

Chemicals from biobased feedstocks

integration on multiple
length scales



Prof. dr. Harry (J.H.) Bitter

Inaugural lecture upon taking up the post of Professor of Biobased
Commodity Chemistry at Wageningen University on 12 juni 2014



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Mister rector, colleagues, family, friends and all those who are interested welcome! Welcome at the journey I like to undertake with you in the world of the conversion of biomass to chemicals. What I like to share with you is how interesting this field is and how much I enjoyed working in this field and how much I like to continue working in this field. Also I will show the scientific and technological challenges I will address with my group.

First of all, why do we want to use biomass as a feedstock for producing chemicals, materials and fuels. To answer that question I like to refer to the last letter written by Prof. Wubbo Ockels, who passed away in January 2014, in which he stated “The problem is that Humanity needs to find a sustainable balance with its environment, with our home the planet Earth and its Nature”. When we do not find that balance we deplete our planet and make it inhabitable for future generations. The question is now how are we going to achieve that balance?

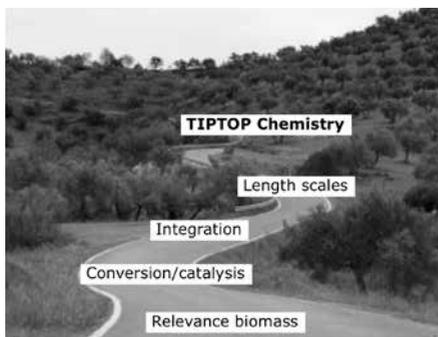


Figure 1: Travel guide of my lecture

To answer that question I like to undertake a journey with you and with a journey comes a tour guide (figure 1). I will first explain the relevance of biomass, next I will discuss the role of the chemistry i.e., what are the conversions we are going to perform. I will discuss about integration and lengthscales as also mentioned in the title of my lecture. This will finally lead to what I will call **tiptop** chemistry and technology. I will discuss that in more

detail later. The stops shown in the tour guide in figure 1 will be dealt with. With respect to achieve the sustainable balance mentioned before, biomass and biomass use is very important. But is that really new? When we look back to

prehistorical ages humans were also using biomass. People gathered in nature what they needed for food, feed, housing, clothing, heating. All was used and humanity and nature were in balance. In fact this is what we are still doing today. Still we use biomass for heating, we burn part of the biomass. We use biomass for food, which is the most important use of biomass. We use it as cattle feed, we use it for construction, look for example at the ceiling or the floor in this aula, they are made from wood. Thus we are still using biomass as we did in

prehistoric times. Then what is the difference? Why is there now so much attention for biomass? One major difference with the past becomes clear from figure 2 which shows the number of inhabitants on the planet as function of time. Different scenarios are suggested for the future number of inhabitants on earth but the orange curve in figure 2 (UN-medium) is regarded as the most likely. At the end of this century there will be around 10 billion people on the planet. This is substantially more than in prehistoric times. But that is not the only difference. I showed you an image of prehistoric times where people lived in tents and wore animal skins for clothing. Please look around you: who is still living in a tent and is wearing only animal skins? Those numbers are not high. So compared to prehistoric times we are not only with more people we also need more resources, we need mobile phones, we need computers, we need our plastics. This combination is the challenge we have to address. We are with more people on the planet, we want to maintain or even increase our standard of living yet we need to sustainably use the resources of our planet.

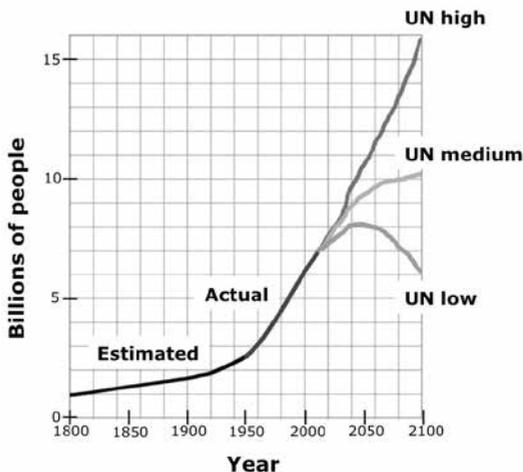


Figure 2: estimated number of people on the earth
(adapted from wikipedia)

How did we satisfy our needs in the past? As I explained, in the old days we used biomass however in the last 150 years we mainly used oil as most important resource for satisfying our needs. We are very much depended on oil nowadays. Oil is used as (feedstock for) fuel, it is used to make chemicals. However there are a few drawbacks when using oil. First the oil reserves will deplete. The question is how large are the oil reserves. This is a fierce debate and the answer is always: 50 years. We got that

answer 20 years ago and still we get that answer.

Nevertheless there is a limit to the amount of oil available. Moreover oil is not renewable at least not on an acceptable time scale. When we use oil as feedstock the products made from it will at the end of their life be disposed (dumped) or will be burned to CO_2 .

Biomass however is renewable at a reasonable time scale. The general idea is as shown in figure 3.

Biomass, e.g. plants, trees, grass, is produced by photosynthesis from water, CO_2 and sunlight. This biomass is converted to products we want and at the end the products can be burned to make CO_2 and water again in that way closing the cycle. Clearly a balance is needed. To achieve sustainability

we should not consume the feedstock faster than it can be formed again. That balance is

achievable with biomass, with oil this is not possible. With oil we produce CO_2 at a much faster rate than that CO_2 can be converted back to oil. I have to admit that also for the case of biomass this cyclic picture is idealized. In practice we cannot convert all CO_2 back in the biomass. There are always some losses. Nevertheless it is better than using oil or other non renewable resources such as gas or coal.

What kind of biomass can we use to produce the chemicals we want? One can think of plants but also other biomass sources such as corn, corn stover, sugar beet pulp, wheat straw, algae, grass or even waste water. This is a selection of feedstocks from which we will prepare our chemicals.

However we have to choose the feedstock with care. There is always the discussion which is called the food versus fuel discussion. Take corn as an example. Suppose we use corn to make chemicals or fuels, what will be left for food or feed? We need to find a good balance between chemicals on one hand and food/feed on the other.

When we can use the whole corn plant we will not interfere between food and fuel. We can eat the corn and convert the stover and plant residues to chemicals. Please note that we should also leave part of the plant on the field to prevent depletion of the soil from important nutrients. Chemicals and fuels produced from the edible parts of the biomass are called first generation chemicals/fuels. Those prepared from the non edible parts are called 2nd generation fuel and chemicals.

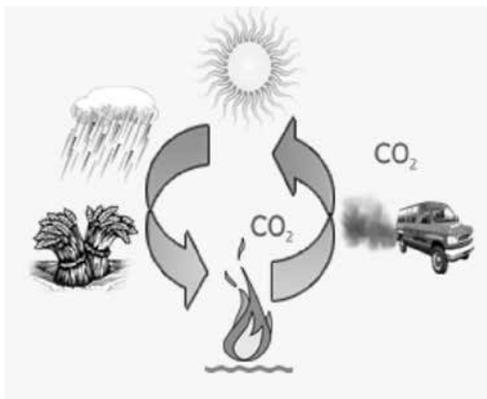


Figure 3: closing cycles using biomass

So in fact when I have the whole biomass I have to split it into fractions. That is also shown in figure 4. On the left side we have the biomass, on the right side a range of products that can be made is shown. The process to separate the biomass into all these fractions is called *biorefinery*. This refinery is very similar to something we are good in today. The principle of biorefinery is

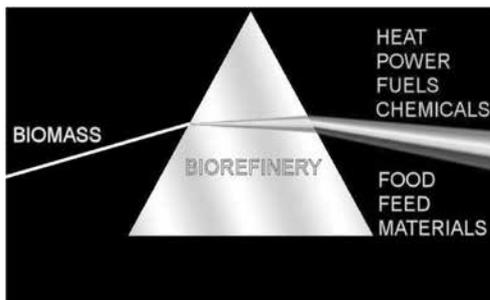


Figure 4: principle of biorefinery

the same as that of an oil refinery. The latter is executed on a massive scale nowadays. After the biorefinery we have a range of products we can further use. We have food, feed, feedstock for materials, chemicals and fuels. That is a wide range of materials that can be made. But what is wise now, what should we make from the biomass? It might seem now that we already know how to process the biomass. That is not true. We know to a certain extent how to separate the biomass into different fractions. But as I will show later in more detail how to convert these, still complex, fractions to the desired products/chemicals remains challenging. Before

going into some more detail on how to convert biomass first what do we want to make. To evaluate the potential of the different products often the F-ladder is used (figure 5). It shows from bottom to top products with increasing value but with decreasing market size. On the bottom is (land)fill, that costs money so that is something we should not do with biomass. The next one is fuel, the market size is large but the added value is low. On top of the ladder are the pharmaceuticals. They have a high added value but their market size is small. The functional materials such as chemicals are in the middle. They have a decent added value and are used on a decently large scale. Therefore chemicals are a good choice to be prepared from biomass.

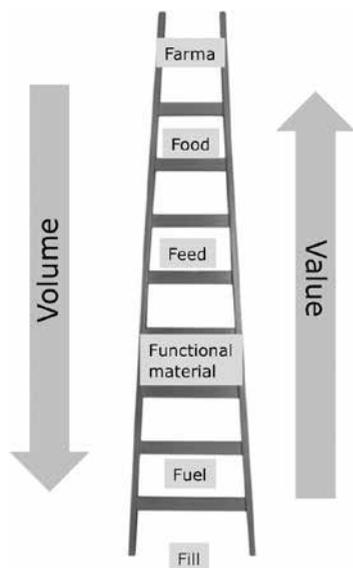


Figure 5: F-ladder showing volume and value of biobased products.

I just mentioned the term biorefinery. Refining is something we can do very well nowadays. Crude oil is converted in an oil refinery to products we use in daily life. When you travel to Pernis the

refineries are clearly visible. In such a refinery the crude oil is by chemical and catalytic processes converted to the desired products. The processes occurring in such a refinery and in a biorefinery, that is my profession. Especially the catalysis which is a part of the processes occurring in a refinery is my background. So refinery is something we can already do however refining biomass is not the same as refining oil. The reason for that is shown in table 1. All matter consists of molecules (the smallest part of a compound which still has all the properties of that compound). When we split the molecules further we end up with elements (or atoms). The elements present in biomass and oil are shown in the table. Clearly biomass has less carbon (C) and more oxygen (O) in the molecules from which the biomass is built. This is excluding the water which is often present in biomass. It can contain upto 50 % of water. This, the different composition of elements of biomass compared to oil, makes the conversions of biomass challenging. My research will focus on how to deal with this challenge i.e. how to effectively convert the molecules present in the biomass.

Oil		Biomass	
Element	Percentage (% weight)	Element	Percentage (% weight)
C	83-87	C	50
H	10-14	H	11
N	0.1-2	N	0.5
O	0.1-1.5	O	35
S	0.5-0.6	S	0.1
Metals	< 0.1	Ash	2

Dry biomass! 50% moisture

Table 1: general comparison of oil and biomass composition

There are three pathways to convert biomass (figure 6). The starting material here

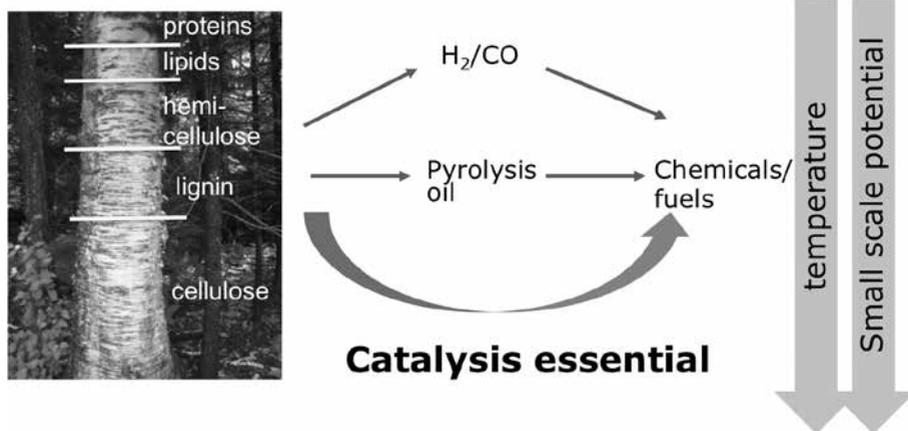


Figure 6: conversion pathways for biomass

represented as a tree (which is not the most suitable source of biomass since trees grow slowly) which consists of different (major) fractions i.e. cellulose, lignin, hemicellulose, oils and proteins. From these fractions we want to make chemicals and maybe some fuels. The first method is to start all over. The biomass is gasified to H_2 and CO (syngas) and from that the desired molecules can be prepared. For the formation of syngas a lot of energy is needed which is released again when the products are made from the syngas. Thus efficient heat exchange is essential in this route.

A second, bit lower temperature route is the pyrolysis. From the biomass an oil is prepared which can then be further converted to the desired products. The advantage of this route is that initially an oil (bio-oil or pyrolysis oil) is formed which can be processed further in a refinery. Unfortunately the properties of that pyrolysis oil are not the same as those of fossil oil which still makes the conversions in a traditional refinery a challenge.

We will focus ourselves on the third route i.e. we want to convert the molecules already present in the biomass while keeping as much of the functionality of the original biomass molecules in tact. The main advantage is that significant heat

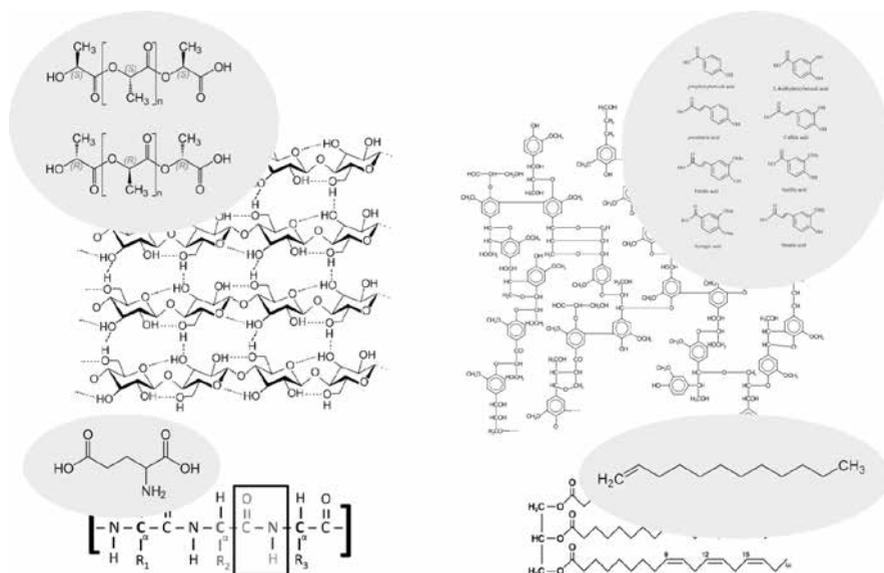


Figure 7: general structures of the major molecules present in biomass and potential products (cellulose, lignin, proteins and lipids). In green potential products (poly lactic acid, aromatics, aminoacids, alkanes/alkenes)

exchange can be prevented in that way which allows the execution of the reactions on smaller scale. For example a mobile unit can be placed on a farm during the harvesting of beet. The beet leaves can then be converted on site to a more valuable compound which can increase the income of the farmer. Of course the conversions and units should be simple, I do not expect the farmers to become chemists.

What are the molecules present in the biomass and what can we make from it? Figure 7 shows the (generalized) structure of the major components present in the biomass. When starting with biomass and after activation, for example milling, one obtains a soup which consists mainly of lignin, cellulose, proteins and lipids. The structures of these molecules are shown in figure 7. In the same figure I show molecules which can be made from these different fractions. These molecules retain a significant part of the functionalities already present in the biomass molecules which is beneficial as discussed before.

The point is what do we really want to make? From the biomass a large number of molecules can potentially be prepared. Therefore it is desirable to make platform molecules, that are molecules from which, in a relatively simple way, the desired products can be made. Succinic acid is a known example of such a platform molecule. Succinic acid can be made by fermentation from sugar. In a next step(s) the succinic acid can be converted to for example tetrahydrofuran, gammabutyrolacton, maleimide, maleic anhydride, maleic acid, itaconic acids. This example of a platform molecule is well known however there are also a lot of platform molecules to be discovered. We have to think well about which molecules can function as platform molecules. In addition even when we know what we should make it still is not known how to make it. This is a key question we will try to answer in the coming years. The products made from the platform molecules can be applied in a large range of products such as lubricant, polymers, adhesives, fuel, paints, coatings, etc.

I already mentioned that there is a significant difference in elemental composition of biomass and oil (fossil feedstock); biomass contains more oxygen (table 1). But that is not the only difference. The elemental composition of biomass also changes from year to year even for the same crop. This is related for example to seasonal influences and method of growing the crop. In addition the location of biomass is more flexible compared to that of oil/fossil resources. One year a farmer can grow a certain crop on his land the next year he (has to) can grow something else. Oil on the other hand always emerges from the same well; the location of that well is not that variable. Oil can be extracted from the ground continuously while biomass suffers from seasonal influences. Also the physical form is different, crude oil/fossil resources are often gaseous or liquid while biomass is mostly a solid. The conversion of fossil sources is

well known though still improving while the conversion routes for biomass are still in their infancy.

To effectively convert biomass and make a biobased economy happen we not only need new knowledge on conversions we also need other expertises and insight on different length scales. Why?

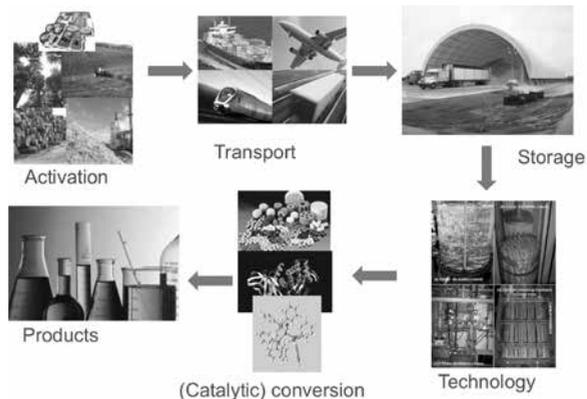


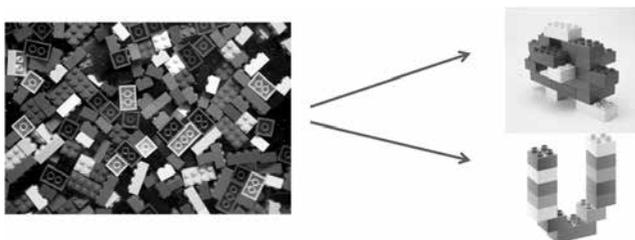
Figure 8: playing field of biomass conversion

The playing field for biomass conversion is shown in Figure 8. A number of steps is needed to arrive at desired products from biomass. Therefore a plurality of knowledge and skills is needed which relates to the flexibility in location and variation in composition of the biomass. First the biomass must be grown and harvested. Often we first produce food and use the rest streams for feed, conversion to fuels and chemicals. Relevant points of attention are where to convert the biomass i.e. locally or more centralized on large scale or small scale? This is an issue often discussed by my predecessor, Prof.em. Johan Sanders and I like to continu that work.

In any case the use of biomass leads to a transport and storage issue i.e. where to convert the biomass, how and how long to store it etc. To give insights in these issues modelling is, next to experimentation, an important tool. The modelling is a stronghold of the Biomass Refinery and process Dynamics (BRD) group and I am very happy that in pratice we i.e. Biobased Commodity Chemistry and the BRD group are already operating for more than one year as one group.

After activation, transport and storage the biomass needs to be converted. For that

Figure 9: principle of TIPTOP chemistry and technology



we need chemical, biochemical and technological knowledge which is present in the group. It may seem now that all is already done and under control however that is not the case. On paper we can make useful molecules efficiently out of biomass but in practice this is still a challenge and a lot has to be done.

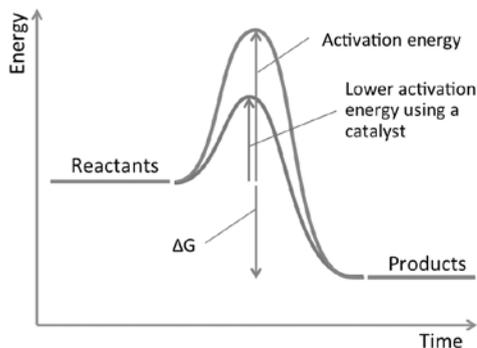
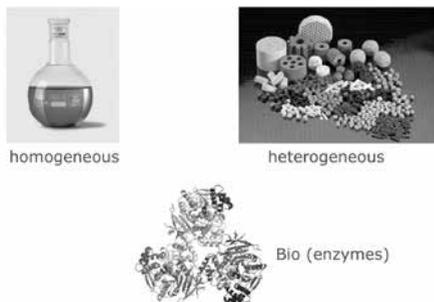


Figure 10: Principle of catalysis

For us chemists one of the challenges is how to deal with the flexibility in composition of the feedstock while we still want to make a limited set of target products. In the figure the lego blocks represent the biomass feedstock. Many children have a box with these lego blocks and they look much alike. However closer inspection reveals that in all the boxes different blocks are present, nevertheless I still want to make the same construction. This is very similar to biomass conversion, making the same products with a variable feedstock. What we need for that is what I call **TIPTOP** chemistry and technology, i.e. **Turning variable InPut into Targeted OutPut** (figure 9). This is what I will investigate with the group the coming years. To deal with the variable input to make targeted output we need efficient, specific and selective conversion processes. To be energy efficient as well catalysts are of crucial importance for these conversions. Catalysis is my background, I got my PhD in that area exactly 17 years ago. After that I worked for 16 years in that field in Utrecht. What I will do now is give you a short introduction into catalysis, and give a short overview of some relevant achievements of me and my group.

Schematically the principle of catalysis is shown in figure 10. We start with reactants, in my case the molecules present in the biomass, which need to be converted into the tailored (platform) products (which are in general lower in energy). This does not happen by itself. To get the reaction going one has to go over the mountain. That mountain is called the activation energy. A catalyst lowers the activation energy thus makes the reaction more efficient, less energy input is needed.

By the way the existence of activation energy is not only bad. Let's take an example of wood. Wood consists for a large part out of carbon. The air around us is for 20% oxygen. The stable form of those two together is CO_2 . Luckily due to the activation energy wood does not spontaneously burn, you need some energy (a match) to start the burning. For your information also our body is for a large part carbon, what if the activation energy was not there.....



Often catalysts are divided in three classes, i.e. homogeneous, heterogeneous and biocatalysts (figure 11).

Homogeneous catalysts are materials that are in the same phase as the reactants and products, often a solution. Biocatalysts are enzymes, these are also active in our body, for example during the digestion of food. The heterogeneous catalysts are often solids while the reactants are gaseous or in solution. This type of catalysts holds great potential for biomass based conversions.

Figure 11: types of catalysts

Though all types of catalysts have their specific challenges there are also some more general challenges. In homogeneous and heterogeneous catalysis often noble metals are used, certainly for biomass based conversions. Since a catalyst is not used during a reaction its price, and noble metals are expensive, is not so important for designing a cost effective process. However the availability of noble metals (Au, Pt, Pd, Ru,...) could become a problem especially when applications are developed in the future which need a large amount of noble metal, for example fuel cells. Moreover also for strategic reasons, i.e. diversification, replacement of noble metals is desired. Therefore the replacement of noble metals in catalysts is a key challenge which I want to address with the group.

A second general challenge for biomass conversion is how to convert selectively only the desired molecules out of the biomass soup to the desired products.

Catalyst stability is the third grand challenge. Biomass based conversions often occur in water, this is a challenge for heterogeneous catalysts. Though my previous research gave some leads on how to stabilize non noble metals.

A great advantage of biocatalysts is their high selectivity and specificity however their productivity per reactor volume is low. The question is however, whether there is a synergy by combining different types of catalysts. Some examples do exist however this research area is still at its dawn.

Let me demonstrate with some examples what the possibilities are of catalysts and where still the challenges are. As first example I like to show the deoxygenation of lipid based feedstocks. We used fatty acids as model compounds. The lipids are not directly applicable in our current infrastructure since it contains too much oxygen. We (and others) developed catalysts which can remove that oxygen. Other researchers [1] showed that nanosized Pd particles on a carbon support were suitable for

deoxygenation however the question we had was can we do it better?

We used Pd on carbon nanofibers as a catalyst [2]. We optionally introduced oxygen groups on the surface of the carbon support. It turned out that the catalysts based on the oxygen containing supports were more active (figure 12).

We attribute this to a beneficial mode of adsorption of the reactant on the oxygen groups of the support. If true this can contribute to TIPTOP chemistry and technology.

By modifying the surface of the catalysts we might be able to convert only certain molecules from the biomass soup i.e. those who want to adsorb in the right way on the catalyst.

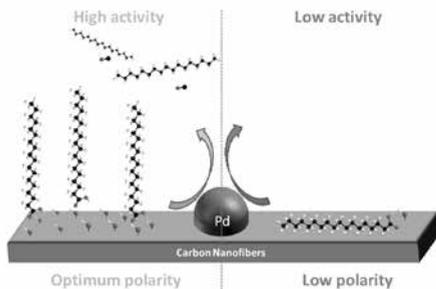


Figure 12: steering catalytic activity by modifying the support; tiptop challenge use of support to deal with variable input

We also investigated the same reaction with the use of non noble metal based catalysts, in this case supported tungsten carbide. It has been shown in the '70s of previous century that tungsten carbide exhibits similar catalytic behavior as Pt like metals [3]. Though this was not shown yet for deoxygenation of fats and oils. We showed [4] that this was indeed possible however we found out more....

When we used a pure carbide the feedstock (fatty acid) was hydrodeoxygenated, that is the oxygen in the feedstock molecules was removed by hydrogen as water.

However when the catalyst was exposed to air the oxygen was removed as CO and CO₂ i.e., the feedstock underwent decarbonylation and decarboxylation (figure 13). Thus we could steer the selectivity of the reaction by a simple change in the active phase. This is an important step in the TIPTOP chemistry and technology i.e. target

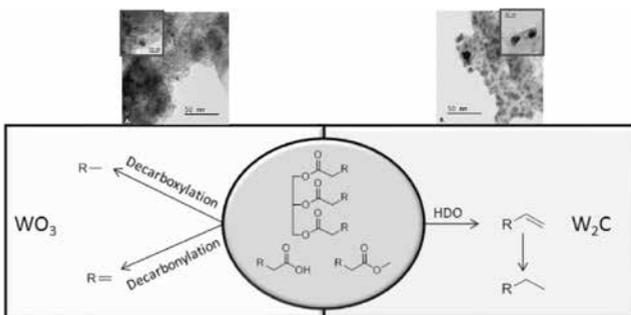
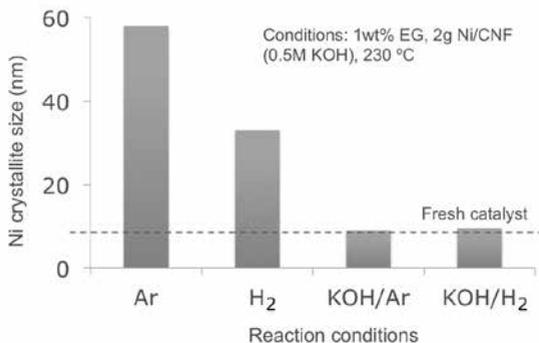


Figure 13: steering catalytic action by nature of active phase. Tiptop challenge: tailored output

Figure 14: Ni nanoparticles can be stabilized by proper choice of reaction conditions. Tiptop challenge: stable catalysts



production of molecules. However to get a good control of this we need to understand the catalysts better which is a part of our future research.

Another important aspect of catalysts, certainly in case of non noble metals, is their stability especially when used in aqueous conditions. We investigated [5] whether the stability of nanosized Ni particles could be enhanced by modifying the reaction conditions. In this particular case we investigated the conversion of ethylene glycol in water to hydrogen. When we performed the reaction under standard conditions i.e. in Ar and no further additives to the solution it turned out that the Ni particles were significantly larger after reaction than before. This is unwanted because larger particles have less surface area per unit weight and are therefore, in general, less efficient catalysts.

When we replaced Ar by hydrogen the stability was higher but still not perfect. When a base was added to the solution the catalysts turned out to be stable (figure 14). This shows that non noble metals can be stable. The precise influence of the composition of the reaction medium on the stability of the catalysts is still unknown and therefore an issue for further research.

Though catalysts and catalytic conversion form the heart of our research, catalysis can not solve all biomass related conversion issues. We also have to have an open eye to the world outside the conversion as I discussed before. Technology is an important issue as well, specifically in my group we look at separation, small scale applications and modelling and control.

Models are needed to identify bottlenecks in a process design or in a whole chain/system. Questions as what is the best location to get the biomass from, where to place the conversion unit, what is the best scale to convert the biomass, what is the best storage option, are crucial to arrive at a biobased economy. In addition control over the process and reactor is also important. I will now show some examples of expertise present in the Wageningen group developed before my arrival here. I will also

discuss how this knowledge can be applied for TIPTOP chemistry and technology.

Catalysis alone, as stated before, cannot do the trick. Catalysis is the engine of our group though, much like the engine in a car. Though a good engine alone does not make the car. I also need the metal/bodywork around the engine, i.e. I need technology. And even then I do not have a car yet. I also need control to drive the car efficiently. This is the same in my group, I need conversion/catalysis, technology and systems/control to get to the most efficient use of biomass (figure 15).

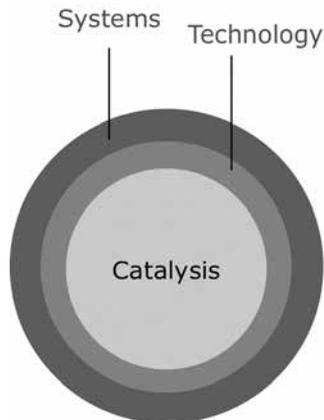


Figure 15: integration of disciplines needed to achieve biobased economy

An example of combined conversion and separation is the use of wastewater as feedstock. Most wastewater contains still valuable molecules although in low concentrations. These molecules can be reclaimed by evaporating the water but that is very energy intensive and therefore expensive.

A more smart solution is to convert the molecules present in the wastewater to something which is insoluble. That is indeed possible. Dr. Elinor Scott from my group shows that valuable bulk chemicals can be made from polyhydroxybutyrates (PHB) which in turn can be made via a bacterial conversion of wastewater which contains volatile fatty acids (figure 16). This process involved different (catalytic) steps and is a smart way to combine separation and conversion. This is a topic we will further investigate for other molecules.

When one molecule is converted to another the properties of the molecule and of the material made out of it can change significantly.

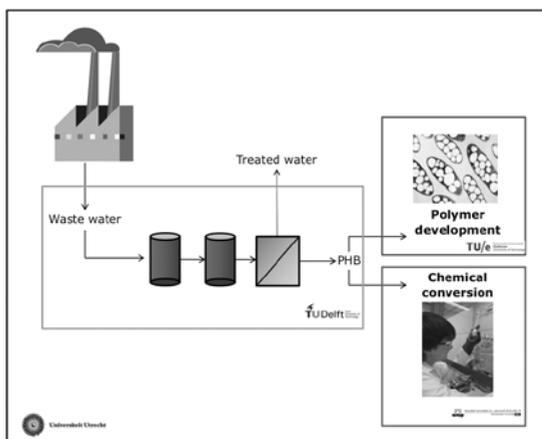
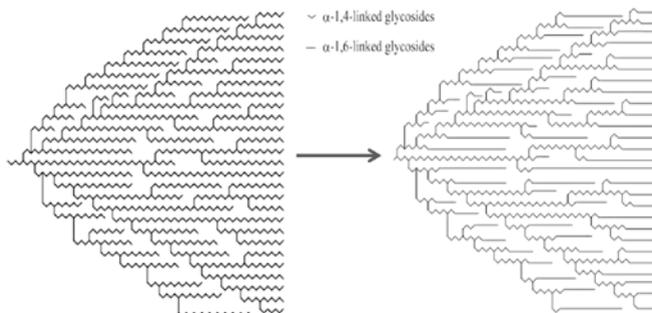


Figure 16: waste water as feedstock. Tiptop challenge: tailored output, easy separation

Figure 17: new products from starch. Tiptop challenge: tailored output, new molecules.



How the materials properties depend on their chemical composition and structure is investigated by Dr. Piet Buwalda in the group. He is also research director starch at Avebe in the Netherlands so the research focusses on starch and poly saccharide related materials. An example of starch conversion is given in Figure 17. By enzymatic conversion the branched structure of the starch can be changed, in other words the building blocks in the starch can be connected in a different way. That gives new materials with new properties which have potential applications as in pharmaceuticals, food and adhesives. Also further chemo-catalytic modification of the prepared starch derivatives is a topic of research in the group.

Small scale technology can be beneficial for different reasons. Since the scale is small the investment costs per unit are low. This opens the possibility to have decentralized units for processing for example in developing countries or with farmers. Both can benefit economically from this small scale approach. The technology was developed by Dr. Marieke Bruins and Prof.em. Johan Sanders and it was shown that this works well for the starch extraction from cassava (figure 18).

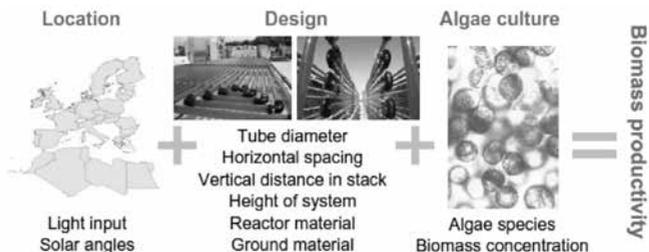
The next question is whether this extraction can be extended with a simple conversion unit to create more value for the owner of the unit. The conversion needs to be simple and safe, farmers are not chemists.

To take this next step chemical, technological and modelling knowledge is needed which is available in the group.

Figure 18: small scale cassava extraction unit. Tiptop challenge: small scale



Figure 19: modelling to understand/optimize. Tiptop challenge: modelling for efficient pathways and units

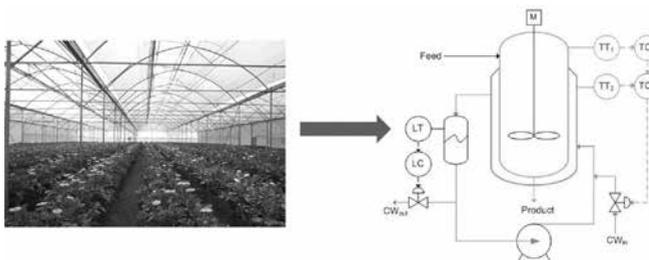


Dr. Ton van Boxtel and Dr. Rachel van Ooteghem use modelling to get insight into bottlenecks of production facilities. A specific example is the work of Dr. van Boxtel on the use of algae based biomass (figure 19). By using different models it was possible to determine what the influence of different parameters was on the optimal location for an algae production plant. Some crucial input here was species of algae, amount of sunlight, availability of water, availability of infrastructure, etc. Using this ability it is now also possible to determine the optimal mix of products which can be made from biomass. For the reaction networks need to be known or determined, rate constants need to be obtained as well as prices of products and production steps.

Control and systems analysis is also an expertise of the group. Dr. Karel Keesman and Dr. Gerard van Willigenburg used their knowledge of control upto now mainly in an agrotechnological setting. For example control theory was used to control the atmosphere in green houses. This knowledge can also be used for the control of chemical reactors. When applied in a proper way a reactor can learn from itself and adjust reaction parameters (feed rate, adding of auxiliary feeds e.g. base/acid, temperature) to keep its performance within specified parameters and prevent catalyst deactivation (figure 20).

Upto now I discussed what the challenges are that my group and I are going to address with our expertise in Wageningen. Wageningen UR is an eminent

Figure 20: systems and control. Tiptop challenge: control for stable catalyst operation



environment for me to perform the research since at Wageningen UR we have knowledge on all aspects of biomass and biomass conversion from primary production, to logistics, to conversion, to socio-economic aspects. Upto now I focussed on staff and PhD students but the BSc and MSc students are the one who have to make the transition from a fossil based world to a biobased world. But which expertise do you need for that? I advice to choose a study which you like. In case you have doubts about several studies take the most abstract one. Make sure that you are good in what you do and be motivated. Eventhough you should get expertise in a single science field also keep an eye onto other science fields. Then you will have the right expertise to make the transition to a biobased economy flourish. But do not forget: do it because you like to do it.

I hope I have shown you during this journey in the biomass conversion world how exiting this world and work is. One of the pioneers on this topic is my predecessor Prof. Johan Sanders. Johan, I am honored to have the possibility to succeed you. The focus of the group will change a bit but the new group will be built on the fundamentals you made (Figure 21).

This is a time of change not only scientifically but also organisationally. The Biobased Commodity Chemistry group of Prof. Johan Sanders will merge with Biomass Refinery and Process Dynamics group (previously known as systems and control group) of Prof. Gerrit van Straten. The new group is the group I introduced today and will be called Biobased Chemistry and Technology (BCT). Gerrit I like to thank you as well for what you have achieved and on which I can build further.

I specifically want to thank all the staff members of BCH and BRD, your enthusiasm and knowledge is crucial for the desired change to a biobased economy.

Figure 21: merger of biobased commodity chemistry (BCH) and biomass refinery and process dynamics (BRD) to biobased chemistry and technology (BCT)

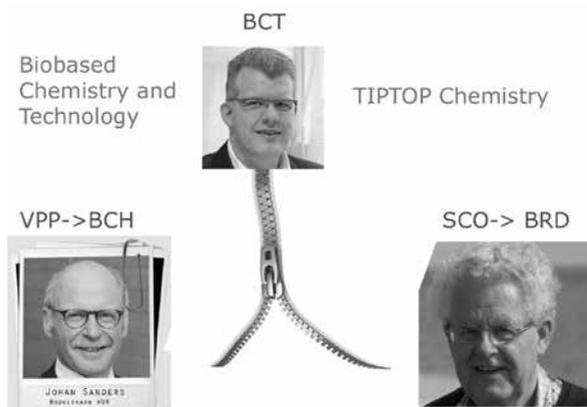




Figure 22: special thanks to all the members of the BCH and BRD (now BCT) group

A group cannot function without support staff, without technicians, analysts and secretariat. Thank you for your help and dedication since the time I arrived. Also a special thanks to all the group members I did not specifically mention, post docs, PhD students, Msc students and Bsc students. Only together we can make it happen (figure 22).

Lets go back in time. Exactly 17 years ago, 12 June 1997 I had another highlight in my academic career. I defended my thesis at that day at Twente University. My co-supervisor was at that time Dr., now Prof., Seshan. Prof. Seshan is here in the audience and I like to thank you specifically for the guidance at that time and for all the fruitfull discussions we had in the time since then.

I also like to thank all my colleagues in Utrecht, Wageningen and all family and friends, especially Helma, Stijn and Nora. Without you I would not be where I am now. I hope that you can together with me join a future which is more sustainable due to our efforts. I am confident that TIPTOP chemistry and technology is for quality of life.

Ik heb gezegd.



Figure 23: Thank you all

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Prof. dr. Harry (J.H.) Bitter

'Biobased feedstocks (biomass from agro-food rest streams) are eminently suitable for the sustainable production of chemicals needed in our society. Catalysis plays a crucial role in efficient feedstock conversions. New conversion pathways and catalysts have to be developed to make the transition from the current use of fossil based feedstocks to biobased feedstocks. In addition an integrated thinking on different length scales (global, local, reactor, molecule) is essential to assure the most efficient and sustainable use of resources.'