The Economics of Biomass-to-Liquids Fuels

Abstract

To combat the climate change and for reasons of the security of supply the European Union and its member states have adopted a strategy to increase the use of energy from renewable resources until 2020 and beyond. One long run sub-target of this strategy is to increase the proportion of renewable energy for fuelling purposes to 20 percent. This ambitious is not reachable with current technology. The paper discusses alternative forms of renewable energy. This discussion identifies biomass-to-liquid (BtL) fuels as the most promising way to accomplish the target. The evaluation of the future role of BtL is difficult due to complex and uncertain interdependencies between factors of influence. The paper develops the basic structure of a SD-model to capture the numerous effects and their dynamic feedbacks.

Key words: Renewable energy, climate change, dynamics, biomass-to-liquids

1. Introduction

In the context of the Kyoto-process the membership states of the European Union have accepted to bear substantial abatement efforts with respect to the emission of greenhouse gases. If one looks at the abatement progress of the recent years one has to admit that the development is unsatisfactory, especially with regard to the emissions caused by road traffic. Let us use Germany as an example: CO2-emissions from stationary sources have declined there considerably from 1990 to 2004. In the same period, the emissions from road traffic have *increased* (BMWi 2005).

This statement summarizes diverging and complex developments: with respect to automobiles, we have on the one hand a positive development – the fuel-efficiency of the engines of modern German (and European) automobiles has steadily increased by a good amount during the period under review. However, on the other hand, several factors counteracted this development:

- The number of automobiles has increased and the number of kilometers traveled has grown.
- The average automobile is good deal heavier today than it was back in 1990, because people prefer cars that are safer and more comfortable which adds to weight.
- Most important, on average people – even in Europe – prefer today a bigger and more powerful car, which increases fuel consumption.

Despite the efficiency progress made by car manufacturers these counteracting factors only allowed for a reduction of CO2-emissions caused by automobile traffic of about 3 percent during the period under review.

This somewhat disappointing result looks like a jackpot if we compare it to what has happened to the emissions of commercial vehicles: the CO2-emissions caused by trucks have increased during the period 1990-2004 by an amount of 55 percent! Adding up emissions from private cars and commercial vehicles there is an increase in CO2-emissions of about 7 percent compared to 1990. In 2004, the proportion of CO2-emissions from road traffic to overall CO2-emissions was 21.2 percent. Of these 21.2 percent, only 1.4 percentage points originated from the remaining traffic (air, railway, water). Therefore, road traffic is by far the most important source of CO2-emissions caused by overall traffic. This picture is not only true for Germany but also for the European Union as a whole. With regard to the then 25 member states (EU-25) the fraction of traffic caused CO2-emissions was 26 percent in 2004. Of this percentage, about 85 percent were due to road traffic (EU 2006).

According to forecasts made by the European Commission the traffic sector will increase with an annual growth rate of 2 percent during the next decade (European Commission 2003, 149). Without altering the existing structures this will not only lead to a further increase in emissions but also to a decrease in the security of supply because the European Union is depending in a high degree on energy imports. In its Green book "Towards a European Strategy for the Security of Energy Supply" the European Commission notes that the European Union covers half of its energy demand by imports at present. If no appropriate measures are taken, the dependence on imports from countries outside the European Union will have grown to a value of 70 percent by 2030, according to the forecasts of the Green book (EU 2002). An overall judgment of the security of supply must take into account that the proportion of natural gas and crude oil will increase, which means that the growth rates of these imports are even higher. This is not good news with respect to the security of supply because natural gas and crude oil originate mainly from regions, which are politically quite unstable.

Therefore, in addition to environmental aspects there are important arguments related to energy policy, which make strong points for reducing the use of fossil energy sources. It is true that the amount of CO2-emissions is determined by the employment of fossil resources in the total economy, but there are three reasons why the transport sector is of special relevance: First, it is a quantitative important sector – only the energy sector emits more CO2. Second, the emissions of this sector have increased since 1990 whereas the emissions of the energy sector went down during this period. Third, the substitution of currently used fossil fuels is difficult given the actual state of technology, substitution possibilities are limited quantitatively, and substitution currently does not pay. These reasons, taken together, challenge researchers to find substitution paths that from all three viewpoints – technology, availability, and economic efficiency – may long run alternatives to fossil fuels.

The most important paths that researchers discuss are hydrogen, natural gas products, and biomass products. The last seems to have an especially promising future. There are several different uses of biomass: wood pellets for heating, ethanol from sugar cane, sugar beet or corn, etc. A technologically ambitious but very promising approach is the transformation of biomass to liquid fuel. This approach is called Biomass-to-Liquid approach or for short “BtL” approach. Although BtL is under research in the United States as well, it plays a more important role in Germany. At least four research institutes develop different methods of BtL production. At present Choren Industries (Freiberg, Germany) is the front-runner with its “Carbo-V-Process” because it currently already constructs an industrial prototype plant which is supposed to be followed by the construction of a full-scale industrial plant starting in 2008.

This paper investigates the role BtL can play in a sustainability strategy by employing the system dynamics method. The production of BtL is embedded into a highly complex system, characterized by many interacting positive and negative feed back loops and by delays. Feedback loops exist because of the interaction of alternative BtL-technology paths, alternative uses of biomass, and different ways of biomass production, to name just a few examples. Delays exist because of the time to build the necessary infrastructure, the relevance of learning curve effects, sluggish adjustment of (administered) prices, etc. These conditions aggravate rational policy decisions, as we know from a vast body of empirical research that studies the influence of delays, feedback effects and nonlinearities on human decision making (e.g. Brehmer 1992, Doerner 1980, Moxnes 2004, Diehl and Sterman 1989). The paper shows the value of the system dynamics method to clarify the mutual dependence of these complex interacting forces. It is part of ongoing research and aims at building a first simple model to allow for understanding the dynamic complexity of BtL in a sustainability strategy.

The paper is organized as follows. In the next section, it reports about the role of biomass fuels in the political strategy of Germany and the European Union to demonstrate that there is a definite political commitment for developing the use of renewable resources. Then, it reflects about the potentials of three paths of substitution of mineral oil: hydrogen, natural gas, and biomass. It is argued that hydrogen and natural gas are not very promising substitution paths. Consequently, the next section discusses advantages and disadvantages of different types of biomass fuels. This discussion leads to the conclusion that BtL-conversion is an especially promising way to employ biomass for fuel production. The currently most sophisticated BtL-process is the Choren Carbo-V process. Its fundamental properties are shortly described to illustrate the basic steps of BtL production. In order to understand the dynamic complexity and the uncertainties of the prospective BtL path, a first simplified system dynamics model is developed.

2. The Significance of Biomass-Fuels in the Political Strategy of Germany and the European Union

Because of the unsatisfactory development of greenhouse gas emission and because of the growing dependency from energy imports the European Union has initializes several programs to increase the use of renewable energy sources. The directive 2001/77/EG requires the member states of the European Union to increase the proportion of energy from renewable resources to 12 percent of total energy consumption by 2010 (EU 2001). The directive 2003/30/EG (“Biofuel Directive”) has set a target of 2% biofuel usage by the end of 2005 and 5.75% by the end of 2010 (EU 2003a). In the Green Book "Towards a European Strategy for the Security of Energy Supply", the EU Commission submitted an action plan to increase the use of biofuels to at least 20 percent by 2020 (EU 2002). This strategy creates a politically induced demand for biofuels that significantly exceeds the currently given production capacity: In 2005, the 2 percent target was not met. The agreed target would have required a production of 4.35 million tons of biofuels but in fact, only about 3.7 million tons were produced. (Only Germany not only reached but also exceeded the target.) Some of the member states have to raise their production of biofuels dramatically.

The promotion facilities offered by the Biofuel Directive were stated more concrete with respect to tax privileges and subsidies in the Directive 2003/96/EG ("Energy Taxation Directive") (EU 2003b): To promote the use of biofuels ember states may reduce the taxation on biofuels up to 100 percent. Tax exemption or tax reduction may only apply to pure biofuels and to the biofuel content in the case of mixed fuels. To prevent overcompensation the member states are required to decrease the subsidies to extra costs of biofuels compared to conventional fuel. The member states must check the amount of extra costs each year. The Energy Taxation Directive encourages the member states to differentiate the size of the subsidies according to the ecological balance, to competitiveness, and security of supply in order to promote these targets. It is well known that the taxation mark up on the producer price of fossil fuels is quite high in Europe ranging from 27.6 Eurocent per litre to 73.8 Eurocent per litre. In fact, the tax rate commands in most member states the consumer price much more than production costs. This makes it technically simple and administratively cheap to install a system of subsidies by reducing the taxation of biofuels.

3. Significance of non mineral oil based fuels

As we have already discussed there are three main paths to reach the targets stated above: hydrogen, natural gas, and biomass. These paths are mutual dependent because hydrogen may be produced from natural gas or biomass; biogas – a substitute for natural gas – may be produced by biomass; synthetic fuels may be produced from natural gas or from biomass, etc.

a) Hydrogen

For using hydrogen to power vehicles the most promising technology seems to be the hydrogen fuel cell technology. Modified internal combustion engines constitute an alternative – but among the bigger car companies only BMW follows this path. Both technologies are still under development and a broader use of hydrogen is not expected before 2030. There are several reasons why the use of hydrogen to power cars will not start earlier and why there still is uncertainty about the role hydrogen will play in future traffic.

Hydrogen fuel cells are still big and heavy. In addition, they need big cooling aggregates which decrease useable space and add to weight.
An even bigger problem is the storage of hydrogen. Gaseous hydrogen exhibits a small energy density with respect to volume. To use hydrogen for powering mobile fuel cells it has to be compressed and stored in pressurized tanks as gas. Alternatively, it can be liquefied and stored in a thermally insulated container (cryogenic tank). A third possibility, which is under research, is the use of crystalline materials to store hydrogen at greater densities and at lower pressures. All three methods are characterized by high production cost and high conversion costs. In addition, the technology is not ready for mass use – and will not be in the foreseeable future.

A further problem with the use of hydrogen to power vehicles is the need for erection of a complete new infrastructure in parallel to the current fuel station infrastructure. This constitutes a complex problem due to the fact that "various 'chicken-egg' mechanisms interact in a highly integrated fashion, and the mechanisms are highly non-linear" (Struben 2005, 1). Hence, even if the technical problems described above are resolved one can hardly assume a fast setup of the hydrogen infrastructure.

Finally, the evaluation of any hydrogen path with regard to environmental concerns depends to a large extend on the employed production process. If hydrogen is extracted from methane or natural gas (by steam reforming or water gas shift reaction) or coal (by gasification) there is no saving on CO2-emissions. With respect to environmental concerns the extraction of hydrogen from water by electrolysis seems to be the best way provided that the needed electricity stems from renewable sources like wind power, water power or solar energy. The cost-effectiveness of electricity produced from these sources depends heavily on the location of the respective plants. Another point is that the amount of usable wind and solar power fluctuates noticeably due to seasonal and atmospheric conditions. Therefore, quite huge control and storage capacities are needed, which increases the total costs of a hydrogen producing system relying on renewable resources considerably. A central argument in the debate is that the direct use of electricity produced by renewable resources is much more cost-effective with regard to greenhouse gas reduction than the detour made by using it for electrolysis to power hydrogen vehicles (Nitsch et al.1997; Kolke and Friedrich 1998).

b) Natural Gas

Natural gas can be used directly to power vehicles. For this purpose natural gas is used in compressed forms. Internal combustion engines can use natural gas with minor modifications. The technology is well-known, in practical use since several years, and technical mature (Poelz and Salchenegger 2005).

In principle, the environmental impact of natural gas for powering vehicles is positive compared to conventional mineral fuels. Natural gas powered vehicles emit 25 percent less CO2 and 75 percent less CO compared to vehicles powered by fossil gasoline (Umweltbundesamt 2006).

But, the use of natural gas for powering vehicles has several serious disadvantages. Despite the better emission characteristics the combustion of natural gas still adds to the green house effect. From a German perspective it further has the disadvantage that it must be imported because Germany has nearly no domestic sources of natural gas. Above all there are usage rivalries because natural gas is used in heat production and in the production of electricity where it plays a growing role to balance the fluctuations of wind and solar power electricity production. Taking all these arguments together there are serious doubts with respect to the long run importance of natural gas as a way to power vehicles.

c) Biomass

The third option to substitute mineral fuels is the use of biomass as a feedstock for biofuels. I use the word “biofuel” here as a collective term that covers all liquid or gaseous fuels, which are produced from plants, part of plants or plant residues. There is a big variety of crops that can be used as feedstock; the processes to convert biomass to biofuels differ; and biofuels differ in their characteristics – for all these reasons it is difficult to evaluate the cost-effectiveness of the biomass well-to-wheel conversion processes.

Quantitatively, there are currently only two forms of biofuels relevant: bio-ethanol and biodiesel. Bio-ethanol is predominantly produced from plants and parts of plants that contain big shares of sugar or starch. Such plants are sugar cane, sugar beets, and corn. Switchgrass and sweet sorghum are two other possible feedstock types for the production of bio-ethanol. In Europe and North America bio-ethanol is used in form of ethanol fuel mixture. Typically, blends of ethanol and gasoline with 5 to 10 percent ethanol are allowed or required, respectively. This types of gasoline-ethanol blends can be tolerated by modern engines without any modification. If engines are modified appropriately they can tolerate higher proportions of ethanol up to pure ethanol. In general, these modified engines can be fuelled by gasoline as well. Consequently, in mass use there are no difficulties with respect to fuel logistics because in case no ethanol is locally available the vehicles just use gasoline. The erection of a separate ethanol infrastructure is not needed, which simplifies the logistic considerably and keeps the cost of distributing ethanol low. Despite of these advantages the cost-effectiveness of bio-ethanol is under discussion for two main reasons: first, given the current state of technology only the starch or sugar containing parts of a plant can be used for conversion – the rest of the biomass remains unused; second, the conversion process requires a large energy input.

Currently, ethanol is the most important bio fuel worldwide. The by far largest volume of ethanol for fuelling purposes is produced and consumed in Brazil. In 2003 the output was 10 million (metric) tons, which covered 10 percent of the street traffic fuel demand. The second most important ethanol producing country is the United States, producing 8 million tons of ethanol in 2003 – an output that is equivalent to about 1.5 percent of the street traffic fuel demand. The production volume in Europe was 0.5 tons in the same time period. (The Source for these figures is Specht 2003, 36.)

The development in the United States sheds some light on socially relevant side-effects of biomass use for fuelling purposes. In the U.S. bio-ethanol is produced almost completely from corn feedstock. The growing of corn is subsidized in the U.S. since a long time. This has lead to an increase in supply and a decrease in the market price. The market price in the U.S. was driven down so far that growing of corn in Mexico decreased dramatically, because it became cheaper to import corn from the U.S. We all know that Mexico is depending on corn because it is on of its most important foodstuffs. The boom of bio-ethanol production in the U.S. lead to an increase in demand and an increase in the market price, which hit the Mexican population unprepared: the corn price has doubled within a short time period. This story shows that it is essential to consider the system structure in which the promotion of biomass is embedded. The effects within this system reach far beyond the direct impacts on technology and cost, which are often solely taken into account.

In Europe and especially in Germany biodiesel is a significantly more important biomass fuel than ethanol. Biodiesel is produced, in general, by the transesterification of vegetable oils from oil seed crops (rapeseed, soybean, sunflower, etc.). In principal, residues of vegetable oils or animal fats can be employed. Biodiesel can be used pure or blended with conventional diesel. There is an ongoing dispute regarding the suitability of bio-diesel for the use in modern high performance diesel engines. Volkswagen, for example, has once permitted the use of pure biodiesel but has withdrawn this permission for most of its currently manufactured vehicles.

Like bio-ethanol biodiesel has the great advantage that the existing distribution infrastructure may be used. There is no need for creating a complete new infrastructure as it would be the case with hydrogen. A weak point with biodiesel produced from biomass is the fact that only parts of the plants can be used. The rest of the biomass remains unused.

At least from a European Perspective bio-ethanol as well as biodiesel is not an ideal substitute for fuels from fossil energy sources. The arable areas suitable for growing the feedstock needed for bio-ethanol and biodiesel is limited. The German Federal Environmental Agency (Umweltbundesamt - UBA) has estimated that about 2 percent of conventional diesel may be substituted by biodiesel due to the limitations given by the area of land suitable to grow rapeseed. The UBA believes that the ecobalance of bio-ethanol and biodiesel is not satisfactory, arguing that both fuels should not be subsidized because the funds could be used more efficiently in other areas, e.g. the promotion of consumption reduction (UBA 2006).

The scepticism with regard to the well-to-wheel analysis of bio-ethanol and biodiesel on the one hand and the plan of action of the European Union laid down in the Biofuel Directive to increase the use of biofuel poses the question, whether there is an alternative with a better ecobalance. Especially in Germany the production of Biomass-to-Liquids fuels (BtL-fuels) is at the centre of the technological and political debate.

BtL-fuels are manufactured by a multi-stage conversion process that uses solid biomass as an input. The feedstock may be virtually any biogenic resource: plants like those used for the production of bio-ethanol or biodiesel, straw, waste wood or even the organic parts of residential waste. A big advantage of BtL compared to bio-ethanol or biodiesel is the fact that the whole plant (not only parts of it) can be used for conversion purposes. This means a much higher volume of biomass available for biofuel production given the area of arable land (Wuppertal-Institut 2006, 9).

4. Technology of BtL-Production

All the BtL-processes that are currently under development follow the same fundamental principles: In a first step the usually a high proportion of water containing biomass has to be grinded and dried. The next step is gasification of the dried biomass to a synthetic gas (syngas). After purification the “Fischer-Tropsch-Synthesis” is used to liquefy the syngas. By this chemical synthesis carbo-hydrogen chains are formed from carbon monoxide and hydrogen. The Fischer-Tropsch-Synthesis is well known since quite a long time, and it was used in Germany during World War II to synthesize fuel from coal. The technical problem is that the technology of the coal-to-fuel synthesis used in huge facilities cannot simply scaled down to the smaller facilities needed to produce BtL. Moreover, today environmental concerns have to be taken into account that played no role in a war economy.

The most difficult step is the production of the syngas from the dried feedstock. This part of the conversion process is a thermo-chemical conversion, in which the gasified biomass is decomposed into the main components hydrogen and carbon monoxide. The control of this process is a complicated but very important part of the conversion because the product gas has to have specific properties in order to be usable for synthesis.

In Germany the BtL-process is actively researched by four labs: Choren Industries, CUTEC-Institute, FZK-Institute, and Technical University of Freiberg. The processes researched at these institutes share the same basic conversion steps, but in their details they differ considerably. These differences lead for example to different requirements regarding the kind and state of the feedstock. Hence, in the end an overall evaluation of BtL is not possible but one has to distinguish between the different processes. At present (March 2007) only the Choren process has reached the stage of turning to a demonstration plant on an industrial scale. It seems therefore appropriate to use the implementation plans of Choren industries as a guideline when modelling the system aspects of producing BtL-fuels. (For the following details see Choren 2007.)

The Carbo-V process offers a number of advantages compared to the production of bio-ethanol and biodiesel: The high temperature combustion in the Carbo-V gasifier yields in connection with the following process steps a high-grade gas that is free from tar, chlorine, and sulphur. In the Fischer-Tropsch synthesis carbon and hydrogen are recombined into long chain paraffin and waxes. The synthetic diesel is then derived from the raw synthesis product in a multistage process. Because the specifications of the fuel can fine-tuned by altering the form and the length of the fuel molecules it is possible to match the requirements of the engine constructors – hence, the terms “synfule” and “designer fuel”. This fine-tuning cannot be achieved in the currently used conventional fuel refining processes. The possibility to optimize engine and fuel in a consistent process leads to very low emission combustion, which is an important side effect of BtL. Another advantage is that the available biomass per hectare is larger because the whole plant can be used and not only parts of it as is the case with bio-ethanol or first generation biodiesel. Finally one should note, that as any form of biomass may be used – not only biomass containing high proportions of sugar or starch – monoculture is not essential and, at least partly, extensive cultivation may be cost-effective.

In 1998 Choren Industries started the operation of a pilot plant in Freiberg, Germany to test the Carbo-V process with a variety of feedstocks. In 2003 the first industrial prototype plant was put into operation and the first synthetic fuel from wood shreds was produced.

In October 2007 the first industrial scale plant will start to operate in Freiberg. It will convert about 10 tons anhydrous biomass to 2.5 tons SunDiesel. With a planned yearly output of 15,000 tons per year it needs a feedstock of about 60,000 tons anhydrous biomass.

From the data of this plant we can draw conclusions on the dimensions of the full scale plant, which presumably will be put into operation around 2010 at the location of Lubmin, Germany. The production capacity of this full scale plant will be about 250,000 tons of SunDiesel. Taking the proportions of the Freiberg industrial scale plant the full scale plant needs a feedstock of around 1 million tons of anhydrous biomass. The crop yield per hectare depends on a lot of factors: what kind of energy plant is employed, the quality of the soil, climate, the use of fertilizers, the use of herbicides and pesticides, etc. (This alone constitutes a complex system which is worth to be investigated by SD-methods, because, for example, the incentives to use herbicides not only depend on the kind of crop but also on climate, soil, and political regulations; the development of the quality of the soil over time depends on the type of plant that is grown, but also on the volume and kind of fertilizers employed; the cultivation method (monoculture, use of herbicides) influences the biodiversity which feeds back to the amount of infestation.) In a SD-model the yield per hectare will be an interesting parameter (or maybe a variable) for which sensitivity analysis may produce interesting insights into the substitution potential of BtL, the need and the prospective amount of subsidies, etc. For the moment, let us assume an average value of biomass produced on cultivated land of 15 tons anhydrous mass per hectare. In this case an area of cultivable land in the order of 700 square kilometres. Because in Germany even rural areas are quite densely populated, 700 square kilometre of cultivable land can very well mean that the feedstock for one full scale plant has to be grown on an area of about 1.000 square kilometres. Given the size of Germany and the intensive use of land for other purposes the number of full scale industrial BtL-plants is, presumably, better treated as a discrete, not a continuous number.

5. BtL-Fuel Technology as Part of a Highly Nonlinear Complex System

The future role of BtL-fuel in a consistent strategy of environmental, economic, and social sustainability is not only depending on technological feasibility, but it depends also on numerous ecological, economical, social and political factors. Some of these factors are:

- Biomass potential
- Biomass composition
- Biomass sources
- For fuelling purposes available biomass potential
- Substitution effects
- Costs of growing biomass
- Transport costs
- Learning curve effects
- Political targets with respect to energy, environmental, and agricultural policy

This list is by no means exhausting. The evaluation of the future role of BtL is difficult due to complex and uncertain interdependencies between the named and other factors of influence. To support this claim let me point to some specific feed backs:

- The profitability of BtL depends on uncertain future technological and organizational developments, which are reflected in learning curve effects, but it also depends on cost effects of substitutes that span from mineral oil to hydrogen.
- The kind of biomass used as feedstock influences the cost of BtL production, but it also influences the profitability of the different BtL-processes that are under development, because they show different transport costs.
- The kind of feedstock has an important impact on the rivalry created by the use of biomass to produce BtL: sugar cane, sugar beets, and corn are heavily used to produce bio-ethanol. The use of those crops for BtL-production creates a direct rivalry. But there emerges also rivalry if arable land is used to grow BtL-feedstock because this land cannot be used for other purposes. The intensity of rivalry in turn depends of kind of biomass – it will be small if waste wood is used.
- On the other hand the use of waste wood creates another rivalry: Until recently, waste wood was just what the name literally says. Not so anymore! “Waste” wood is used in dramatically increasing amount to produce wood pellets, which are used for heating purposes. This has lead to a substantial increase in prices which trickle down to the prices of other kinds of biomass.

This short list that could be easily expanded should be a sufficient motivation to try to capture the numerous effects and their dynamic feedbacks in a SD-model. To the development of such a model I turn in the next section.

6. A SD-model for BtL

The model presented in this section has not the purpose to deliver a fully fledged description of the dynamically complex interactions sketched above. Rather, it is meant as a device to stimulate the discussion about the benefits and costs of the use of BtL over time, to help to organize this discussion by providing a framework that enforces consistency, to help to reveal so far not noticed feed backs and to improve our understanding of the working of the system. Some of the insights the model should deliver in the long run concern questions like:

- What will the path of the quantitative use of BtL be over the next two decades?
- What factors influence this path in which way?
- What role do substitutes play? Which substitutes are close substitutes, which not?
- How look the different learning curves like? Which influence do they have?
- To what extent is the use of BtL depending on government subsidies? What are the effects of different forms of subsidies?
- What will be the impact of the use of BtL on environmental issues like greenhouse gases and other emissions?

- What is the relevance of different types of feedstock and different types of crop growing methods on BtL-costs? What are the environmental impacts of these differences?

In this sense, the following reports only on the first phase of a longer research program. This first phase comprises the identification of the basic feed-back structures of BtL-fuel production as a starting point for a more detailed model.

The structure and the most important feed-backs of this basic model are given by the following causal loop diagram (see Fig. 1).

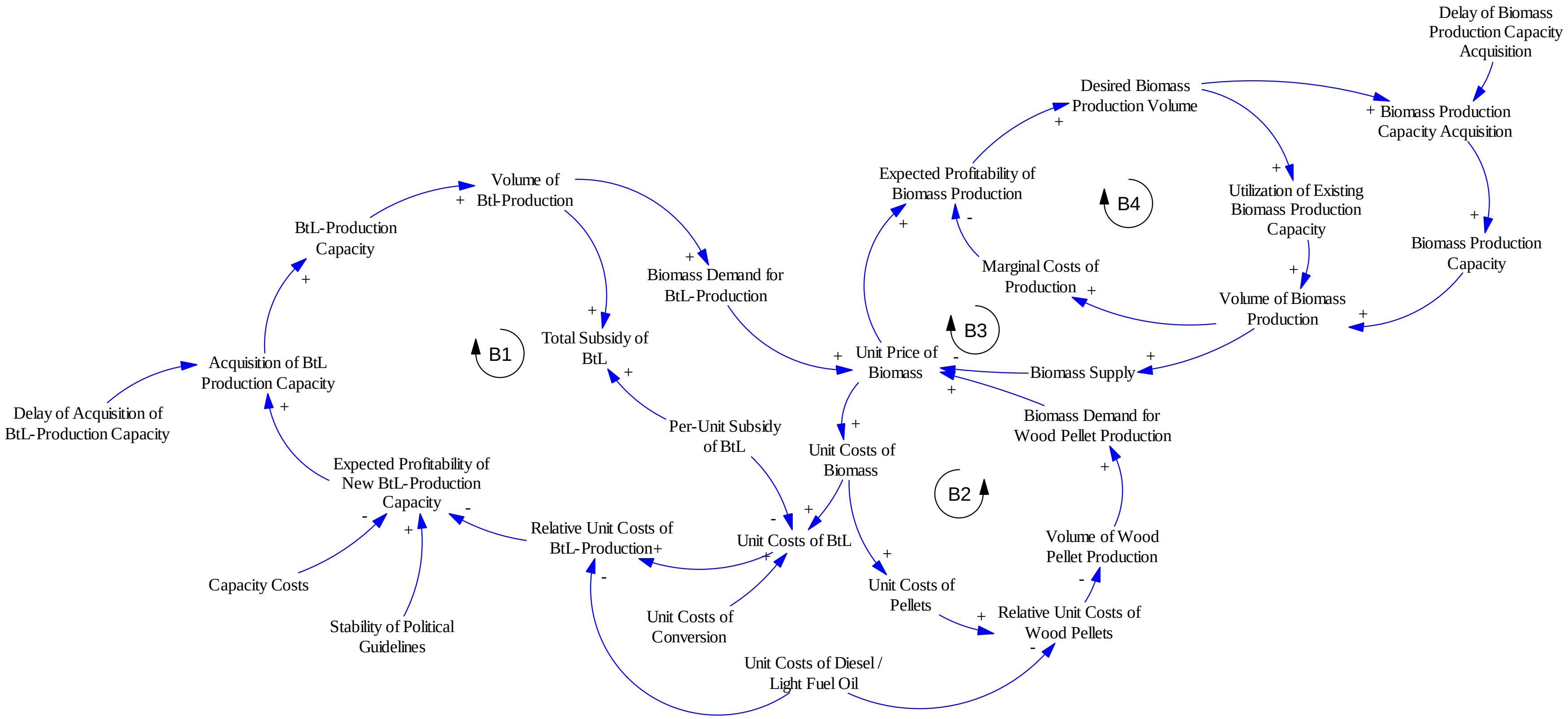

Figure 1: Simplified causal loop diagram of a basic BtL-fuel model

The causal loop diagram of figure 1 mirrors the most basic dynamic interdependencies of the BtL-system. It comprises the BtL-production and capital acquisition cycle, the influences of the existing and future biomass capacity, the influence of alternative use of biomass, the influence of the price of mineral fuel, the impacts of subsidies, and of political guide lines.

What is left outside of the model for the time being, are the interdependencies with other alternative fuels like hydrogen, liquefied natural gas, bio-ethanol, and biodiesel. Moreover, alternative approaches to produce BtL-fuel are not included – the diagram assumes that only one BtL-technology exists. The same is true for biomass feedstock types and – with the exception of wood pellets (chipped wood) – for alternative biomass uses. Outside of the model boundaries is also the political decision process. Finally, the model assumes a closed economy, so that neither biomass nor BtL are exported or imported. Mentally, the model mirrors the situation of Germany.

Before starting to discuss what the interrelations that are implemented in the model, it seems necessary to reflect on the objects that were left outside at this stage of evolution.

The exclusion of hydrogen and liquefied natural gas seems to be appropriate: as explained above at current most observers believe that hydrogen used either in combustion engines or in fuel cells will play no significant role before 2030. The time horizon of the presented model is the next two decades – that means the time *until* 2030.
Liquefied natural gas, on the other hand, currently plays an important role as a fuel but the interrelations with BtL-fuel are weak. There is no rivalry with respect to the feedstock and, as will be argued below, liquefied natural gas has no impact on the supply and demand of BtL-fuel – with one potential exception, the indirect effect on the political process and, therefore, the size of BtL-subsidies. But if the political decision process is left outside the model boundaries then the effect of a re-evaluation of liquefied natural gas and its impact on policy should left outside the boundaries as well.

The exclusion of bio-ethanol and biodiesel cannot be justified on grounds of weak interrelations. Obviously, there *are* strong interrelations between bio-ethanol and biodiesel on the one hand and SunDiesel on the other hand. Both factors are excluded at the moment for simplification. They will be included into a further developed version of the model.

Competing methods of BtL-production are not included because they are just not in the stage the Choren Carbo-V process is. At present, it is impossible to say whether these approaches will ever reach the level of industrial production. If the future shows they will and if the importance becomes clearer they should be included.

Not to differentiate between different types of feedstock (which are related to different costs) and not to differentiate between different uses of biomass is a major drawback of the current version of the model. But as is the case with alternative renewable fuels a future version of the model will take care of this weakness.

To leave the political decision process outside the model boundaries is quite normal for an economic model. From an economics viewpoint the decision process is just too erratic. In Germany, for example, there is a basic agreement to subsidize energy from renewable resources but, what exactly will be subsidized and what the size of subsidies will be is unforeseeable because it depends on which party is power, which pressure group works most effectively, etc.

Again, a major drawback that will be fixed in one of the next model development steps is the exclusion of imports and exports. One can even speculate that the basic model alone, when simulated with realistic figures, will show that Germany will either have to import biomass or BtL-fuel produced abroad if it is to reach the targets set by itself and the European Union.

I will turn now to the interdependencies implemented in the model. Let us start with the unit costs of BtL, which are part of the balancing loop labelled B1. The unit costs of BtL are influenced by the biomass costs and by the conversion costs. The unit conversion costs cover all variable inputs like work and energy. Moreover, in the first version of a numerically specified model I will assume that the unit costs cover capacity costs as well – this is because data on the so defined costs is available from other sources. The unit costs of BtL are also influenced by government subsidies. In real life, there is a whole bunch of different forms of subsidies, reaching from research and development grants via subsidies for regional development to agricultural subsidies. The simulation model can be used to answer the question what size subsidies must have over the simulation period to stimulate the needed acquisition of capacity.

The expected long run profitability that triggers the acquisition of new capacity depends on the relative unit costs of the BtL-production. With some simplification we may treat BtL-fuel and fossil fuel as perfect substitutes. The unit costs of fossil fuel are outside the model boundary. As long as the unit costs of fossil fuel are smaller – and are expected to be smaller in the long run – than the unit costs of SunDiesel, BtL-fuel cannot be produced profitably in the eyes of the investors because no one will buy it at a price that covers its variable costs. If so, no new capacity will be acquired.

The belief in long run profitability requires additionally a credible political commitment. Assuming that the government really wants to follow the BtL-path in the long run, it will guarantee subsidies of a size that make capacity acquisition profitable. If so, then Choren will build plants following a time path that is feasible.

This makes a big difference to generic models of capacity acquisition. (For a generic model of capacity acquisition, see for example Sterman 2004, 609-615). Usually capacity acquisition is modelled as a continuous process. In the BtL-scenario, Choren plans for the next decade the construction of five very similar plants. As I argued above, given the needed area for growing the feedstock and given the size and population density of Germany the number of plants will presumably be limited and best modelled as a discrete variable.

Another deviation from a generic model of the production process relates to production capacity an actual production. Normally, on has to make a distinction between capacity and production volume given by the rate of capacity utilization. This is not the case here. The politics behind BtL-fuel are so that either nothing is produced at all or the capacity that is erected is utilized in its full amount: If the government is convinced that the BtL-path makes sense in the long run for environmental reasons and for reasons of security of supply then it will subsidize BtL-fuel in the one or other way in an amount that makes production profitable for the producers. In that case all of the existing capacity will be used.

The same logic says that the demand for biomass stemming from BtL-production is just the amount of SunDiesel produced times the conversion rate (in the case of the Choren process one to four). There are just no other factors that influence the biomass demand for BtL-production.

An increase in the biomass demand for leads to an increase in the price of biomass. This in turn increases from the perspective of the users of biomass the unit costs of biomass. With this element the balancing loop B1 is closed. If subsidies are modelled as per-unit subsidy it is straight forward to calculate the size of total subsidies by multiplying the production volume by the per-unit subsidy.

If unit costs of biomass increase so do unit costs of wood pellets. (Recall that wood pellets represent for the time being all other alternative uses of biomass.) If unit costs of wood pellets increase then the relative unit costs of wood pellets increase as well. (The latter are costs relative to substitutes. Here it is assumed that light fuel oil and wood pellets are substitutes for heating purposes. If the unit costs of light fuel oil increase the relative unit costs of wood pellets will decrease.) With higher costs of pellet production the production volume will decrease as well as the biomass demand for pellet production. A lower biomass demand will decrease the unit price of biomass, which closes the balancing loop B2.

The loops B3 and B4 reflect the biomass supply. An increase in the unit price of biomass raises the expected profitability of biomass production. With raising expected profitability the desired biomass production volume increases. This leads on the one hand to an increase in the utilization of existing capacities. (More fertilizer is used, for example.) This in turn leads to an increase in production and in marginal costs. The increase in marginal costs leads to a decrease in expected profitability, which closes the balancing loop B3.

An increased desired biomass production volume leads, as we have just seen, to an increase in the utilization rate and to an increase in the amount of biomass output. With some delay it also leads to the acquisition of new capacity, to a larger production capacity, and to a greater output volume. An increase in output means an increase in biomass supply and therefore a decrease in the unit price of biomass. This closes the balancing loop B4.

7. Conclusion

The European Union has adopted a strategy to increase the use of renewable energy resources considerably. The discussion in this paper has shown that among the alternative proposals to increase the use of energy from renewable resources for traffic purposes the biomass-to-liquid technology is most promising. But BtL-production is embedded into a complex dynamic system with several feed backs. This complexity makes it hard to evaluate the role BtL-fuel can play in a strategy of ecological, economical and social sustainability. The proposed SD-model is a way to catch the complex interdependencies concise way. By the same time it can serve as a device to discover not yet perceived effects. The model in its current for is part of work-in-progress. The next step will be to specify the model numerically and to do basic simulation runs. In following versions, the model will be extended gradually to capture important effects that have been neglected for the time being.

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