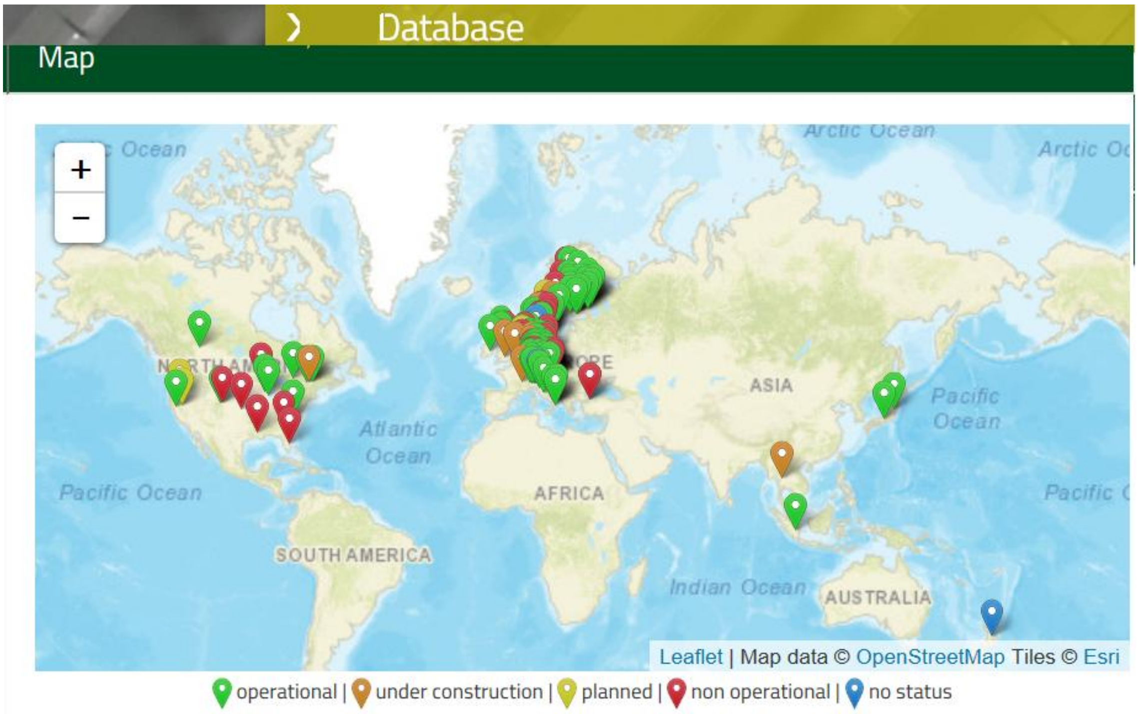


Figure 14: Thermal BM gasification worldwide (IEA Task 33 database) [10]

That means thermal gasification technology for Biomass is worldwide approved. The technology is available, commercial supplier can deliver the equipment.

In small scale CHP units, the commercial standard is approved with subsidies.

For large scale conversion plant, the commercial standard is in small numbers approved such as for MSW, Co- firing, CHP, and BM gas fired industrial kiln furnace, (e.g. as for cement industry) up to 150 MW fuel input and more. Nice examples are documented and shown by Valmet.

Investors support that technology not so widely without subsidies. Project cannot easily be multiplied. There is a stable international know how exchange, a large intensive congress and conference activity, but competition seems not to work on that worldwide BM thermal gasification supplier market place. Supplier go frequently of business and plant need often public support.

There are no large BTL, BM to syngas, BM to SNG plants, also no large CHP IGCC units commercially in operation even the technology is available and in very rough fossil applications widely approved.

There is a big gab in-between medial communicated and raised expectations of implementation and the real commercially implemented plants.

3.2 BIOMASS GASIFIER GENERAL 2018 (AT PRESENT) IN RELATION TO FOSSIL GASIFICATION

Please note that the following two diagrams, Figure 15 and Figure 16 have the same identical scale for x- and y-axis.

666

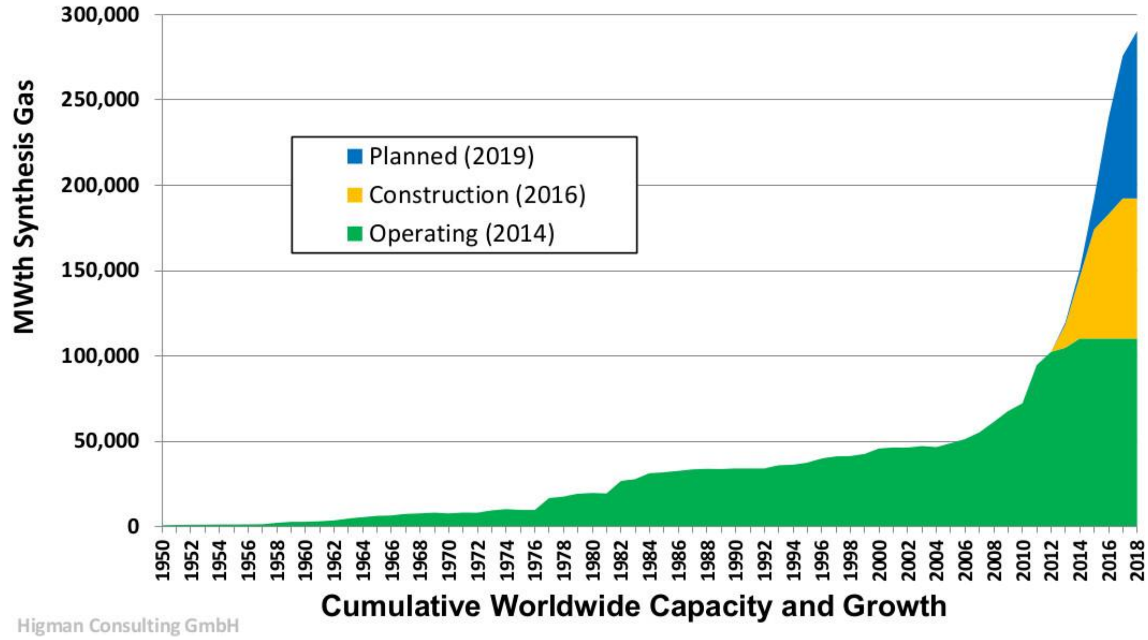


Figure 15: History of thermal gasification worldwide (GSTC) [6]

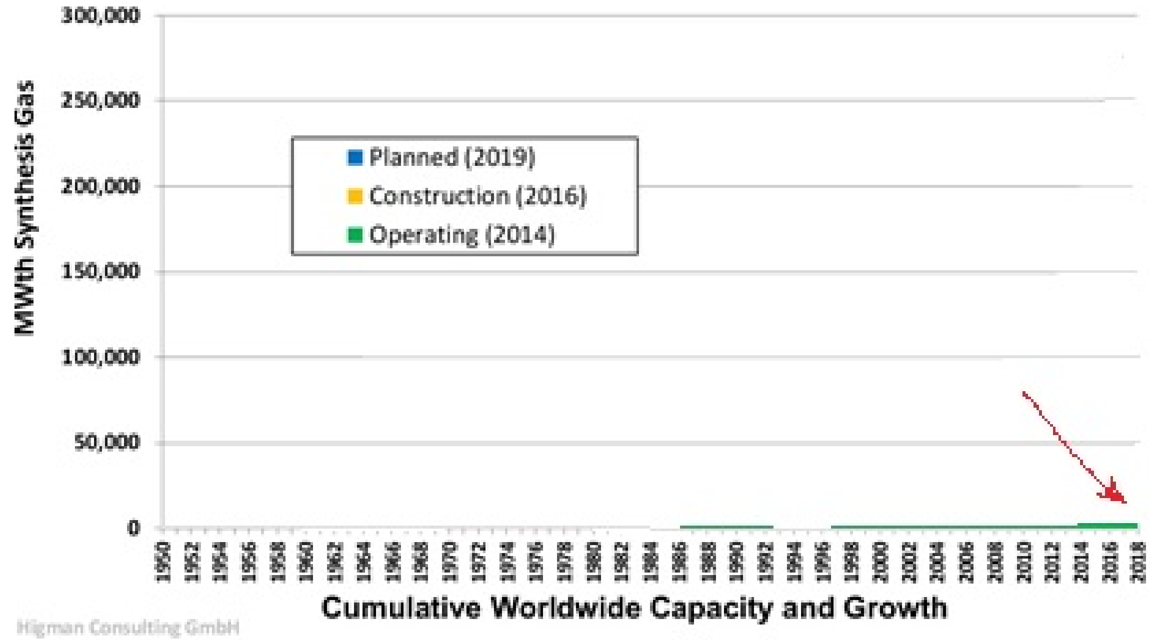


Figure 16: History of thermal biomass gasification worldwide (adapted by ETECA GmbH)

When comparing the installed capacity of fossil fuel gasifiers with that of biomass gasifiers, it quickly becomes clear that these areas are far from each other and the installed power is nearly not comparable.

Nevertheless, it should be noted that the use of this technology has a much greater (positive) environmental effect than its application in the smaller biomass sector because gasification in a fossil environment leads to an increase in efficiency. Imagine the environmental impact of those fossil plants, if they would still run with older, not efficient technology.

So even as a proponent of renewable technologies, it can be said that fossil fuel plants also should be renewed with gasification technologies, to reduce CO_2 emissions during the time of transition towards more renewable energies (RE).

For fossil fuel gasification plants, CO_2 reduction is no argument for implementation in first step, it’s a positive side effect. Accepted higher complexity is compensated by this technology with higher efficiency, better fuel stock usage, and successful commercial yield.

The number of media reports from projects, research projects and conferences in the field of biomass gasification plants is not in line with the actual impact of the existing projects.

However, the graphs also show that industrial scale implementation has only begun in recent years (not included are R&D nor precommercial, nor demonstration plant).

The technology of gasification is largely approved and worldwide available. If any doubts, use multiple steps and convert the biomass firstly to coal (torrefaction) and then convert the biomass in a coal gasifier. In most cases it is enough to dry and stabilize the biomass feedstock.
Missing implementation of large-scale biomass gasification plants must be found somewhere else than in technical issues.

3.3 PROJECT DRIVERS FOR BIOMASS THERMAL GASIFICATION PROJECTS

This chapter shows the different drivers behind a project.

General drivers for thermal gasification

- Financial benefit
- Political strategies and financial long-term support of conversion technology
- Fossil fuel replacement due to climate changes
- CO_2 reduction
- Climate change
- In fossil fuel and petrochemical conversion plants worldwide approved commercially application due to costs and climate mitigation
- Large companies’ strategical portfolio shifting towards “sustainable/green mind”
- Recycling and looping of waste of production processes

Syngas for heat

- Cleaner exhaust gas in relation to combustion applications:
- Easy refit for existing coal combustion power station
- fuel for Kiln furnace application
- fuel for brick furnace
- any process heat over low caloric gas burner

Power

- Mobile decentralized application
- High efficiency
-

CHP with gas engine and IGCC

- Low emissions (PM and NOx)
- High efficiency for electric power
- Fast load change
- Reduced cost approved for fossil fuel gasifier IGCC
- Demonstrated (BIGCC) in Värnamo (Sweden) 1993-1999 (3500h operation) and Bahia (Brasilien)2006
- Reduced cost approved for small-scale gasifier with gas engine

BTL and BM to SNG drivers

- Replacement of fossil fuel for
- due to climate impacts.
- Interesting research application
- Popular trends
- Media attention for "greenification" activities
-

Communicated customers and market for fossil fuel for

- Aviation
- Surface traffic
- offshore pleasure and cargo vessel
- heating oil
-

BM to petrochemical drivers

- BM as input replacement of fossil fuel for CO_2 reduction and general as impact mitigation against climate change and more sustainability
-

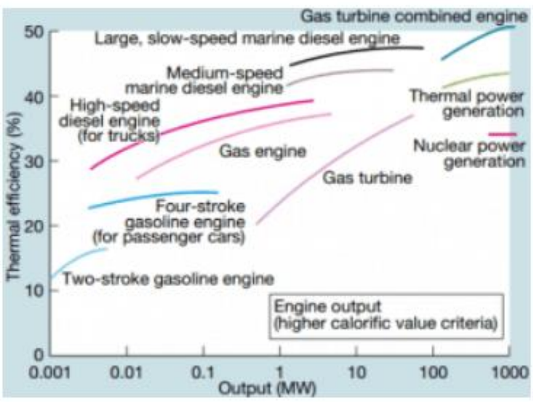
4 Efficiencies of biomass conversion with gasification systems

4.1 GENERAL INFORMATION

Sankey diagrams are showing the challenges that arise when biomass is to be used for various applications. The Sankey diagrams below should serve as a thought-provoking impulse to assess whether the corresponding conversion paths may be meaningful or not.

Biomass gasification CCS technologies are not discussed in this report. For this topic, another report from Task33 exists and can be accessed under:

http://ieatask33.org/download.php?file=files/file/publications/bio-CCS/Implementation%20of%20bio-CCS%20in%20biofuels%20production_final_isbn.pdf



Takaishi, Tatsuo; Numata, Akira; Nakano, Ryouji; Sakaguchi, Katsuhiko (March 2008). "Approach to High Efficiency Diesel and Gas Engines" (PDF). Mitsubishi Heavy Industries Technical Review. 45 (1). Retrieved 2011-02-04.

Figure 17: Conversion efficiency in different system [15]

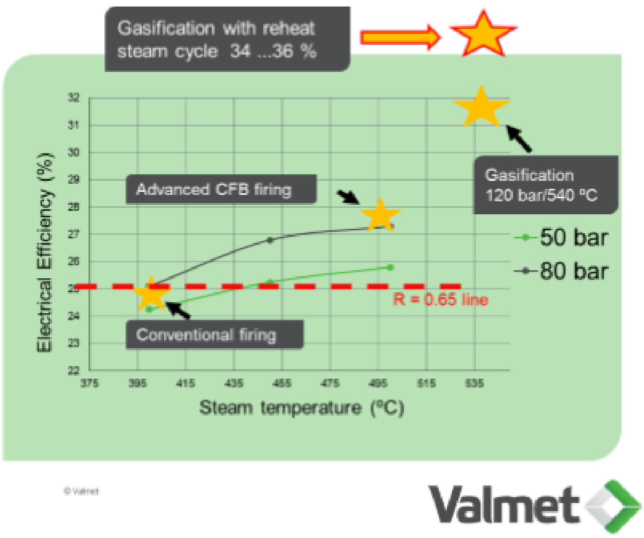


Figure 18: Conversion efficiency steam power station [16]

Table 4, Figure 19 and Figure 20 are showing efficiencies for several CHP-Scenarios from converted biomass. Efficiency is a strong possible project driver.

Process efficiency		large Heat only	small Heat only	small CHP (engine)	large CHP (steam)	IGCC el. power	IGCC +CHP
η_q	thermal *efficiency*	93%	80%	49%	52%	0%	28%
η_e	electrical *efficiency*	0%	0%	31%	28%	44%	44%
η_{tot}	**overall efficiency**	**93%**	**80%**	**80 %**	**80%**	**44%**	**72%**

Table 4: Possible efficiencies for different plant sizes and applications [17]

The gasification efficiency depends on the size of the plant and the chosen gasification technology. For this report the gasification efficiency was assumed to be between **80% and 93%**. The assumption is based on realised CHP plants and manufacturer data.

Following diagram (Figure 19) visualizes the numbers in Table 4.

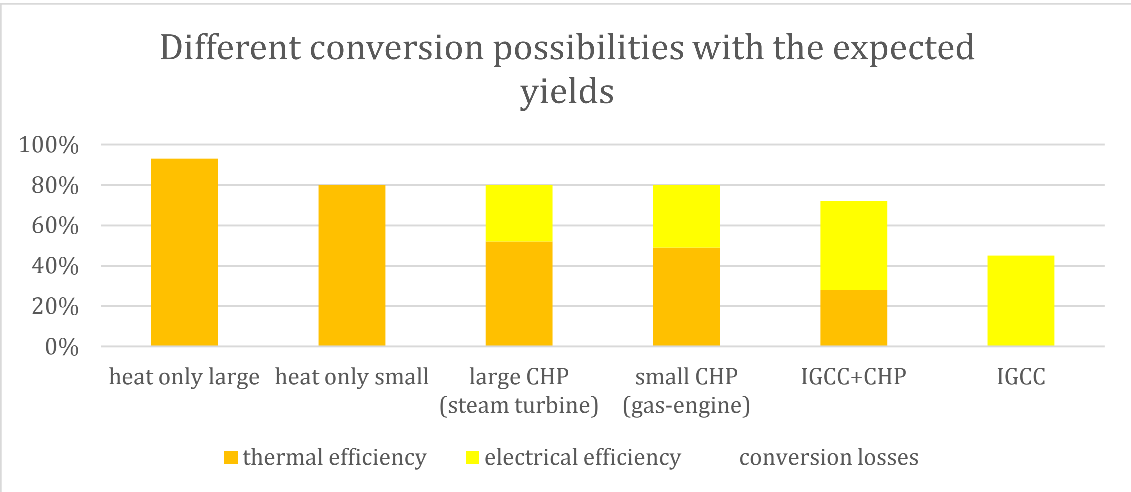


Figure 19: Possible conversion heat scenarios sorted for best chain efficiency for heat

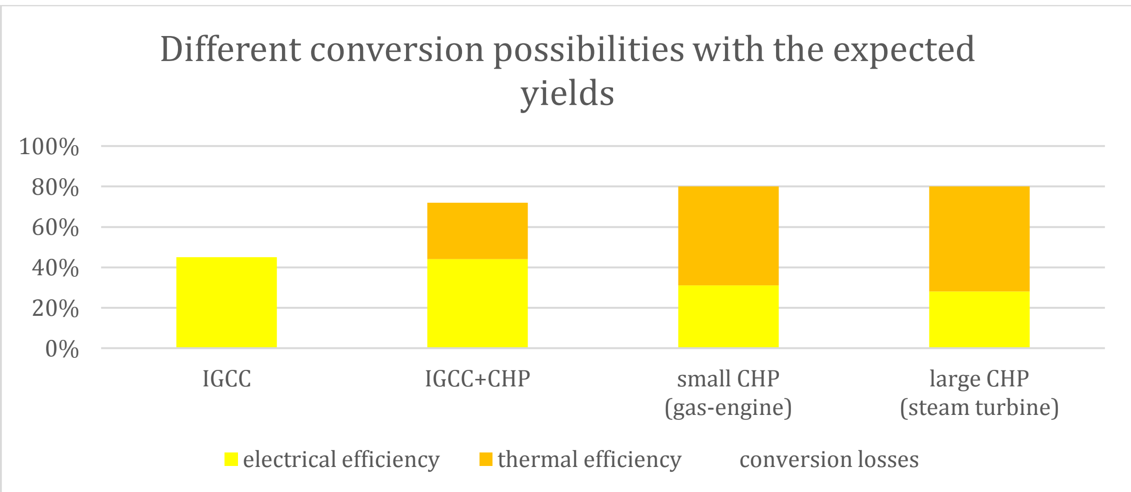


Figure 20: Possible conversion heat scenarios sorted for best electricity chain efficiency

4.2 BIOMASS GASIFICATION FOR HEAT ONLY

Figure 21: Example picture for district heating [18]

4.2.1 BM gasification, syngas to combustion for process heat (cement kiln furnace)

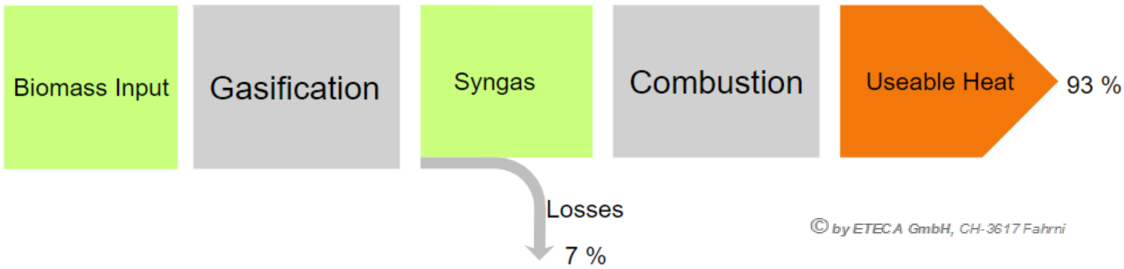


Figure 22: Biomass thermal gasification (large units)

Figure 23: Example gasifier plant by Valmet [1]

4.2.2 BM gasification, syngas to combustion for district heat only

This technology is alternatively available instead of biomass combustion. Applications from small scale to large scale are available. Advantages are seen in lower exhaust gas emissions. Implementations are made where high demand on emission reduction are required. It is a suitable solution where existing combustion plant have to be refitted, replaced or have to be modified with expensive filter installations. Due to the similar complexity of clean combustion and gasification technology, the consideration leads more often to gasification technology. A similar fact seen for the coal gasification is replacing the coal combustion.
(same Sankey as 4.2.1 see also Fig. 22)

4.3 BIOMASS GASIFICATION FOR ELECTRICAL POWER ONLY

To convert syngas in a gas engine, gas turbine or over the IGCC technology does not make sense due to the low overall efficiency. No application realized are known. The product gas used directly for a mechanical conversion is widely demonstrated.

4.3.1 BM gasification + IGCC for electrical power only

The theoretical approach of IGCC behind BM gasifier as standalone power station is discussed. The overall efficiency of 44% and in future up to 55% is proven for coal application.

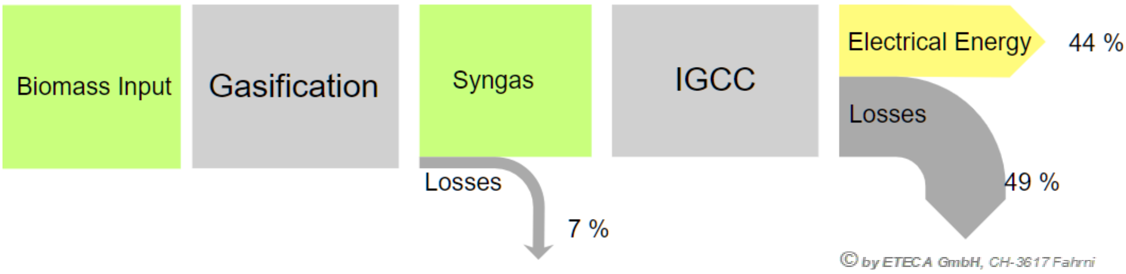


Figure 24: BM and fossil thermal gasification CHP, endues power over IGCC el.power-µ= 44%

No BM application are demonstrated with el. power only, but for CHP application see in this Report chapter 4.4.4.

Summary of successful operated coal gasification IGCC:

IGCC power plant	Buggenum	Wabash River	Tampa	Puertollano	Vresova
Location	The Netherlands	USA	USA	Spain	Czech Republic
Year of commissioning	1994	1995	1996	1998	1996 (2005)*
Electrical capacity	253 MW	262 MW	250 MW	300 MW	351 (430)* MW
Fuel	Black coal + biomass	Black coal + petroleum coke	Black coal	Black coal + petroleum coke	Lignite
Gasifier type	Prenflo	E-Gas	GE	Shell	Sasol-Lurgi (GSP)*
Net efficiency Hu	43%	39%	41%	42%	44% (41%)*

**2005 plant expansion*

The five coal-based IGCC power plants currently in operation worldwide
© TU Bergakademie Freiberg

Table 5: Example plants with efficiencies [19]

http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2006/Projekt-Info_09-2006/projekt_0906internet-x.pdf

For IGCC plants, CCS application are widely discussed and researched and could be an interesting approach for CO_2-mitigation but is not further considered. See the IEA Task 33 report [44].

4.3.2 Co-feeding of BM into coal gasifier + IGCC for electrical power

This approach could be a very economical way to reduce CO_2 on existing powerplants.

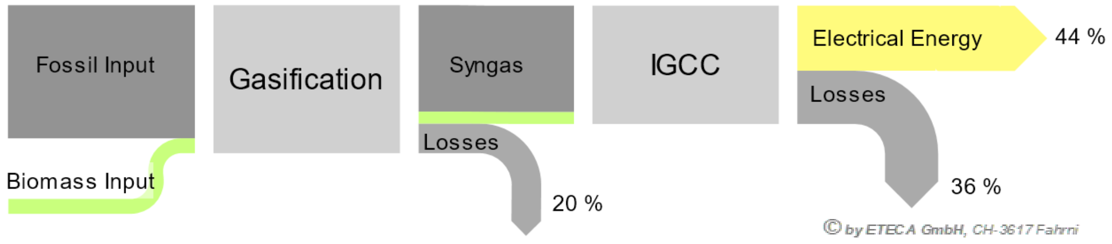


Figure 25: BM and coal thermal gasification CHP, power over IGCC µ=44% in future >50% [19]

4.3.3 Co-gasification for coal powerplants

According to common public information, no projects were implemented yet. It could be a very reliable, cheap and interesting pathway for mitigation.

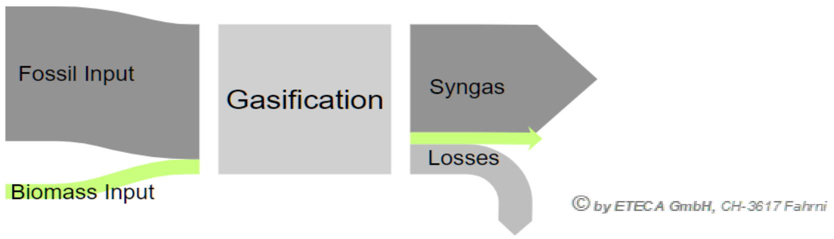


Figure 26: How co-gasification can be implemented

Due to gasification characteristics, certain share of biomass could be slipped with acceptable consequences for the process. The Sankey-diagram is mentioned as an example with about 10% biomass input. This share can of course be smaller or higher due to gasification process tolerances.
The evaluation and accounting of the CO_2 reduction is like co-combustion.

4.4 BM GASIFICATION FOR COMBINED HEAT AND POWER (CHP)

Figure 27: Example picture for CHP plants [18]

This type of conversion is numerous proven, demonstrated and also economical feasible when a waste is used or converted in a gasification process and valuated in CHP units.

4.4.1 Gas engine conversion

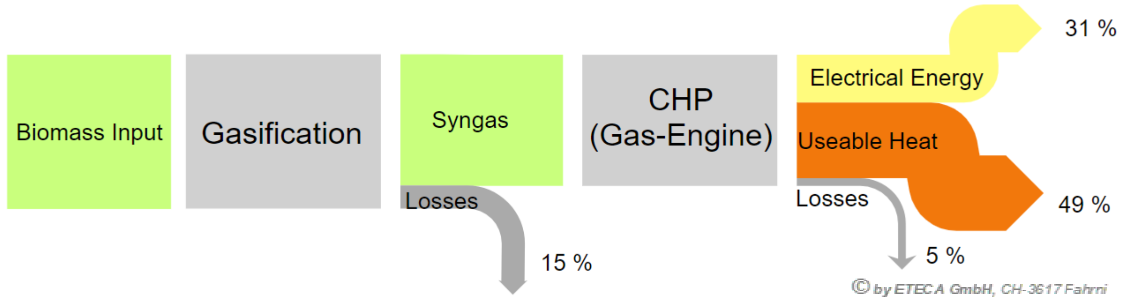


Figure 28: BM thermal gasification CHP, endues heat and power total efficiency µ=59%

This technology is state of the art! We find in central Europe 2019 more than 1000 units successfully in operation and there is a large number of manufacturers. A wide number of different turn key units from 50 kW to 5 MW are available.

For examples like the plants Stans, Horboure or Skive, see:

http://ieatask33.org/ -> database [10]
http://fee-ev.de/11_Branchenguide/2018_Industry_Guide_Biomass_Gasification_EN.pdf [20]

4.4.2 Gas turbine conversion

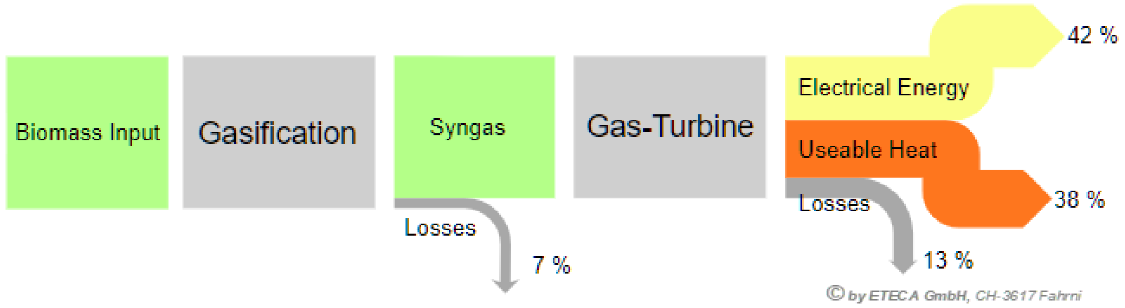


Figure 29: BM thermal gasification CHP, heat and power over gas turbine µ= 32% + …..%

This technology is widely used is for raw untreated natural gas application on offshore oil and gas platforms and it is mentioned here because it can be assumed that we will find many gas turbine applications for BM or IGCC for BM to produce electric power only.

Due to its rough heavy-duty systems of turbines and similar and even so problematic gas composition as a raw natural gas there should be many gas turbines converting examples to find using the syngas from BM gasification. Such as in faraway forest camps with a lot of waste wood or in tropical areas with a lot of BM waste in general.

Unfortunately, no projects were implemented yet. It looks like turbine manufacturer search for series and a large market before they develop a syngas turbine for a client. The size limit for gas turbine is around 4MW up to 400MW, due to physical parameters.

See also T33-WS 2016 Luzern Siemens gas turbines 4-400MW page 12:
http://www.ieatask33.org/download.php?file=files/file/2016/IGCC.pdf [21]

Interesting is that never-ending repeating story of micro-gas-turbines in the range of 50-200kW.

The mechanical physical truth is: they work, but with a disappointing low efficiency of less than 20%. There are absolutely no chances to rise the efficiency with the traditional axial turbine concepts.

4.4.3 Steam turbine conversion

This solution is state of the art for biomass and municipal solid waste conversion. Economic challenging is the fact that the feedstock preparation is costlier and needs more space compared to any other common fuel (oil, coal, gas…).

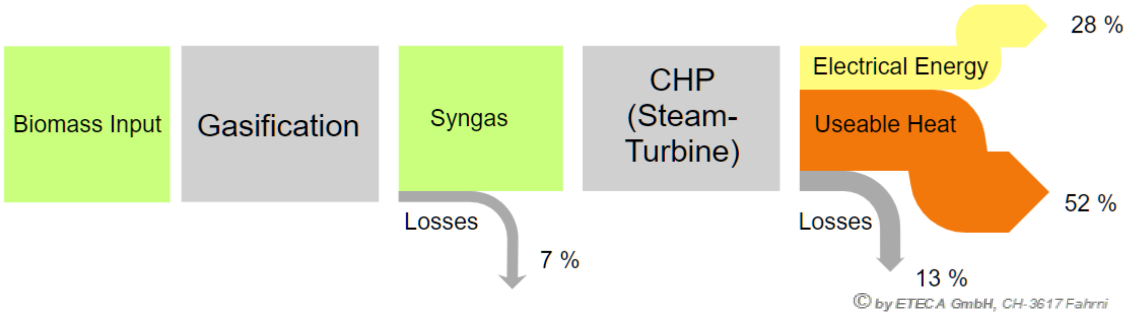


Figure 30: BM thermal gasification CHP, heat and power over steam turbine μ= 28% + 52%

Example:

MSW Gasification for District heat (Lahti Energia in Kymijärvi II) over combustion (redundance NG)

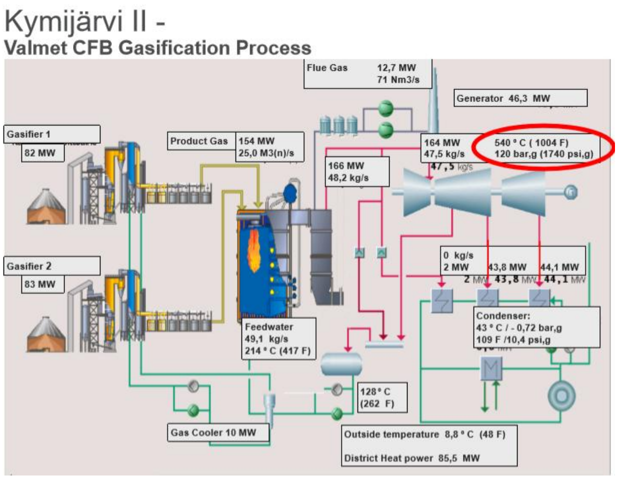


Figure 31: Example implementation of steam turbine in Finland [1]

See also information for Lahti out ofT33 workshop Siemens Steam turbines 45kW -1900 MW:

http://128.131.132.12/download.php?file=files/file/minutes_and_presentations/Skive_Oct2010/Copenhagen%20workshop/12Siemens.pdf [22]

4.4.4 BM gasification and IGCC CHP conversion

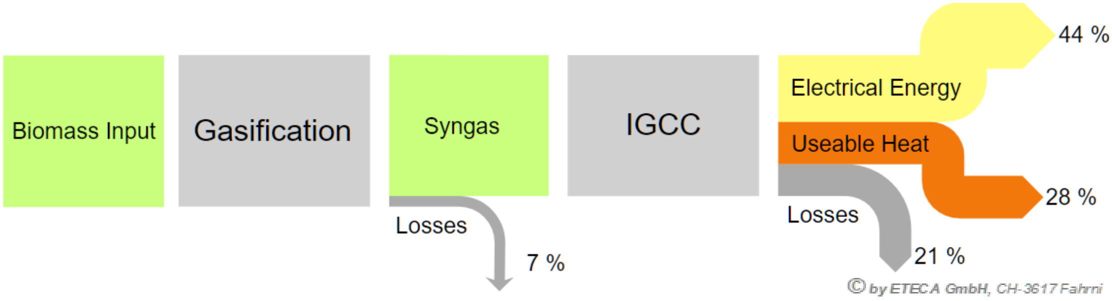


Figure 32: BM thermal gasification CHP, endues heat and power over IGCC µ= 68%

Figure 33: Picture of Värnamo demonstration plant, Sweden [23]

Remark: for Coal gasification there is a number of successful IGCC power station in operation.

4.4.5 BM gasification for co-firing in coal boiler for CHP plant

Remark: for BM gasification there is a number of successful power station in operation.

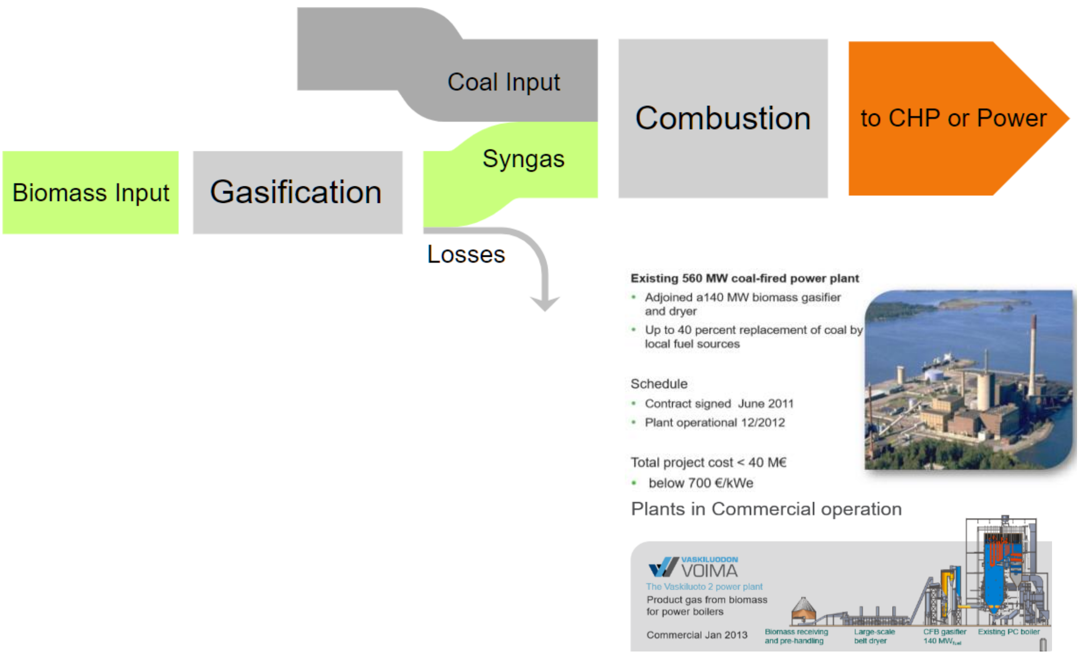


Figure 34: Biomass thermal gasification for coal boiler power production with example [23]

4.5 BIOMASS TO LIQUID (BTL) AND BIOMASS TO GAS (SYNGAS OR SNG)

4.5.1 Large scale BM to SNG-plants

Various small pilot plants were built to produce Bio-SNG. A demonstration plant (30MW$_{input}$ and 20MW$_{output}$ SNG) was also successfully implemented (2015-2018) in Sweden.

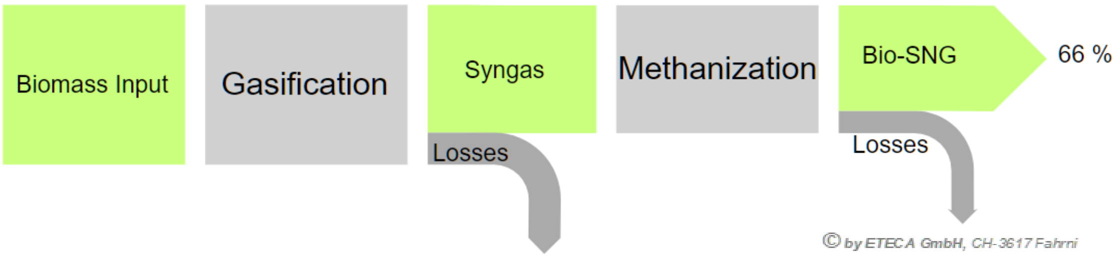


Figure 35: BM gasification for Bio-SNG efficiency

4.5.2 Large scale BTL

For biomass gasification conversion plants, when the feedstock is already a commercial fuel and has already a value (e.g. 3€cts/kWh), then it is far more difficult to achieve a commercial bankable application. Process output on the free market and commercial conditions must be more valuable than the input material. If not, the conversion costs must be covered by long term strategical financial support decision (e.g. subvention).

BTL over gasification is demonstrated in many examples in pilot plants:
- Güssing with FT for Diesel,
- Chemrec for DME
- CHOREN FT for Diesel.........

In Europe not one of this demonstration projects and facilities above are 2019 in operation. The only BTL demonstration project in operation in Europe is Bioliq, under strong collaboration with TU Karlsruhe.

The overall efficiency varies strongly and can be assumed for approximately 50%.

Many similar large BTL gasification projects in Scandinavia promoted and driven from well known company's. are abandoned or shifted into other BTL projects (without gasification). For some of this projects even existed official environmental approvements and building permissions. Even so there is no such project implemented or in operation 2018.

In the Database T33 IEA Bioenergy listed find Biomass thermal gasification projects for BTL see Figure 36:

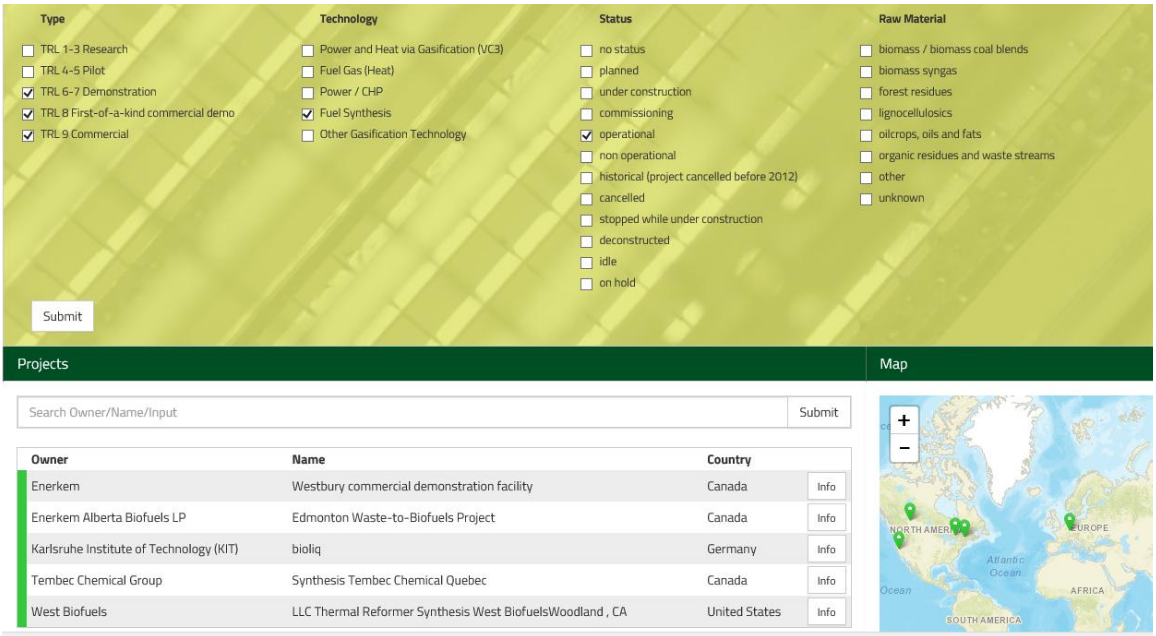


Figure 36: Database T33 IEA Bioenergy listed Biomass thermal gasification for BTL [10]

4.6 GASIFICATION FOR PETROCHEMICAL APPLICATION

The concept of co-gasification in large-scale Petrochemical gasifier facilities is discussed but none is in operation and not any realization fulfilled.

This solution is mention here because of its simple concept and easy implementation.

Figure 37: Biomass thermal gasification

5 Facts, challenges and considerations of BM gasification

5.1 GENERAL

As implementation of renewable energy technologies is a complex learning experience under special public observation and high expectation.
There is a large confusion of expressions as different player have different interests to present themselves, a project, a certain technology in a certain way. Also, each player has different motivation to support a technology or to bash or hype a certain value chain. Some examples of confuse expressions which rises mostly high unrealistic expectations:

- Using words like "pilot- and demonstration-", "early commercial-", "commercial-", "first of its kind", "commercial-plant", "commercial prototype" is confusing. Nobody knows exactly what those expressions are meaning. Sometimes it seems that this expressions by purpose are misused.
- Announcements that a technology will be commercially available in one or 2 years… and that in the last 20 years and for the next 10 years (e.g. the micro gas turbine)

Unfortunately, "human being" like more to talk than to act. Excuses of failures are quicker available than reliable analyses and conclusions. I would like to give some example:

- In within the Task 33 we were focusing on all the nice large BTL, BM to syngas, BM to SNG projects with little implementation success and did almost missed that hundreds of the small-scale CHP units went in to successful operation.
- We have large research activities for CO_2 neutral BM aviation-, surface transport- and offshore vessel-fuel but rarely the simple question is discussed:
  - "is it the right value-chain and substitution an efficient way to replace fossil fuel with positive economical result" or is it
  - "the responsible way to use biomass" or do we have soon a
  - Additional not only fuel versus food, but also fuel versus timber, boards and paper problem (because of the widely wished fossil fuel substitution by biomass)
  - Is it the right message that aviation goes green when the negative rebound effect is fact?
- There was a lot of effort and investment done for biomass demonstration plant, who should have the potential for CO_2 mitigation with little success, but with loud public media attention of "world changing" projects. On the other hand, we did not recognize that the fossil fuel and petrochemical industry already mitigates incredible amount of CO2 with the same gasification technology by refitting and installing hundreds of very large size thermal gasifier.
- We have always heard the excuse that fossil fuel is too costly when a project starts to struggle and misuse that argument to avoid the question:
  - are we using the right technology in the right place?
  - is large substitution of fossil fuel realistic with large GW biomass conversion plant? and
  - if yes, what strategical change we must face in harvest, logistics and supply for large size biomass project?
  - can we leave this CO_2 mitigation activity to free liberated market economy?
- We assume that there is enough biomass for large energy conversion units available, but already a 100 MW fuel input conversion plant affects drastically the biomass flow of an existing national forest industry during the normal 20 years of conversion plant lifetime.

5.2 INPUT, BIOMASS FUEL, FEEDSTOCK

In de past 150 years, the reserves of fossil energies have been constantly reported as "sufficient for the next 30 years”. This means that there are always enough raw materials available for fossil applications. This is ensured by the new development of oil fields (e.g. in the deep sea and the Arctic) and new production technologies (e.g. fracking).

With biomass plants, the feedstock is already a problem, as it is limited, and various branches of industry harvest their share.

5.2.1 Worldwide biomass availability for all purposes

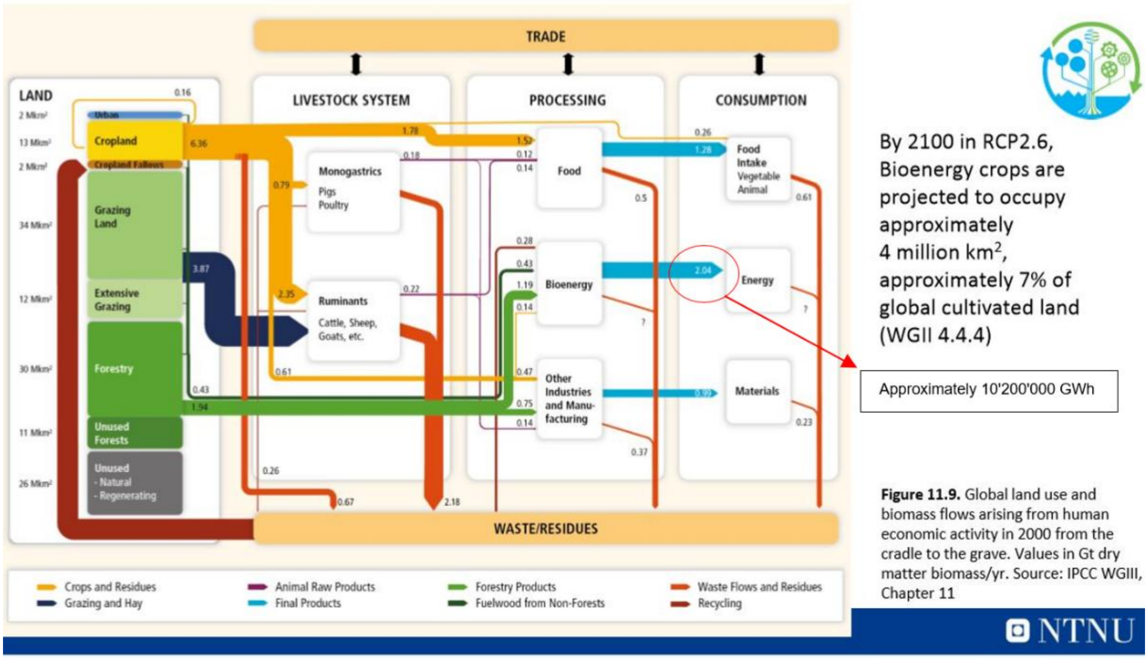


Figure 38: World biomass flow [24]

So, we need to plant the biomass now, which we want to use in 10, 20, 30 or 40 years e.g. on arid terrain.

5.2.2 Fossil fuel applications promoted shift to biomass based fuel

Every traffic path wants today to go green. At least they say so! Two simple numbers help to understand the challenge:

> Refinery output 2013 = 3 916 Mt = **38 000 TWh**
> Biomass is available in 2100 for energy approx. = **10 200 TWh**

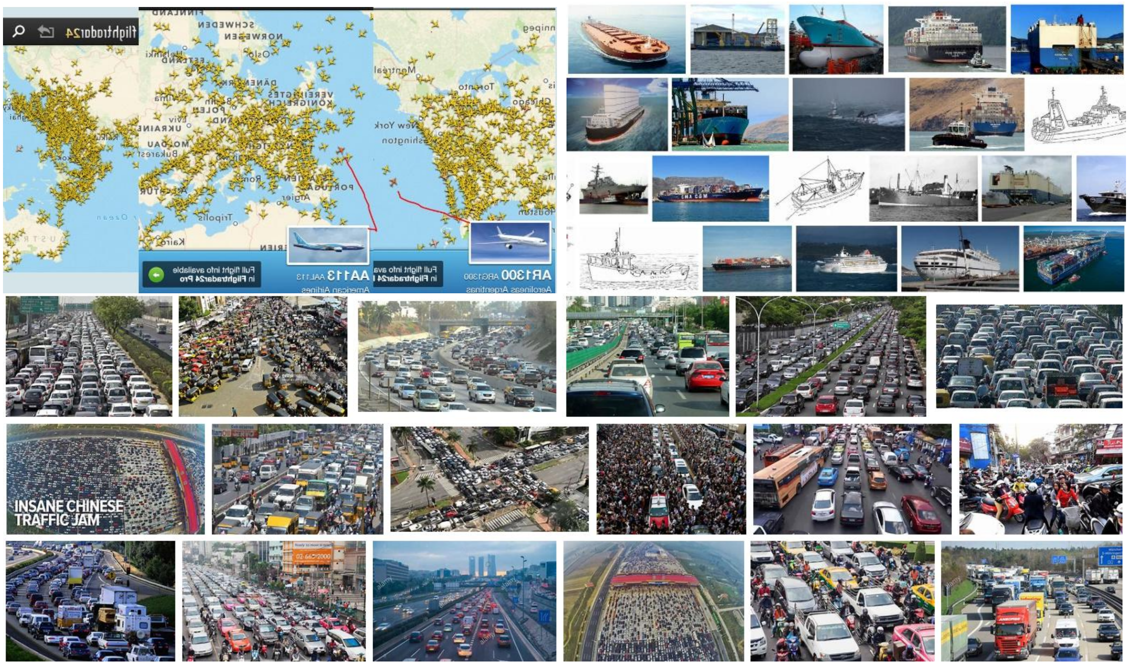


Figure 39: Paths that all would like to be "green" [18]

So, if all fossil paths are to be replaced by biomass, roughly 4 times more biomass must be available. Furthermore, the available biomass resources cannot be increased so quickly. In principle again, what is to be harvested in 30 years must now be planted.

5.2.3 Fuel replacement

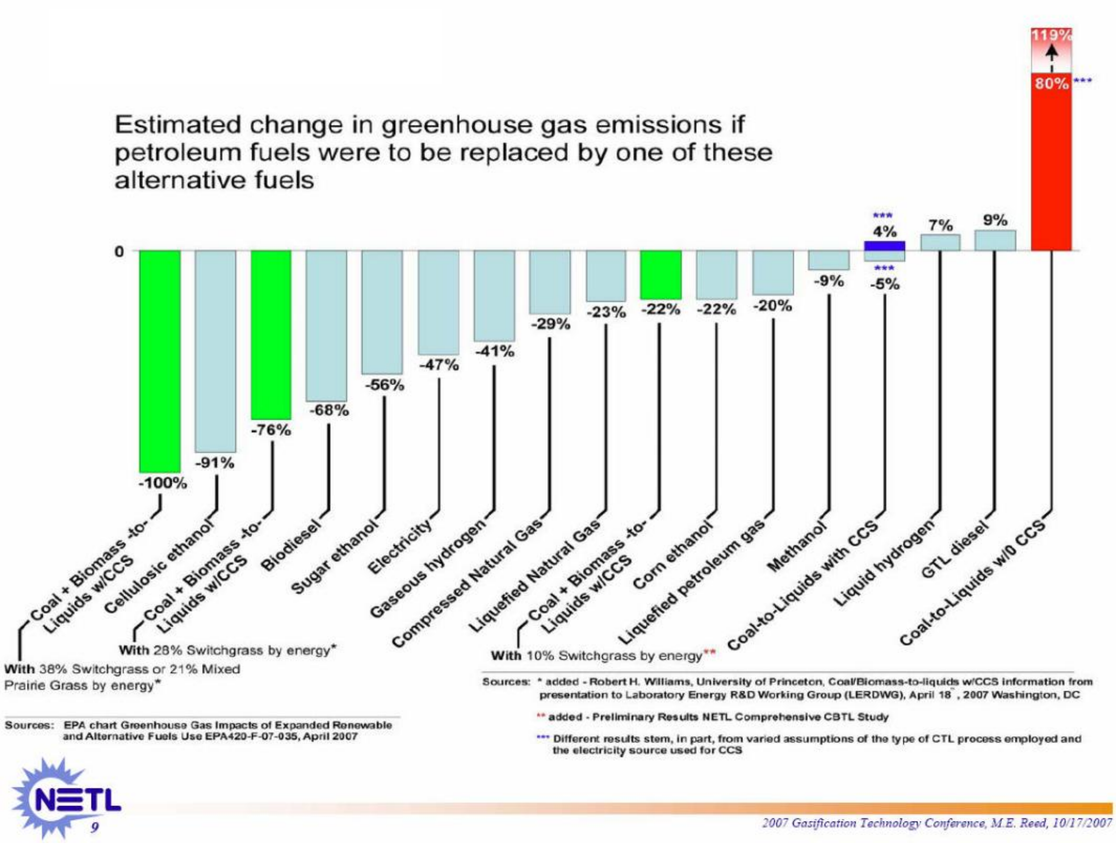


Figure 40: Comparing CO_2 impact of fuels [25]

5.2.4 Feedstock for energy

The following figure shows the woody biomass flow in Sweden. As can be seen, there are many branches of industry and utilization routes that are dependent on biomass. Free, unused resources are for example the categories "stumps", "branches and crown mass”, "wasted roundwood". However, aware that this material is not easy and inexpensive to obtain (stumps) and possibly not of valuable quality (leaves and small branches).

So, if a BTL plant is to be built somewhere, in order not to compete with another industrial branch for a resource (which would result in a price increase), it is estimated that a maximum of 20% of the material can be used for a new built plant.

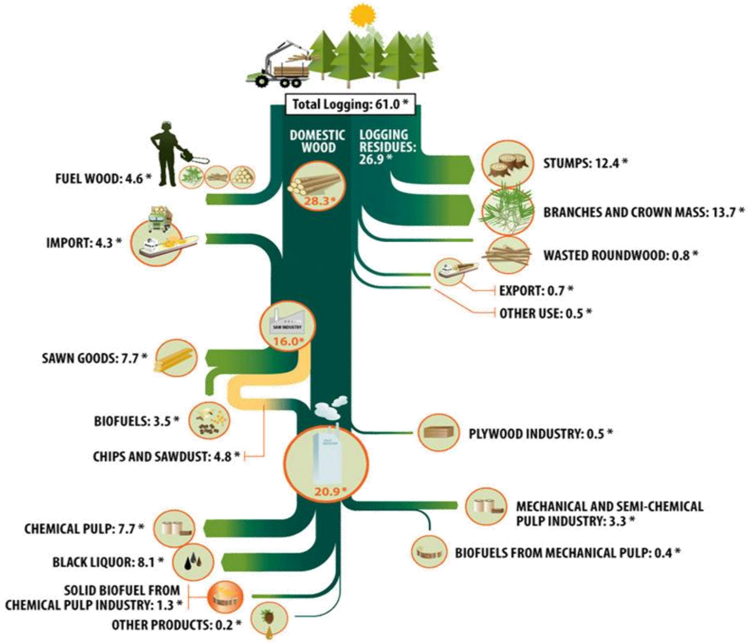


Figure 41: BM management where and how to get and optimize feedstock for energy use [26]

The following example shows the required forest area for different plant sizes. Based on the figure above (Figure 41), the proportion of forest harvest available for energy generation was set to 20%. Of course, this can vary depending on the region.

The growth rate is an average of different tree species. [27]

Sustainable harvest per year (10m^3/ha*a)		1000	m^3/km^2*a
Energy content		1.5	MWh/m^3
Sustainable energy per km^2 per year	*1'000 x 1.5=*	1'500	MWh/km^2*a
Share for energy conversion		20%	
For «energy use» per km^2 per year	*1'500 x 20%=*	300	MWh/km^2*a
BTL conversion efficiency		50%	
BTL output per km^2 per year	*300*50%*	150	MWh$_{BTL}$/km^2*a

Table 6: Calculation of forest grow and energy harvest per year

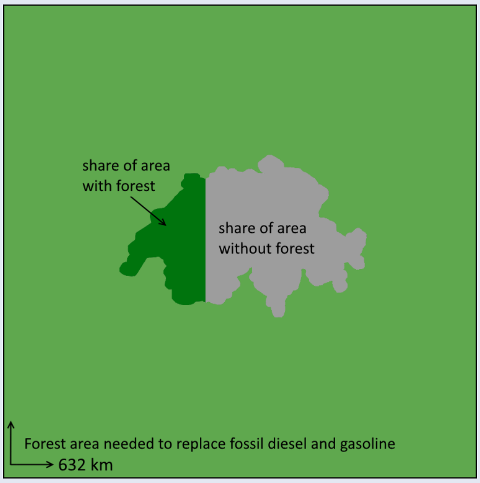
Out of those variables and assumptions it results that for **1MW$_{BTL}$ output 58. 4km^2** corresponding to a surface from **7.6x7.6 km** length of sustainable harvested forest area is needed.

Those numbers are corresponding to the power a defined forest area can deliver. To convert this number to an actual BTL plant, also the yearly running hours are to be considered (e.g. 7'500h/a). Calculated with those hours, a 1MW$_{BTL\text{-}output}$ plant with 7'500h/a needs a forest area of **50km^2.**

To make this figure easier to understand, 3 sample calculations were carried out for Switzerland, Germany and Finland. The calculation was based on how much forest a country would have to have to cover its fuel consumption with BTL diesel.

Switzerland

Area	41’285	km²
Forests	12’540	km²
	30.3%	share of total area
Population	8'482'152	(2018)
Fuel consumption gasoline & diesel	59'927	GWh/a
Cor. to Continuous power	6.8	GW
Necessary forest area	399'515	km²
Factor	**32**	(needed area to cover fuel demand)/ available area



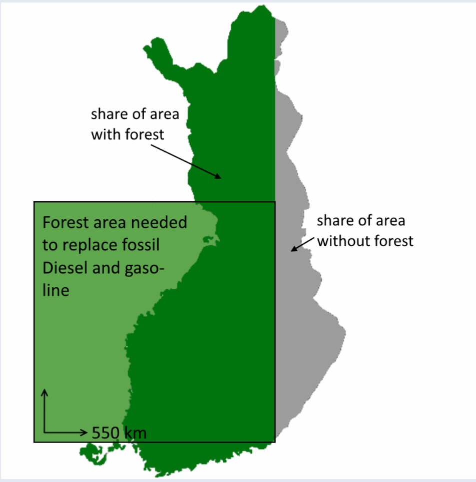
The forest available for energy use in Switzerland is by a factor of 32 too small. Even total forest cover in Switzerland would not be enough to cover fuel consumption, as the country is simply too small. As can be seen, 632x632km of forest area would be necessary. [28] [29]

Germany

Area	357’578	km²
Forests	114’190	km²
	32%	share of total area
Population	83m	(2018)
Fuel consumption gasoline & diesel	678'537	GWh/a
Cor. to Continuous power	77.5	GW
Necessary forest area	4'523'584	km²
Factor	**40**	(needed area to cover fuel demand)/ available area

The forest available for energy use in Germany is too small by a factor of 40. Even a total afforestation of Germany would not be sufficient to cover the fuel consumption, because the country is too small. As can be seen, 2’127x2’127km of forest area would be necessary. [29][30]

Finland

Area	338'424	km^2	
Forests	222'180 73%	km^2 share of total area	
Population	5'520'535	(2018)	
Fuel consumption (gasoline & diesel)	45'368	GWh/a	
Cor. to Continuous power	5.2	GW	
Necessary forest area	302'456	km^2	
Factor	**1.4**	(needed area to cover fuel demand)/ available area	

Finland has a very high share of forest (73% of the total area). Thanks to this fact and the low population density, Finland could nearly cover its fuel consumption with BTL plants. But in this calculation, it is not considered, that Finland is already using a lot of material for energy use and it would be hard to harvest 20% for BTL purpose. Also, the forests are growing slower than assumed, due to its northern position. [39][31] [32]

In all calculations above, it was assumed that 20% of the sustainably harvested wood can be used to produce fuel. Existing plants that use wood to generate energy already today were not considered. This would make the calculations even worse, respectively the factors higher.

5.2.5 Logistics and transport

Logistics and transport costs have a significant influence on feedstock costs for large plants. Northern, densely wooded countries are always looking for solutions to reduce transport costs. By increasing the energy density of the transported material, using pyrolysis and gate refraction, attempts are made to reduce transport costs.

Not only the distance, biomass need to be transported is a challenge for large plants. Also, the logistic. When transported (as an example) with 40t trucks, about 240 trucks per day are needed for getting enough input material for 1 GW Biomass input. Imagine if a truck had to be unloaded every six minutes. Every 6 minutes a lorry from a radius of about 85km should arrive (if the plant is located in the middle of a huge forest, otherwise the transport distances will become even longer).

Following visualization shows the amount of trucks needed for different plant sizes. It is not by chance that all large coal-fired power plants are located directly next to the coal-mining areas or a harbour. This means that the extracted material can be fed into the plant with reliable simple logistics.

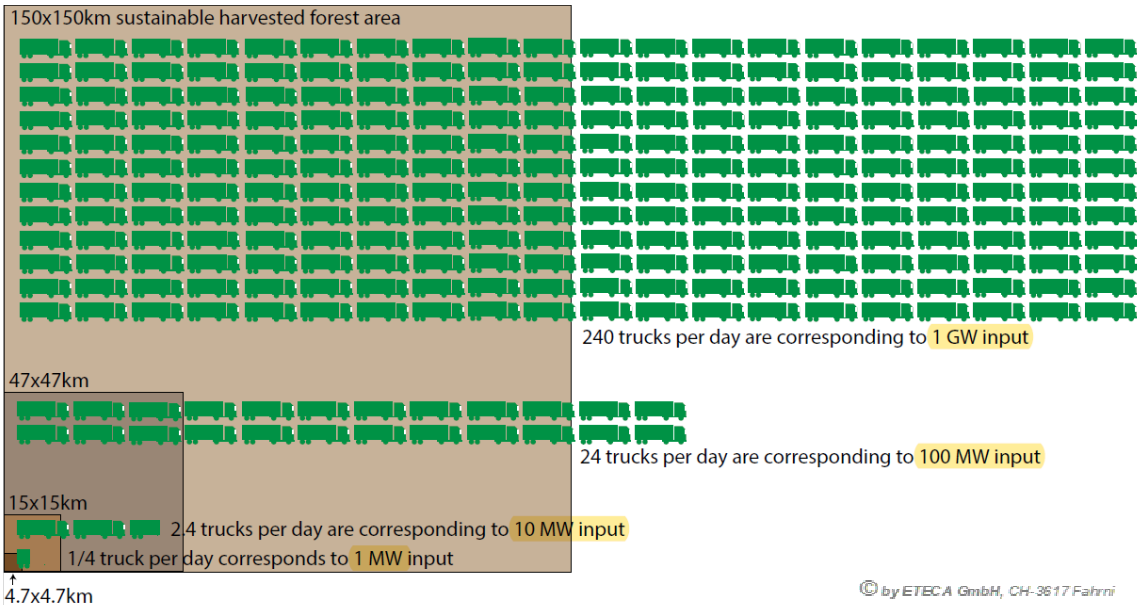


Figure 42: Large plants are a challenge for logistics to transport the woody feedstock

From this follows the rough principle: **4.2 MW** of input material can be procured with **one truck per day**. (Based on the assumption 1 Truck:40t, thereof 25t load with a volume of:100-120m^3)

Local deposits, which compensate for supply bottlenecks, are also a challenge for large plants.

Figure 43: Huge wood deposit in Sweden (< 1TWh) [33]

The numbers used here are inconceivable. As a possible clue, we use 43, which shows a wood deposit in Sweden. The quantity of wood shown there corresponds to 1.7% of the biomass required for the substitution of fossil fuel. Not worldwide, of course, also not for Sweden or Germany but only for Switzerland.

5.2.6 Fuel preparation for gasification

Generally, it can be said that homogenous fuel is one of the most important factors to run a gasifier plant successfully and smoothly. But in reality, homogenous bioenergy fuel is in most cases not the fact. Tolerances of humidity, quality, size, wood structure and type are wider than wished. Even on pellets today the most normative product with small tolerances on the energy market, has after storing remarkable changes of humidity and heating value and physical stability. For operating a gasifier with bioenergy means with chips, saw dust, pellets etc. it is highly advised to consider that fact very strongly.

Fluctuating fuel quality affect in a negative way so the energy production, the number of shut downs, efficiency, wear and tear and the operating costs.
For this challenge the solution is often a feedstock conditioning with a drying belt furnace, heated with waste heat from the gasification process.

5.2.7 Fuel, impact and energy prices

The figure below shows the fuel costs usual on the market (source overview in Annex 2 at the end of the document). The figure helps to classify the biomass. It is also possible to estimate how high the process costs of a plant may be if it is intended to produce for a certain market. The graph also shows that fuel costs are not quite fixed but have a certain range. Fuel costs are influenced by various factors. In addition to the usual market fluctuations, quantity can also have an influence. For biomass, transport costs also play an important role (see chapter above). Fixed and long-term contracts can help to obtain planning security for a plant.

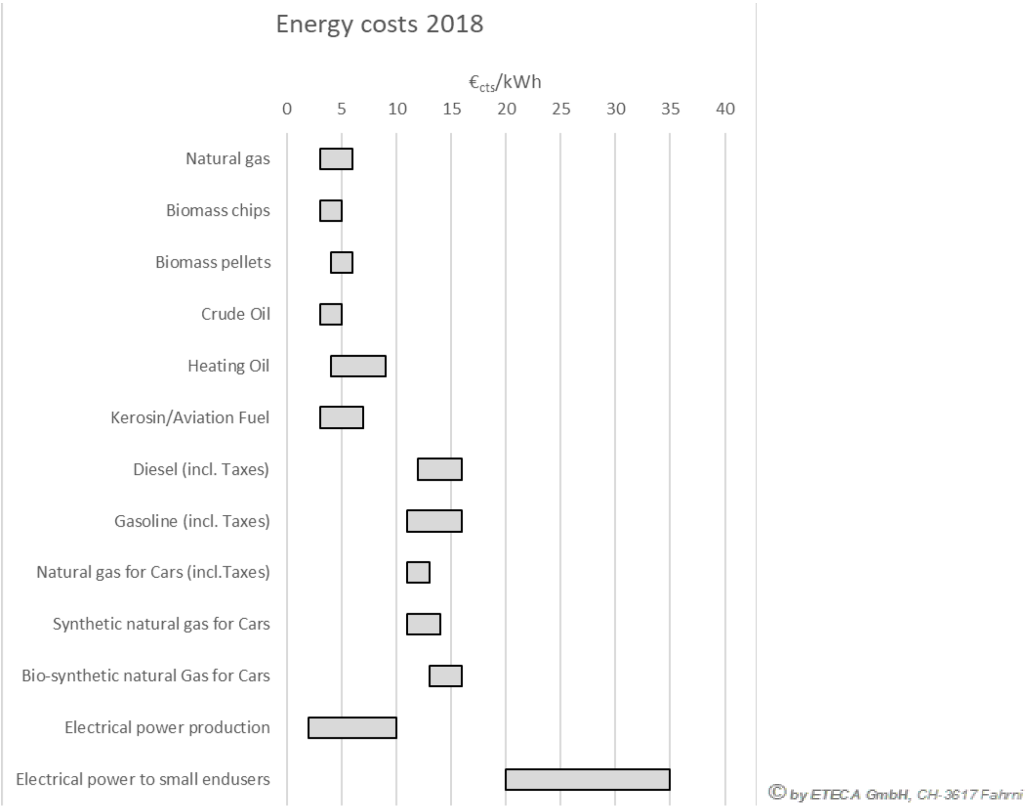


Figure 44: Prices of fuel in Euro cents

5.3 CHALLENGES OF HARDWARE

If the project is cleanly constructed, designed according to today's knowledge and if maintenance and servicing are considered, there is no reason why biomass cannot be converted via gasification.

For small-scale plants, there are several examples, also for large plants successful implementations are shown, e.g. Valmet.

The key to success is described with the KISS-principle:

KISS - Keep **I**t **S**imple and **S**traightforward

When combining two systems, with each one owning a problem, unexperienced managers are expecting that there will be two problems to solve. The fact is, there will be at least four problems because the accumulation of problems is always an exponential function.

5.3.1 Specifications of a project

Technical specifications are describing a plant. As more reliable and complete they are, as easier it is to communicate in within the different stack holders, clients, suppliers etc.

Helpful therefore are also to include in the specification's schemata, layouts and Sankey diagrams to underline information and avoid misunderstanding. Already here in the specification it is useful to show and point out the measuring points for operation, test runs and PTP (**P**erformance **T**est **P**rotocol) relevant information. Also interface points, connecting points must be described exactly for hardware, processes and software. As earlier in the project stage and clearer the specification is as better. Also, here it must be described wear and tear information, maintenance procedure, consumables needed and operation and maintenance manpower as well spare parts list.

- Input & output Specification
- Consumables specifications for normal operation
- Operating specifications are also advised to point out such as:
    - Maintenance Information

For project developers the PTP is necessary to claim warranties and declare technical approval. See Performance Test Protocol for Small Scale Gasifier IEA Task 33 [34].

5.3.2 Unfulfilled specification and modification a normal fact

Every system has parts that require almost no maintenance. Static structures are usually fixed and do not require much maintenance. All moving parts and parts in which heat, gas or other media are transported are always under great strain and require close observation and maintenance. Before a system goes into operation, these parts must be identified, and a maintenance plan must be drawn up (and followed).

	Fuel preparation	Fuel Feeding system	Gasifier	Filters	Gas Cooler	Heat Coupling	Motor Generator	Control System
Failures appeared	●●	●●●	●	●	-	-	-	●
Modification after commissioning	●●	●●●	-	●	-	●	●	●
Expected running hours not achieved		●●	●●	●●	●	-	-	
More maintenance than expected		●●●	●	●	●●	●	-	●

●●● very often ●●often ● sometimes - barely

Table 7: Probability of failures in prototype and early commercial CHP gasifier

Biomass projects are infrastructure projects and have a life span of about 20 years. Of course, this can also be 5 years longer or shorter. If a plant is built, it must be ensured that the material used either has a service life of 20 years or that suitable spare parts are available.

5.3.3 Biomass fuel feeding system

The Fuel Feeding System is a component that is always underestimated. It plays an important role in the overall system and is subject to considerable wear and tear. Small changes in the quality of the input material (e.g. size of the chips, type of wood) can damage the system. Since such influences cannot always be avoided, spare parts must be made available during the construction of a plant. The check and maintenance intervals must also be kept adequate.

A report published on the website of IEA Task 33 describes the challenges in the fuel feeding system: http://www.ieatask33.org/content/publications/biomass_feeding [35]

5.3.4 Ramping up

In large biomass projects there are usually to high expectation for the implementation of Facilities. Underestimated time frames to ramp up a plant are usually.

As an example, below, there is a very interesting evaluation made in the USA over the coal IGCC plants in traditional large coal facilities, business with professional suppliers and operation staff:

Availability ramp up [36]

A further issue to be considered is that with a complex technology such as IGCC, there will be a certain amount of bedding-in time before the long-term availability rates are achieved.

Figure 6-4 shows the actual ramp up of operational availability of a number of coal-based IGCC plants. A visual impression would suggest that the long-term availability figure sets in in about the fourth to fifth year of operation, which contrasts poorly with the oil-based units such as ISAB or Sarlux shown in Figure 6-2, with availabilities close to 90% already in the second year. The experience on chemical product applications of oil gasification confirms the latter data, which is also a reflection of the difference in maturity between oil gasification and coal gasification. It should also be remembered that some of the early difficulties, (e.g. integration issues in Buggenum related to syngas firing of the gas turbine and 100% air-side integration) are now well understood.

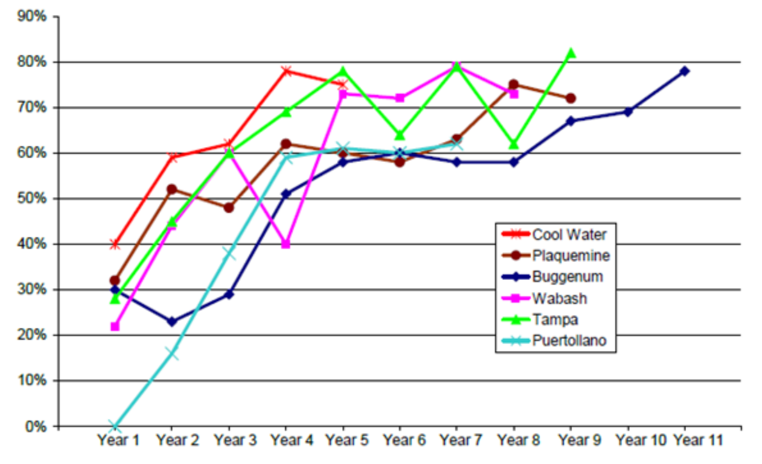


Figure 45: Availability Ramp up in Coal-based IGCCs [36]

So, if this information is considered, why do we usually underestimate the implementation time in the field of renewable energies?

5.3.5 Normal operation, daily work and field reality

New first of its kind projects have mostly following constant properties: They take longer to plan than expected. They take longer to build than expected. Permission procedure are not so clear, this is also time consuming.

Adaption and modification are normal case on any complex projects, but mostly not considered enough. Wear and tear of exposed components is a normal fact, but are often ignored, till a problem appear then when key components must be replaced, the drama starts. Wear and tear expenses are mostly higher than expected.

Some facts to consider for new implementation that can lead to conflicts:

- investment costs are higher than expected
- construction time takes longer than excepted
- commissioning time is longer
- education costs are higher
- spare part and maintenance cost are not calculated right
- maintenance is underestimated
- revisions and refitting always cost more than expected
- unexpected shot downs occur
- unexpected costs incur

An old Chinese proverb says:

> Man has three ways of acting wisely:
>
> First, through reflection, that is the noblest, second, through imitation, that is the easiest, and third, through experience, that is the bitterest.

5.4 PRODUCTION OUTPUT AND WASTE

The product of a plant must meet the requirements of the chosen market and fit into the applicable standard (mainly gas and liquid fuel).

Similar challenges occur as with input material (keyword transport and logistics). Long-term purchase agreements are also desirable.

Also, products must be produced in the range of the usual market prices to be able to be marketed.

If by-products or production waste are to be recycled or sold, certain standards also apply to these, see the following paper [4].

If by-products must be disposed of, the legal disposal paths (and costs) must be observed.

5.5 A BIOMASS CONVERTION PROJECT

There are hundreds of project management books and lectures etc. No new method should be created here. Also, projects in the field of biomass gasification are subject to the normal project management rules and challenges.

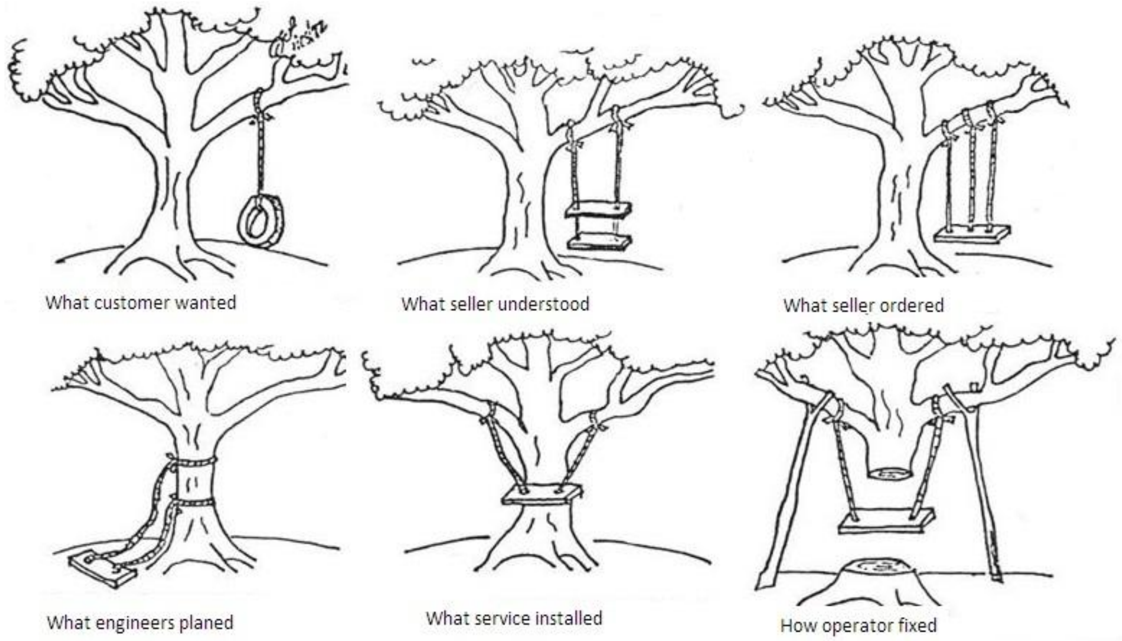


Figure 46: One project, different understandings

In projects, the focus often is on the simple and known points (like the colour of equipment) and a lot of enthusiasm is put into starting and advancing on the easy jobs. Contrary to any logic, the points which could be problematic and costly are postponed until it is too late.

So, point out and solve first the risky, costly and time-consuming tasks in a project, before making the nice and easy jobs.

5.5.1 Project steps

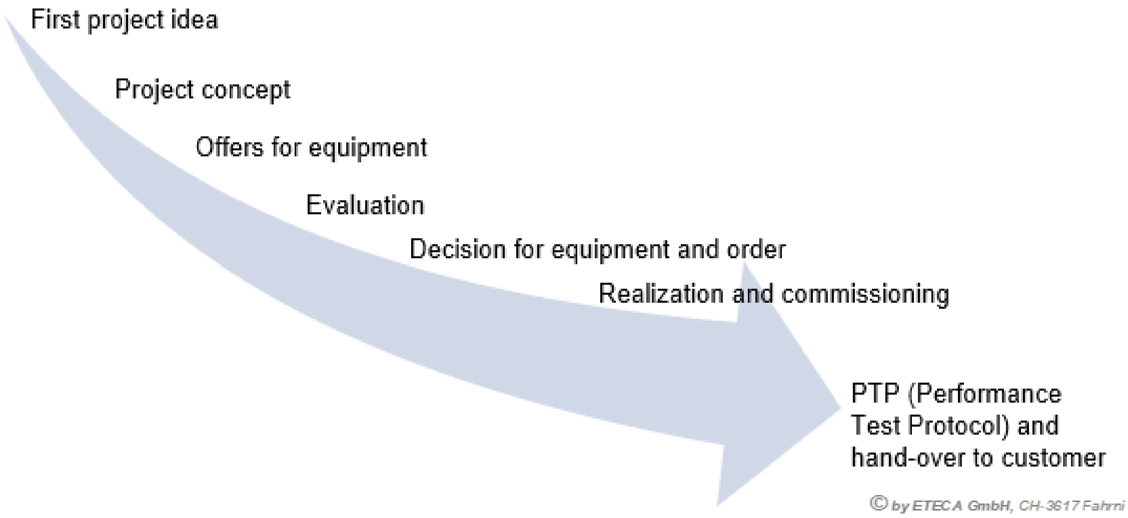


Figure 47: Project steps

An investment in a biomass gasification plant should always be a sustainable long-term project. We should be remembered that, in addition to the environmental aspect, the economic as well as the social aspect also belong to a project.
Well educated staff is a must and knowhow must be available from several person. Such complex project does not allow key persons who are concentrating all the know-how in one head.

It is therefore worthwhile to plan a project with a holistic view and for the expected lifespan of the equipment considering the different project steps and involved party as well the timeframe with different milestones.

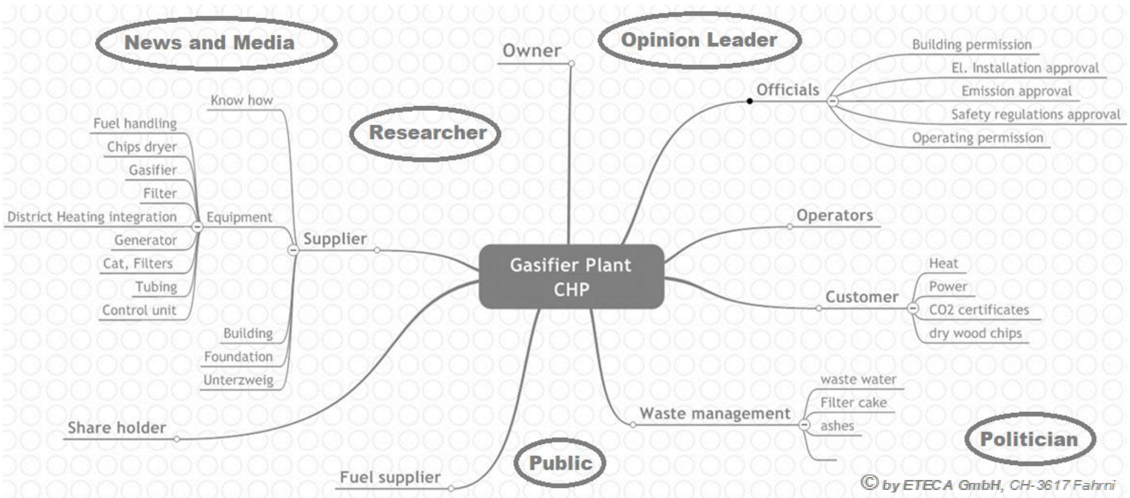


Figure 48: Example of project-boundaries and involved parties

5.5.2 Time frame and contracting involved parties

The following figure roughly shows a project plan. The figure is intended to illustrate what needs to be organized before a decision is made to build a plant.

When the decision will be made to realize a biomass conversion project not only contract for hardware and construction must be ready, also contract drafts for output delivery, feedstock delivery, spare parts and maintenance should exist (do not forget production waste!).

All these prepared contracts are part of the whole project, must be signed at the same time or even before the decision is made and the hardware is ordered.
Also, the ramp up time is drawn here again, which must be considered with the planning and calculation of the plant OPEX and CAPEX cost with sufficient attention.

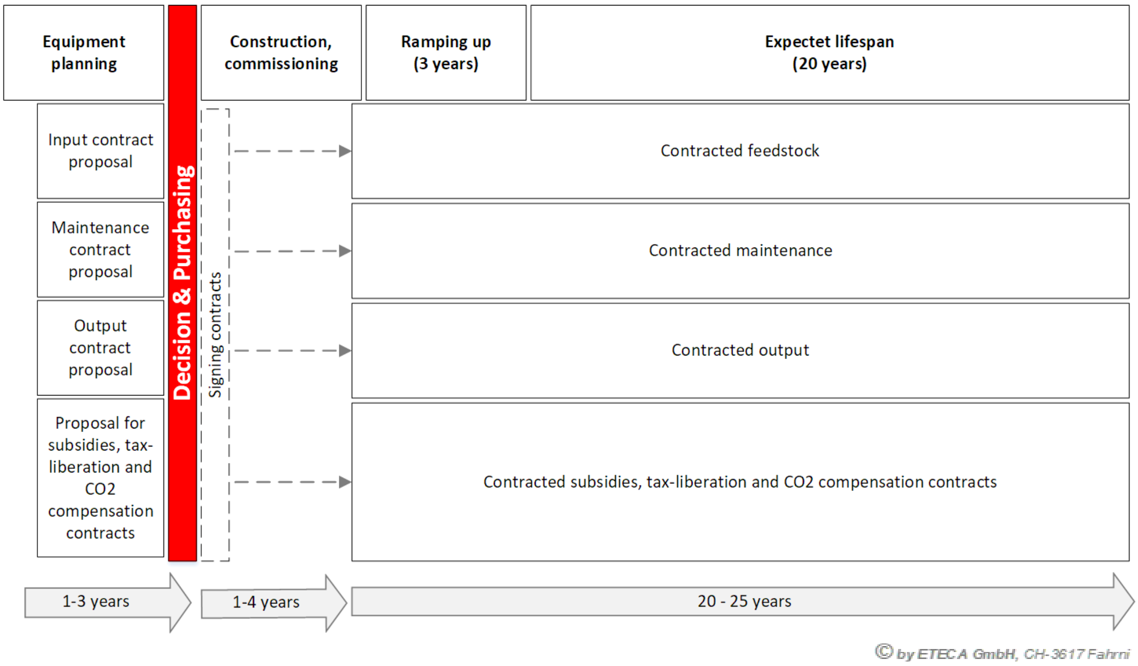


Figure 49: Important project considerations

5.5.3 Human

In a project, the human being is just as important for its success as the right technologies itself. Various people have different roles and interests in a project. Also, not every person is suitable for every role. Decisions are made by people. Also, the maintenance and the observation of a plant are made by humans. Depending on the attitude and behaviour of these people, a system, a project may or may not work. Success factors finally always depend on human. Considerations:

- All "important" persons must be able to identify themselves with the plant and the project.
- Not every person, every function, is interchangeable.
- If a change of staff is foreseeable, the training of possible successors must be carried out at an early stage.
- Everyone has a limited view of a project, but different views result in the overall picture.
- Culture of Communication is very important:
    - Adequate communication to external and internal stakeholders
    - No hyping and excessively promotion and promise
    - Towards governmental project supporters, contradiction information than to private investors about economic situation

A non-exhaustive enumeration of roles that people can play in a project are:

- Researcher, Inventor
- Bankers
- Project Manager
- Marketing manager
- Share holder
- Officials
- Engineers
- Plant manager
- Staff and Operators
- End-user and Customer
- Public opinion

Well educated operating staff is often not considered enough, when staff have unforeseen absences a lack of manpower appears, then as consequence the rest of the staff must work more, and the risk of failures is higher, or the needed staff is replaced by lower educated persons. They learn by doing but output of the plant suffers, and production cost are rising. And finally, all this factor leads to higher costs for OPEX and CAPEX.

5.5.4 Medias over new project

Media reports can support a project. However, they can also lead to unnecessary pressure to succeed. By simplifying facts, a plant is quickly hyped to be the "saviour of the world" machine.

Such expectations can never be fulfilled.

Also, the above-mentioned project roles have different interests in using the media. Researchers and universities need resources to fund research. Plant constructors are looking for customers, operators are looking for buyers for products and investors want their returns to rise.

6 Strategical decisions and business cases

Like any other project, a biomass project must also be strategically positioned. The question for which market to produce must be answered. The figure shows various fuels. Each fuel is classified

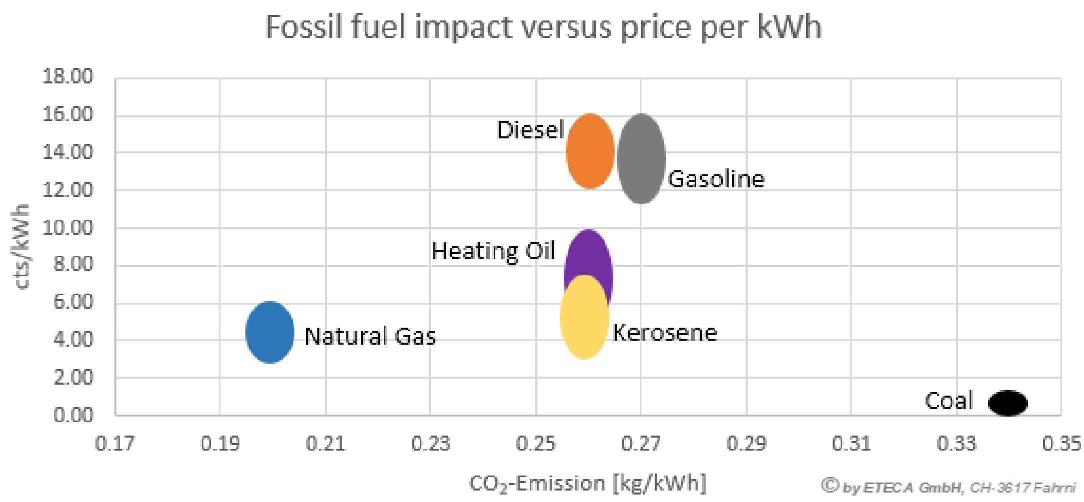


Figure 50: Price and mitigation potential of different target markets

in a price scale (Y-axis) and an environmental impact scale (X-axis).

If a project owner prioritises the financial aspect, it is obvious that his project must go into substitution of diesel or gasoline fuel. When he prioritises the most possible mitigation of fossil CO_2 he must investigate coal substitution projects. But here project owner must claim the highest possible mitigation subsidies for CO_2.

When the conversion efficiency is considered, heating oil substitution may also be a good strategy (district heating).
In those applications the CHP plants are offering an additional benefit with the production of two marketable products, heat and electricity.
Electricity is not marked in the graph above as its price is very variable and has time to time even negative values. Also, the CO_2-Emissions of electricity production is varying from nearly 0 to 1.4 kg/kWh (Lignite).

It’s clearly seen, that substitution of natural gas has neither a substantial emission reduction value, nor offers a valuable market price. In contrary, in a transition phase natural gas can be a meaningful substitution fuel to replace diesel, gasoline and heating oil. Also, this technology is reliable and state of the art.

And in general, it has always to be considered: It is a false assumption that the gasification of biomass, or the processing of biomass in general, is a "universal solution" for CO_2 mitigation. Of course, biomass can contribute a part to the replacement of fossil fuels, but to replace them completely with biomass is utopia!

6.1 EXAMPLE BUSINESS CASES

To show that some projects and conversion paths are not meaningful, a few business cases are listed below.

6.1.1 No business case BM to SNG

The following graph show the simplified levelized costs of energy (LCOE) of a plant that produces natural gas out of wood. It becomes clear at first glance that such an investment will not generate any profit.

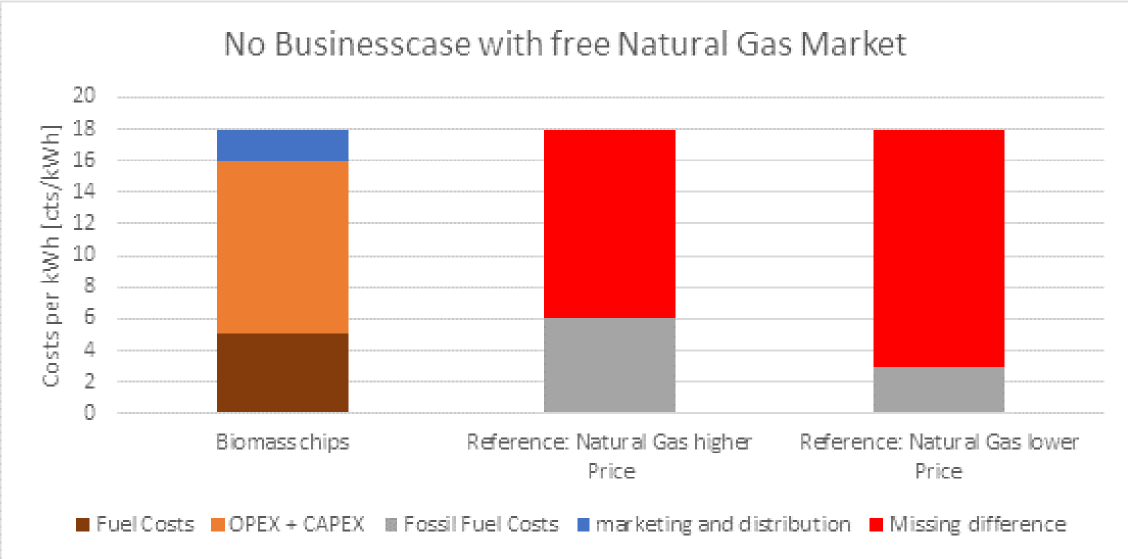


Figure 51: LCOE of BM to SNG plant

BM to SNG projects can be discussed, but only as mitigation projects. For the free market, installations will be far removed from profitability.

6.1.2 No business case to free volatile market for feedstock

As in Figure 51, the bars for natural gas are doubled in Figure 52 too. This is to show that some price fluctuation occurs in the open market. These fluctuations can quickly make a plant uneconomical.

Of course, the prices for biomass also fluctuate on the free market. However, it is not to be assumed that the biomass prices become more favourable, if a large plant is added. Such a plant would let the prices rise rather. However, a BTL plant has no influence on the prices of diesel, as it is too small (no matter how big it is) to produce a substantial share.

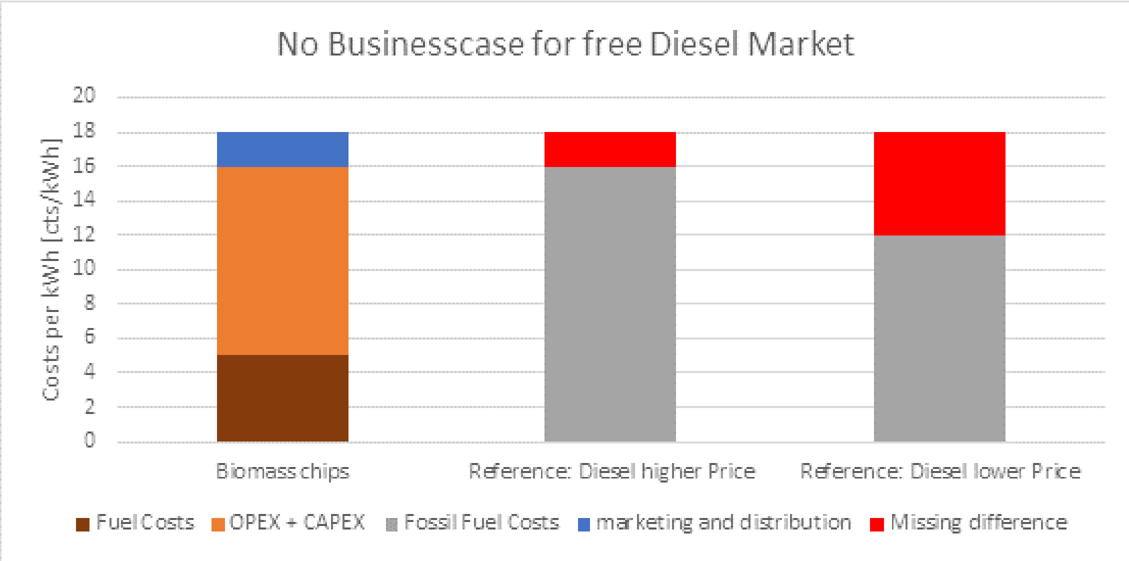


Figure 52: LCOE for a BTL plant

6.1.3 Business case with subsidy

Of course, a BTL plant can also be profitable. There are various scenarios for this. But all of them include a kind of subsidy. These can be direct or indirect, e.g. in the context of tax exemptions.

Following Figure 53 shows a possible, profitable, business case.

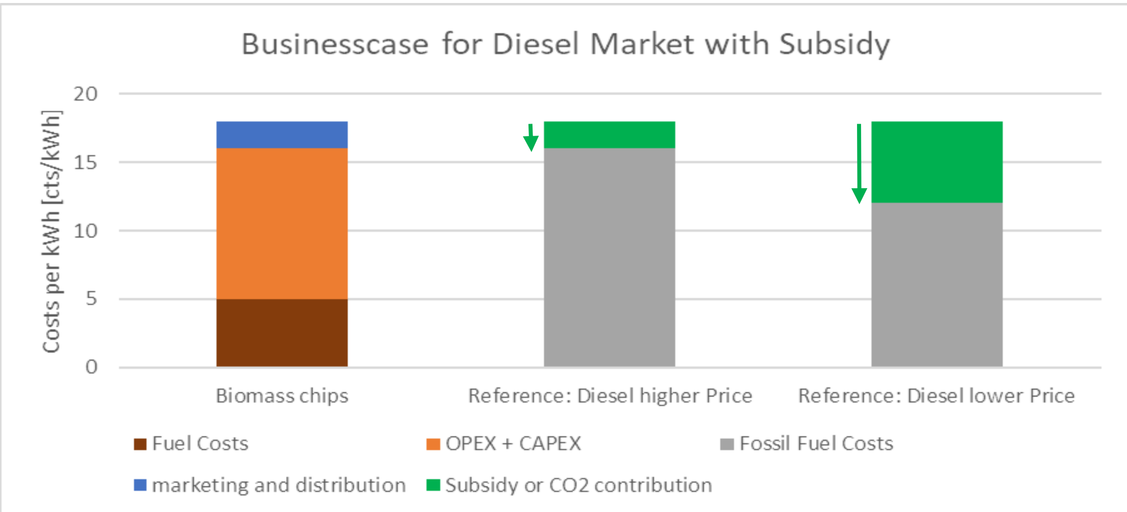


Figure 53: LCOE with subsidy

Subsidies can improve the economic efficiency. Here, however, it must be ensured that the subsidy is guaranteed in the long term.

For countries such as Switzerland, where natural gas and SNG can be used tax-exempt in the transport sector, BM to SNG plants could work. Here too, however, the question arises as to whether this starting position can be guaranteed in the long term. The price of biomass must also be defined and constant over the long term (i.e. over the entire service life of the plant). Such conditions correspond to an indirect subsidy.

6.1.4 Considerations about possible business cases

As it is it possible to see Figure 44, Figure 51,Figure 52 and Figure 53, the prices for fuel varies quite dramatically. One of the differences comes from traffic and government taxes established for road construction and traffic infrastructure. Other differences come from different production and distribution costs. Still on the international market natural gas, crude, oil heating oil and kerosene are tax-free, and that fuel don't include any mitigation fee for CO_2.

So, biomass is a valuable feedstock and it should be carefully considered in what fuel marked it should be converted. It does not make sense to use biomass feedstock with a price of 5 cents/kWh, to try to place a BM to SNG project who competes then to the national gas market with a price of 3 cents/kWh.

It is somehow unfair and scandalous, if we ask for mitigation on the one hand and ask for a new renewable pathway to survive straight away in the so called “free unregulated market”.

There was no energy carrier unregulated introduced and without financially secured, supported by some warranties or subsidies in the past. So, it was or still is with nuclear, fossil oil, natural gas, and coal. They all are directly and indirectly supported and regulated by governments and the public hand.

The financial difference must be covered in such long-term approach by mitigation fee or subsidies etc. Also, it does not make sense, if we place a conversion plant with a life span of 20 year in a free market, when we consider that renewables stay tax-free forever and e.g. Diesel is taken for granted for higher price including taxes.

It is a political strategical issue in what energy carrier it shall be produced renewable fuel. That should be decided based on production price, good efficiency over the value chains and best mitigation strategies. It is a must that warranties or financial compensation are given for prices of feedstock and prices for take over the production to the market. As well labour costs and education must be established on that long-term frame. Intelligent and well-educated people walk away from an unstable project.

It cannot be that there is a project established for hundreds of millions of Euro paid by public taxes, and then after three year it will be closed due to so called financial new situation, or with the excuse it is not any more feasible.

That such a project is not feasible is in the physical matter of conversion, and in the lower density of the biomass, as well we must mention that any fossil energy carrier is free available from the ground. Not so for Biomass. If there is nothing fossil left in the ground, the company walks away and make a new borehole. So, humanity have done before and probably we do as well in future and ask at the same time for renewable to be sustainable harvested and they should be at the same price level as fossil. What a joke! It was the same joke 30 years ago for photovoltaic!

As a logical consequent it is necessary to set up with a long-term strategy renewables Energy such as Biomass. But we should be aware that we know what we are doing.

For that Figure 54 must also be considered. Does it really make sense to use a process with 50% efficiency to produce a fuel that is then processed with 25% efficiency?

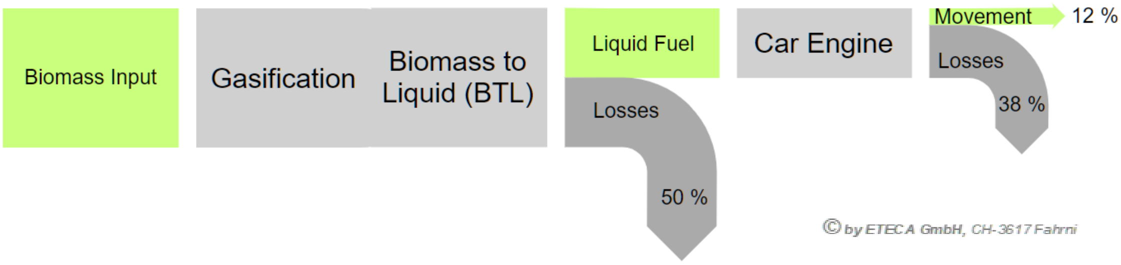


Figure 54: BM gasification value chain BTL endues traffic efficiency µ=12,5 %

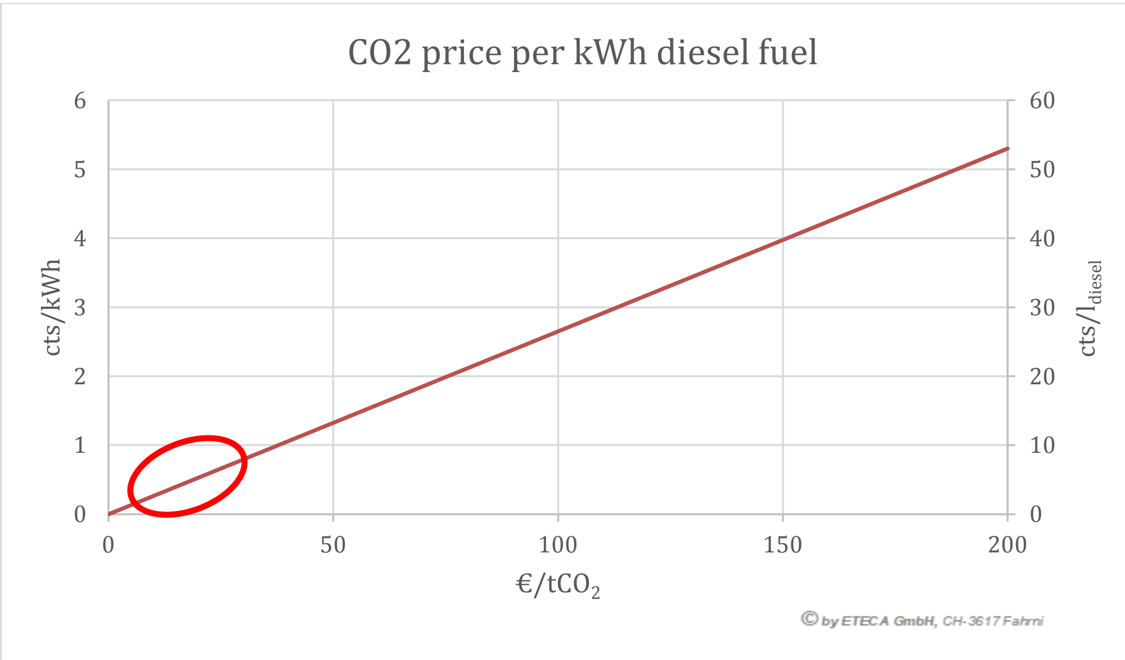


Figure 55: Influence of the CO_2 tax per ton on the energy price, the circle shows the actual market price of CO_2

If project costs, CAPEX and OPEX must be covered with a CO_2 mitigation fee, out of Figure 55 shows how high the CO_2 price must be to cover e.g. the biomass fuel price. To get an easier understanding, two different scales were applied, one shows cents per kWh, the other cent per litre diesel fuel.

6.2 SUCCESS WITH CHP SMALL-SCALE UNITS

Based on the following circumstances:

- Low emissions (PM and NOx)
- High efficiency for electric power
- Reduced cost approved for small-scale gasifier with gas engine
- Long term stable feed in tariffs or renewable energy investment contributions

Plants become success stories, in that they can be connected to existing plants and industries and thus, for example, be used to recycle waste that would otherwise have to be disposed of. The yield is marketable heat and electricity.

The Figure 57 explains the context. See also FEE "Branchenguide 2018" for industrial manufactured CHP units in central Europe.

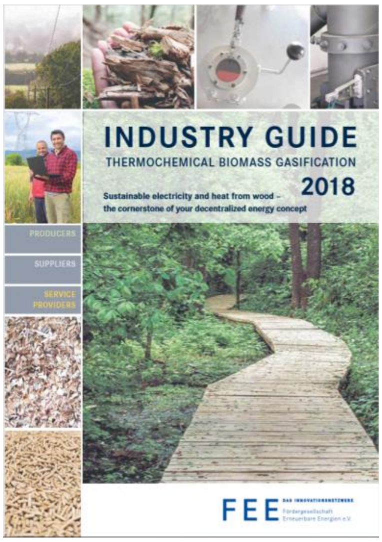


Figure 56: Scan of the "Branchenguide 2018" [20]

http://fee-ev.de/11_Branchenguide/2018_Industry_Guide_Biomass_Gasification_EN.pdf

See example in chapter 6.3.1.

6.3 TO LEARN ABOUT STORY'S

The following plant stories may already be mentioned in the rest of this report.

6.3.1 Story 1: Eschholzmatt and hundreds of other small-scale plants

A saw mill owner in mountainous rural area nearby a village with 3000 habitants surrounded from farmland and forest realized this gasification project.

With the waste wood from the sawmill and the small frame wood factory he already operated a small district heating system with biomass boiler. He realized an extension with CHP gasifier unit to that district heating. The thermal power is chosen to cover all year around baseload of the district heat grid to run the CHP on this baseload to have maximum technical achievable full load running hour on the gasifier. At least more than 7500 hours a year.

The low value heat is used for drying wood fuel for the gasifier or for seasonal shift storages.

So, his waste problem became the fuel input for the CHP unit with the power of 280 kW_{th} and 140 kW_{el}.

The unit produces heat for the district heating, electrical power prior for the own factory and low temperature heat for fuel conditioning. He has enough local employs which can take care when the automatically operation of the gasifier has an interruption, that mean to run and maintain this gasifier. The person who was in charge of waste logistic became a fuel input specialist. In general, this successful business model could be shown with sketch below:

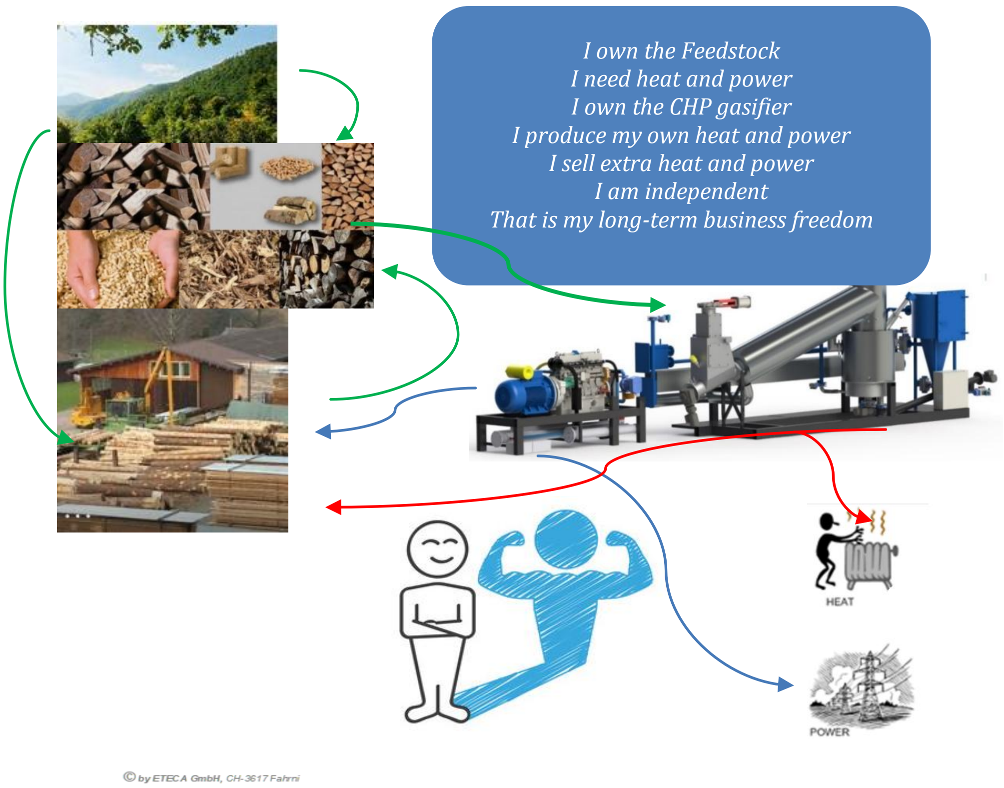


Figure 57: Success of small-scale CHP thermal gasification units

6.3.2 Story 2: Babcock&Wilcox Volund CHP B&W Harboore

Figure 58: Picture of Harboore [7]

See detailed description under:

http://ieatask33.org/download.php?file=files/file/2016/Status_report.pdf

This communal owned CHP plant is in successful operation in the last 20 years using wet feedstock of local available green cut Biomass. A 3.7 MW_{th} up-draft gasifier is in place. The recovered tar is seasonally stored and used in a tar oil-boiler for winter heat peak load for the district heating.

The product gas is used to power two Jenbacher gas engines with a maximum rating of 648 and 768 kW_e power.

The 20-year success story is based on: Locally owned; locally harvest Biomass (garden-, road edge-, and forest waste); locally sold heat and power, tar recovery is seasonal stored and reused; local staff employed; no extra stakeholder benefit must be earned. CO_2 neutral fully looped system. Creating local employees, proudness and independency.

6.3.3 Story 3: Skive

Out of "IEA Bioenergy Success Stories":

At the Skive gasification demonstration project in Denmark, a bubbling fluidized bed (BFB) gasifier is used to produce gas from wood-based biomass. This gas is then cleaned catalytically and used in IC engines in a combined heat and power (CHP) application. The capacity of the plant is 6 MW electricity and 11 MW heat. The heat is consumed in the local district heating network and the electricity is sold to the grid. Besides providing 70% of the district heating production for 8,500 households in the community, the facility aims toproduce40 GWh of electricity annually. Wood pellets consumption would amount40,000 tons per year, with annual CO_2savings of 26,000 tons.

After several years of intermittent operation, the plant has now reached a high availability and operation and outage is fully under control. Persistent efforts to improve fuel quality and alter the catalytic tar reformer have helped decreasing the forced outage and time consumption when maintaining the catalysts. This means that the energy consumption in Skive now primarily is covered by renewable sources.

See "Wood-fuelled gasifier plant at Skive District Heating Company, Denmark [38]

https://www.ieabioenergy.com/wp-content/uploads/2018/02/5-Gasifier-Skive-DH_DK_Final.pdf

Figure 59: Photo of Skive plant [39]

This example shows, that a plant needs its ramping up time which can be demanding for all stakeholders. Toughness, effort and the ability to deal with failures of the involved parties helped to overcome the challenges. The initially difficult project turned into a success story.

6.3.4 Story 4: EMPA

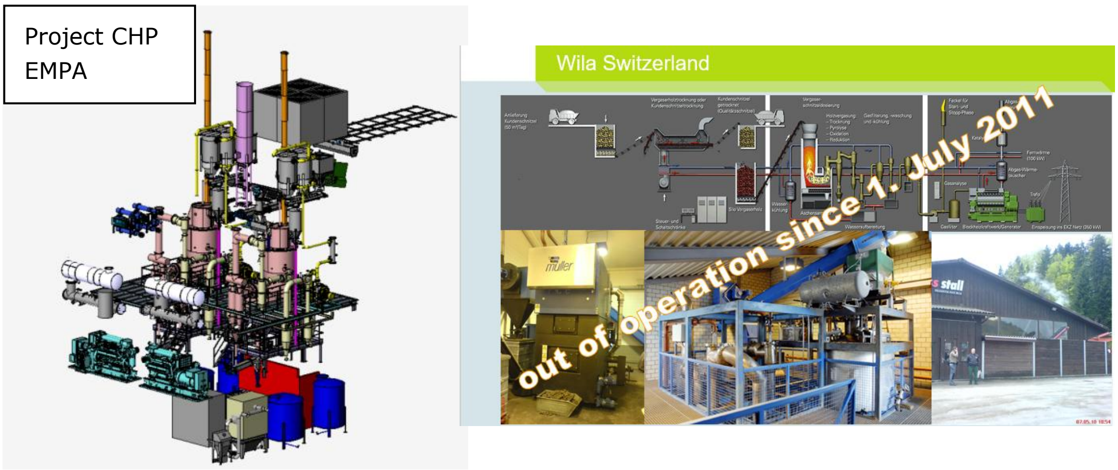


Figure 60: EMPA-CHP project [40]

The wood power gasification CHP plant in operation from 2007 mid 2011 operated with demolition wood was in the year 2008 the base technology for the EMPA CHP project of 2 x 350 kW el output. The final decision to build the CHP unit was made by EKZ September 2010. Detail drawings for the project where established, building permission was received 2011 but neighbors opposed due of fears of smoke and smells emission and a legal process begun which ended in the court. In July 2011 the EKZ decided to close down the WILA gasifier CHP plant due of economical reason. The operating personal where shifted into the EMPA project as knowhow carrier. One year later October 2012 court decision was positive for the EMPA project. First parts where ordered such as the gasifier steel body and detail planning where completed. Construction of Building where started. Some parts like water treatment where redesigned what leaded to additional project costs. April 2013 construction was stopped by EKZ the project owner and asks the client and end-user of the energy for financial contribution. EKZ canceled the project in October due the reason that the energy contracting is to risk full. To adapt the project with a turn cheaper turn key container solution was not considered even building and operating permission with high effort where achieved. Even that millions of CHF where invested the project was closed, the valuable know how disappeared. The heat is now produced by a NG boiler.

Lesson learned:

- An idling project which cannot be realized, (due to legal reason in this case) leads to a loss of the project pressure and drive. That kills the motivation of decisionmakers and involved people.
- If we search long enough for weal points than we always find a reason, an argument to stop a project.
- it made be, that key decisions maker and supporter in a company changes his job and the project does not find the same support any more.
- If there is no an operating plant as a reference or an example it is hard to promote a new project. Even a closed plant of the same kind as of a new project it is not supporting success at all.

6.3.5 Story 5: GoBiGas

From Gobigas website [41]:

GoBiGas is a demonstration and research facility, where Göteborg Energi has conducted large-scale biogas production by means of gasifying forestry residues. The plant is no longer operational and is in the process of being conserved as we consider possible uses for it in the future.

In contrast with conventional biogas production, where different substrates are digested to biogas, the idea behind GoBiGas was to produce large amounts of biogas by gasifying forestry residues such as tops and branches.

The decision to build the demonstration plant GoBiGas 1 was taken by the Management/Board of Göteborg Energi and the City Council in 2008 – 2010. The project was awarded financial support from the Swedish Energy Agency.

The plan was that GoBiGas 1 would be followed by a much larger plant, GoBiGas 2, which would commercialise the technology. The plans for the second stage were shelved in 2015 when the biogas market had not reached the development that was forecasted in order to reach profitability in the project.

The technology in GoBiGas has been developed in close cooperation with Chalmers University of Technology and the project's suppliers. The production of biogas has followed two stages – gasification of the biomass, followed by methanation of the product gas to biogas.

The GoBiGas plant was inaugurated in the Spring of 2015 and in December the same year biogas from the plant was delivered to the grid for the first time. Since its start of operation, the plant has produced and delivered 65 GWh of biogas and in February 2018 the plant reached its maximum capacity of 20 MW. The plant has primarily used pellets as fuel.

In April 2017, the Management and Board of Göteborg Energi decided to actively search for a new owner for the plant. That process was concluded in March 2018 when Management and the Board decided to discontinue the project and stop operations.

Furthermore, see Wiki [42]:

Göteborg Energi opened the first demonstration plant for large scale production of SNG through gasification of forest residues in Gothenburg, Sweden within the GoBiGas project. The plant had the capacity to produce 20 megawatts-worth of SNG from about 30 MW-worth of biomass, aiming at a conversion efficiency of 65%. From December 2014 the SNG plant was fully operational and supplied gas to the Swedish natural gas grid, reaching the quality demands with a methane content of over 95%. The plant was permanently closed due to economic problems in April 2018. Göteborg Energi had invested 175 million euro in the plant and intensive attempts for a year to sell the plant to new investors had failed.It can be noted that the plant was a technical success and performed as intended. However, natural gas is at a very low price given market conditions globally. It is expected the plant is to re-emerge around 2030 when economic conditions may be more favourable, with the possibility of a higher carbon price.

Authors remark:

Calculation of Gobigas plant 2015-2018

Investment:	200’000’000 CHF
Production:	65’000MWh Bio-SNG
Assumption	20MW output
Result:	3.1 CHF per kWh_{output} Bio-SNG
Market price for output:	*0.03CHF/kWh SNG*

If the Project would be setup for 7000hr for 15years and so operation nominal load than it looks 30 times better:

Production:	20MW*15y*7000h =2’100’000’000 kWh_{output} Bio-SNG
Result:	0.095 CHF per kWh Bio-SNG
Market price for output:	0.03CHF/kWh NG

Of course, this does not include feedstock and operating costs. It is only the depreciation of the investment.

Many questions are unanswered in the lessons learned report of the project owner:

If such a plant is built with industrial standard then; why it is possible to rise 200’000’000 swiss Francs and not an operating fund of 200’000’000 more for 15 years as a warranty to get the long-term experience, the long-term employees and build up reliable documented knowhow for first of its kind Bio-SNG production?

Why not a normal ramp up period is integrated in such a program and why there is no several years designed max load operation as a target in the project frame?

6.3.6 Story 6: Värnamo

Customer	Sydkraft AB
Planning company	Sycon AB / Foster Wheeler Energia OY
Type of plant	CHP Demonstration and test facility
Type of technology	Pressurised Biomass IGCC
Special features	Pressurised CFB gasification, hot gas clean up, air extraction from GT
Fuel power	18 MW
Heat power	9 MW
Electrical power	6 MW
Electricity production	3600 h operation as IGCC, 8500 h of gasification
Fuel	Wood chips, pelletised wood, bark, straw, RDF
Description of the site	Vaernamo (Värnamo), Sweden is located about 230 km north of Malmoe (Malmö). The region is mainly forest and agriculture land. Wood fuel is collected within a radius of 50 km. Power is supplied to the public grid while hot water is supplied to the district heating network at Vaernamo. Since the plant is a test facility, hot water is produced in neighbouring biomass grate fired boilers, when the plant is out of operation. The demonstration programme was concluded in year 2000 and the gasification plant has been mothballed since then.
Period of installation	The plant was constructed September 1991 – March 1993. Commissioning of the combined cycle on liquid fuel was concluded in March 1993 and the integrated plant in March 1996. The test programme was concluded in the end of 1999.
Total costs	Investment 230 million SEK / 25 million Euro
Financing	23 % public funding and 77 % private financing

PLANT PERFORMANCE

The accumulated operating experience amounts to about 8500 hours of gasification runs and about 3600 hours of operation as a fully integrated plant as per the end of 1999. The test runs have been very successful and the plant has been operated on different wood fuels as well as straw and RDF. One of the last tests included operation on 100% straw, which was accomplished without disturbances or problems.

Statements of the Customer and Planning Company

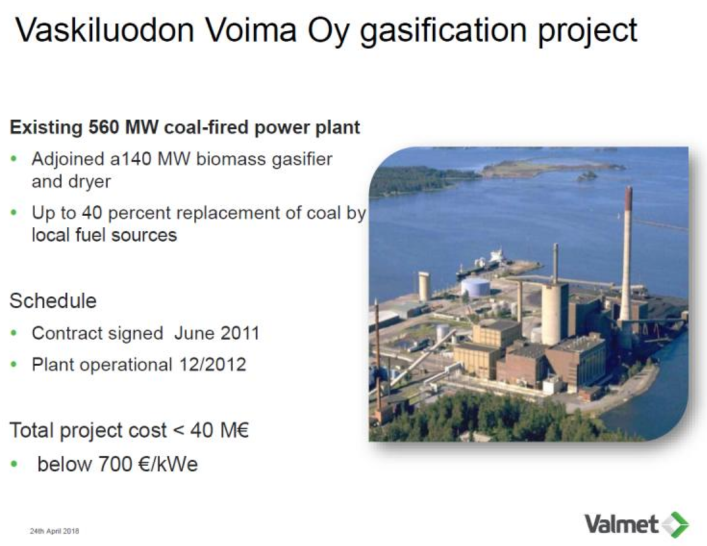
The Vaernamo Demonstration project was very successful and many important results were achieved. It is seldom that development projects of this kind are kept within budget and time schedule, but it was done in Vaernamo. The plant has been mothballed since 1999 when the test programme was concluded. Under the present market situation in Sweden is it not possible to operate the plant on commercial basis. However, a restart of the facility looks promising today and there are ongoing discussions to make use of the plant for further R&D work. The focus today is on waste fuels for power production and synthesis gas production in order to demonstrate alternative transportation fuels.[i]

Figure 61: Facts and plant owner statement from Värnamo plant

Lessons learned:

This last both examples Värnamo and Gobigas typical showing that no plant can be operated without a long-term strategy and without several cost coverage. These shut downs of both plants the responsible owners have again claimed that these plants are not economical. This fact, and the fact that the plants cannot compete with fossil fuel, where already known at the beginning. Likewise, no ramp-up was granted to either plant nor long-term operation for at least 5 years after ramping up was foreseen and secured initially. So, what is that excuse worth and is not highly irresponsible and social ecological incorrect to invest millions of $ and not to secure a long-term experience with.

6.3.7 Story 7: Vaskiluodon Voima Oy



A success story straight forward simple and clear.

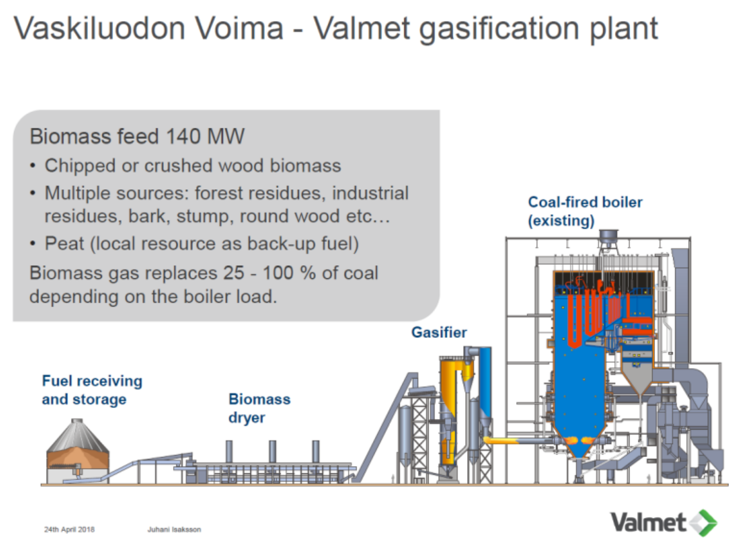


Figure 62: Explanation of Voima plant [1]

7 Conclusion

Historical implementations of gasifier applications had always a very logical reason. This can either be lack of energy or to avoid a negative impact. It can be assumed, that these logical drivers will persist in future as well.

The IEA is following the gasifier technology since the 1970s. Most knowhow available at the IEA is around research and demonstration projects and well documented open access. A very interesting and helpful tool is the database and the different status reports, available on the webpage. [10]

If the coal gasifier scene is considered (developments since 2000), it becomes clear that the gasifier technology itself is available, built multiple times for different applications and is in operation today by thousands (see chapter 3.1). Most of the already implemented biomass gasifier, are small-scale CHP plant. Larger plants are mostly built for research and demonstration purpose (e.g. BTL or BM to SNG plants). Multiple larger plants are in operation, those are either heat, or CHP applications. At the technical level, there is no reason, why larger biomass gasifier plants are not implemented in large numbers.

There are different possible value chains that all have their efficiencies. All value chains are technically realizable.

Biomass is not available limitless. To operate a plant, the feedstock must be harvested in a sustainable way. That means all what is used, must be reforested.
Transport a logistics for biomass feedstock are important and restricting factors for the plant size due to economic reasons. Smaller plants (up to about 10MW Feedstock) can be operated in nearly every area. For larger plants a closer look and to logistic, feedstock prices and transportation is crucial. As the reliable biomass feedstock is unavoidable for a successful plant operation, the feedstock must either be controlled by the plant owner (own forest, or own waste) or guaranteed with long term contracts.

With new technologies or alternative applications of gasification technology, it must always be considered that the development and implementation of a plant takes time. Just as every new technology takes time to function properly. If an existing technology is to be used in a new working environment (e.g. alternative input materials), a "start-up time" must be considered. For example, as an American study [36], written by a company that develops IGCC plants, shows that ramping up always takes 3-5 years until a plant is 100% ready for operation.

New first of its kind Projects have mostly following constant properties: They take longer to plan than expected. They take longer to build than expected. Permission procedure are not so clear, this is also time consuming.

Business cases that are promising, are already implemented. This are mostly CHP or heating applications. There are successful applications from small to large scale gasifier. Gasifier plants with more than one conversion step for BTL and BM to SNG have no economic base as long mitigation of CO_2 has not a certain value.

Typical examples show that no plants can be operated without a long-term strategy and without several cost coverage. Shut down of an existing plant claiming it is not economical is a poor excuse. This fact, and the fact that the plants cannot compete with fossil plants, were always already known before a plant is built. Therefore, to avoid this, there must be long-term contracts with consumers, feedstock supplier and investors as well. Subsidies also must be guaranteed over the expected lifetime of the plant. To leave a biomass conversion plant and project to the free market is a no go.

The stories told in the chapters 6.3.1 till 6.3.7 showed that good working biomass gasification plants are feasible and in operation with different success factors. A project that is well calculated and planed with the adequate technic, operated with persons who are identifying themselves with the plant, integrated in a stable frame with long term contract over lifespan, brings a long-term mitigation of CO_2.

8 Abbreviations

BECCS	Bio Energy Carbon Capture and Storage
CCS	Carbon Capture and Storage
BTL	Biomass to Liquid
BM	Biomass
CEN	European Committee for Standardization, German: Europäische Norm (EN)
CHP	Combined Heat and Power Small-scale gasifier CHP mentioned in this paper mentioned means: up to 10 MW biomass feedstock input or approx. 3 MW_{el} output
IEA	International Energy Agency
LCOE	Levelized Cost of Electricity
LL	Lessons Learned
ORC	Organic Rankine Cycle
PG	Producer Gas (the Gas produced by thermal gasification), equal SYMGAS
R&D	Research & development
RE	Renewable Energy
SCCER	Swiss Competence Center for Energy Research
SYNGAS	Syngas is usually the product of gasification, equal PG
SNG	Synthetic Natural Gas, or Substitute Natural Gas, also bio-SNG if it is produced by RE
SNG	Incorrect: Sustainable Natural Gas, better use Renewable Natural gas (RNG)
TG	Thermal Gasification
IGCC	Integrated Gasification Combined Cycle
BIGCC	Biomass based Integrated Gasification Combined Cycle (with Thermal Gasification)
MSW	Municipal Solid Waste
RDF	Refuse-derived fuel (dt. Ersatzbrennstoff)
NG	Natural Gas
FT	Fischer Tropsch

9 List of figures and tables

9.1 LIST OF FIGURES

9.2 LIST OF TABLES

10 Literature and Links on the Web

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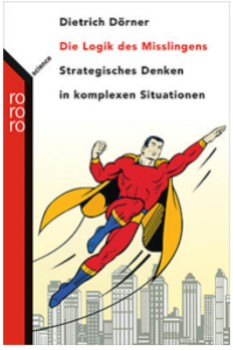

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11 Annexes

Annex 1: List of historical documents

(see Annex document)

Annex 2: List of references for fuel prices

Natural gas	https://www.bdew.de/energie/strom-und-gaspreisanalysen-januar-2018/
Biomass chips	https://www.carmen-ev.de/infothek/preisindizes/hackschnitzel/graphiken
Biomass pellets	https://www.carmen-ev.de/infothek/preisindizes/hackschnitzel/graphiken
Crude Oil	https://www.cash.ch/rohstoffe-edelmetalle/rohoel-274207/iet/usd
Heating Oil	https://www.effizienzhaus-online.de/heizoelpreise-entwicklung
Kerosin/Aviation Fuel	https://www.indexmundi.com/de/rohstoffpreise/?ware=kerosin
Diesel (incl. Taxes)	https://www.clever-tanken.de
Gasoline (incl. Taxes)	https://www.clever-tanken.de
Natural gas for Cars (incl.Taxes)	https://www.clever-tanken.de
Electrical power production	http://www.epexspot.com/en/
Electrical power to small endusers	https://1-stromvergleich.com/strompreise-in-europa/

Further Information

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