Biorefinery

The bridge between Agriculture and Chemistry

Prof. dr Johan P.M. Sanders

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Rector Magnificus,
Members of the board of Wageningen University and Research Center,
Professors,
Students and members of the academic community,
And all of you demonstrating your interest with your presence here

Beginning with the introduction of the steam engine, we have become increasingly dependent upon fossil resources for our energy supply. Up until approximately 250 years ago, most of our energy, materials, food, and feed were supplied by the wind, water power, and biomass. We fed grains and apples to our horses that transported people and goods, we fed wood to our stoves for heating ourselves as well as the handcraft processes and, from more or less the same raw materials, we fed ourselves and the animals that produced our meat, milk, and wool.

The new challenges in a biobased Economy

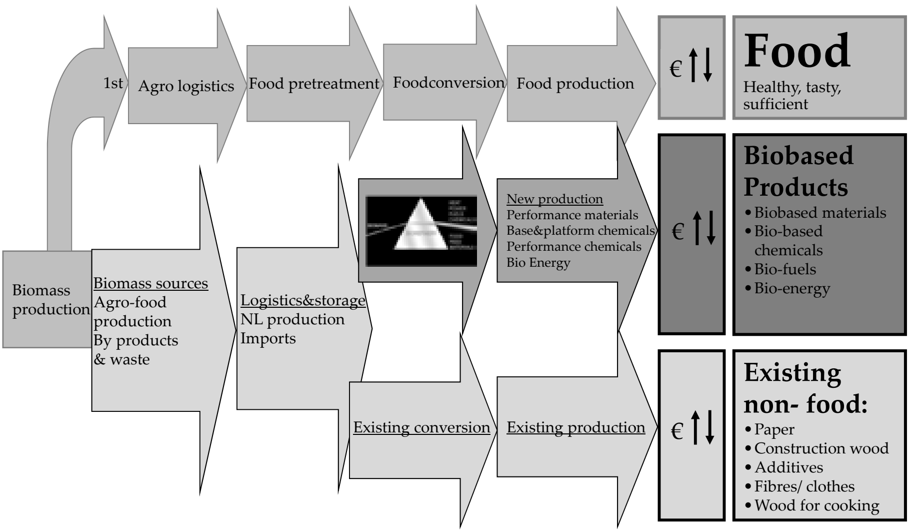


Figure 1. Actual applications of biomass

Currently, we all realise that biomass is employed for food and most of us are aware that a significant amount of biomass is used for non-food; however, not many realize that we would like to use this same biomass as a substitution for the considerable amount of the fossil resources that we learned to use over the past 250 years. We speak about a BioEconomy if, some 30% of our raw material use is derived from biomass.

There are many reasons why people can be interested in such a BioEconomy. It is worth understanding these various drivers (Figure 2) because people often only believe that the reason why he or she believes something is important, is also the reason why it is important for the ot her 7 billion people in the world. All other drivers are disregarded even though we might learn significant information from these other drivers.

Many drivers for the Biobased Economy

- Shortage of cheap oil
- High energy prices
- Security of energy supply
- Climate change by green house gasses
- Rural development
- Developing countries
- Geo-political conditions

Figure 2. Different drivers to be interested in the Biobased economy

In the USA, many people contend that biobased raw materials should be utilized in order to become less dependent on the few countries with an abundance of oil for their transportation fuels. They convert corn into ethanol and use coal for its distillation because that is the most economical. To them, the European argument for a reduction of greenhouse gas emissions is not the issue as, by using coal, they emit about the same amount of CO_2 that the use of corn could have prevented. In Europe, if we employ sources of heat, preferably by heat integration, we can produce corn ethanol with an improved sustainability to even 60% CO_2 reduction (P. Börjesson, May 2009).

If we look at certain figures to determine the challenges:

Biomass use today, and in 2050

	Mton
Food, incl. feed*	4 – 5000
Wood, paper, cotton	2000
Wood for cooking	4000
30% of 1000 EJ in 2050 =	20 000
All bulk chemicals in 2050	600 (=2000 input!)

*Excluding grass and seafood

Figure 3. Today's and future biomass utilization (dry matter base)

If we genuinely want to substitute 30% of the raw materials that we expect to require in the year 2050, then we need 20 000 Million tonnes of biomass, approximately twice as much more than we use today! The unpleasant message that keeps many people awake and can easily be misused by populists or parties with vested interests is that this will never be possible and will lead to hunger for many more people than the current one billion.

The positive message is that, for farmers and downstream in the value chain, there will be a significant amount of work to do. Farmers will not need to be paid European subsidies in the future to reduce their production.
During the next 40 minutes, I would like to show you some of my results of my journey over the past 10 years and also show you how we could address the challenges mentioned above without the uncertainties; how to benefit from the developments without incurring the disadvantages. So, I do not agree with Johan Cruijff in his popular saying that 'every advantage has a disadvantage'. We should not condone this way of thinking because it makes us unproductive and creates extensive, unnecessary costs to our economy here in the Netherlands. How can we obtain the advantage without having the disadvantage?
When I became responsible for the research program on environmental issues during my employment at Gistbrocades in Delft, my management asked me why we were not earning money with the new wastewater technology that we had developed to clean fermentation residues and had recently introduced as a product on the market.

At that time I had developed a model that was beneficial during my 30 year career: If one wants to solve an environmental problem, several solutions can be selected, the most popular being hiding or negating. The first real life approach of achieving

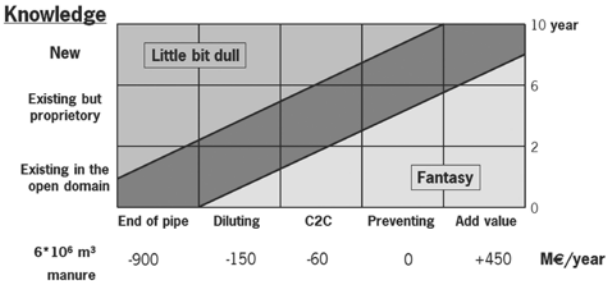


Figure 4. How to benefit from the advantage without the disadvantage

genuine results are the 'end of pipe' solutions. As an example I took the manure problem in the Netherlands that, 30 years ago, was estimated to be approximately 6 million m3, the annual costs to solve these issues 'end of pipe' were estimated to be around 1 billion guilders. For manure this approach has not been chosen. One step better was to 'dilute' and disburse the problem within the limits of the resilience of nature by spreading the manure at a cost of 150 M guilders. This is the wide spread approach since 30 years for our manure problem. One step better is the application of the waste materials as the raw material for another process. It is still an investment because you will require equipment and energy, although you save some money on the raw materials. Politicians are currently in favour of this solution and refer to it as 'Cradle to Cradle', and it only costs 60 M guilders or in recent valuta, 60M€. A better solution is, of course, to prevent the problem; by definition, this costs zero Euros. However, many people disregard that you might solve the problem and simultaneously 'add value' and gain a net result of perhaps 450 M €.

This all sounds simple, but why are so many people infatuated with the 'end of pipe' or 'spreading' modes and so fond of C2C? The answer is that you will need new technology while, with the 'end of pipe' mode, you can often reuse existing technologies. If employed in a sector within the orange corridor in Figure 4, a person can earn an income in an honest way. The triangle on the lower right side however is fantasy since, if one could earn a significant amount of money with the existing technology, it would have already occurred. The triangle on the top left is dullness: why develop a new technology and spend an extensive amount of time and research money for a technology which will still cost a significant amount of money every year of its operation?

The only important ingredient that is lacking is the vision and fortitude that you can earn money and simultaneously solve the problem. What you see in Figure 4 is actually a 'Profit/Planet' model. During the time at Gist brocades, 'People' did not yet exist. Here, in Wageningen, it was one of the first things I learned and, since then, I always ask the question before the beginning of every project: do we address all PPP (People, Planet, Profit) aspects at the same time? IF not, do not begin your project and do not believe that you can start fulfilling only two of the P's and fill in the third at a later stage. From the start, you should ask yourself: how can we fulfil the People and the Planet requirement while, at the same time, earn money. If you do not ask this question, you certainly will not receive the answer and will adhere to the populist wisdom of 'every advantage has a disadvantage'. While our Government indicates that the Netherlands is/ should become a 'Knowledge' Economy, again and again, we arrive at half solutions to the problem. If we consider the manure problem as an example that has not been solved during the past 30 years in spite of considerable efforts and false favourable impressions, the economic difference between 'dilution' and 'adding value' is 600 M€/year. If we did 'solve' 10 such problems in the same way, we forego the income of 6 billion €/ year which is just the amount of money our Prime Minister was required to locate in his budget. Up until now, we could afford these half solutions because we were rich enough with our annual natural gas incomes of 12 billion €.

Who of you believes that:

- The chemical industry will mainly be dependant of oil in 20 years time?
- Small factories can be more economical than large ones?
- Increasing the efficiency in our food chain will supply enough energy for all our road traffic?
- The high demand for biomass always will increase the number of people with hunger?
- Employability in agriculture can only become less?
- The steam engine should be regarded as a desired technological development?
- Conditions outside the Netherlands always are better to develop the BioEconomy than within?

Figure 5. Questions that will be addressed

In academic research in the BioEconomy, raw materials and the related CO_2 reduction often play the dominant role. During my more than 25 years in the industries of Gistbrocades and AVEBE, I learned much more about the financial boundary conditions and certainly about the capital cost of processes. In the forthcoming decades, we will require many innovative processes with the 'new' biobased raw materials. Hence, not only the capital cost per unit product will play a role but also the absolute amount of money that should be invested for a 'first of a kind, new process'. I have experienced, at least three times in my industrial career, that the sitting management did not dare to invest 60 M€ or 100M€ in a commercial plant even when the process developed up to the pilot scale promised a favourable return on investment. We need to lower the investments required in absolute terms for new processes while we will also need a significant number of new processes in the recently initiated BioEconomy.

What I did not learn very well in my career is how to thank people for their special performance.

That is why I would like to begin with that before I present the results which I would not have had without their support.

Upon my departure from my previous employer, AVEBE, my Management team presented me with a small clock with an inscription: 'A day has 24 hours and then you will have the night'. I happened to use such a sentence that I copied from my grandfather when people said they were short on time.

Madeleine, my wife, received the same clock at the same occasion with another inscription: 'A day has 24 hours and then you will have Johan'.

Figure 6a. Inscription at the back of a desk clock present from AVEBE R&D Management team

- Madeleine, you have given me extensive freedom to follow my passion and explore the many new developments in several work places. Often, you were alone and had to solve our problems on your own especially during my last 12 years while I was working here at Wageningen when you were in Groningen where we

live. At the same time, you have developed yourself. You gave me my balance as a person but also balance in the hours devoted to work or to the family.
In the third half of our life, I want to achieve more balance in the activities that we will do together, e.g. the equilibrium we need on our tandem that I hope we can find back this summer once your new hip has healed that was operated on last week.

Figure 6b. Driving the tandem requires equilibrium

- I would like to thank the Board of Wageningen University and especially the previous Rector for helping me to develop a new chair even after my unfortunate beginning in Wageningen.
- The Management of the Science Group of Agrotechnology and Food in all of its changing compositions.
- The (PhD) students and the staff members of what we first called the tabouret (leerkrukje) 'Valorisation of Plant Production Chains' and that received the status of a full chair in 2012 as 'Biobased Commodity Chemicals'. Together with our colleagues from other Wageningen and other University groups and not to forget the 'Food and Biobased Research' as well as the 'Plant Research International' Institutes in Wageningen, we made great progress. I would like to demonstrate certain highlights from these results.

Chair Biobased Commodity Chemicals 2013

Figure 7. Chair of Biobased Commodity Chemicals in summer 2013

- I would especially like to thank my Secretary Gerda Bos who contributed significantly to the results of our Chair and who afforded me the power and the pleasure to work toward our goals every day here in Wageningen. I am happy with my successor, Harry Bitter, who is an experienced chemist, trained in Utrecht and Twente University. He will be able to pave the bridge between chemistry and Agriculture, which is the strong position of Wageningen UR.
- Finally, I should thank the many companies and our government for their financial support and for the challenges that we have explored

Analysing the playground

In the pursuit of substituting fossil resources with biomass resources, we must first analyse our playground and degrees of freedom. The costs of the products that are produced from fossil resources consist mainly of capital and raw materials, some labour costs, and certain additional costs. We can compare the cost of the 4 product groups that are produced from fossil resources: Heat, Electricity, Transportation fuels, and bulk chemicals. In the Netherlands, each of these is responsible for approximately 20% of our national energy consumption, and each is about 600PJ.

This is relevant when the electricity and heat that is consumed to produce chemicals is allocated to this last group.

The costs are expressed as €/GJ of end product since heat and electricity cannot be expressed in weight or volume. Heat is an inexpensive product because coal can be exploited whereby the conversion yield is 100%, and the capital costs (in orange) are low as well. Electricity has a conversion yield of approximately 50%, and coal can be

How biomass can best complete with fossil feedstocks

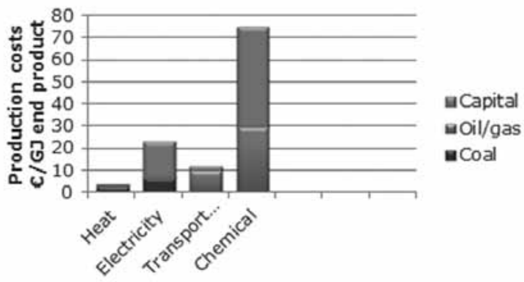


Figure 8. Cost of the 4 main products produced from fossil resources

used as well. The capital costs are considerable to optimize the conversion yield as extensive heat exchange is required. Transportation fuels are produced from oil, which is more expensive than coal. The conversion yield is high, and the capital costs are modest. The average bulk chemical requires approximately 3GJ input from oil and natural gas to produce 1 GJ of chemical building block. Furthermore, significant capital is required for all of the chemical steps that are required to develop the functionalities required for chemical products.

Where are the chances for biomass as the raw material?

The Figure depicts two product groups that incur minimal capital cost. This indicates that biomass cost should not be greater than the fossil costs if the end products do not become more expensive than those produced from fossil resources. Therefore, biomass for heat production should compete with coal (and sometimes natural gas), and biomass for transportation fuel should compete with oil if the capital cost for the conversion to a liquid fuel is not greater than that of fossil, which in fact is not the case. In Brazil, crude cane sugar costs between 6 and 8€/GJ while oil at a price of

100$/barrel is equivalent to approximately 10€/GJ. There is not much opportunity, but it can be done. In Europe, beginning with beet sugar or wheat/corn as the raw material creates higher costs for the fuels; however, this is compensated in some countries by lower taxation.

There are two product groups that have relatively high capital costs. Maybe, for these groups, the biomass costs might be higher if the capital costs can be reduced.

For electricity, this will not be the case because large power plants have been constructed, benefitting from economies of scale since capital cost is dominant in the integral cost price. As we will see later, the capital cost is high because of the heat exchange capacity that is required to obtain the optimal conversion yields. Lange(2001) performed a study in 2002 comparing many chemical factories as well as power plants and came to the conclusion that the heat exchange capacity is the fundamental reason for the economy of scale in these types of processes. Therefore, it is possible that there could be some reduction in capital cost if the biomass power plant can be built larger than the existing fossil ones. There is a limit, however, in the size of a power plant because large power plants require investments in excess of one billion euros. Logistics and cooling could also become a problem, while the room for increased raw material cost will not be much greater than 5-10%.

For the production of bulk chemicals, however, there might be some hope:

Capital costs per ton of bulkchemical product vs heat dissipation

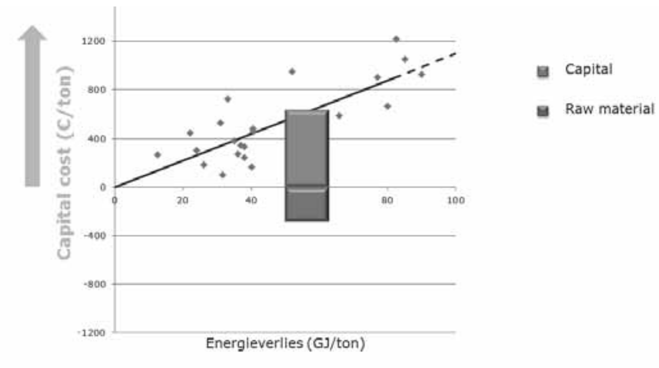


Figure 9a. Correlation of capital costs for the production of bulk chemicals with heat loss over the entire production chain

We recently studied the production of approximately 40 different bulk chemicals. We ascertained a correlation between the capital costs for each of these chemicals with the amount of energy that is lost in the entire product chain to synthesise this chemical (Scott, et. al. 2013).

Figure 9a depicts the same cost breakdown for the average chemical product as does Figure 8, however, the costs are now expressed as €/tonne of product. The blue dots indicate the calculated capital costs for approximately 40 bulk chemicals. Life cycle analyses of all of these chemicals have become available within the past 10 years which made the calculation of the energy losses over the entire production chain quite simple: Energy losses =INPUT(raw materials + energy) minus OUTPUT being the caloric value of the bulk chemical. The capital costs have been calculated by subtracting the raw material cost, labour costs, and estimated margin from the market price. Although still a simplification of the actual process, we can reason that capital costs can be considerably less if we begin with biomass raw materials that do not require extensive energy losses to provide the final product. Biomass components are very appropriate for this because they already have existing functional groups.

Figure 9b illustrates the window of opportunity for higher costs of the biomass raw materials if the capital cost can be reduced. The left bar (future potential) forms the extreme shift while the middle bar provides the average cost breakdown if 50% of

Processes with lower need for heat exchange, have lower capital costs per ton of product and can be economical at smaller scale

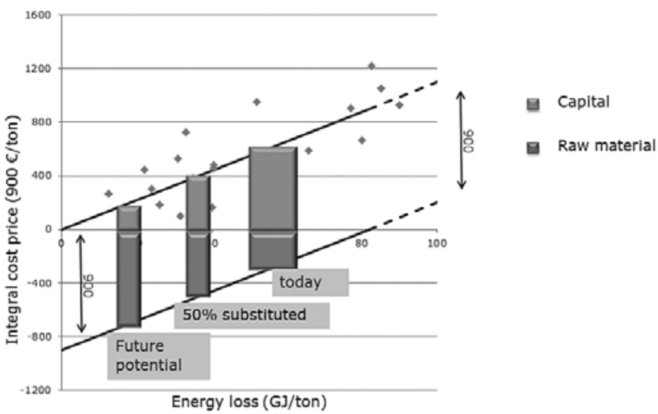


Figure 9b. Beginning with functionalized biomass components will enable lower capital costs that compensate for higher raw material costs

fossil resources have been substituted by the appropriate biomass raw materials. The total costs of the chemical products will not be changed, in each case constituting 900€/ tonne as it is in the current industry.

Conclusion I is that the chemical industry is the only sector that allows a higher cost for its biobased raw materials because these can be compensated by lower capital costs. A second important conclusion, Conclusion II, has been made in the recent study that, because of the lower capital costs per tonne of product, the scale of operation is also a less important factor in the competition between companies of the future. It is anticipated that factories producing 10 000 tonnes of product per year can become as competitive as the large petrochemical factories that have annual capacities of 200 000, and even 500 000, tonnes. The dominant competitive factor will become how to obtain the most appropriate raw material/conversion process combination. The sourcing is an additional risk factor when financing must be obtained, especially in times when biomass raw materials are not available yet as commodities. For the introduction of completely new products, more moderate factories will also be a competitive factor since this affords time to develop the market. I would like to make another important conclusion that pertains to employability.

Employability can grow with 40 000 jobs to supply the dutch chemical industry with 50% of biomass raw materials (now being ca 80 000 fte)

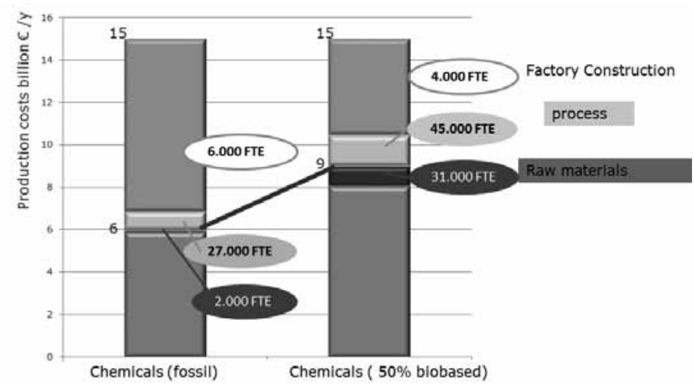


Figure 10. Employability in a biobased chemical industry will grow without incurring a higher cost of production

Figure 10 demonstrates the same cost breakdown data as in Figure 9 for the actual petrochemical industry and for the chemical industry that has shifted to 50% biomass for its raw materials but now the macroeconomic numbers are mentioned: The chemical industry in the Netherlands has a turnover of approximately 45 billion €. 15 billion € is added value. Another 15 billion € are the costs for the production of the building blocks comprising about 15 million tonnes of product. The other 15 billion € encapsulate the costs to produce the polymers and employ these as raw materials for a significant number of products. This 15 billion € costs is independent of the raw materials that have been exploited for the production of the building blocks as long as the biobased substitute the identical chemical molecules ('drop in' chemical). Within the 15 billion € costs to produce the building blocks, there will be major changes, and also in employability:

For the production of the actual fossil resources for the Dutch chemical industry, approximately 2000 fte labour is required in the oil and natural gas industry for research, exploration, drilling and production, transport, and trading of almost 600 PJ of raw materials. If we substitute half of these raw materials, we will require 300PJ or about 20 million tonnes of biomass. If these biomass components are more suitable for the production of approximately 7.5 million tonnes of product, it could be possible to reduce the inputs to around 15 million tonnes or even less. Since these 15 M tonnes are just a specific group of the biomass components that are suitable for the production of the building blocks, while other components from that same biomass can be applied for the production of transportation fuels or electricity, I assume that

Various crude estimations of the amounts of labour in Agriculture can be made using quantitative data from (KWIN-AGV, 2012) for sugar beets, starch potatoes, corn, and grass with, respectively, 750, 850, 750, 450€/ha or 25, 26, 21,15 hours. If we assume a harvest of 20, 12, 15, and10 tonnes dry weight (15 GJ / tonne), then labour costs around 3 €/GJ. Transport/ logistics will cost about 1€/GJ labour costs. If we require 250-300PJ, this will cost more than 1 billion in labour costs while the production of 300 PJ oil or natural gas will cost about 40-50 million€/year. 1 billion € at 35 000€ leads to 30 000 jobs.

Beginning our calculations with hours at about 10 GJ/hr, 250 PJ will, therefore, require 25 million hours, which is equivalent with 12500 fte. Considering 1/3 for logistics, we calculate 16 500 jobs. If calculating with the seasonal character of work in agriculture, the number of jobs would be higher, reaching the estimate presented above of 30 000 jobs, partly in the Netherlands, partly elsewhere in the EU.

It is difficult to calculate exact data because only a component of the biomass is actually employed for the production of chemicals, as direct building block, or as raw material to heat the processes. Other components from the biomass will be utilized for the production of electricity, fuels, feed, etc. In fact, we will need to harvest much more biomass than the 15 million tonnes required to substitute half of the fossil resources for the chemical industry. At the same time we will harvest some other 30 Mtonnes that can be applied for transportation fuels and electricity. In fact the chemical industry will enable the availability of raw materials for fuels and electricity under economic conditions.

The biorefining of the harvested goods will also need labour
Exploiting data for the production of sugar by the SuikerUnie (Cosun), for approximately 1000 fte for the production of 1 million tonnes of sugar, a more complex biorefining might cost more. We assume a learning curve, therefore, the 45 million tonnes will require 15-25 000 fte. This additional labour force will be required within the Netherlands.

Where to produce this extra Biomass?
A portion can be produced in the Netherlands by increased field yield. In Denmark, additional 10 Million tonnes of biomass can be produced (Gylling, 2013). This will not require the entire amount of labour as stated above, although harvesting and logistics correlate with the amount while certain other labour correlates with agricultural surface. Furthermore there will be a change from less labour intensive crops to more labour intensive crops.
Some crops will come from abroad possibly from Europe. This will increase labour in European agriculture.
Some raw materials will be derived from the increase in the efficient use of existing streams of Biomass. These will not lead to a higher number of jobs in agriculture but will in the biorefining industry.

Although exact numbers of employment are very difficult to give, it is fair to conclude that for the first time in 250 years after the broad application of the steam engine, the production of the same goods will require more labour, which can be implemented without increasing the costs of these products.

we will need some 45 M tonnes that need to be cultured, harvested, stored, transported and biorefined. A farm of 100 ha will produce about 1000-2000 tonnes of biomass (dry weight). If this farm requires 1 fte, then the 45 million tonnes require about 30 000 fte additional jobs in the Netherlands and abroad because the Netherlands will be too small to source all of this volume. A Danish study by Gylling et al (2013) concludes that for the additional production and application of 10 Million tonnes of biomass, about 20 000 new jobs are required. About half of them in agriculture, because of more labour required to collect residues hat now are left in agriculture, but also because of change in land use from less labour intensive crops like grass to more intensive crops like sugar beet.

In the Netherlands we will be able to find similar additional biomass in the country, while the other biomass required will come from outside the Netherlands from new sources or from a more efficient use of the biomass that is already imported or produced for animal feed use.

With a much bigger chemical industry the total number of jobs for the new chemical industry will, therefore, become 31 000 fte just for the raw materials supply. If we calculate with 35 000€ income per fte, then the increase in labour costs will be around 1 billion €/ year (see also in the BOX).

Once harvested and transported, the biomass must be biorefined to obtain those components that are suitable as the building block for the chemical industry, possibly as crude sugar, amino acids, or organic acids. The other components that are not suitable for the chemical industry must also be obtained from the biorefinery, but these costs are allocated to other products. In fact, the raw material stream of the biorefinery is much larger than just the 15 million tonnes, but, again, this is allocated to the other applications. The labour required to obtain the 15 million tonnes in factories such as the sugar and starch industry will be approximately 15-25 000 fte. The new biorefineries will perhaps require more than twice this amount if we also include the biomass components for the other applications. The petrochemical industry (45 billion€) employs almost 80 000 fte. (Deloitte, 2013). The current 15 billion € building blocks industries employ about 1/3, i.e., 27 000 fte of this total. If no position is reduced because of the new raw materials, the processing of the raw materials to building blocks will employ about 45 000 fte. There will be a reduction of labour in the construction of factories. If we assume 30 years of amortization of a factory and 20% of the investments as labour costs, the actual situation requires 6000 fte for the design and construction of factories while the new BioEconomy situation will employ only 4000 fte.

The third conclusion, Conclusion III, is that the chemical industry based on 50% biomass will create an abundance of new jobs. This is revolutionary in a way because not only in agriculture but also in the process industry we have only observed reduction of labour because of the ever growing productivity achieved by automation taking over human and animal labour with machines. (Brynjolfsson, 2012)

Conclusion IV is that, when the chemical industry can afford to pay higher prices for components with suitable molecular structures that lower the need for capital, the other biomass components that result from a biorefinery can become available at a much lower price, enabling the electricity and transportation fuel sectors to obtain their raw materials at competitive prices. Therefore, Conclusion V is that the chemical sector is key and could pave the way towards our biobased economy. The Netherlands, Belgium, and North Rhine Westphalia are collectively in a very unique position in Europe as their chemical industry is as substantial as 10% of their GNP. On a European level, this is only 3%. The Netherlands should draft its own plans for the future raw materials supply, especially now that the gas supply is hindered by earthquakes and by exhaustion of the reserves.

Capital, raw materials, seam engine vs Labour

- Using biomass in the chemical industry large scale is not essential;
- Using biomass in the chemical industry can create many jobs;
- For the steam engine economy of scale is essential
- The steam engine made many jobs redundant
- *To maintain jobs, it might have been better that Karl Marx spend his time on the technology of the steam engine in stead of spending his time on the Capital as the main cause of trouble!*

Figure 11. Consequences of the inadequate energy efficiency of the steam engine

Figure 11 summarizes, in hindsight, that the steam engine that requires significant heat exchange capacity is especially not very efficient and has not been the most sustainable development. We might have been in a more prosperous position with electricity from wind mills, waterpower, or even photovoltaic cells. Additionally, engines using hydrogen have a much higher conversion yield than the most superior engines based on combustion. The dialectics described by Karl Marx between technologies and institutions would have come to completely different conclusions if Karl Marx (Marx, 1867) had understood the basis of why so much Capital was required by technologies that did not need to be economic with their energy inputs: energy has been too inexpensive while we only recognized the effect on Climate Change when significant amounts of the fossil resources of this world had been depleted.

The way to go

In the second part of my lecture, I would like to elaborate on how we can cope with the challenge of obtaining enough biomass resources without the repercussions of increasing the number of people that suffer from hunger. On the contrary, biobased processes, especially those that can be operated on a moderate scale, fulfil the design rules that have been summarized in Figure 12.

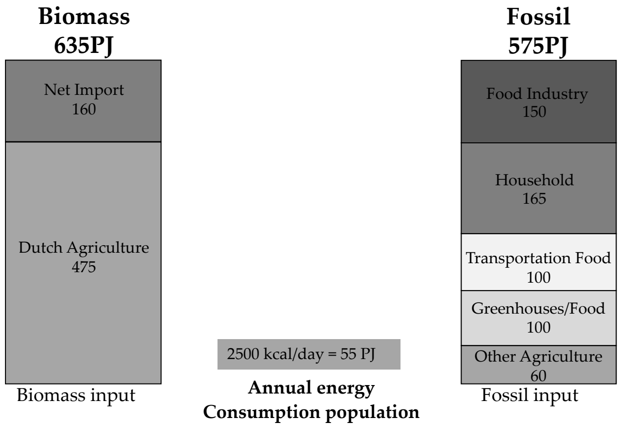
How to get the advantage without the disadvantage?

- Increase field yield but *keep components on the field that are required for soil fertility*
- Use all biomass components and *choose the right raw material*
- Use each component at its highest value:
  (molecular) structure is much better than caloric
- Reduce capital cost to speed up innovation and to *benefit from small scale without the disadvantages*

Figure 12. Design rules for the BioEconomy

Figure 13 exhibits the amount of raw materials that are required for our daily food supply in the Netherlands. Per caput, we receive approximately 2500 kcal digestible energy to eat every day. On an annual basis, this is about 55 PJ. The amount of raw materials from biomass origin is about equal to 635 PJ while the fossil requirements for the different components in the food chain are almost 575PJ. The input is about 20 times more than the output! If we could be at least twice as efficient in producing our food, then we would save about 600PJ, which is the same amount of energy as is currently being used by all road transportation in the Netherlands. Why have we not been more efficient before? There was not much of a reason for that: in Europe, at least, there was agricultural overproduction, and farmers were compensated to reduce their yields. On the fossil side, the costs were very low, and we believed that we would have unlimited resources. Both paradigms have shifted, and it is our challenge for all projects that we begin to envisage a world in which these two resources are no longer available in excess. Becoming twice as efficient, still a tenfold higher input than output, will half our footprint from the 6 million hectare of today to approximately 3 million hectares. In the Netherlands, we have about 2 million ha of agricultural land comprising half grass land and the other half in cultured land. If we would require almost 30% of our actual energy supply from biomass, this would require about 3 million ha of 20 tonnes/ha harvested biomass per year. The Netherlands, with its technology base, could change its 30% energy base to biomass using about the same amount of land as today if we make our food chain more efficient!

Expressed in energy our daily food needs a twenty fold higher input per output!



Reducing the raw materials by 50% will

- **Reduce footprint from 6 million ha to 3 million hectare**
- **Supply all energy for road transportation without the need for any new hectare!**

Figure 13. Our food chain has a net energy yield of only 5%

Back to the chemical industry. Figure 14 depicts a schematic representation of the chemical industry in Rotterdam. On the left, the import of approximately 140 million tonnes of oil is represented. The oil is cracked and refined into several fractions such as diesel, kerosene, bitumen, and Naphtha. This latter fraction is one from which, actually, all chemicals are produced. As a first step the base chemicals like ethylene, propylene, benzene, toluene and xylene are produced from Naphtha. Ethylene and propylene can be polymerized to obtain polyethylene and polypropylene. The base chemicals are also employed to obtain other building blocks that are more functionalized by the introduction of oxygen and/or other atoms. Then, more to the right in the scheme, the more functionalized, the higher value per tonne of product, the lower, in most cases, the annual volume of the product. Each square represents a factory and each colour represents the owner of the factory, i.e., the more yellow, the more Shell. On the left of the scheme, the chemicals have high energy content per tonne of product; on the right side, they have lower energy content. It is obvious that, in moving from left to right, energy is lost in the value chain, and this leads to the capital costs as indicated above.

Chemical production in the Port of Rotterdam

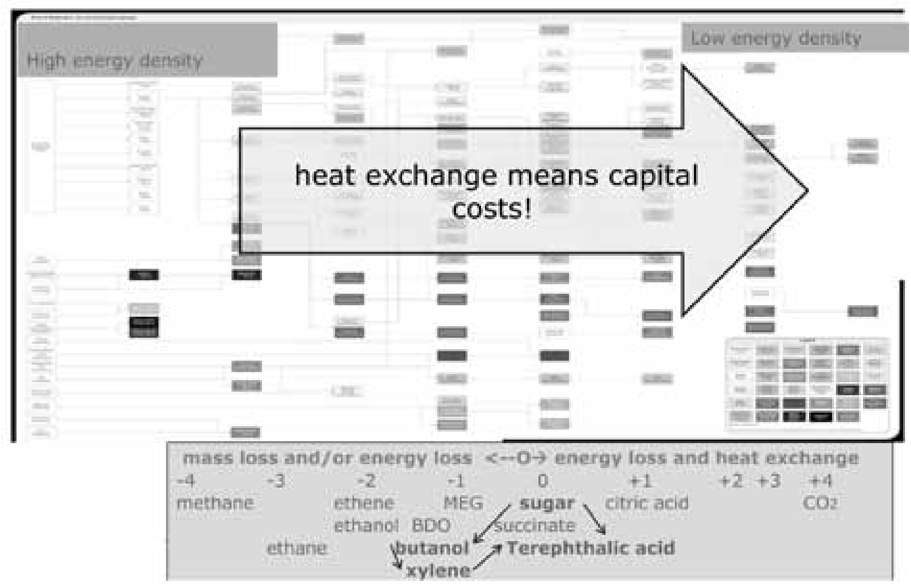


Figure 14. The chemical industry in the port of Rotterdam

If one begins with biomass as the new raw material, it would be wise to limit the need for moving from the left to the right but also in the reverse direction because each movement will cost heat exchange and, therefore, capital investment.
In the grey zone in Figure 14, the degree of oxidation is expressed with the numbers and certain chemicals are placed in the scheme. In general, one can state that beginning with sugar that possesses a degree of oxidation of zero (calculated by (the number of oxygen*2 minus the number of hydrogens) divided by the number of carbons in the molecule)), moving to the left will cost molecular mass, which traditional chemists do not like because in traditional chemistry the influence on the cost price is caused mainly by the capital and the oil, however, for biomass, the loss of mass would not be serious. Mass loss can be prevented by traditional chemical means, i.e., employing hydrogen, to increase the energy density of the molecule.

Example: Glutamic acid and other aminoacids in byproduct streams

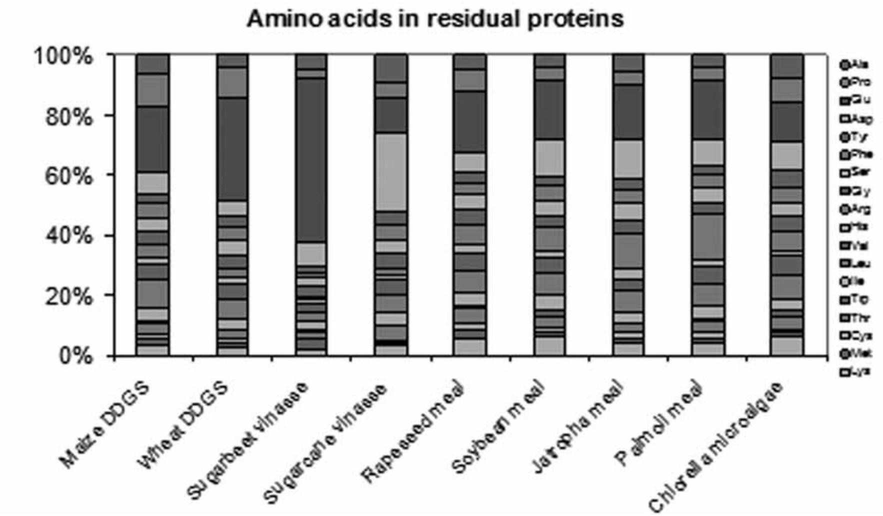


Figure 15. Glutamic acid is present in many agricultural residues (Lammens, et. al. 2012)

However, this will cost capital because of the required heat exchange capacity. Moving to the right in the grey scheme will also cost capital investment because of the oxidations that occur when heat is generated.
Let us use Terephthalic acid as an example. This chemical, with an annual production volume of around 8 million tonnes, is used to make the plastic bottles for a significant number of drinks such as Coca Cola.

A popular route in the USA is to start from sugar and convert this to butanol that is further converted into xylene (not even taking the losses to by-products into consideration) that is furthermore oxidized to terephthalic acid and should not be regarded as a wise strategy if a shorter route could be discovered from glucose directly to terephthalic acid. In our Chair, we have studied the use of several amino acids as building blocks to produce bulk chemicals. An example is glutamic acid, a non-essential amino acid, with a high availability in many agricultural residues as exhibited in Figure 15. Even though glutamic acid is one of the 20 building blocks of proteins, it is not required in animal feed or in human food because we can synthesize these non-essential amino acids ourselves.

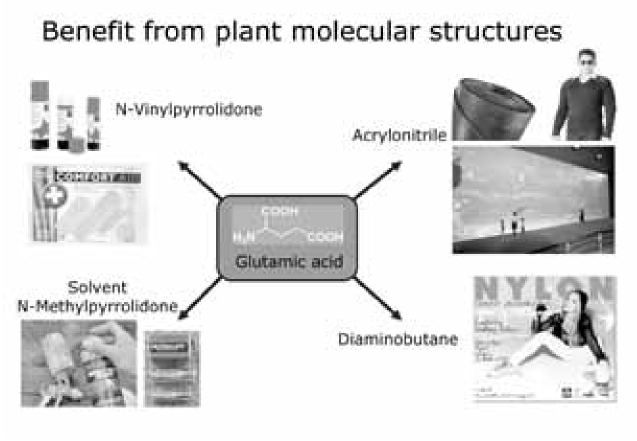


Figure 16 demonstrates that we have been able to convert glutamic acid into 4 different medium volumes and bulk chemical products such as Acrylonitrile, Diaminobutane that is used to make nylon, and the solvents N vinyl pyrrolydone and N-methyl pyrrolidone.

- Figure 17 exhibits how the structure of glutamic acid can simplify the production of this last solvent as compared to the traditional route of beginning with natural gas and nitrogen from the air. The first step is an enzymatic decarboxylation to GABA (that is often present in some waste streams as well) and the second step at modest reaction conditions gives us the desired product (Lammens, et.al., 2010).
- In the petrochemical route, 8 reactions are required, each with their respective losses and each with their capital requirements because each step is a factory.

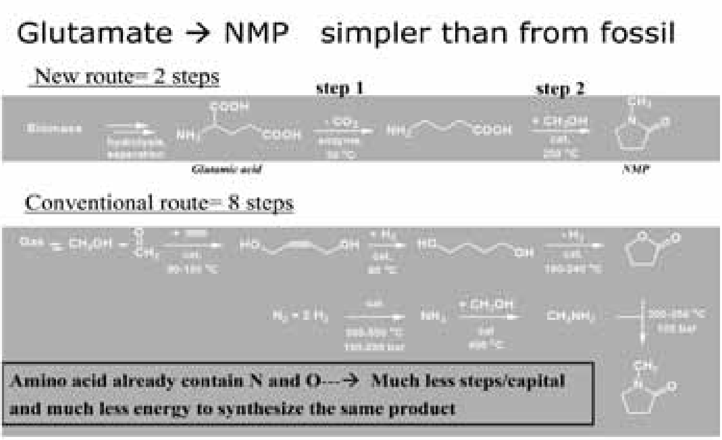


Figure 17. Glutamic acid is a suitable building block for the synthesis of N methyl pyrrolidone

Good use of residue makes ethanol factory profitable!

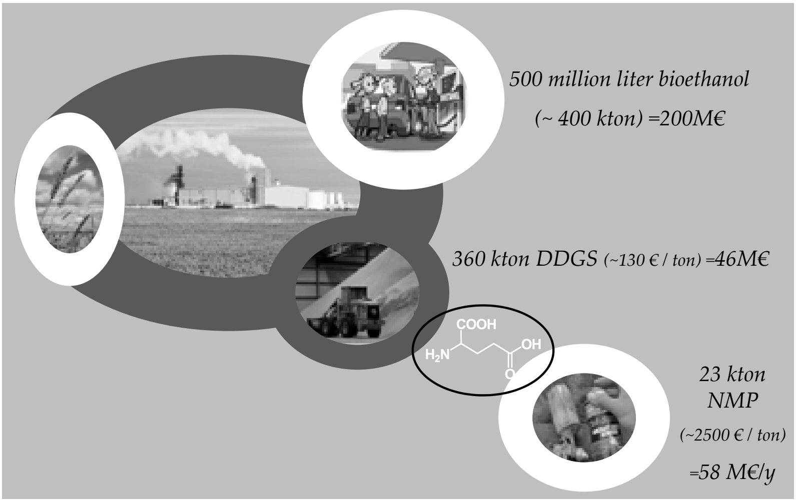


Figure 18. An ethanol biorefinery can significantly benefit from the side products

A bioethanol factory, including the many in the world that utilize corn as the raw material, produce almost the same amount of residue with a value of 46 M€ in addition to the annual 400 000 tonnes of the main product ethanol from the Abengoa factory in Rotterdam with a market value of approximately 200M€. This residue is also referred to as DDGS (dried distillers grain with solubles). Approximately 10% of this residue is consists of glutamic acid. If we could isolate this glutamic acid and convert it to the solvent NMP, the mere value of this 10 % would be more than the original value of the DDGS waste stream. The 90% waste of this DDGS stream can obtain an increased value if, simultaneously, the components that limit their application in animal feed such as potassium and phosphate can be reduced and/or other components of this side stream can be valorised to bulk chemicals. This indicates that biorefineries that are successful in valorising more than just one product can achieve a very positive economic margin. I do not need to tell you that if we could be successful in isolating the other amino acid components from this DDGS, the value will be even greater.

Figure 19 exhibits an early example of the principle that our Chair has focussed on: the use of the molecular structure of residues. The Belgian company Solvay (Solvay, 2012) has already begun to establish its third factory that produces epichlorhydrin from glycerol, which is a waste stream from the biodiesel industry. In a petrochemical process, chlorine is required to functionalize propylene. The lots of energy that are accumulated in chlorine must be dissipated from the process which

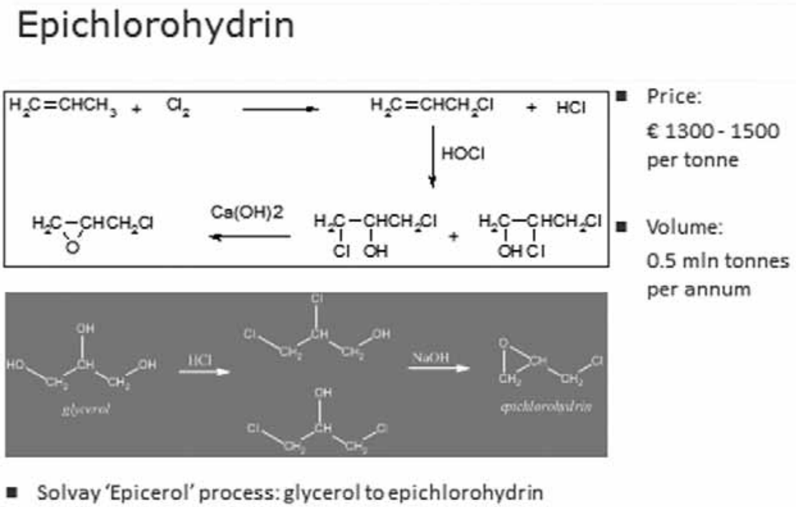


Figure 19. The petrochemical process to epichlorhydrin as well as glycerol as the building block

expends heat exchange capacity and, in this case, under quite severe conditions of the corrosivity of chlorine. Also in the biobased process, no chlorine needs to be produced so, in this aspect, less electricity needs to be produced that is required for the synthesis of chlorine. This process already is a nice example of the much lower capital required while, in this specific case, the raw materials are not more expensive than the fossil ones. This will probably lead to a very interesting margin for Solvay.

Innovating for the environment: window dressing or structural...

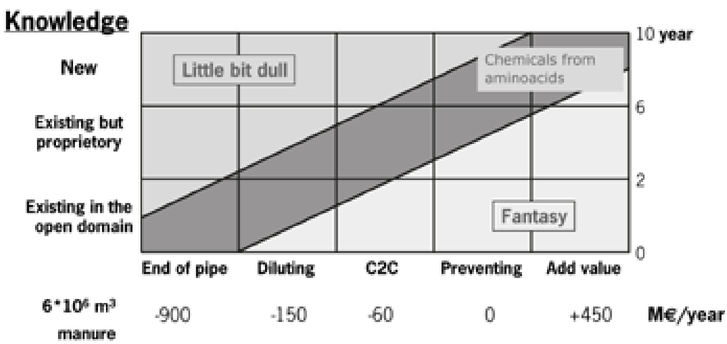


Figure 20. Using amino acids or other functionalized biomass components will reduce CO2 emissions at low capital cost

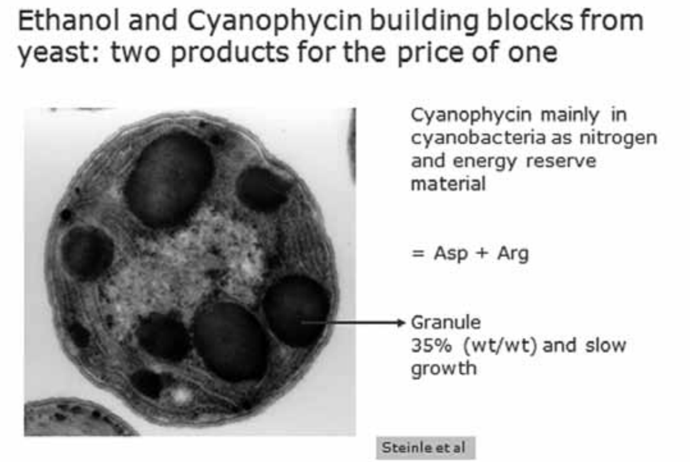


Figure 21. When Cyanophycin can be produced in yeast that is used for ethanol production, the capital costs allocated to amino acid production are very modest.

Figure 21 provides an example of how we can perform many increments in a process with only minimal capital costs. Together with the University of Munster, we have transferred the genes for the synthesis of a very special protein from Cyanobacteria into yeast. (Steinle, 2009)The protein is special because it consists of only two amino acids and not all 20, and the protein is insoluble at neutral pH and soluble at high pH. If we cultivate this yeast in a fermentor that contains waste nitrogen components, these will be absorbed by this yeast and all converted and concentrated in these insoluble protein granules that can be purified at low costs because of their solubility properties. If this yeast happens to be the yeast that simultaneously produces first or second generation ethanol from starch or from lignocellulose, then the process to accumulate these protein granules does not cost any capital investment. It is very Dutch: ‘two products for the price of one’. The only investment that must be made is to isolate the yeast cells, open them, and purify the Cyanophycin peptide. The two amino acids (arginine and aspartic acid) can be separated and these can be employed as building blocks for the production of three chemicals: acrylamide, butane diamine (for nylon production)(Könst, et.al. 2010) and urea as a fertilizer (Könst, et. al. 2009)

During my time at Gistbrocades, I saw quite a few fermentations, and Delft really was one of the centres of excellence in the world for fermentation of baker’s yeast, Penicillin, and enzymes. However, producing bulk chemicals by fermentation would have never become a beneficial technology if we had not thought accordingly to what I previously explained in that we must reduce the need for heat exchangers. In typical optimized industrial aerobic fermentations, at least 50% of the energy that is

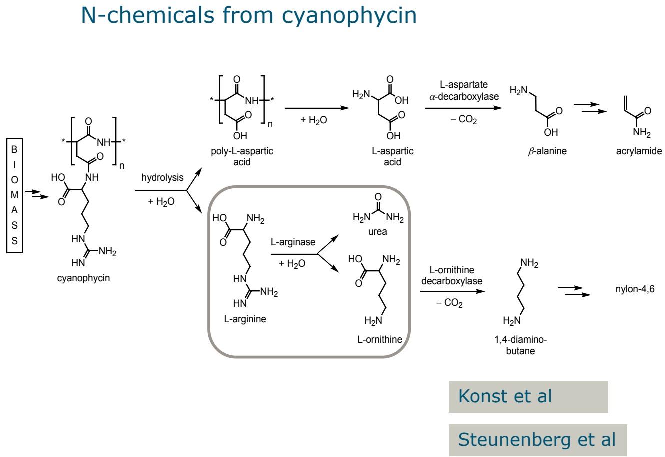


Figure 21a. Arginin and aspartic acid are suitable building blocks for bulkchemicals such as butandiamine and acrylamide

in the input sugars is converted into heat. That signifies a loss of raw materials, and it indicates significant required investment not only for cooling the fermentor but also for the compression of air that is required in an aerobic process. There are some anaerobic processes such as ethanol production, acetonne /butanol production, and lactic acid production that incite energy yields of approximately 95%. Because the microorganisms in these anaerobic processes receive significantly less biological energy available per sugar molecule that enters the cells, they attempt to increase the rate of uptake and consequent conversion in order to receive enough energy for cell growing. Therefore, as a consequence, the rate of production increases sometimes more than 5 times, which is attractive since the fermentor size can be much more moderate in addition to the fact that the reactor can be much less complicated than the aerobic fermentor. Six or seven years ago, I approached my former colleagues in Delft who were aware that I made certain important contributions to Gistbrocades such as the establishment of genetic engineering as well as the protein engineering but also the introduction of Phytase, an enzyme that had reduced the phosphate in the Dutch environment much more than the banning of phosphate from washing powders. Twice, I received my coffee and, twice, I could explain how we anticipated the advantages of this novel technology, however, at DSM, they only perceived disadvantages and no advantages. Now, 5 years later, we are performing four projects with this concept that are sponsored with the financial contribution of DSM and two other projects which are being performed in Wageningen and 100 percent financed by an industrial partner.

Aerobic fermentation have low yield and therefore high heat production and thus high capital costs

This holds for tradional products like
glutamic acid, lysine and penicillin

Anaerobic fermentation have high yields (if expressed as energy yield)
E.g. ethanol, lactic acid, butanol

For bulkchemicals this leads to the required low integral costprice of: 600- 1600€/ ton

Figure 22. Anaerobic fermentations enable the competitive production of bulk chemicals

There is an on-going debate regarding raw materials of the first and the second generation. Second generation raw materials are regarded as not being suitable for our food chain. Burning wood for cooking is approximately half of the biomass we use worldwide in our food chain, as I previously indicated. This already demonstrates that we should analyse the issues more efficiently before we make conclusions. Utilizing wood for cooking in the third world induces enormous problems with deforestation, soil degradation by erosion, and gender problems. To incorporate our biomass resources back into the technical domain of efficient utilization of our scarce inputs such as the availability of land and biodiversity, we see that many people continue to focus on the amount of biomass that can be obtained per hectare, but they have no concerns regarding the quality of that biomass that is reflected in composition, process-ability, storability and availability.
Figure 24 illustrates (Brehmer, et. al. 2009)) that it is more effective to begin with a crop incorporating a significant amount of proteins if the objective is to produce animal feed or chemicals that contain nitrogen or with a crop containing extensive amounts of oil when you are interested in producing lubricants.

Many people, including politicians, hope that second generation raw materials will solve the issue of climate change because they claim that, if waste streams are exploited, they are always inexpensive which, of course, is not the case. Second generation biofuels require large factories and, therefore, require substantial raw materials that are not available in these high concentrations in Europe as they are in the USA in the form of corn stover in the mid-West. In Europe, lignocellulose can be utilized as a raw material for transportation fuel costs of approximately 140€/tonne, or 9€/ GJ, while only about half of this biomass can be converted into ethanol. The costs of the raw materials will be doubled, and a waste problem results that, in Europe, cannot be solved at a low cost.

Total crop yields

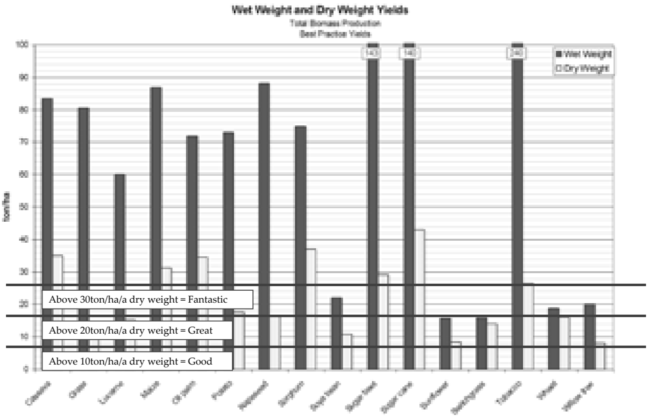


Figure 23. Some crops have very high yield of (dry weight) tonnes per hectare

In accordance with this line of thinking, it can be reasoned that wood would not be attractive as a raw material because the process ability is complicated, and it requires also land to grow. What about agricultural or industrial residues such as straw that is abundantly available in the world and which is the resource of choice in the USA for the production of second generation ethanol?

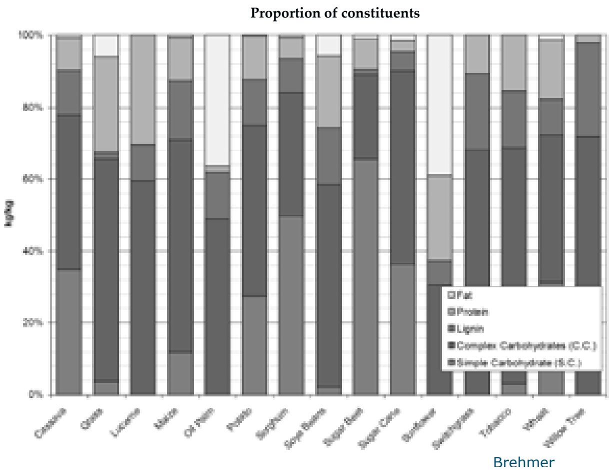


Figure 24 composition of the harvested crop has a significant impact on the economy and sustainable use of the hectares used

Second generation ethanol costs a lot of capital and energy and will not give much value! *False hope?*

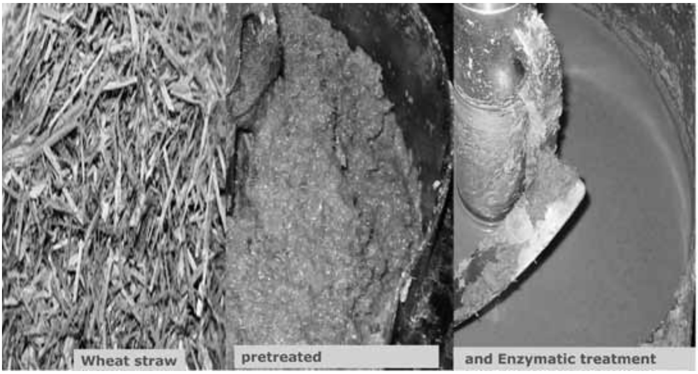


Figure 25. Wheat straw, Ca(OH)2 pre-treated wheat straw and pre-treated and cellulase treated wheat straw

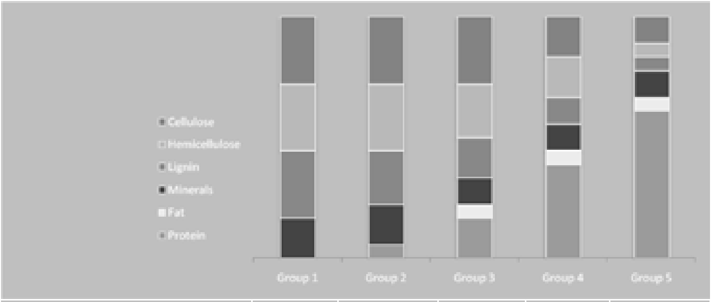
Figure 25 shows wheat straw that has been pre-treated to open the structure for the enzymes that will enable the production of ethanol (Maas, et. al. 2008)

The concentration of straw in water that can be processed is very limited.

With straw at 15% dry weight concentration, the concentration of ethanol produced will be limited and, again, there is a need for significant heat transfer to distil the ethanol from a low concentration of only five percent.

I, personally, do not predict a future for this so called second generation technology (in Europe) because the technology is very capital intensive and, therefore, can only be operated on a large scale. A lignin rich waste stream can only be converted into product after energy intensive concentration. As the required scale requires enormous quantities of raw material, these will not be available on the European level without substantial transportation costs which will make the technology not competitive. Furthermore, the prices for this type of biomass has been driven to exorbitant levels by the governments that mandate electricity companies to exploit biomass for power generation. If (agricultural) input costs are allocated to these side products by the European Directive 2009/28/EC on an energy base, then it will be very difficult to achieve 60% CO_2 emission reduction, which will be regarded as the sustainability criterion from 2017 onwards (FQD, 2009/30/EC) .

Biorefining of agricultural residues ..



Protein content	0	5 %	15 %	35 %	50 %
Examples	Wheats straw	Cocoahulls Corncobs Sugarcane leaf	Coffee pulp Rape straw Beet leaf	Rape meal	Soy meal
Cost (€/ton)	50-80	50-110	100-140	150-180	300-350

Figure 26. Agricultural residues containing certain protein lead to an improved economic process as compared to lignocellulose residues

For the European scenario, we again require a scale of operation that is in accordance with the availability of raw materials. How can we prevent the high capital dependency, and how can we receive higher value from a biomass waste stream?

If we rank agricultural residues by the fraction of protein and when we will begin to fractionate the components, we at least will enhance the value of that same protein as it can be employed in a more valuable application than from the original residue.

When examining the first group with only minimal protein such as wheat straw, it would be best to not address the first group because of the previously mentioned reasons. The 5th group with high protein content such as soy meal, should also not be addressed because it already has a high value. However, all three groups in between are candidates for European second generation technology. In examining the group with a protein content of approximately 35% such as rape meal, this group is just good enough for a pig feed component. The 3rd group is just good enough for cattle feed because it contains some protein and many fibrous materials, while the 2nd group is not currently valuable enough to be collected from the fields.

Biorefinery enables power generation at 45€/ton and high quality 2[nd] generation fermentation raw materials for 200€/ton

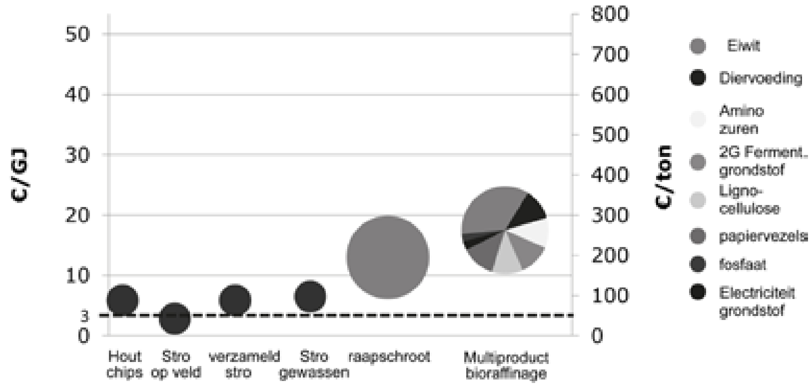


Figure 27. Rapeseed meal can be a beneficial substrate for high value proteins, chemical building blocks, animal feed components, as well as raw material for power generation.

We were challenged by Essent, the Power company, to design a biorefinery process that would lead to increased value products as well as low cost raw materials that can compete with coal for power generation.
Currently, because of the mandate and subsidies, the cost for wood pellets that are imported from Canada have prices at least two times higher than the coal prices, as indicated in Figure 27 with the dotted line.

Straw on the field is inexpensive but, by collecting it and washing it to obtain a quality sufficient for power generation, it is as expensive as wood in Europe. In considering the rape seed meal, which is more expensive, the cost will increase even more after fractionation, but this will be rewarded because the protein receives a greater value per tonne of protein, the amino acids become available at modest prices, and there will be lactate produced from the cellulose and the hemicellulose. Lactate, of course, can be utilized for the production of Poly lactate, a novel biopolymer that is currently used for packaging and insulation. Lactate can also be employed as a substrate for the production of bulk chemicals in a more improved manner than other second generation fermentation substrates because we predict that the purity and the concentrations are much better than the sugars that are obtained from second generation processes in the manner that they are developed by the US ethanol producers. Unexpected for many people is that the lactate can substitute starch in animal feed and thereby, again, I demonstrate that the 'food vs fuel' debate is an artificial debate because cellulose that you cannot eat is converted into a starch substitute that pigs and poultry, at least, can consume. Finally, the undigested cellulose and lignin become available at the price of coal for the power companies.

Innovating for the environment: window dressing or structural...

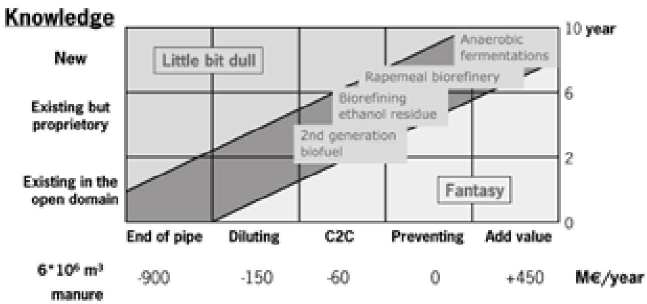


Figure 28. Anaerobic fermentation will prevent the need for high capital inputs; rape meal biorefining can be performed on a reasonably moderate scale; ethanol residues, once formed, can be processed into valuable products; waste streams can be converted into transportation fuels but these have only limited values.

Since this process was designed to be economical even on a small scale, we anticipate that the most moderate investment to enable economical operation will be approximately 20 Million € at a volume of 40 000 tonnes/year, much less than the 250 M € that are required for US second generation ethanol production and, even more importantly, the 2nd generation biodiesel operations that require even more capital (760 Million Euro or even more) for one individual plant such as the NesteOil factory in Rotterdam(Neste oil, 2012)
The Achilles Heel of biorefinery projects is the fact that there is more than one product to bring to the market and several companies with different interests and cultures must collaborate.

Small scale biorefineries close to the fields of production

If we address the size of operation for the primary production and the first processing of the harvested crops, then we can further exchange capital for labour and simultaneously reduce the need for energy and transport:

Figure 29 exhibits the traditional value chain of sugar beets: they are harvested and placed at the side of the field where they are collected by a lorry that brings them to the factory that produces crystalline sugar. As a residue, molasses is produced and shipped, e.g. to a baker's yeast factory such as the one where I began my professional career, Gist brocades in Delft. The sugar in the molasses is an inexpensive substrate,

Small scale biorefinery reduces transport cost and seasonality

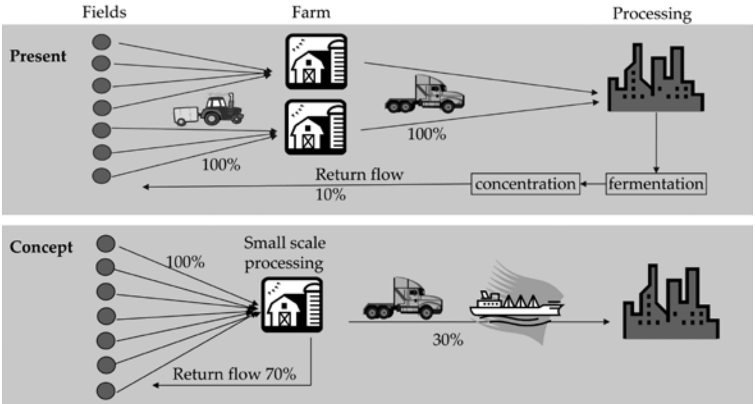


Figure 29. Schematic representation of a traditional beet sugar value chain traditional compared to a future small scale

and the other components of the molasses that are not used by the yeast were discarded into the North Sea until our government directed us to build a waste water treatment plant. That was the nice technology that I mentioned in my introduction, but it happened to not be suitable to discarding the minerals which was not regarded as a problem: Gist brocades purchased an evaporator and. with a Central Heat and Power plant (CHP), energy was provided at low cost. Then the problem was not solved at all because the Vinasses containing the concentrated minerals that were originally present in the beets that had previously been cultivated on 50 000 ha had to be distributed again over an agricultural surface of approximately the 50 000 ha, which still is a major logistic operation.

- If we could process the beets close to the fields and recycle most of the water from the beets containing the minerals, then much less water will need to be transported over the roads. The minerals do not need to be concentrated because, if the size of operation is around 500 ha, the distance to recycle is 1 km to the right and 1 km to the left. Furthermore, the farmer would incur lower costs for his minerals. In addition, if we can produce an intermediate product that can be stored over the entire year with simple process steps, we would facilitate the more difficult and more capital intensive steps to be performed during 12 months per year and not just for the 4-5 months of the traditional beet- campaign in the central factory (Bruins, 2012).

All of this would reduce a significant amount of capital cost, reduce the amount of energy required to concentrate the minerals from the molasses, reduce transport costs, and, at the first step in the chain, there would be additional work to perform which makes the farmer more independent as an entrepreneur.

In the beginning, the Sugar Union was very sceptical about our plans since they were the champion in large scale factories in Europe, just having had their consolidation of 5 factories to 3 and, finally, to 2 factories in the Netherlands. Now they are sponsoring our research whereby we designed a process that requires approximately half of the energy per tonne of sugar beets as compared to the traditional processes in order to produce sugar. This also includes the downstream processes that address the residues of sugar production, i.e., ethanol or baker's yeast production.

Small scale beetsugar crystallisation(2-500ha)

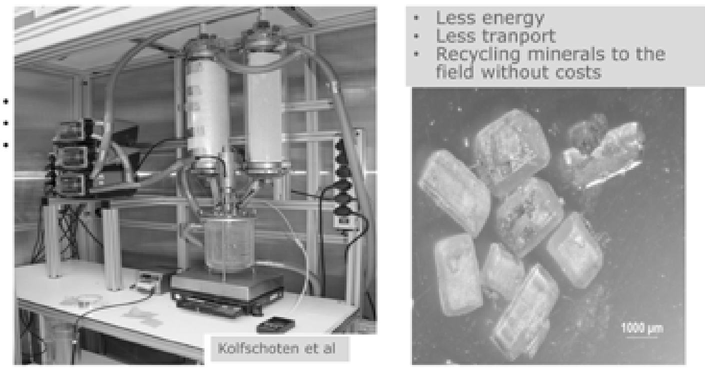


Figure 30. Demonstrates a laboratory set up for the production of the beet sugar crystals from crude beet juice

Figure 31 illustrates a respectable result of small scale biorefineries that we designed almost 10 years ago: a mobile factory that can be transported to the fields to process the cassava roots to a crude starch meal within a short time following their harvest. This will strengthen the position of the farmer because the roots should be processed within 24 hours after harvest. When a farmer wants to sell his harvested roots to a large factory, the 'man at the gate' indicates that he already has enough roots

Mobile cassava starch refinery in Africa

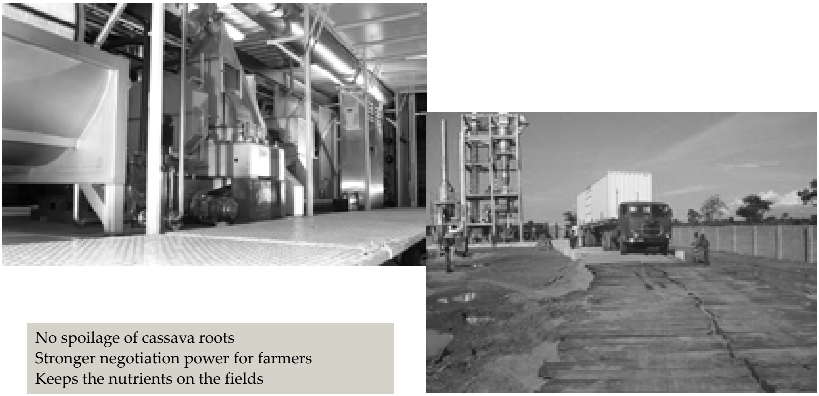


Figure 31. Production of starch from fresh cassava roots in a mobile factory

available. The farmer can either attempt to locate another factory 100 km further at the end of his working day while the roads become dangerous and probably hear the same story at the other central factory, or he can begin negotiating, while both men know that, every hour, the transfer price will decrease. While processing nearer to the fields, the minerals from the root that would have been discarded into the river by traditional factories can now be recycled without any problems. These mobile factories, of which there are now more than 6 in operation in Nigeria, are a very positive example of where People, Planet, and Profit can go hand in hand with all of the advantages and not having the disadvantages.

In the Netherlands, we import shiploads of animal feed to supply the protein and energy for our animals. As a consequence, we import an enormous excess of minerals. We refer to this as our manure problem that I took as my reference in one of my introductory slides to show how PPP can go hand in hand. We naturalized, over the past 40 years, spending a significant amount of money for spreading manure and we have even become enthusiastic about certain C2C solutions in the last few years, but this money could be used for employment and for capital investment if we were to work for the best mode: simultaneously earning money and prevention. If we would construct a moderate scale refinery for corn, we could feed the starch to pigs and the proteins to cattle since the benefit of this corn-protein is rather minimal for pigs, and cattle do not discriminate the difference with the protein of high quality for pigs. If we would also construct a small scale biorefinery for grass, we could obtain most of the protein which is very valuable for pigs, and the remaining grass fibres can be fed to cattle. With only minimal effort, we can increase the field yield of grass in the Netherlands. That was never required or possible since pigs do not eat unfractionated grass, and cattle had enough with the actual production of grass.

Mobile grass refinery unit Grassa (the Netherlands)

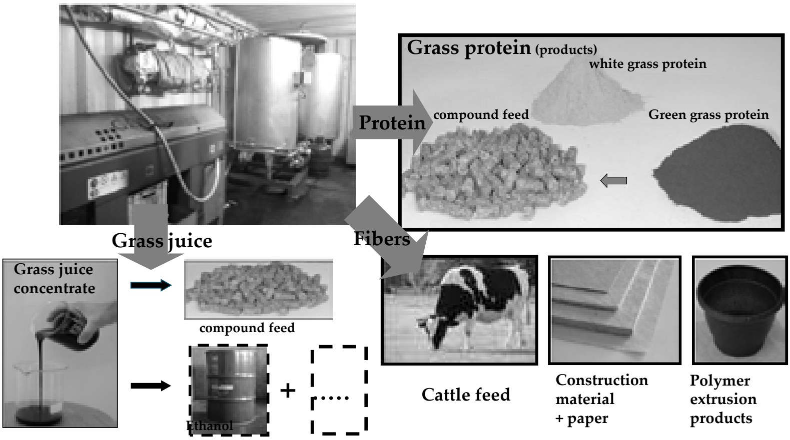


Figure 32. Part of the GRASSA! Biorefinery in a sea container

In the Netherlands, we could produce almost all of our own animal feed with small scale corn biorefineries that have been developed by Byosis and ACRRESS in Lelystad and with small scale grass biorefineries as developed by GRASSA! which are now on the verge of commercial introduction.

This GRASSA! process can segregate grass into 4 fractions: protein suitable for pigs and cattle; fibres suitable for cattle as well as the paperboard industry; and the production of electricity. The juice contains minerals but also amino acids and sugars that can be exploited as animal feed; however, some can better be used to produce chemicals.
As can be seen in Figure 33, protein has the highest value, having the equivalent economic value as soy meal from Brazil. The value of the protein is higher than the value of the grass it originates from, demonstrating that biorefinery can create value. However, the costs of the biorefinery are too high to be compensated by the value of protein alone which is the reason that, in the near past, grass biorefineries had not been commercialized. The Bioeconomy that has just been initiated will also valorise

the by-products, such as the fibres and the juice components, to substitute fossil resources. The juice contains amino acids and organic acids that are not required as animal feed and can possess a high value as a building block for the production of bulk chemicals as has been previously substantiated. The same grass can procure a much higher value and also a higher expected margin if we would decide to optimize our fractionation exercise. If we were able to split the same tonne of grass

Just protein is no sufficient to cover the costs

bioraffinery	3 products		8 products	
	income	costs	income	costs
Grass costs		60		60
Process costs		120		440
protein	120		120	
fibers	30		30	
Juice components	55			
minerals			75	
Organ. acids			60	
Amino acids			75	
sugars			12	
sugarpolymeren			225	
fat			60	
totaal	**205**	**180**	**657**	**500**

Figure 33. The costs and value of a simple and a more complex grass biorefinery

into 8 different products as indicated in Figure 33, then we could triple the income and the margin even more. In this more sophisticated biorefinery that can only be developed after the less complicated is implemented, we use the biomass in a more efficient way thereby also reducing Green House Gasses even more than in the simpler case. However, we have to follow the learning curve from simple to more and more complex technologies in the decades to come.

Combining the corn and the grass biorefineries leads to a special outcome since both crops in their actual application contain components that obtain a lower value in the non-fractionated crop than could be obtained after the biorefining. If corn is fed to cattle for protein and energy, cattle receive the starch that is actually a very high value energy source for pigs. The cattle are content with the fibres from grass that is of no value to pigs. If the grass is fed to cattle, the value of the protein is not appreciated by these animals, while it is appreciated by the pigs after the protein has been unlocked by the biorefinery process. We might also improve the quality of the protein for cattle by a process that makes the grass protein ‘resistant’ for the activities of the first stomach of the cow so that the essential amino acids in the grass protein can reach the blood of the cow. Actually, they receive some of their protein added into their diets, but these current proteins are imported soy proteins. The unlocking of the grass proteins will enable substitution of soy proteins for cattle in an economical manner.

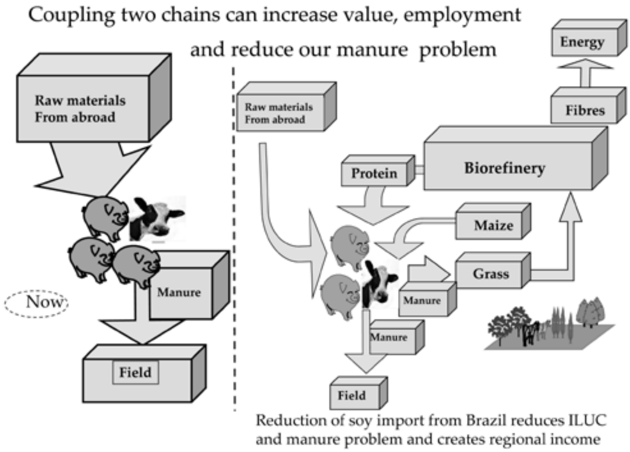


Figure 34. Integration of corn and grass biorefineries to produce animal feed in the Netherlands

Innovating for the environment: window dressing or structural....

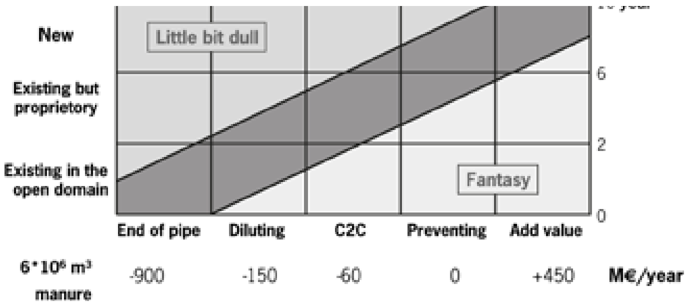


Figure 35 examples of small scale biorefineries where minerals can be recycled without much capital and energy inputs, where environmental problems are reduced, where the negotiation power of small holders can be improved, and where we improve the efficient use of our scarce inputs

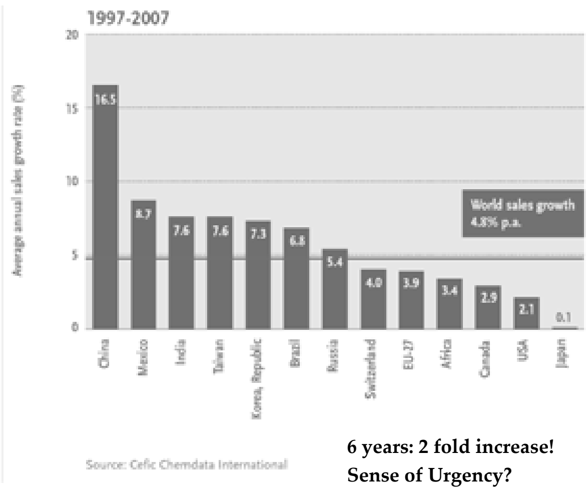
Since, with this grass biorefinery, we can now supply the protein in an optimal quality for pigs and poultry. We can also better exploit the potential of grass lands in the Netherlands since they can produce more than 15 tonnes (DW)/hectare, however, since cattle do not require more than, on average, 8 tonnes per hectare, this potential of Dutch agriculture is not well-used. The fibres that result from this additional volume of grass that can be cultured and fractionated in the Netherlands can be fed to cattle to substitute for the less starch they obtain from corn, when this starch is fed to pigs and poultry in the future. Biorefinery will contribute to a more efficient use of the different components from crops and the agricultural inputs such as land, water, and minerals.

Will the chemical industry be reactive enough?

The final question to answer is where I perceive the bridge between agriculture and Chemistry:

- The chemical industry in Europe faces significant challenges to overcome: the annual growth rate is, in China and Mexico, 16 and 9 %, respectively, and only approximately 4% in Europe (Figure 36) .
- Competitiveness, which has been positive for a significant period of time, is diminishing to modest due to the extensive growing markets elsewhere but certainly also because of the raw materials available in the Middle East and the recent developments on Shale gas in the USA (Deloitte) where a substantial amount of chemicals, especially those with 2 and 3 carbons, benefit from this new fossil resource and make the position of the European chemical industry even less competitive.

Chemicals sales growth rates of selected countries and regions



6 years: 2 fold increase!
Sense of Urgency?

Figure 36. Annual growth of the chemical industry in different areas

It is evident that our chemical industry must innovate, but how? Without the inexpensive fossil resources that are available in other locations around the World and without the rapidly growing markets that the industry was accustomed to, I see only one way to follow whereby the use of relevant biomass building blocks and technologies will be beneficial if these can be applied by circumventing the need for large scale and risky investments and if the buildings blocks that favour these possibilities will be available in large enough volumes. These new raw materials can be sustainably cultivated in Europe and will create employment. The use of chemical building blocks will make the use of other components from the biomass more economical in their application as transportation fuel and electricity raw materials. Small scale chemical factories can be employed for the substitution of existing chemicals, but they are also a very valuable technology to introduce new chemicals with improved properties. These types of chemicals were very difficult to introduce in the past decades because they had to compete with existing chemicals that benefitted from economies of scale. Customers accepted certain inadequate performance because of the price difference of existing chemicals compared with the new ones.

By exploiting the most appropriate biorefinery technologies in combination with the correct type of biomass, we supply raw materials for the chemical industry, for the production of electricity and transportation fuels and simultaneously for animal feed production. We are also afforded an opportunity to substitute capital costs by labour and change the direction of the development of requiring less and less labour inputs per economic output that began with the onset of the steam engine. Many politicians would like additional employment, but they have not noticed this fundamental change of opportunities as they believe that they remain dependent on the large companies of today with all of their large scale capital investments. They are captured in their unprejudiced belief in 2nd generation transportation fuels that, at least in Europe, is far too expensive to provide us with the answer to sustainable use of biomass. They at least do not foresee that the production of biobased chemicals could be initiated by a new group of companies, e.g. the agricultural companies that have the raw materials and the biorefinery expertise. These new factories do not need to be built in the big ports or large chemical complexes, but they probably will benefit from their location close to the agricultural raw materials, which might even be in countries without much chemical tradition.

Natural strenghts of the Netherlands for BBE

- Major seaports Rotterdam, Amsterdam, Terneuzen, Delfzijl
- Strong agriculture inclusing food-bio-refineries
- Compound feed industries and forage: 40M tonnes/year
- Outlets for wet and dry biorefinery side products & Major European market outlets
- Strong chemical industry
- Strong knowledge base
- Unique combination of strenghts in SW and NE Netherlands!

However our Government is defending the vested interests of companies and her own with a very un-leveled playing field

Figure 37. The Netherlands has a unique combinations of strengths to develop a solid Bioeconomy

The Netherlands is one of the few places in the world with a combination of strengths that places us in a very strong beginning position for a bioEconomy that is competitive with the fossil world that has magnified over the past 250 years: We have strong seaports and strong agriculture including food biorefineries. The Netherlands has the greatest amount of biomass available each year per inhabitant and per hectare. We have many attractive outlets for the products from the biorefineries including the chemical industry and not to forget that we have a very strong knowledge base for all of the essential issues of this BioEconomy. The combination of these strengths is important: If one wants to use biomass efficiently and economically, then the fractionation into different components is important. If one builds a biorefinery, as an example, in the middle of Germany because there is substantial inexpensive corn available, and one produces 3 products of which only two find a nearby market, then the third one must be transported to a seaport or can be utilized with a lower value nearby. Also, after the year from establishment of the factory we learn that corn prices have increased. These problems will not occur if a factory is constructed nearby the sea and contracts farmers for 2/3 of the required volume of raw materials. If one of the harvests in the upcoming years is greater than 2/3, then the biorefinery can absorb this additional volume with no problems and at the world market prices. This greatly benefits a farmer who has invested to improve his field yield then the answers given in the past here in the Netherlands for the existing sugar (C- prizes) or starch biorefineries. If the harvest is lower than the 2/3, then a greater volume can be sourced from the other side of the ocean. Thus, again farmers can benefit from the bioeconomy here in the Netherlands. The Netherlands has its own combination of strengths, but with the development of a Biobased Economy here in this Rhine, Maas, Scheldt delta, we can become an example for

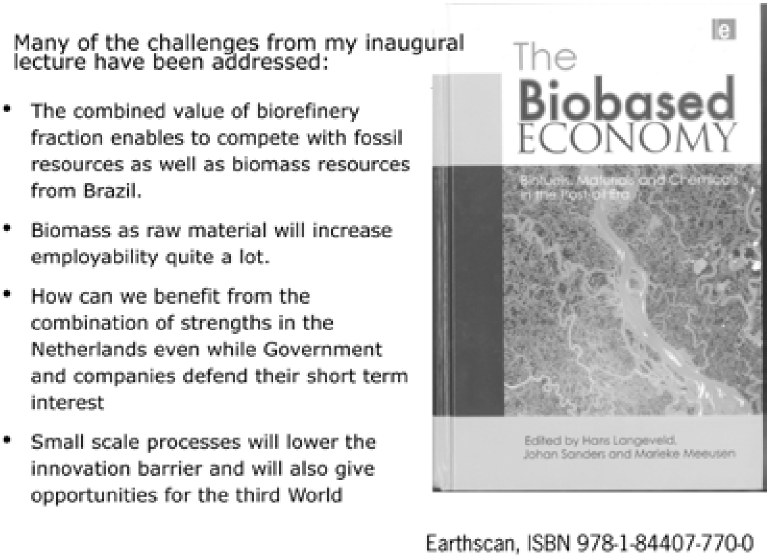


Figure 38. Conclusions

other densely populated deltas in the world where, with our knowledge and experience, we can contribute to a more sustainable world and earn money at the same time.

As a conclusion, I would like to state that most of the challenges put forward in my inaugural lecture, 'Groene chemie door boeren met energie' and the many new challenges we met over the past 10 years have at least been addressed in this farewell lecture. Wageningen UR is in a good position to contribute with solutions that fulfil all People, Planet and Profit conditions.

I am satisfied that I have been able to contribute to the development of what we now refer to as the BioEconomy, and I am proud that I was and will continue to be a part of the Wageningen UR community to employ all of the knowledge available in and connected to Wageningen for this essential novel era that has now just begun.

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