Cascading of Biomass

13 Solutions for a Sustainable Bio-based Economy

Making Better Choices for Use of Biomass Residues, By-products and Wastes

Report
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Preface

The bio-based economy has gained momentum in the past years. Research concerning better use of biomass in the bio-based economy is part of CE Delft's expertise and we feel the discussion concerning the 'good use' of biomass will remain and will increasingly be at the core of the bio-based economy debate.
Cascading is often mentioned as essential to a sustainable bio-based economy. Because different definitions circulate it is not instantly clear what cascading entails. In this research project the concept of cascading is further elaborated.

Added to this theoretical discussion, 13 real cascading examples are elaborated on. These examples show that cascading can contribute significantly to the bio-based economy. Chapter 3 elaborates on the benefits of these cascading options.

Furthermore, in Chapter 4, the influence of government policy on these cascading examples is discussed, along with options to improve policy to stimulate sustainable use of biomass by cascading in the bio-based economy.

We hope that this both theoretical and practical approach will help the discussion concerning cascading in the bio-based economy.

We would like to thank our supervisory committee, with the following people from PBL and several ministries, for their input and comments:

Ralph Brieskorn	Ministry of Infrastructure and Environment
Rob Cornelissen	Ministry of Infrastructure and Environment
Roeland Bosch	Ministry of Economic Affairs, Agriculture and Innovation
Fons Gribling	Ministry of Foreign Affairs
Lindsey Wuisan	Ministry of Infrastructure and Environment
Jan Ros	The PBL Netherlands Environmental Assessment Agency (PBL)

The conclusions presented in this report are CE Delft's conclusions, not necessarily those of the supervisory committee.

Delft, August 2012

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Contents

Summary

As part of their sustainability agendas, the Netherlands, the EU and other countries view the ‘bio-based economy’ as an adequate and viable way to reduce their environmental impacts, specifically their greenhouse gas emissions. Furthermore, creating economic opportunities, spurring innovation, being self-sufficient in fulfilling the domestic energy demand and making the shift from non-renewable resources to renewable resources are important reasons to focus on a bio-based economy. This report is part of a continued collaboration between The PBL Netherlands Environmental Assessment Agency (PBL) and CE Delft to explore the sustainable use of biomass in the bio-based economy. In February 2012, the PBL, in collaboration with CE Delft, published the PBL Note: Sustainability of biomass in a bio-based economy (PBL, 2012). This CE Delft report is a follow-up of that PBL Note.

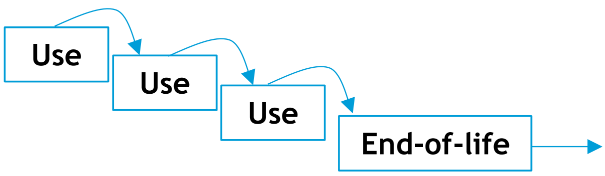
Cascading is an important option that deserves attention in the quest for deciding the approach that needs to be taken to achieve an efficient and sustainable bio-based economy. In this study the concept of cascading is explored and it is shown that cascading can contribute significantly to the bio-based economy; between 10 and 12% of the target emission reduction in the EU of 2,235 Mton CO_2 per year in 2030 (compared to 1990) could be fulfilled with the cascading options we explored. Since 1990 significant progress has been made in reaching the climate targets. Compared to current emissions (2010) 1,371 Mton CO_2 eq. per year should be avoided. The biomass cascading options explored in this study could contribute to almost 30% of that figure.

The following biomass streams are considered: woody biomass, agricultural residues and processing residues and wastes. Therefore we focus on the ‘conversion’, ‘use’ and ‘end-of-life’ phases of the life cycle. Almost all of the considered options are based on biomass residues and by-products. New sources of information (used in this study) indicate higher availability of residues than estimated in earlier studies (e.g. PBL and CE, 2012).

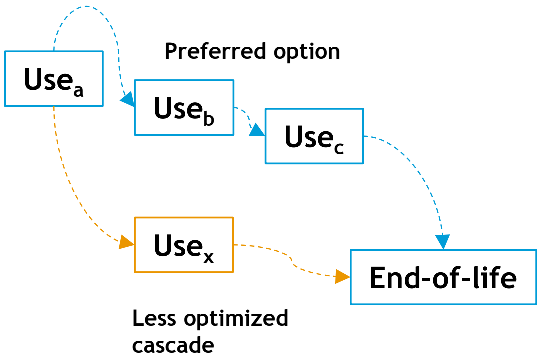
Different definitions of cascading circulate. Two topics are of key importance. Firstly, cascading is about making *choices* between different applications. Secondly, because the choice for a specific application influences future possibilities, a *chain approach* is necessary.

These definitions are not mutually exclusive, in fact, it may be necessary to incorporate all three to ensure the best environmental performance.

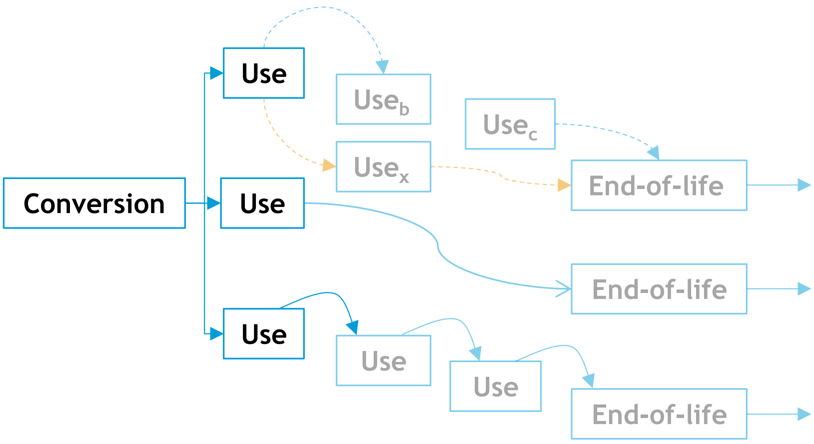
1. *Cascading in time*
   Subsequent use in time ensures a long(er) life span of the biomass; the option which leaves as many options at the end-of-life open, should be preferred. A typical example is paper recycling.



2. *Cascading in value*
   Cascading in time can be optimised by cascading in value to ensure the highest value possible is achieved when choosing between alternatives, and the value over the whole life cycle is maximised. An example is use of straw for ethanol production (which can subsequently be used to produce e.g. plastics), which provides benefits with respect to the original function.



3. *Cascading in function*
   What people call 'cascading in function' is actually co-production, which can be achieved by using bio-refinery. Co-production is the production of different functional streams (e.g. protein, oil and an energy carrier) from one biomass stream, maximising total functional use. A nice example is grass refinery. Of course, after cascading in function cascading in value or time follows; the two figures above are additional to the figure below.



Thirteen cascading cases were studied for a range of biomass streams. The cases were chosen based on expert opinion within CE Delft, literature research and feedback from the supervisory committee. In all cases the cascading option provides added value (e.g. production of biogas from manure), while maintaining the original or current function (fertilization). These cases could be characterised as a more optimized utilization of available biomass feedstocks with respect to greenhouse gas (GHG) emission reduction. The considered cases concur with EU waste policies, aiming at maximization of material reuse and energy recovery from wastes. In two cases (cascading options 12 and 13 – concerning paper end particleboard), the alternative to the current application of the biomass represents an undesired shift from a more effective (a cascaded option) to a less effective application.

For all options an indication of the potential GHG emission reduction is given, and, when relevant, an evaluation of three important factors determining this potential, i.e.:
– the supply of the biomass feedstock;
– the level of development of the technology;
– the ability of the market to absorb production.

Technological development is an important factor for further development of many of the cascading cases mentioned, but as shown in Table 1, policy hampers the cascading solution in many cases. In Table 1 the list of cascading options (the number corresponds to the order in Chapter 3, where the options are grouped according to the biomass type) is presented, along with the CO_2 benefit and the existing policies which influence this cascading option (a '+' indicates a positive policy effect, and a '-' a negative effect). Only the part of the chain which would be changed when applying cascading is described and quantified. The rationale is that in case e.g. subsequent incineration with energy recovery already happens this does not provide a benefit additional to the current situation.

The total, and maximum, CO_2 benefit amounts to between 332-407 Mton CO_2 eq. per year, of which the higher figure should be regarded as an optimistic potential. The potential amounts to around 30% of the target emission reduction of 2,235 Mton CO_2 per year in the EU in 2030, relative to current emission levels.
The four options with the highest potential CO_2 benefit, account for around 77% of the total benefit:
– straw to ethanol for chemistry;
– manure to biogas;
– grass refinery;
– additional paper recycling.

Table 1 **CO_2 benefit for the cascading options and the influence of current Dutch (NL) and European (EU) policy (the number corresponds to the order in Chapter 3)**

	Cascading option	Benefit in CO_2/year (Mton)	Influence of current policy (+ → stimulates the cascading option, - → hampers the cascading option)
Examples of 'cascading in time'			
2.	Bio-ethanol to chemistry (instead of to transport)	30 Mton (max.) - additional to option 1	- Biofuel obligations (EU) - Double counting of second generation biofuels (NL/EU)
10.	Recycling of (additional production of) bio-plastics	0,3 Mton (recycling of current bio-plastics) 40 Mton (substituting 30% of plastics for bio-plastics incl. recycling)	+ Recycling targets for plastics (NL/EU) - Focus on biodegradability (e.g. Dutch packaging tax) (NL/EU)
12.	Paper recycling instead of incineration of waste wood for energy recovery	200 Mton (max.)	+ Recycling targets (NL/EU) - Subsidies for energy sector to use this as energy source (NL)
13.	Production of particle board Instead of incineration of waste wood with energy recovery	6 Mton (max.)	+ Recycling targets (NL) - Subsidies for energy sector to use this as energy source (NL)

	Cascading option	Benefit in CO_2/year (Mton)	Influence of current policy (+ → stimulates the cascading option, - → hampers the cascading option)
4.	Chemicals from waste fats	6.5 Mton (max.)	+ Double counting of second generation biofuels, generating a shift from low-efficiency use to biofuels (NL/EU) - No level playing field between chemistry and fuels (NL)
11.	Additional recycling of paper	50 Mton	+ Recycling targets (NL/EU)
Examples of 'cascading in value'			
1.	Straw utilisation for ethanol production	123 Mton (max.)	+ Double counting of second generation biofuels (NL/EU) - Subsidies for use of straw for bio-electricity (NL)
3.	Anaerobic digestion and processing of manure	50 Mton (max.)	+ Subsidies for biogas (NL) - Laws which complicates the use of digestate as fertilizer (EU)
6.	CO_2 as feedstock in greenhouses	3 Mton (max.)	- Lower gas price for greenhouses (NL)
7.	Bio-cokes for chemistry	1.8 Mton (NL) – 9 Mton (EU)	- Subsidies for energy sector to use this biomass for electricity production (NL)
8.	CHP vs. small scale bio-energy prod.	17 Mton (max.)	- Subsidies higher for bio-electricity and lower for bio-heat (NL)
9.	Electricity and heat production from bio-waste	19.2 Mton (max.)	+ Landfill bans and taxes (NL)
Examples of 'cascading in function'			
5.	Grass refinery	31.6 Mton (protein to feed) 60 Mton (protein to food)	- Subsidies for energy sector to use this as energy source (NL)

In these figures the paper and particleboard cascades, which together account for an additional emission of 206 Mton CO_2 when all recycling is eliminated, but which are not emissions which are currently occurring, are omitted. They are very important to include in policy discussions because of current energy policies.

It is a major transition from a fossil economy to a bio-based economy. This transition demands collaboration of various stakeholders in previously unrelated sectors, changes in infrastructure, maybe a change in consumer behaviour because of possible changes, but most definitely governmental policy which creates a level playing field. Other topics important in future policy are the introduction of sustainability criteria for all sectors in the bio-based economy and withdrawing policy which hampers cascading. It is important for all stakeholders to realize that choices must *and can* be made by different stakeholders on different levels and in different phases of the life cycle or chain. We hope that this both theoretical and practical exploration will help the discussion concerning cascading in the bio-based economy.

Samenvatting

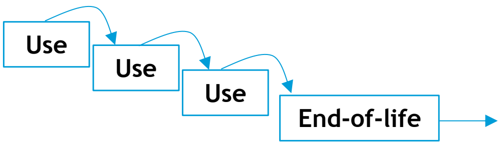
Milieu, en specifiek het broeikaseffect, staan hoog op de duurzaamheids-agenda van Nederland en Europa. Het versterken en uitbreiden van de 'biobased economy' wordt gezien als een goede manier om milieu-impacts te reduceren en broeikasgasemissies te verminderen. Ook het opraken van niet-hernieuwbare (fossiele) grondstoffen en de wens om meer zelfvoorzienend te zijn, zijn belangrijk redenen om over te schakelen van fossiele grondstoffen naar biogrondstoffen. Dit rapport 'Cascading of Biomass, 13 Solutions for a Sustainable Bio-based Economy' maakt onderdeel uit van een samenwerkings-verband tussen het Planbureau voor de Leefomgeving (PBL) en CE Delft; in februari 2012 publiceerde het PBL, in samenwerking met CE Delft, de notitie 'Sustainability of biomass in a bio-based economy' (PBL, 2012). Het huidige rapport is een vervolg op die studie.

In dit rapport wordt het concept 'cascadering' onder de loep genomen en laten wij zien dat cascadering van houtige biomassa, van reststromen uit de landbouw en de industrie en van afval (allen op basis van Europese beschik-baarheid en dus vertaald naar de bijdrage aan Europese doelstellingen), een significante bijdrage kan leveren aan een duurzame Europese economie. Ten opzichte van de huidige emissies (2010) moeten de broeikasgasemissies nog 1.371 Mton CO_2-eq. per jaar lager zijn volgens de Europese CO_2-reductie-doelstellingen voor 2030. De biomassa cascaderingsopties die in deze studie zijn doorgerekend kunnen voor bijna 30% bijdragen aan het behalen van deze doelstellingen in 2030.

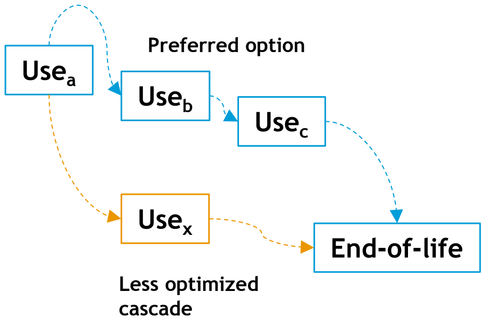
Omdat we ons gericht hebben op bovengenoemde biomassastromen zijn de levenscyclusfasen met betrekking tot verwerking, gebruik en de verwerking na het einde van de levensduur van belang. Uit recente literatuur, gebruikt in deze studie, blijkt dat de beschikbaarheid van residuen - een belangrijke biomassastroom in deze studie - groter is dan aangenomen in de eerdere PBL-notitie (PBL en CE, 2012).

Er circuleren verschillende definities met betrekking tot cascadering. Deze kunnen onderverdeeld worden naar drie types. Hierbij zijn twee aspecten van belang. Ten eerste gaat het om het maken van *keuzes* tussen verschillende toepassingen. Omdat de keuze voor een specifieke toepassing de mogelijk-heden later in de keten beïnvloedt, is een *ketenbenadering* belangrijk. Deze drie types van cascadering sluiten elkaar niet uit; ze vullen elkaar aan en het is zelfs mogelijk dat toepassing van al deze verschillende manieren van cascadering nodig is om de totale milieudruk over de gehele keten te minimaliseren.

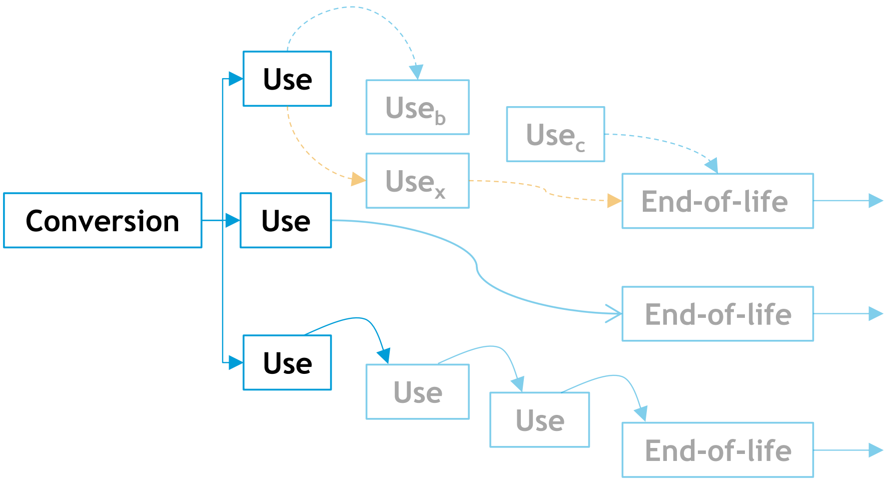
1. *Cascadering in de tijd*
   Hierbij wordt biomassa herhaaldelijk gebruikt, dit zorgt voor een langere levensduur van de biomassa. Gebruik van biomassa in de toepassing die de meeste mogelijkheden openlaat aan het einde van de levensduur heeft de voorkeur. Bij dit type cascadering komt duidelijk de ketenbenadering naar voren. Papierrecycling is daarvan een goed voorbeeld (zie ook Hoofdstuk 3).



2. *Cascadering naar waarde*
   Hierbij wordt biomassa gebruikt in de toepassing met de grootste toegevoegde waarde (economisch, milieukundig of anderszins). Dit type cascadering benadrukt het 'keuze-aspect; niet elke toepassing is even waardevol. Een voorbeeld van cascadering naar waarde is het gebruik van stro voor de productie van ethanol voor gebruik in de chemie (zie Hoofdstuk 3).



3. *Cascadering in functie*
   Hierbij wordt biomassa door middel van coproductie gescheiden in verschillende functionele componenten (bijvoorbeeld eiwitten en suikers), waarvan de opgetelde waarde hoger is dan de waarde van de oorspronkelijke biomassa. Bioraffinage is een methode om cascadering in functie toe te passen, grasraffinage is een typisch voorbeeld. Hierbij wordt uit gras o.a. eiwitten, suikers en vezels gewonnen (zie Hoofdstuk 3). Voor een optimaal resultaat over de gehele keten wordt cascadering in functie gevolgd door cascadering in tijd of waarde; cascadering in functie 'produceert' functionele stromen die vervolgens ergens ingezet kunnen worden.



In dit onderzoek zijn dertien opties voor cascadering van biomassa onderzocht die zijn gekozen op basis van bestaande kennis binnen CE Delft, literatuur-onderzoek en suggesties van de begeleidingscommissie. De opties leveren een grotere klimaatwinst op door efficiënter gebruik van dezelfde hoeveelheid biomassa.

De opties passen in het huidige Europese beleid ten aanzien van optimalisatie van (her)gebruik van materialen en energieterugwinning uit afval.
Twee opties zijn bijzonder; papierrecycling en het gebruik van afvalhout voor spaanplaat. In deze gevallen is de voornaamste huidige toepassing al gecascadeerd; papier wordt gerecycled tot papier en afvalhout verwerkt tot spaanplaat. Vrij recent is echter de beleidsfocus op energieterugwinning. Een effect hiervan kan zijn dat papier en afvalhout niet meer gerecycled wordt, maar gebruikt wordt voor bio-energie, wat leidt tot een slechter milieu-resultaat.
Voor alle opties is de potentiele klimaatwinst berekend en zijn de volgende aspecten onderzocht:
- het aanbod van dat type biomassa;
- de stand van zaken van de technologie;
- de marktvraag m.b.t. de producten.

Technologische ontwikkeling is een belangrijke factor voor verdere ontwikkeling van meerdere cascaderingsopties, maar wordt sterk beïnvloed door overheidsbeleid (stimulering of wetgeving).

In Tabel 2 is de lijst met cascaderingsopties weergegeven (het nummer komt overeen met de volgorde in Hoofdstuk 3, waarin de opties gegroepeerd zijn naar type biomassa). Ook de CO_2-winst en beleid dat invloed heeft op de opties is weergegeven (met een '+' wordt aangegeven welk beleid de cascadering stimuleert, met een '-' beleid wat de cascadering ontmoedigt). Voor de opties is enkel het additionele effect berekend. Dit betekent dat dubbeltelling wordt voorkomen; als verbranding met energieterugwinning nu al wordt toegepast wordt dit niet als CO_2-winst geteld.

De totale en maximaal haalbare CO_2-winst ligt tussen 332 Mton en 407 Mton CO_2-eq. per jaar. De hogere waarde moet beschouwd worden als een optimistische inschatting. Deze CO_2-winst kan worden vertaald naar een percentage van de CO_2-doelstelling voor Europa. In 2030 moet er 2.235 Mton CO_2-eq. per jaar minder worden uitgestoten dan in 1990; bovengenoemde cascaderingsopties kunnen daar van 10 tot 12% aan bijdragen. Het huidige klimaateffect van papierrecycling en gebruik van afvalhout in spaanplaat (samen 206 Mton CO_2-eq. per jaar) zijn hierin niet meegenomen. Deze twee ketens zijn belangrijk om in de gaten te houden omdat het overheidsbeleid momenteel optimale cascadering ontmoedigt.

77% van de potentiële CO_2-winst in Europa wordt gerealiseerd door vier opties:
- bio-ethanol uit stro, toegepast in de chemie;
- biogas uit mest;
- grasraffinage;
- optimalisatie van papierrecycling.

Tabel 2 De cascaderingsopties, hun CO_2 winst en de invloed van beleid (Nederlands en Europees)

	Cascaderingsoptie	CO_2-winst per jaar (Mton)	Invloed van huidig beleid (+ stimuleert de cascaderingsoptie, - → ontmoedigt de cascaderingsoptie)
Voorbeelden van cascadering in tijd			
2.	Bio-ethanol (uit stro) naar de chemie	30 Mton (max.) - (additioneel aan optie 1)	- Biobrandstof verplichtingen (EU) - Dubbeltelling van tweede generatie biobrandstoffen (NL/EU)
10.	Recycling van (extra productie van) bio-plastics	0.3 Mton (bij recycling van huidige productie van bio-plastics) 40 Mton (bij substitutie van 30% van de huidige conventionele plastics voor bio-plastics, en recycling hiervan)	+ Doelstellingen m.b.t. plasticrecycling (NL/EU) - Focus op biologisch afbreekbare verpakkingen (bijv. de Nederlandse verpakkingen belasting) (NL/EU)
12.	Papierrecycling (i.p.v. gebruik voor energietoepassingen)	200 Mton (max.) (*verlies*, indien papierrecycling vervalt)	+ Recycling doelstellingen (NL/EU) - Subsidies voor de energiesector (NL)
13.	Productie van spaanplaat (i.p.v. gebruik voor energieterugwinning)	6 Mton (max.) (*verlies*, indien spaanplaatproductie vervalt)	+ Recycling doelstellingen (NL) - Subsidies voor de energiesector (NL)
4.	Chemicaliën uit afvalvetten	6.5 Mton (max.)	- Dubbeltelling van tweede generatie biobrandstoffen (NL/EU) - Geen gelijk speelveld tussen de chemie en de energie sector (NL)
11.	Optimalisatie van papierrecycling	50 Mton	+ Recycling doelstellingen (NL/EU)
Voorbeelden van cascadering in waarde			
1.	Productie van bio-ethanol uit stro	123 Mton (max.)	+ Dubbeltelling van tweede generatie biobrandstoffen (NL/EU) - Subsidies voor het gebruik van stro voor bio-elektriciteit (NL)
3.	Biogas uit mest	50 Mton (max.)	+ Subsidies voor biogas (NL) - Regelgeving die het gebruik van digestaat in de landbouw compliceert (EU)
6.	CO_2 als grondstof in kassen	3 Mton (max.)	- Lage aardgasprijs voor kassen (NL)
7.	Bio-cokes in de chemiesector	1.8 Mton (NL) - 9 Mton (EU)	- Subsidies voor de energiesector m.b.t. gebruik voor productie van bio-elektriciteit (NL)
8.	WKK (i.p.v. decentrale bio-energie productie)	17 Mton (max.)	- Hogere subsidies voor bio-elektriciteit dan voor bio-warmte (NL)
9.	Elektriciteit en warmte uit GFT-afval	19.2 Mton (max.)	+ Stortverbod en belastingen op afval (NL)

	Cascaderingsoptie	CO_2-winst per jaar (Mton)	Invloed van huidig beleid (+ stimuleert de cascaderingsoptie, - → ontmoedigt de cascaderingsoptie)
Voorbeelden van cascadering in functie			
5.	Grasraffinage	31.6 Mton (eiwitten naar voeder) 60 Mton (eiwitten naar voedsel)	- Subsidies voor de energiesector voor gebruik als energiebron (NL)

De transitie van een fossiele naar een biobased economy vergt een gezamenlijk optreden van actoren uit voorheen gescheiden sectoren, veranderingen in infrastructuur, mogelijk aanpassingen in consumentengedrag (door veranderingen in bijvoorbeeld voedselaanbod), maar vooral beleid dat een gelijk speelveld creëert en het meest optimale gebruik van biomassa stimuleert.

1 Introduction

1.1 Cascading in the bio-based economy

As part of their sustainability agendas, the Netherlands, the EU and other countries view the 'bio-based economy' as an adequate and viable way to reduce their environmental impacts, specifically their greenhouse gas emissions, and to create economic opportunities and spur innovation. Apart from the obvious use of biomass for food and feed, biomass can be used to produce energy (electricity or heat) or energy carriers (e.g. biogas or liquid bio-fuels for transport), materials and also chemicals, and thereby replace fossil-based resources. These are the purposes which represent the bio-based economy (BBE) and which the Dutch government would like to see increase in the future.

It is now becoming clear that the supply of produced biomass is constrained by sustainability issues (e.g. loss of biodiversity) and by the aim not to compete with the food sector. So the question is: 'What are the best places in the economy where biomass should be used?' And 'Can the same biomass be used a number of times by recycling or cascading of options?' In short: what is good use of biomass? At this point in time, around 13% of the global energy use is supplied from renewable (not necessarily sustainable) sources. Biomass is responsible for over 75% of this amount, of which almost 90% consists of woody biomass. Burning biomass in a traditional way to produce heat and/or power is the main technique used.
To a limited (but increasing) extent, liquid biofuels for the transport sector are being produced from agricultural crops. Biomass is also being used in the chemical sector (for example for making soap), the paper sector and as an end-product (such as construction material for the building trade). Long-term global analyses concerning agricultural residues and forest residues show that it is possible to develop biomass potential amounting to some 100 EJ from these sources (IPCC, 2011 and WBGU, 2008). This is 20% of the current global energy consumption.

The Netherlands is expected to be able to produce between 101 and 157 PJ (quantified in avoided use of fossil fuels) of biomass in the year 2020, which mainly concerns woody residues, manure and the bio-segment of mixed waste flows. This translates to 3.4-5.3% of primary energy use in 2020 (Koppejan, 2009). To reach the obligation of 20% renewable energy in 2020, or 410 PJ, The Netherlands will have to depend on import of sustainable biomass to reach its obligations. PBL/CE Delft earlier reported (PBL and CE, 2012) that Europe should be able to produce half of its own biomass demand, and import the other half.

Because biomass can be used to substitute for fossil sources, it may have certain advantages; lower resource dependency, in theory a closed cycle of CO_2 emissions and no depletion of fossil resources. Use of biomass can, however, also result in undesired environmental impacts: e.g. no or negative CO_2 reduction because of indirect land-use change (ILUC) and loss of biodiversity. The goal of a bio-based economy should be to have as low an environmental impact as possible. This study explores the opportunities within a bio-based economy for applying 'cascading'. Chapter 2 will show that cascading can be interpreted in different (partially complementary) ways, the most common one, and most central to the concept, being the subsequent use in time of biomass for different purposes. As earlier work by CE Delft and PBL has shown (PBL and CE, 2012) cascading is one of the options that deserve attention in the quest for deciding the approach that needs to be taken to achieve an efficient and sustainable bio-based economy.

1.2 Goal

The PBL Note on the sustainability of biomass in the bio-based economy showed that for the EU, the sustainable biomass supply can meet 10% of the final energy and feedstock demand in 2030. This might increase to 20% under optimistic scenario assumptions (PBL and CE, 2012). The goal of this study is to explore the concept of cascading and to get a better understanding of the opportunities for cascading within the bio-based economy. Furthermore, the potential scale and subsequent impact on scenario results will be evaluated. This will give an indication of the amount of primary production and associated environmental impacts which can be avoided, which will be linked to the scenario results from the PBL/CE Delft study. Policy focused on optimal cascading may result in more 'optimistic' scenario assumptions. The main research questions in this study are:
1. What is cascading within the bio-based economy?
2. What are substantial cascading option within the bio-based economy?
3. What is the potential contribution of cascading in the bio-based economy?
4. How can policy contribute to implementation of sustainable cascading in the bio-based economy?

The goal of cascading within the bio-based economy is to create a sustainable system in which biomass is used efficiently and effectively and in which cascading options are optimally implemented. Cascading is just one of the options to improve the bio-based economy (BBE). The main important options are:
- sustainable production of biomass;
- more efficient conversion of biomass;
- energy and material use reduction by design e.g. better insulation of buildings;
- **use of waste and by-products;**
- **use of biomass for sector/products where biomass has the highest added value (economic, environmental, social);**
- **bio-refinery.**

The latter three options will be explored in this cascading study. This does not mean the first three options are not important, but that they deserve separate attention and, like cascading, could further improve the bio-based economy.

When evaluating cascading options it is important to identify the possible reference systems and their environmental impact. In line with LCA-rationale; it is important that no problem-shifting takes place. Numerous questions relating to the use of biomass come to mind:
- What is the type of biomass used, e.g. virgin, by-products from processing, or waste?
- Where does the biomass originate?
- Are nutrients recycled back in the system?
- To which phase of the life-cycle does the cascading option apply, e.g. primary production or waste treatment?
- What is the time-frame of the option?
- What are the indirect effects of the practice, e.g. ILUC or substitution of virgin materials?

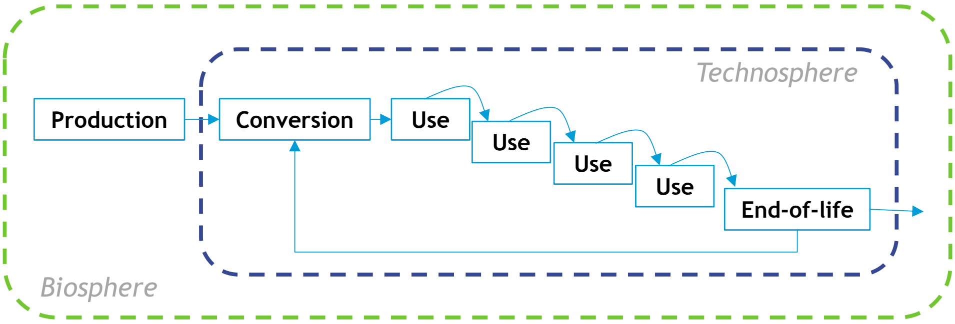
– What is the value (either economically or societally) of the cascading option and its alternatives?

Evaluation of cascading options will illustrate the importance of taking a systems perspective, as the questions related to use of biomass above indicate. Furthermore, the possible potential of making different chain-choices will be elaborated on as well as the possible barriers to implementation, especially those that are policy related. Current policy may or may not favour the options which score best on reduction of environmental impact. Suggestions for environmental policy geared towards best-scoring cascading options will be elaborated on.
It is a major transition from a fossil economy to a bio-based economy. This transition demands collaboration of various stakeholders in previously unrelated sectors, changes in infrastructure, maybe a change in consumer behaviour, but most definitely governmental policy which creates a level playing field. This study will show how policy can contribute to sustainable cascading in the bio-based economy.

1.3 Scope

The PBL/CE Delft study on sustainability of biomass in a bio-based economy showed that potential sustainable biomass supply may be limited in the EU to somewhere between 10 and 20%. Therefore, it is important to explore smart and innovative ways of using biomass; cascading is one of those ways. Cascading is not necessarily a new concept; recycling of plastics combined to incineration with energy recovery at the end-of-life is standard practice in the Netherlands. This means the biomass, or the feedstock, is put to use more than once, maximising chain efficiency, as illustrated in Figure 1. In this study, the following biomass streams are considered: woody biomass, agricultural residues and processing residues and wastes.

Figure 1 **Cascading illustrated in the biomass production and utilisation chain**

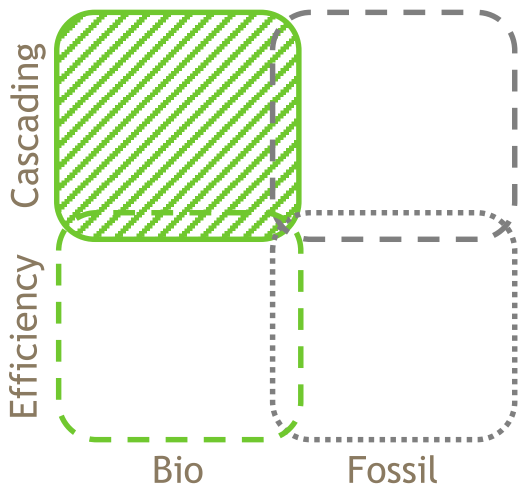


There are numerous practices which reduce resource requirements and have environmental benefits relative to current practices, but which do not fit into the scope of the current study. Examples are: insulation of houses, green energy, more efficient cars, commuting by public transport or by bike instead of by car, a vegetarian lifestyle. Furthermore, central to the bio-based economy, crop yields could be increased significantly in certain regions, e.g. due to technological development. This study does not, however, aim to explore everything which is 'good' or 'better' from an environmental point of view. It aims to explore how cascading can contribute to a bio-based economy, and will therefore focus on the 'conversion', 'use' and 'end-of-life' phases of the life cycle. Even though production is not of primary concern, indirect land use change (ILUC) effects will be taken into account because of their importance on total impact of biomass use. The results will show what the environmental benefits of cascading within a bio-based economy could be, and the policy measures which can be taken to achieve the most effective situation.

Cascading is an option for both the bio-based and the fossil economy

Cascading is an option for the fossil economy as well as for the bio-based economy, and is applied in the current economy. Recycling of plastics, combined heat and power production in gas fired power stations and energy production based on plastic waste are all fossil cascading options. In a number of cases such fossil cascading is mixed with bio-cascading. For example the recycling of fossil PET mixed with PlantPET, the energy production from municipal waste or the use of waste heat from a bio/coal power plant. Furthermore, in both the bio-based economy and the fossil economy, gains in efficiency (of e.g. production processes) can be made. The overlap between the bio-based economy and the fossil economy and between cascading and efficiency gains are illustrated by Figure 2.

Figure 2 **Overlap between the bio-based economy, the fossil economy, efficiency gains and cascading**



Cascading within the bio-based economy will be the focus of this study. It is almost impossible to strictly exclude cascading in the fossil economy and efficiency gains in the bio-based economy. As illustrated by Figure 2, there is overlap between the bio and fossil economy, and between efficiency and cascading. When options include fossil components or links to efficiency measures, as is expected, this will be elaborated on.

Efficiency potential of the fossil economy is explicitly excluded in this study. Food is the main biomass application. This sector is, however, usually excluded from the definition of the bio-based economy, partially because of its importance, partially because of the relative size of the sectors. Several interesting cascades and efficiency gains could be made within the food sector, which could have far-reaching environmental benefits. These options are beyond the scope of the current study, however, some interesting issues will be mentioned, when it relates to the cascade cases discussed here.

1.4 Contents

This study will elaborate on the concept of cascading and will evaluate interesting cascading cases. In Chapter 0 a number of relevant cascading concepts and innovation concepts with strong links to cascading will be introduced. These concepts will help identify the key topics concerning sustainable cascading in the BBE. In Chapter 3 thirteen interesting cascading cases will be discussed, as well as their potential contribution to the BBE in 2030 in terms of CO_2 reduction potential. The technical background to the cascading cases is given in Annexes A, B and C. In Chapter 4 policy that concerns the bio-based economy and which could influence cascading, will be discussed. The conclusions from the case studies will be linked to current policy measures. This chapter will conclude with a set of suggestions to policy makers regarding changes to policies and additions to policy which can stimulate sustainable cascading in the future bio-based economy.

2 Cascading in the bio-based economy

2.1 Introduction

Cascading can be interpreted in different ways. In general it is regarded as the efficient subsequent use (in time) of (e.g.) biomass for different purposes (Dornburg, 2004). An example is the use of biomass to produce bio-plastics which can be recycled after use and incinerated with energy recovery when recycling is no longer an option. PBL defines cascading as postponing the time at which the biomass is incinerated (with the object of energy recovery) as long as possible (PBL, 2010), while first using it in the food industry, the feed industry and the chemical industry. Or put differently; using it in higher value applications first (PBL, 2009). This is corroborated by the Dutch Ministry of Economic affairs, Agriculture and Innovation in their 'Hoofdlijnennotitie' Biobased Economy (Ministerie van EL&I, 2012). Cascading is sometimes interpreted as bio-refining, in which several products are made from one biomass source. The term bio-refinery is used as a label for a wide range of activities which have in common that biomass is separated into different functional components, which can be used as feedstock or directly as products (CE, 2006). In this case the cascade does not refer to the subsequent use over time, but dividing a source into different products at one point in time. The question is whether these interpretations are inherently different, mutually exclusive or complementary. As will be shown in the following sections and summarized in the Section 2.4, these ideas are complementary and are *not* mutually exclusive.

2.2 Cascading concepts

As the diverse interpretation of cascading mentioned above shows, cascading needs to be more specifically defined. Furthermore, as cascading is proposed as a method to achieve a more efficient bio-based economy, in which sustainability is an important aspect, special attention needs to be given to sustainable cascading. Lansink's Ladder and Moerman's Ladder provide interesting input into the discussion of what cascading should look like within the BBE. When given a choice of what application to choose for biomass, they order these options on preferability.

2.2.1 Lansink's ladder

This cascade of waste treatment options was originally designed by Ad Lansink, member of the Dutch House of Representatives in 1979. It is, in extended form, included in the Dutch National Waste Treatment Plan (VROM, 2007) and also similarly in the European Waste Directive (EU, 2008). The options for waste treatment are mentioned in order of preferability and thus provide a cascade. Therefore, they are useful for biomass sources other than waste.

- reduce or prevent formation of waste;
- design for sustainability; minimise environmental impact at end of life;
- reuse of product;
- recycling of material;
- incinerate with the purpose of energy production;

– burn;
– landfill.

2.2.2 Lansinks' Ladder specified for biomass

Lansink's Ladder was translated to a cascade of options specifically catered to biomass, often mentioned as 'Moerman's Ladder' (LNV, 2010). The first four options of the ladder refer to the food-part of the biomass economy. Food and feed are usually not included in the concept of the bio-based economy, but they are important to take into account because of the high societal value of food and feed. In the Hoofdlijnennotitie Bio-based Economy it is acknowledged that sustainability issues concerning food and the bio-based economy should be part of future assessments (I&M, 2012).
Furthermore, it is important to ascertain whether practices fall within the food-for-fuel debate or the food vs. feed debate.

Options in the food and feed economy:

1. Prevent food losses.
2. Use as food.
3. Convert to food.
4. Use as feed.

Options in the bio-based economy:

1. Provide input in the bio-based economy.
2. Process to produce fertiliser by fermentation (and produce energy).
3. Compost to produce fertiliser.
4. Produce energy or energy carrier.
5. Incinerate (and produce energy).

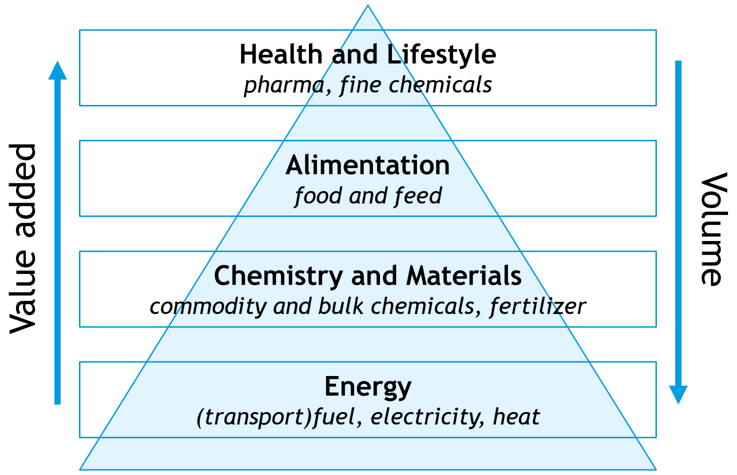
Least desirable option:

6. Landfill.

2.2.3 Value

Both Lansink's Ladder for waste treatment and Moerman's Ladder for biomass use list options in order of preference. Part of the rationale is that biomass (or some other material in the case of waste treatment) may still be used in an application lower on the list after use in a higher value purpose first. If not as a material or product, then at least to produce energy (e.g. biogas from manure). Value could be said to be highest when as many options as possible for subsequent use are left open. This means value may not be always be economic value, although it very often is. Policy may, however, frustrate market trends or equilibria, resulting in e.g. the food vs. fuel debate.

Figure 3 Value pyramid



Based on Ministerie van LNV, 2007.

The demand volumes of different applications of biomass are linked to the added value in Figure 3, which shows that the economic value is higher for the smaller volumes involved in the top of the cascade and lower for the larger volumes at the bottom. Sustainability is, however, always a function of social, economic and environmental factors – summarized by the 3P approach: *People*, *Planet* and *Profit* are all relevant aspects of sustainability. The products at the top of the pyramid may be higher in economic value, but because the goal is to be as sustainable as possible when following the cascades, *People* and/or *Planet* may overrule *Profit*. This is also illustrated by Moerman's Ladder where use of biomass in food and feed applications is deemed more valuable than use in the bio-based economy.
The food-for-fuel debate illustrates this point; policy designed with the object of creating a more sustainable energy system in developed countries shifted the rows as shown in the pyramid in Figure 3. Biofuel from 1st generation biofuel sources may have been one of the causes of increased food prices in certain cases, something which is especially problematic in developing countries. It shows the necessity of always considering people, planet and profit aspects in sustainability issues where value is artificially assigned by e.g. policy.

On the other hand, people, planet and profit interests may coincide. One of the approaches that can be taken in determining the value of biomass is functionality. Bio-refinery (elaborated on in Section 2.3.2) may provide ways to extract as much value as possible from a biomass source in the conversion phase, resulting in the production of different products at the same time, maximising value. Through bio-refinery, biomass can be separated into different functional groups, e.g. sugar, oil, protein and other carbohydrates. These can all fulfil different purposes, e.g. they can serve as input for the production of chemicals or can be used as an energy source. If the original function of the biomass can be sustained (e.g. fertilisation by manure), while others are added (e.g. production of biogas from manure) bio-refinery can help optimize biomass systems.

Value of energy (exergy)

An approach to establish value which is interesting when biomass is used as an energy source is the concept of exergy. Energetic applications can be placed in a similar pyramid as shown above. Not all 'Joules' are equal; e.g. low temperature heat is not as useful or valuable as high temperature steam. Exergy refers to available energy and is, like energy, expressed in Joules. In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. The exergy of high temperature steam is higher than of low temperature heat, and can therefore do more work per Joule.

Exergy studies often warn that use of natural gas for heating houses (the standard in the Netherlands) is exergetically very inefficient. Even if the energetic efficiency of burning natural gas for heating of households is 100%, the exergy efficiency factor of this process is only 24%[1]. Use of natural gas to heat houses can be made much more exergy efficient if electricity and heat are co-produced (e.g. a combined 40% electricity efficiency and 40% heat efficiency leads to an efficiency of 50%[2], thereby doubling the exergy efficiency). Because heat is of lower value than electricity, cascading heat leads to a big improvement in de exergy efficiency. Similar to using functionality to determine the value of biomass for use in products, exergetic value can be used to determine the most effective use, energetically.

2.3 Innovation in the bio-based economy

As pointed out by various experts, institutes and government visions, the bio-based economy demands is a transition in which several stakeholders play important roles (Ministerie van EL&I, 2012; Ministerie van LNV, 2007; Annevelink, 2010). Innovation on different levels can stimulate sustainable cascading in the
bio-based economy. Cascading is not a new concept. Cascading within the bio-based economy, however, needs cooperation between previously relatively unconnected sectors; e.g. the chemical industry, energy companies, agriculture, waste treatment industry and the food industry. Policy can help create a level playing field between sectors and at the same time stimulate sustainable use of biomass.
Three interesting examples of innovation which could stimulate sustainable cascading are elaborate on in Sections 2.3.1, 2.3.2 and 2.3.3; Industrial Symbiosis as an example of system innovation, Bio-refinery as an example of process innovation and Cradle to Cradle as an example of product innovation. These examples of innovation illustrate the grey area between cascading in the bio-based economy and increasing efficiency; they create a greater chain or system efficiency, partially by making cascading easier. Government can play an important role in stimulating these concepts by giving subsidies, stimulating investment in R&D and creating policy which either obligates or does not hamper such practices.

2.3.1 Industrial symbiosis

Industrial symbiosis is the sharing of resources and/or services and the exchange of waste streams and/or by-products by industries. This can take place in an eco-industrial park, which is an example of Industrial Ecology (Kalundborg Symbiosis, 2012). By physically linking these industries so they can exchange waste streams and by-products, the whole system (the set of industries) is made more efficient and the environmental performance is enhanced. Furthermore, it can have extensive economic benefits because of reduced costs for e.g. waste-disposal, transport and resources. The concept of

---

1 The exergy value of natural gas is 100% because of the possibility to use it for all kinds of options. The exergy efficiency of heat is calculated by dividing the temperature change over the absolute temperature $\frac{\Delta T}{T} = \frac{90-20}{20+273} = 24\%$.

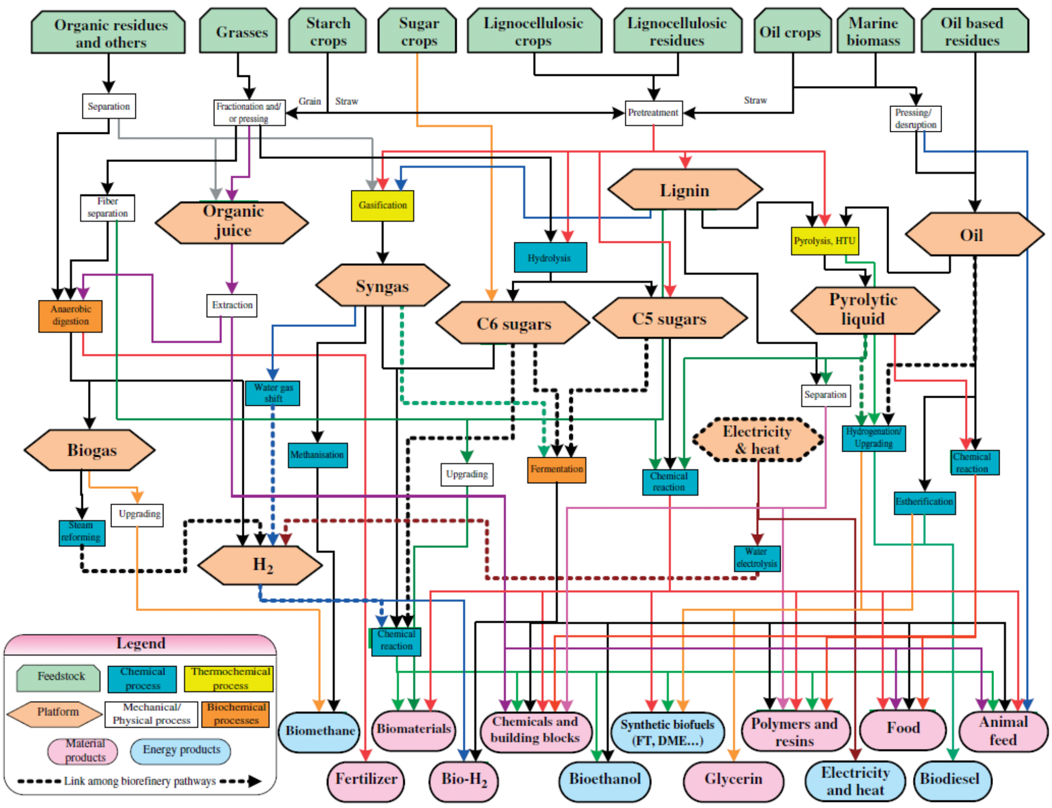
2 The exergy value of electricity is 100%. Combining heat and electricity results in an exergy efficiency of $40\% + 40\% \cdot \frac{90-20}{20+273}$=50%.

industrial symbiosis is important for a bio-based economy in which cascading is to play a significant role; cascading implies subsequent use of a material and in order to do this optimally a perspective beyond the scope of a single initial industry is essential. Furthermore, geographic concentration of such practices reduces transportation costs and infrastructure costs.

2.3.2 Bio-refinery

Bio-refinery is not a new concept, but has been gaining attention in recent years as an potential important component of a future bio-based economy. The term bio-refinery is used as a label for a wide range of activities which have in common that biomass is separated into different functional components, which can be used as feedstock or directly as products (CE, 2006). Important to keep in mind is that bio-refinery is not one technology applied to one feedstock. This is illustrated in Figure 1, which shows different bio-refinery routes with a focus on energy (Cherubini et al., 2009). There are different types of biomass that can serve as feedstock, different conversion methods, several intermediates (which can be reached from a number of feedstocks), and a range of possible products. Figure 4 is purely meant to illustrate this complexity of bio-refinery options.

Figure 4 Network of different bio-refinery systems



Source: Cherubini et al., 2009.

Feedstock can be either a dedicated feedstock or a residue. Concerning policy it may be important to distinguish between primary feedstock (harvest from agriculture, aquaculture or forestry), secondary feedstock (processing wastes) and tertiary feedstock (such as consumer wastes). Feedstocks have different characteristics, i.e. different concentrations of functional components. Dedicated crops, i.e. sugar crops, starch crops and oil crops, have a relatively high concentration of sugar, starch, oil or protein. Green biomass, such as

grass or agricultural residues such as leaves, consists mostly of water, cellulose and hemicellulose. Lignocellulosic biomass, such as wood and straw, consists mostly of cellulose, hemicellulose and lignin. Aquatic biomass does not contain lignin, only a little cellulose and mostly oils, fatty acids, protein and sugars (WUR, 2010a). Through different mechanical, chemical, biochemical and thermochemical processes, and via different intermediates (or platforms, see Figure 4) a range of products can be obtained, as shown in Figure 4 (Cherubini et al., 2009).
As stated above, bio-refinery is not new; conversion of sugar crops to produce sugar along with a high-protein by-product which can be used as feed is bio-refinery too. Concerning its role in the bio-based economy, the focus is on the production of products other than food; e.g. energy and materials or feedstock for the chemical industry. Interesting is that the IEA includes sustainability in their definition; in the opinion of the IEA Bioenergy Task 42, 'Bio-refinery' can be regarded as *the sustainable processing of biomass into a spectrum of marketable products and energy* (IEA Bioenergy Task 42, p. 4). Many researchers, stakeholders and institutes do indicate that bio-refinery will play a major role in the transition towards a sustainable bio-based economy (Ministerie van LNV, 2007; Annevelink, 2010).

2.3.3 Cradle to Cradle

Cradle to Cradle was developed and commercialised by Michael Braungart and William McDonough and received quite a lot of attention in The Netherlands. Cradle to Cradle focuses on eco-efficacy instead of eco-efficiency. The goal of eco-efficiency is to reduce, avoid, minimise and prevent waste and/or environmental impact. Eco-efficacy intends to optimise. Design of products within the Cradle to Cradle concept should be such that waste can serve as input to other processes or products. It also aims at linking the technosphere and the biosphere in a sustainable way; nutrients which are extracted from the biosphere should return there in a useful form. Recycling as it is currently practised is often defined as 'down-cycling' by Cradle to Cradle; the product made from waste is less valuable that the original product. Cradle to Cradle aims at a system in which materials are 'truly' recycled and in which 'waste is food' (EPEA, 2012).

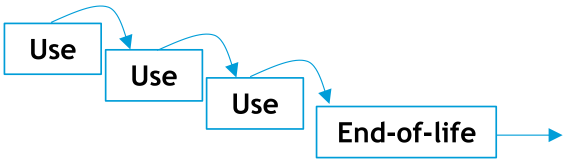
2.4 Conclusions – a strategy for sustainable cascading

As the first-generation biofuels have shown, when substituting biomass for fossils in any part of the economy, care should be taken to ensure that it helps reach those goals of a more sustainable society. Government policy, through subsidies or obligations, can influence value; obligations in the transport fuel sector may pull biomass away from sectors where the biomass can be cascaded and the whole chain would be more sustainable. A 'Sustainable Cascading Strategy' should help create transparency when it comes to choosing an application for biomass and will help policymakers create policy which is geared toward minimising environmental impact. The main goal of applying cascading is achieving an environmental impact which is as low as possible. The goals you want to achieve with cascading do not differ from general optimising principles for the bio-based economy; cascading is a mean, not a goal. It is, however, important to keep in mind that relative environmental impact and costs may change over time. Technological development in the reference system, (depreciation of) CO_2 mitigation costs, market prices and yields of biomass production (Dornburg, 2004) can influence results.

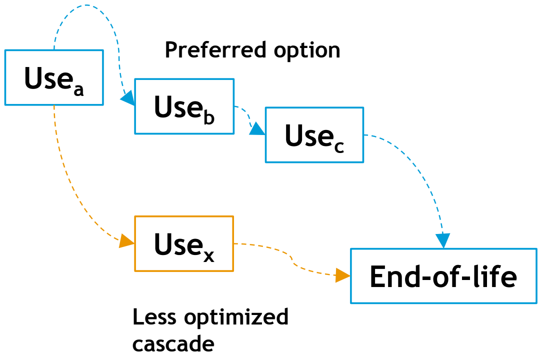
The previous sections show that different definitions of cascading circulate. Two topics are of key importance. Firstly, cascading is about making *choices* between different applications. Secondly, because the choice for a specific application influences future possibilities, a *chain approach* is necessary.

These definitions are not mutually exclusive, in fact, it may be necessary to incorporate all three to ensure the best environmental performance.

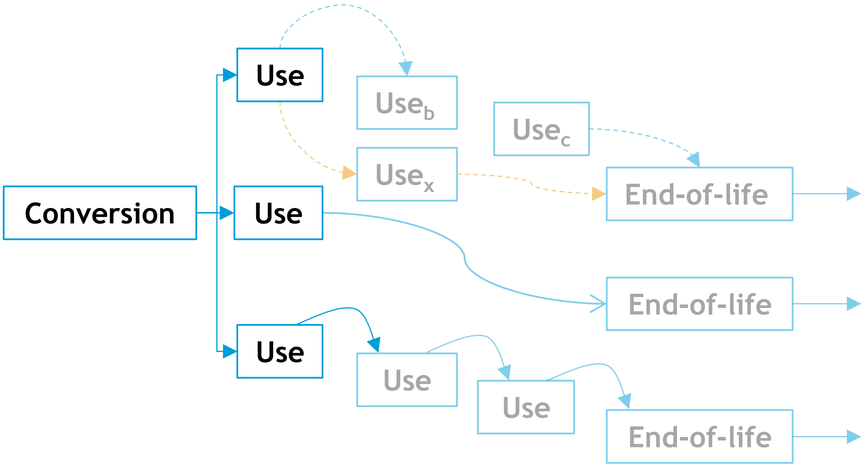
1. *Cascading in time*
   Subsequent use in time ensures a long(er) life span of the biomass; the option which leaves as many options at the end-of-life open, should be preferred. A typical example is paper recycling.



2. *Cascading in value*
   Cascading in time can be optimised by cascading in value to ensure the highest value possible is achieved when choosing between alternatives, and the value over the whole life cycle is maximised. An example is use of straw for ethanol production (which can subsequently be used to produce e.g. plastics), which provides benefits with respect to the original function.



3. *Cascading in function*
   What people call 'cascading in function' is actually co-production, which can be achieved by using bio-refinery. Co-production is the production of different functional streams (e.g. protein, oil and an energy carrier) from one biomass stream, maximising total functional use. A nice example is grass refinery. Of course, after cascading in function cascading in value or time follows; the two figures above are additional to the figure below.

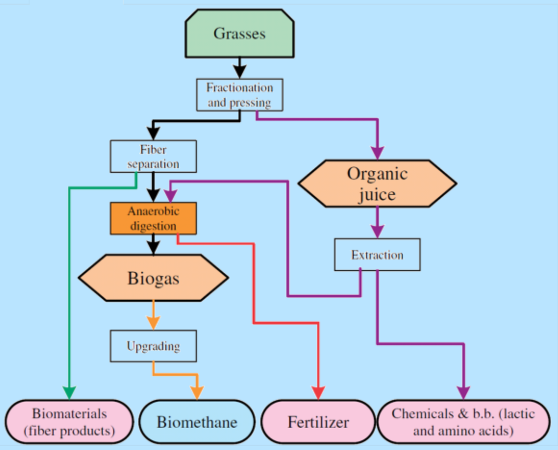


Furthermore, optimizing the design (e.g. by applying Cradle to Cradle principles in the case of products, and Industrial Symbiosis in industrial parks) can result in high value application of by-products and/or waste streams. Through separation of biomass into different functional streams, nutrient-cycles can be closed, which is an important prerequisite for sustainability in the bio-based economy. In the box below an example of co-production is elaborated on; bio-refinery of grass, producing fibres, feed, fertiliser and bio-energy.

Cow or Bio-refinery?

'Green bio-refinery 'or bio-refinery of grasses is a promising technology in the early stages of implementation. In the Netherlands the pilot-project Grassa! aims to produce a high-protein product, which can substitute for soy as animal feed, and fiber for the paper-industry, both from grass (Grassa!, 2011). Residues can be (and are) used as fertilizer, and to produce biomethane, as shown in Figure 5 (Cherubini, 2010). In the future it may even be possible to produce foodstuffs from grass-protein, thereby potentially substituting sustainable bio-refineries for inefficient cows.

Figure 5 Green Bio-refinery



Source: Cherubini et al., 2009.

As stated above, the goals one would want to achieve with cascading do not differ from general goals concerning use of biomass in the bio-based economy. For each subsequent use of biomass, a choice needs to be made between one application and the alternatives. Lansink's Ladder and Moerman's Ladder give a guideline for choosing the preferable option when a choice can be made. Therefore it is necessary to evaluate cascading options relative to the alternatives. *Cascading optimally is equal to achieving the most efficient chain possible*.

2.5 Cascading case studies

The number of cascading cases were studied for a range of biomass streams. The cases were chosen based on expert opinion within CE Delft, literature research and feedback from the supervisory committee, and are presented in Table 3. Following the life cycle of biomass from field or forest to product and subsequently (consumer) waste, they are grouped into three categories of biomass: agricultural and processing residues, woody biomass and consumer wastes. The technological explanation of the cases are given in Annexes A to C.
Table 3 lists the cases. In the first column the biomass feedstock and purpose is given. In the third column the current use of the biomass and the cascading alternative are given. In Table 4 two cases are mentioned separately; in these cases biomass is already efficiently cascaded, but alternative application of the biomass is stimulated through policy.

Table 3 Selected cascading options

Residues (Annex A)		
1. Straw for ethanol production	*Current use*	Green manure *or* feed *or* bedding
	Cascade alternative	Ethanol *and* fertilizer-rich (N, P) lignin stream → Ethanol-derived products such as biofuel, or ethylene (option 1b)
2. Bio-ethanol to chemistry	*Current feedstock*	Naphtha
	Cascade alternative	Straw
3. Manure for biogas production	*Current use*	Fertilizer
	Cascade alternative	Biogas *and* digestate/lignin-rich fraction as fertilizer/soil enhancer
4. Waste for production of chemicals	*Current use*	Landfill/MSWI/energy
	Cascade alternative	Biodiesel production from fatty acids in residue streams (such as cooking oil and C1 slaughter-waste)
5. Grass refinery	*Current*	Feed
	Cascade alternative	Grass-refinery to produce protein, fibre, bio-energy, fertilizer
6. CO_2 as feedstock in greenhouses	*Currently*	Emission
	Cascade alternative	CO_2 capture at production plants (for e.g. biogas, bio-cokes and ethanol) combined to use in greenhouses or algae farms
7. CHP vs. small scale bio-energy production	*Currently*	Emission
	Cascade alternative	Use for district heating or industrial heating or fish farms
Woody biomass (Annex B)		
8. Bio-cokes for chemistry	*Current*	Production with fossil cokes
	Cascade alternative	Production with bio-cokes made from waste-wood

Consumer waste (Annex C)		
9. Electricity and heat from bio-waste	*Currently*	Landfill
	Cascade alternative	Combined heat and power production from MSWI
10. Recycling of bio-plastic	*Currently*	Composting by biological degradation
	Cascade alternative	Production of bio-products (e.g. bio-plastics) which can be recycled within the current infrastructure
11. Additional recycling of paper	*Currently*	Waste
	Cascade alternative	Recycling of waste paper

For the examples shown above the cascading alternative is the preferred application of the biomass. This means the current system would benefit from a shift towards these cascading alternatives. In two cases, however, the alternative to the current application of the biomass represents an undesired shift from more effective to less effective application. One example is use of waste wood for particleboard production; current policy focuses on energy recovery instead of recycling. In these two cases (paper recycling and use of waste wood for particleboard production), as shown in Table 4, current use of the biomass is already cascaded. The alternative use, currently promoted by policy, represents lower value application. These cases will also be summarized in Chapter 3, as potential consequences are large when a shift away from these current cascades would occur.

Table 4 **Current cascading options which may become smaller because of policies**

Woody biomass (Annex B)		
12. Paper recycling	*Current alternative*	Energy
	Cascade	Paper → Building materials
13. Particleboard from waste wood	Current alternative	Energy
	Cascade	Construction products → Particle board → Energy

As stated above, a full technical explanation of the cases is given in the Annexes A to C. In Chapter 3 a summary of all cases is given, as well as an indication of the potential benefits. Chapter 4 will link the knowledge attained in the case studies to past policy and current policy and will give recommendations to policymakers on how to stimulate sustainable cascading.

3 Potential for cascading in the BBE

3.1 Potential cascading options

In the following paragraphs a short description of the studied cascading options will be given. This summary includes a description of the cascading option, along with a description of the current use of the biomass. Full technological descriptions are given in Annexes A to C. Furthermore, an indication of the potential will be given, and, when relevant, an evaluation of three important factors determining this potential, i.e. supply of biomass feedstock, level of development of the technology, and the ability of the market to absorb production.

The level of additionality in comparison with our previous study (PBL and CE, 2012) is difficult to give. In the previous study a total of 3–4 EJ/year of available by-products and residues was estimated to be available for bio-energy, biofuels and biomass based chemicals. The total amount of residues was, however, not further specified. In this cascading study we conducted an in-depth analysis of different specific and recent inventory studies, analysing both the indicated available amounts of different residues in the EU and the basic assumptions on which these were based. The studies included in this analysis indicate availability of surplus straw (not used as feed, bedding) as being 3 EJ/year, comparable with the total estimated availability of residues in the former study. This clearly indicates that the amounts considered in this project are (significantly) larger than the amounts considered in the previous study. Summarizing, there will be some overlap, but without a further in-depth definition of the 3-4 EJ/year mentioned in the earlier PBL note (PBL and CE, 2012) it is impossible to give an indication of the actual overlap.

Figures are given for each cascading case, illustrating the choice that needs to be made concerning how to use the biomass source. For each of the options the alternative (or cascading) option (shown in green) is presented in the same figure as the current use of the biomass (shown in blue). In many cases the cascading option provides added value (e.g. production of biogas from manure), while maintaining the original or current function (fertilization). In other cases the biomass currently provides no function or a negative function (e.g. landfilling of MSW), whereas the cascading option provides a valuable alternative.

Two options show a different picture; the *historic/current* use is an optimized and cascaded chain (paper is recycling and waste wood used to produce particleboard), while the currently developing alternative provides the un-cascaded use (energy recovery). It is important to mention these cases as they show that cascading is not necessarily a new development, and current developments are not necessarily better than historic applications.

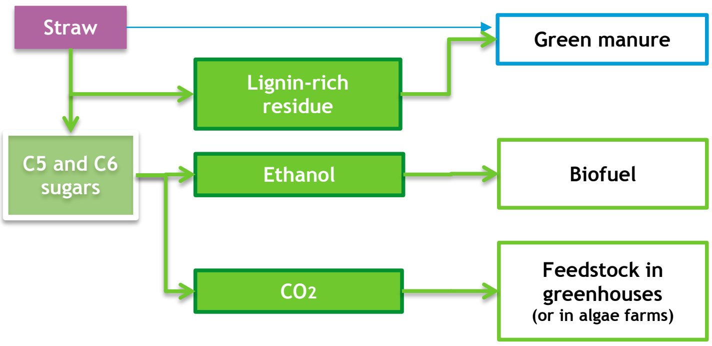
The value of the options are expressed as the climate change benefit that could be achieved (avoided emissions) and this CO_2 benefit is translated relative to the target emissions in 2030, and thus shows the importance of the options in terms of reduction of CO_2 emissions relative to the target. When relevant, energy potential as part of the future (2030) EU-27 economy is added. Most values are quantified based on estimates of availability of biomass. Because these estimates can vary considerably, averages were taken as a starting point. The CO_2 benefits represent the maximum benefit based on the assumed availability of the biomass.

The maximum CO_2 benefits, as shown in Table 5, could increase if biomass availability would turn out to be higher. Because estimates of biomass availability have been decreasing over the past years, these estimates are more likely to present maximum values. Therefore, a range in CO_2 reduction potential is given of between 70% of the calculated maximum based on average availability estimates and the maximum.

3.1.1 Straw utilization for biofuel production

Currently, if straw is not used in animal husbandry, it is used as a green manure and left in the field to provide nutrients and carbon. Alternatively, as shown in Figure 6 it could be collected and the cellulose and hemi-cellulose could be processed into C5-sugars and C6-sugars. A lignin-rich fraction, also rich in nitrogen and phosphor, is separated, and can serve as fertilizer and soil enhancer, thereby maintaining the original function of the straw (to a better extent) when it was used as green manure. As also shown in Figure 4, C5-sugars and C6-sugars can serve as feedstock for a lot of products and materials, for example ethanol which can be processed into PE (discussed in Section 3.1.2) or biofuel (so-called second-generation biofuel). CO_2 is a by-product of the ethanol production, which can be used as feedstock in greenhouses (as described below) or algae farms.

Figure 6 **Cascading option 1: Straw to ethanol for transport**

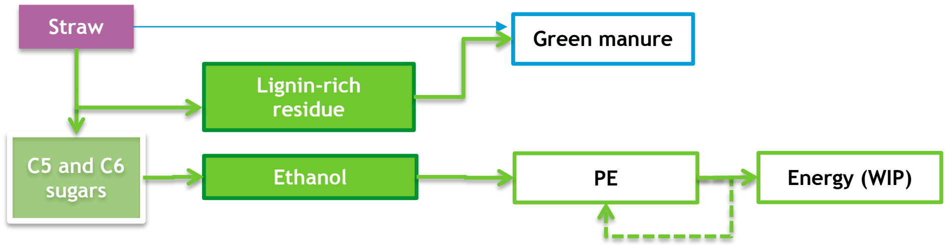


This technology is currently under development; several industries are exploring the possibilities, e.g. Sabic in The Netherlands and DSM in the U.S. Obligations to fuel-companies to increase the biofuel component in the fuel mix can stimulate development of new technologies. Furthermore, bio-ethanol is chemically identical to fossil-based ethanol, which makes substitution relatively easy. Straw currently used as green manure in the EU amounts to 3,224 PJ/year (see Annex A), which translates to around 190 Mton straw per year. With a conversion efficiency of straw to ethanol of 30% (weight), the maximum ethanol production from straw is around 1,688 PJ per year, which is around 11% of the EU wide transport fuel consumption in 2020 (CE, 2010a). According to the Renewable Energy Directive, production of ethanol from straw yields a GHG emission of 11 kg/GJ ethanol, while utilizing a fossil fuel based comparator will result in a GHG emission of 83.8 kg CO_2 eq./GJ (EU, 2009). Thus, using ethanol from straw as a transportation fuel will give a net reduction of 72.8 kg CO_2 eq./GJ. This amount to a CO_2 benefit of 123 Mton CO_2 per year.

3.1.2 Bio-ethanol for chemistry

Bio-ethanol, e.g. produced from straw, can also be applied in chemistry. The 1.7 EJ of ethanol (maximum production from straw as calculated above) can theoretically also be used in the chemistry sector. This sector uses circa 2 EJ of fossil source as feedstock in Europe (CE, 2012b), mainly for the production of plastics, which is also possible from ethanol (CE, 2012b). Applying ethanol in chemistry, e.g. in plastics, gives a higher GHG-emission reduction compared to using it as a transportation fuel.

Figure 7 Cascading option 2: Bio-ethanol from straw to chemistry



Substituting naphtha derived olefins by ethanol derived olefins may have some effect on refinery operations and associated energy consumption and GHG emissions in case the becoming redundant of naphtha requires different crudes to be processed and/or different products assays to be supplied. This is also the case when ethanol is used as a biofuel, substituting gasoline (CE, 2007).

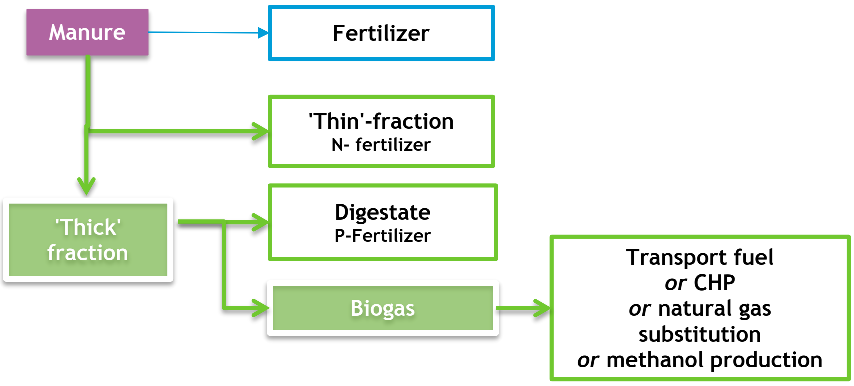
Conversion of ethanol into ethylene (monomer to PE) requires just 2 GJ/tonne ethylene of natural gas giving an associated GHG-emission of 2.5 kg CO_2 eq./GJ ethanol (Ren, 2009). On the other hand, production of ethylene by steam cracking naphtha results, according to EcoInvent, in a total GHG emission of 102 kg CO_2 eq./GJ ethanol. Thus, using ethanol from straw as a feedstock for ethylene will give a net reduction of 91 kg CO_2 eq./GJ ethanol, 25% more compared to use as a transportation fuel. The total CO_2 benefit would amount to 153 Mton CO_2 per year when ethanol from straw is used to produce ethylene, a benefit of 30 Mton CO_2 compared to use as a biofuel. Furthermore, using ethanol in plastics production has the added benefit of the recycling of plastics, whereas biofuel can only be used once.

3.1.3 Anaerobic digestion and processing of manure

Similar to straw, when manure is applied as fertilizer some substances are lost. Separation of the manure in a 'thin' fraction and a 'thick' fraction ensures that the original function, fertilization, can be maintained. Even though this is technologically true, regulations could be improved to allow for better application of digestate as fertilizer. The produced biogas can subsequently be utilised to produce, as shown in Figure 8:

- transport fuel;
- heat and/or power;
- substitute for natural gas;
- methanol production.

Figure 8 Cascading option 3: Manure to biogas

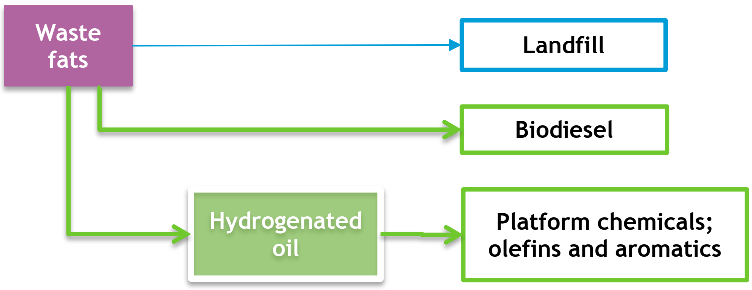


Biogas utilised as transport fuel or as substitute for natural gas is currently in the pilot phase. Green gas is already available at a fair number of gas stations in the Netherlands, but subsidies are still necessary to make it profitable. As the options to increase sustainability in the transport sector are limited, biogas may provide an interesting opportunity. Availability of manure amounts to 1,456 PJ/year in the EU (see Annex A), savings amount to 35 kg CO_2 eq./$GJ_{manure.}$ (EU, 2009)
Use of all available manure would lead to an avoided CO_2 emission of 50,960 kton CO_2 per year in Europe. Conversion of the currently available manure into green gas which could be a substitution for natural gas (efficiency of 10% from manure to biogas, and of 75-91% from biogas to green gas (SNM, 2011) could cover around 0.5% of the current (2007) European gas demand.

3.1.4 Chemicals from waste fats

The availability of low quality and high risk waste fats from consumers and meat processing industries amounts to 100 PJ/year in Europe (see Appendix A.4), which translates to around 2,700 kton/year. Currently these fats are combusted in coal fired power stations or as an integral part of domestic waste in MSWIs with low efficiency, or are landfilled. Conversion into biodiesel is increasing, stimulated by the fact that use of waste fats are double counted in terms of contribution to the RED-target for biofuels. Both these applications, however, are a end-of-life application. An alternative application is the production of hydrogenated oil, which can subsequently be processed into platform chemicals. Both technologies, processing into biodiesel or hydrogenated oils and subsequently platform chemicals, are currently in use.

Figure 9 Cascading option 4: Chemicals from waste fats

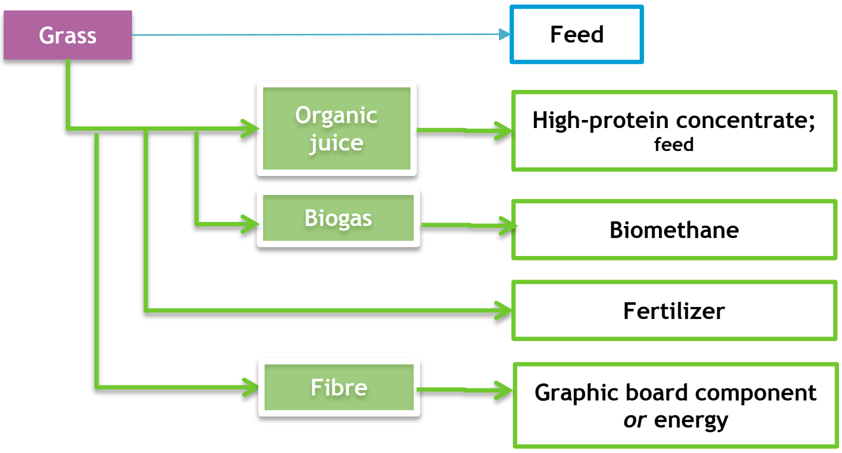


Benefits differ slightly between application as biodiesel or as platform chemicals. The avoided CO_2 emissions are a little over 6.5 Mton CO_2 when all the waste fats in the EU are used to substitute naphtha, and 351 kton when substituting biodiesel from waste fats (See Appendix A.4). Application as biodiesel thus also has a significant benefit relative to landfilling; 6.4 Mton CO_2 when all waste fats are applied as biodiesel instead of being combusted. Application of waste fats to produce platform chemicals thus scores only a little better on CO_2 emission, but because these do not represent the end-of-life application, in chemistry may be preferred.

3.1.5 Grass refinery

Availability of surplus grass in the EU is estimated at 15 Mton dry matter per year from fertilized grasslands, and at 15-20 Mton dry matter per year from natural sources and unfertilized lands (Van Zijderveld, 2012). Grass can be separated into different components, a wet component which can be used as feed, and fibres which can be used to produce e.g. graphic board component or paper, fertilizer and a residue which can be processed into biogas through anaerobic digestion (Courage2025).

Figure 10 Cascading option 5: Grass refinery



The main difficulty of the technology is that the time period within which grass needs to be processed after harvest is short. Therefore, demonstration of the technology with a mobile installation was part of the Dutch grass refining initiative 'Grassa!'. All products from grass refining are interesting for application in the bio-based economy and provide sustainable alternatives, although the technology has yet to prove its financial feasibility. Because this concept is still in the pilot phase, it is difficult to assign a quantified benefit to the bio-refinery of grass. The following exercise provides a rough estimate, in which processing energy and capital goods are not incorporated.

The original function of grass - feed - is maintained in the case of grass refinery. To present a case in which additionality is clear, the potential based on the amount of surplus grass was calculated. This biomass stream can be seen as being 'wasted' and applying it effectively thus means other streams are substituted. Assuming an availability of 30 Mton (dry matter) of surplus grass in the EU per year, grass refinery could potentially produce 6 Mton protein, 9 Mton fibre, 1 Mton fat, 14 Mton sugars (Van Zijderveld, 2012).

Assuming the protein and part of the sugar replace feed, the remaining sugars and fat are used to produce biogas and fibre is used as fuel in coal fired power plants, a rough estimate yields the following benefits (elaboration in Annex A.5):

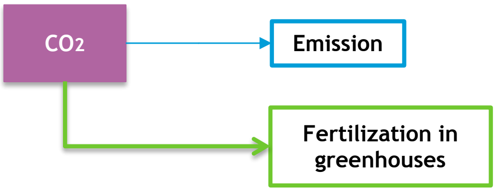
- The high-protein concentrate substitutes soy as animal feed, part of the sugars are added to realize an appropriate VEM[3]-value. Based on protein content and VEM value, substitution of soy could avoid around 5.8 Mton CO_2 eq.
- The remaining sugars (7.8 Mton) and fat (1 Mton) are used to produce biogas, around 136 PJ/ year. Substituting for natural gas, would result in avoided emission of 8.85 Mton CO_2 eq.
- Because market volume for cardboard filler which could be substituted for grass fibres is small, the fibres will more likely be used as fuel in coal fired power plants, with associated avoided emissions of 17 Mton CO_2.

These three applications together amount to a total CO_2 benefit of around 31.6 Mton per year. Benefits could be even larger if the grass protein is used to produce meat alternatives. With a CO_2 benefit of 5 kg CO_2/kg meat alternative (see Section above on 'biodiesel by-product on food instead of feed'), the CO_2 benefit could increase from 5.8 Mton when soy-cake is replaced to 29.8 Mton when protein substitutes food.

3.1.6 CO_2 as feedstock in greenhouses

CO_2 fertilization or enrichment is only possible in so-called high technology greenhouses. CO_2 fertilization in The Netherlands amounts to approximately 125 tonnes/ha/year (ECN, 2006), normally produced by natural gas combustion. The alternative, as currently already applied in The Netherlands, is CO_2 captured from industrial processes (as is done by e.g. Shell Pernis refinery) and power plants (RoCa III power plant).

Figure 11 Cascading option 6: CO_2 for fertilization in greenhouses



Total area in the Mediterranean and in The Netherlands amounts to an estimated 25,000 hectares. Assuming that fertilization levels for The Netherlands are generally representative and that CO_2 enrichment in the Mediterranean would also be achieved by natural gas combustion a maximum of a little over 3 million tonnes of captured CO_2 could be utilized.

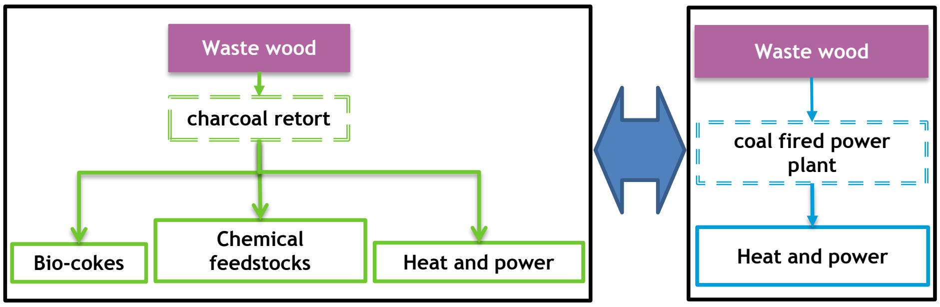
Another option for reusing CO_2 is its utilization as a feedstock for methanol by letting it react with H_2 (e.g. ThinkGeoEnergy, 2012). This option has, however, not been included in the present analysis (see Annex A.6)

[3] VEM = Voeder Eenheid Melk.

3.1.7 Bio-cokes for chemistry

As stated above, wood is expected to be in high demand in the near future, because of its various applications and the current focus of subsidizing renewable energy. Wood can also be converted into charcoal (bio-cokes) power and chemical feedstock by means of slow carbonisation. Bio-cokes can probably substitute calciner grade petcokes, green petcokes and metallurgical cokes in e.g. thermal phosphorus production and production of SiC and TiO_2. Substitution would avoid 4.5 ton CO_2 per ton of calciner grade petcokes (see Appendix B.4). The final product e.g. SiC, does not change, but the chain efficiency is improved with the use of biocokes.
The advantage of this route is not so much the utilizing of biomass instead of coke but lies in the fact that the energy content and carbon content of the biomass is utilized more efficiently compared to e.g. co-combustion in a coal fired power plant.

Figure 12 Cascading option 7: bio-cokes for chemistry

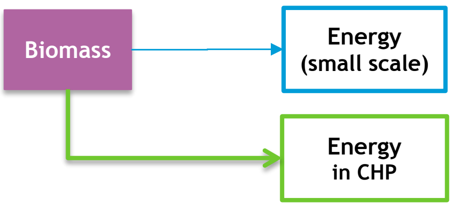


This technology is currently applied at an industrial scale in Brazil, and thus provides a good prospect for application elsewhere in 2030. In the Netherlands, with around 500 kton of petcokes used per year in (amongst others) the aluminium industry, total avoided emissions could amount to 1,8 Mton CO_2 per year in The Netherlands alone.
For the entire EU petcokes consumption, for e.g. TiO2 production, SIC production and anodes, production amounts to approximately 2 Mtonnes/year (OECD, 2010) and total avoided emissions could be as high as 9 Mtonnes of CO_2/year.

3.1.8 Small scale bio-energy production vs. CHP

At least 27 Mtoe of the biomass-based heat will be generated in individual households and another estimated 30 Mtoe will probably be produced in industrial boilers without a steam turbine (ECN, 2011). These technologies are less efficient than CHP facilities. With the biomass needed to supply this heat, a biomass-fired CHP plant could produce 39 Mtoe of heat and 13 Mtoe of power. To cover the gap in the heat demand (18 Mtoe heat), an additional 19 Mtoe of natural gas is required. This option is a clear example of cascading-meets-efficiency measure. Because of the use of a by-product - heat - it does represent a cascading example.

Figure 13 Cascading option 8: CHP vs. small scale bio-energy production

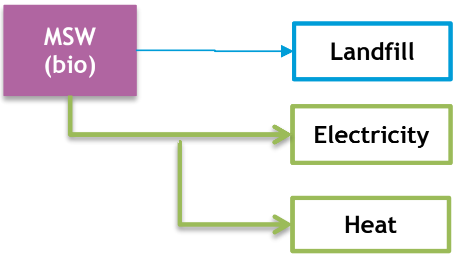


The 13 Mtoe of power will avoid or substitute fossil fuel based power production with a carbon footprint of 130 g CO_2 eq./MJ (CE, 2012c). The associated avoided greenhouse gas emission amounts to 70 million tonne CO_2 eq. per year. The CO_2 emission associated to additional 19 Mtoe of natural gas amounts to 53 million tonnes of CO_2 eq. per year. Therefore, utilizing the biomass in CHP plants instead of, as is planned, in boilers in residential and industrial environments would give a net reduction of 17 million tonnes of CO_2 eq.

3.1.9 Electricity and heat production from bio-MSW

Around 50 Mton of bio-municipal solid waste (MSW) is landfilled in the EU-27 every year (based on EC, 2012). Incineration with energy recovery, as electricity and heat, provides a useful alternative for what would otherwise be waste. Composting also is a valuable application of bio-waste, a little over 60 Mton of bio-waste is already recovered (in another way than energy recovery; EC, 2012). The option of incineration is an example of the overlap between the fossil and bio-economy; bio-waste and fossil waste is mixed in the waste which is landfilled. This option could therefore easily be expanded to included the incineration of fossil waste, which is actually even a little more efficient.

Figure 14 **Cascading option 9: Electricity and heat from incineration of bio-MSW**

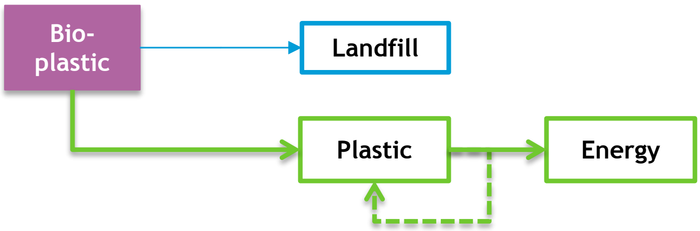


With a potential electric efficiency of 30% (current Dutch average for new installations), 0.17% of the Final Energy and Feedstock Consumption (FEFC) in the EU in 2030 could be met, which translates to 0.49% of final electricity consumption. Combined heat and power (CHP) provides an additional cascading step. When CHP is applied up to 0.33% of FEFC in 2030 could be met (with an assumed electric efficiency of 20% and a thermal efficiency of 40%). Therefore, the avoided CO_2 emission ranges between 9.6 Mton CO_2 (when applying an electric efficiency of 30%) and 19.2 Mton CO_2 (when applying CHP) per year.
The bio-stream is mixed with the fossil stream in MSW. When this fossil stream is included in the figures the results double. Of course, in order to achieve these figures, waste incineration plant (WIP) capacity in Europe should be increased, with such technology that relatively high efficiencies can be achieved.

3.1.10 Recycling of bio-plastic

In current practice bio-plastics such as starch-based plastics or composites, or PLA, are composted or landfilled or are burned in a municipal waste incinerator as a fraction of mixed municipal waste.

Figure 15 Cascading option 10: recycling of bioplastic

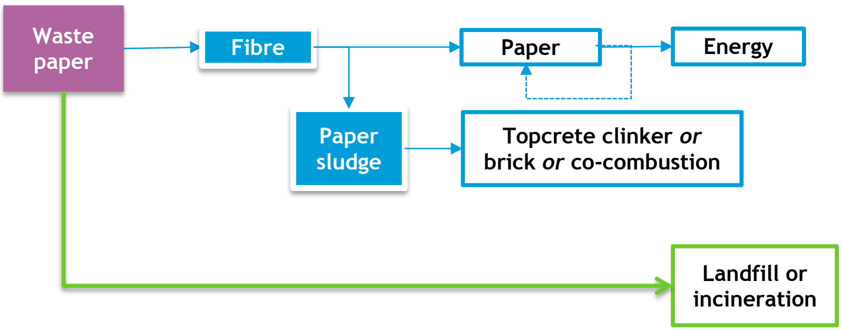


Ideally, bio-plastics would fit within the current recycling schemes would be recycled. PLA, and probably other bio-plastics, can be recycled and by doing this significant amounts of CO_2 emissions can be avoided. For example, production of PLA gives a 3.2 kg CO_2 eq./kg PLA greenhouse gas emission. Recycling of a tonne of PLA (assumed to be comparable to PET) requires approximately 1.2 MJe/kg PLA with an equivalent emission of 0.16 kg CO_2 eq. With a current annual consumption in the EU of 100 kilotonnes, the associated saving in greenhouse gas emissions would amount to 300 kilotonnes CO_2 eq./year. If, however, production of bio-plastics could account for a much larger share of total plastics consumption in Europe, and if subsequently 30% of plastics consumed in the EU (13 Mtonnes out of 44 Mtonnes) would be substituted, the associated savings would amount to approximately 40 Mtonnes CO_2 eq./year.

3.1.11 Additional recycling of paper

There is still potential to increase the recycling of paper.

Figure 16 Cascade option 11: additional recycling of paper



Current average EU recycling rate stands at 55%, while the maximum attainable recycling rate amounts to approximately 80% (CEPI, 2012). This means an additional 50 Mton of CO_2 could be stored in vegetation (see also Annex B.2).

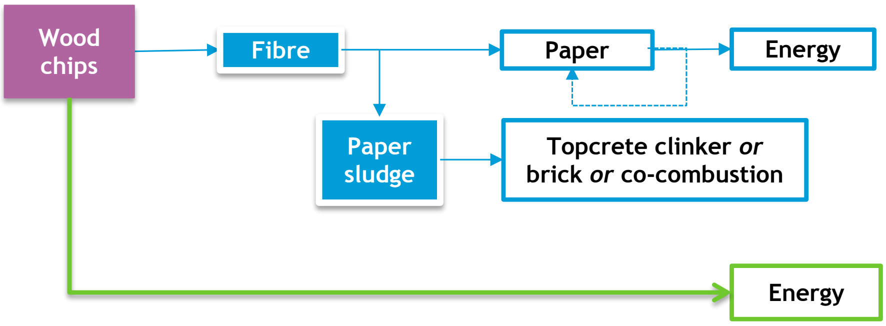
3.2 Current cascades

The following two cascading options are examples of cases where cascading is applied in the current system, but where external driving forces stimulate a shift away from these applications. Both cases concern waste wood; currently a popular upcoming energy source. Both cases pose a threat to a sustainable bio-based economy.

3.2.1 Paper recycling

Current demand and supply of woody biomass in the EU amounts to 950 million m^3 (Mantau et al., 2010), of which approximately 40% is used in energy applications.
This amount is expected to increase; the competition between the subsidized energy sector and wood processing industries is expected to continue and to increase. Paper production is one of the current applications of wood, and the current paper cascade has been optimized to nearly the optimum. Waste paper and cardboard have high recovery rates, application of secondary fibre is maximised and paper sludge applications as a raw material or fuel are maximised. Rerouting of wood from the efficient paper cascade to the energy sector will have serious consequences.

Figure 17 Cascading option 12: Paper from wood chips

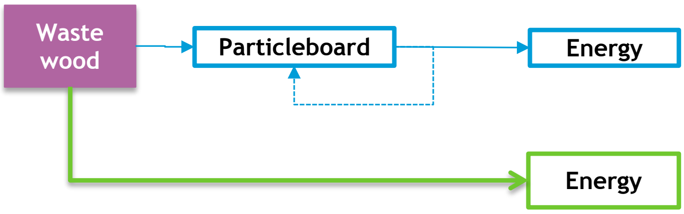


Every ton of wood which is not re-processed, results in 2 tons of CO_2 which is not sequestered (which can be interpreted as a prevented emission). Assuming that 1 ton of secondary fibre substitutes 1 ton of primary fibre and given a requirement of 1 ton of wood to produce 1 ton of pulp and given that 50 Mton of secondary fibre is used in the EU for paper production per year (CEPI, 2012), eliminating half of the pulp introduced in paper recycling schemes would mean an extra requirement of 50 Mton wood. This translates to an extra CO_2 emission of 100 Mton per year. Eliminating all paper recycling would result in an extra CO_2 emission of 200 Mton per year. Such a scenario is not very likely, but it is clear that paper recycling contributes substantially to reduction of CO_2 emission; every 10% (or 5 Mton) which is not recycled is associated with a CO_2 emission of 20 Mton.

3.2.2 Particleboard from waste wood

Similar to the rerouting of wood from paper production to energy, the rerouting from particle board production to energy has consequences with respect to sequestration of CO_2. The current application represents the cascade, and is optimized. In the particleboard industry 3 Mton of waste wood is used for production (CE, 2012a).

Figure 18 Cascading option 13: Particleboard from waste wood



If those 3 Mton of waste wood would be rerouted from the particleboard industry to the energy sector, it would result in a extra emission of 6 Mton CO_2.

In some countries the percentage of secondary wood utilized in panel board is far higher than the average of 25% applied in the EU. In Belgium 50-60% of the feedstock for panel boards consists of secondary wood. Gruppo Saviola in Italy produces a 100% secondary based panel board (Gruppo Mauro Saviola, 2012). However, there are different panel board qualities and it is not clear from available literature if panel board for all applications can be produced for 100% from secondary wood. Therefore, the possible extra potential is unclear.

3.3 Potential contribution of cascading of biomass

The quantification of the 12 cascading option case studies are shown in Table 5. A CO_2 benefit per unit is given, along with a total CO_2 benefit based on the estimated availability of the biomass. When relevant, an energy benefit is given. In 1990 (the reference year for policy) emissions in the (current) EU-27 amounted to 5,588 Mton. The goal is to reduce emissions, relative to this level, with 20% in 2020, and with 40% in 2030, which amounts a total reduction of 1,118 Mton/year in 2020 and 2,235 Mton/year in 2030. The CO_2 benefit is translated relative to the target emissions in 2030. The benefit shown in Column 6 in Table 5 thus shows the importance of the options in terms of reduction of CO_2 emissions relative to the target (rounded off to one decimal place).

Table 5 Relative contribution of cascading case studies per year

	Cascading option	Benefit per unit	Energy benefit	Benefit in CO_2/year (Mton)	Benefit as % of EU CO_2 reduction target in 2030
1.	Straw utilisation for ethanol production	72.8 kg CO_2/GJ ethanol	11% of transport fuel consumption in 2020	123 Mton (max.)	5.5%
2.	Bio-ethanol to chemistry	91 kg CO_2 eq./GJ ethanol (when substituting the feedstock naphtha for straw)		30 Mton (max.) - benefit additional to option 1a	1.3% - additional to option 1a.
3.	Anaerobic digestion and processing of manure	70 kg CO_2 eq./GJ_{CNG}	0.5% of the current (2007) European gas demand	50 Mton (max.)	2.2%

	Cascading option	Benefit per unit	Energy benefit	Benefit in CO_2/year (Mton)	Benefit as % of EU CO_2 reduction target in 2030
4.	Chemicals from waste fats	Substitution of naphtha for naphtha: 2.5 ton CO_2/ton		6.5 Mton (max.)	0.3%
5.	Grass refinery	Feed: 0.48 ton CO_2 eq./ton grass Biogas: 1.01 ton CO_2 eq./ton grass Fibre: 1.89 ton CO_2 eq./ton grass		31.6 Mton - 60 Mton (Feed to food option: 60 Mton)	1.4% - 2.7%
6.	CO_2 as feedstock in greenhouses	125 ton/ha/year	Gas savings: 47.6 PJ	3 Mton (max.)	0.1%
7.	Bio-cokes for chemistry	4.5 ton CO_2/ton substituted calciner grade petcokes		1.8 Mton (NL) - 9 Mton (EU)	0.1% - 0.4%
8.	CHP vs. small scale bio-energy production			17 Mton (max.)	0.8%
9.	Electricity and heat production from bio-waste	9.7 GJ/ton	0.33% of 2030 EU economy	19.2 Mton (max.)	0.9%
10.	Recycling of bio-plastics	3 kg CO_2/kg recycled plastic		0.3 Mton - 40 Mton	0.01% - 1.8%
11.	Additional paper recycling	2 ton CO_2/ton not reprocessed wood		50 Mton	2.2%

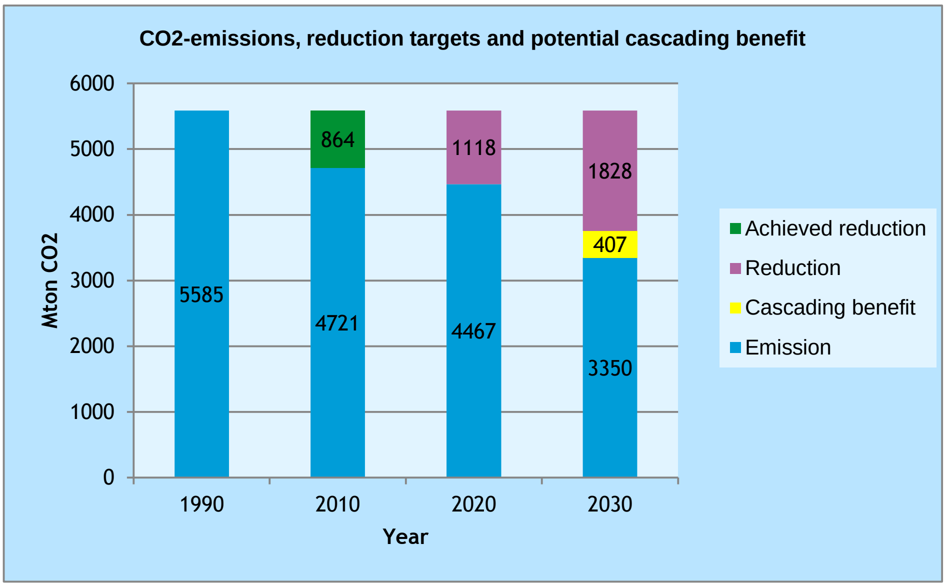
Table 6 Relative contribution of current cascades

	Cascading option	Benefit per unit	Energy benefit (EJ)	Benefit in CO_2 (Mton)	Benefit as % of 2030 EU economy (CO_2)
12.	Paper recycling	2 ton CO_2/ton not reprocessed wood		200 Mton (max.), 100 Mton if recycling rates would be halved	8.9%
13.	Particle board from waste wood	2 ton CO_2/ton not reprocessed wood		6 Mton (max.)	0.3%

The total, and maximum, CO_2 benefit amounts to between 332-407 Mton CO_2 per year, as summarized in Table 5 and Figure 21. This amounts to between 10 and 12% of the target emission of 3,353 Mton CO_2 per year in 2030 in the EU. The latter figure of 407 Mton CO_2 should be regarded as an optimistic potential. In these figures the paper and particleboard cascades, which together account for 206 Mton CO_2 when all recycling is eliminated (as shown in Table 6), but which are not emissions which are currently occurring, are omitted. They are very important to include in policy discussions because of current energy policies, but the other 11 options provide benefits additional to the earlier PBL assessment and are therefore of main interest.

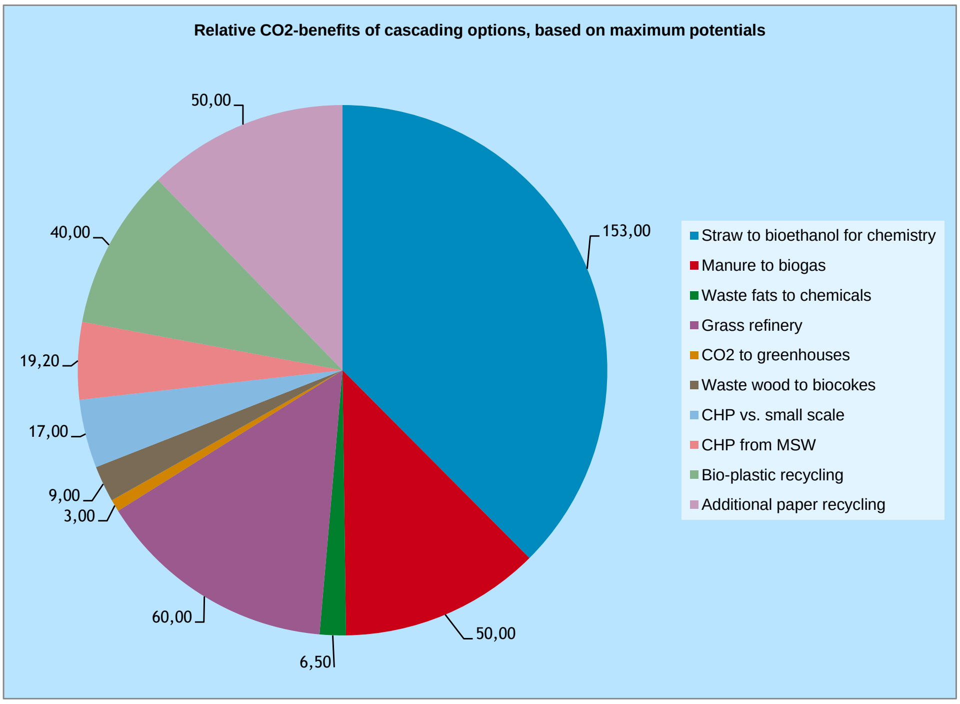
Figure 19 shows that a significant progress has already been made, relative to 1990. Still, in the coming 20 years, reductions of GHG-emissions should be increased to 1,828 Mton CO_2 eq./year. As shown, cascading of biomass can make a significant contribution. This means emission of another 1,371 Mton CO_2 eq. per year should be avoided. The biomass cascading options explored in this study could contribute to almost 30% of that figure.

Figure 19 CO_2 emissions, reduction targets and the potential (maximum) biomass cascading benefit



The 11 biomass cascading options are shown in Figure 20. The four options with the highest potential CO_2 benefit, account for around 77% of the total: straw to ethanol for chemistry, manure to biogas, grass refinery and additional paper recycling.

Figure 20 Relative CO_2 benefits of biomass cascading options



This does not mean these are necessarily the only options to explore; some are the more innovative options, which in general still need more investments for innovation. The other options may be easier to implement. As this study does not include a cost assessment, it cannot be said which of the options provides the best return on investment.

If and to what extent the different options are implemented will depend on the level of technical maturity of the technology and on the willingness of customers (both industrial and private) to accept either a new type of product or raw material or to adapt to a new lifestyle with respect to e.g. food consumption.
Furthermore, policies will significantly influence the rate of implementation. Policies can influence market positions and economic competitiveness of different applications. For example, current biofuels policy stimulates second generation biofuels and makes such application of ethanol probably more attractive than utilization in ethylene production even though the latter application is associated with higher GHG emission reductions.

Given these influences, a distinction between more and less certain options/routes was made, as shown in Table 7. Technological development linked to policy that stimulates such development provides a good first measure of ease of implementation. Furthermore, if the option requires acceptance by private consumers there is a higher possibility that implementation will be limited at best. The assessment of the ease of implementation for the 11 cascading options is shown in Table 7.

Table 7 Ease of implementation of cascading routes, a '+' or a '++' indicates relatively easy implementation, while a '-' or a '—' indicates a more difficult implementation. A '0' indicates it could go either way; some aspect may hamper implementation, some may stimulate it

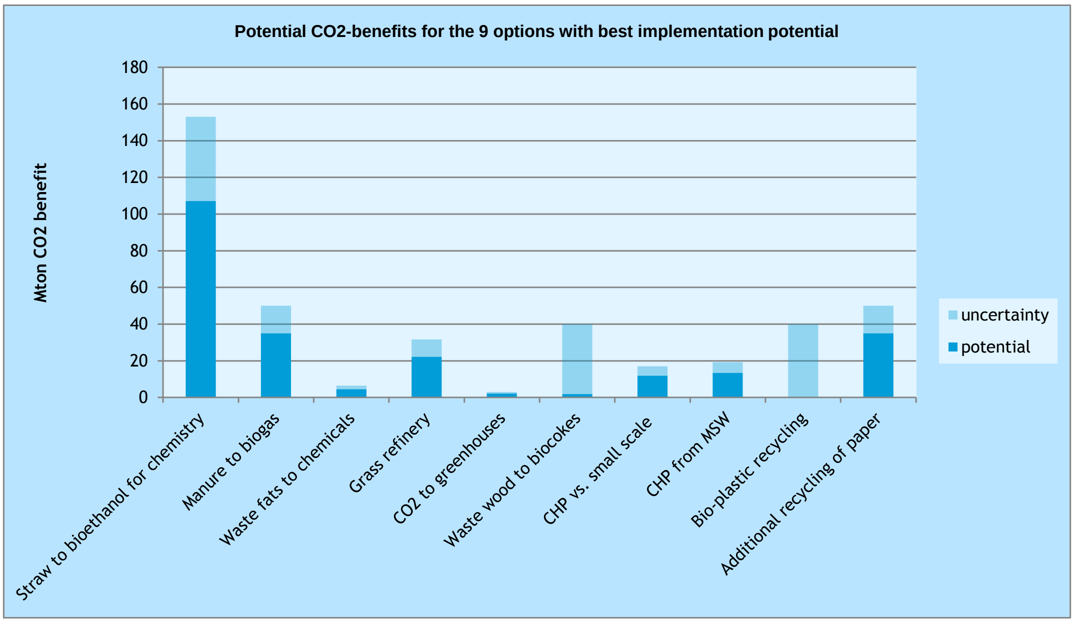
	Cascading option	Status of technological development?	Market penetration of end product or lifestyle change required	Policy required for introduction	Ease of implementation
1.	Straw utilization for biofuel production	Under development, compulsory in USA in 2013	Yes, alternative cars (ethanol)		0
2.	Bio-ethanol from straw for chemistry	Under development, installations on commercial scale are being built (POET/DSM and Abengoa)	Alternative production routes (chemicals) required. In the U.S. obligations related to ethanol from lignocellulose material will be enforced starting 2013	Level playing field between bio-based chemicals and biofuels	0
3.	Anaerobic digestion and processing of manure	Mature	No	Stimulation of nutrient use optimization	0
4.	Chemicals from waste fats	Mature	No	Level playing field bio-based chemicals: biofuels	+
5.	Grass refinery	Demonstrated	Yes, isolated protein is new kind of feed		-
6.	CO_2 as feedstock in greenhouses	Mature	No		++
7.	Bio-cokes for chemistry	Partially mature	Yes, will have to prove consistent high quality	Level playing field between bio-cokes and wood for power and heat	+
8.	CHP vs. small scale bio-energy production	Mature	Yes, substitution of individual boilers in individual premises by collective CHP installations with distribution network		0
9.	Electricity and heat production from bio-waste	Mature	No		++

	Cascading option	Status of technological development?	Market penetration of end product or lifestyle change required	Policy required for introduction	Ease of implementation
10.	Recycling of bio-plastics	Mature	Yes, requires introduction of alternative plastics to the market	Level playing field between bio-based chemicals and biofuels	0
11.	Additional recycling of paper	Mature	No	Higher recycling obligations	++

In Figure 21 the CO_2 benefit is given as a range for the nine options for which no lifestyle change is required. The option which was excluded is the protein from grass refinery to food option. Ranges are presented as falling between 70% of the maximum benefit as presented in Table 6 (indicated by the solid blue bar), and that maximum. For two options a different approach was chosen:

- Bio-cokes: The lower range represents application of bio-cokes in known industries in the Netherlands. The range represents the potential application in various industries across Europe.
- Bio-plastics: The lower value represents the impact if all current bio-plastics would be recycled, the upper boundary the potential when 30% of current plastic consumption would be bio-plastics which would be recycled.

Figure 21 **CO_2 benefit given as range for the 9 options best implementation potential**



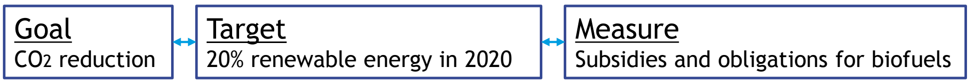
As stated above, these figures are based on averaged estimates of availability of biomass. Furthermore, the maximum CO_2 benefits, as shown in Table 5, could increase if biomass availability would turn out to be higher. The option not included in Figure 21, the feed-to-food option, has the potential to contribute substantially to the CO_2 emission targets. Because implementation would inherently be linked to lifestyle changes, the potential is much more uncertain. It does indicate, however, that the food sector deserves closer attention in the bio-based debate.

4 Policies for cascading in the BBE

4.1 Goals, targets and policies

When discussing policy it is important to distinguish between the goals, the targets and the policy measures. In theory, targets are designed to help reach the goal, and measures are designed to help reach the targets, as is illustrated in Figure 22.

Figure 22 Example of goal-target-measure relationship



Reality has shown (e.g. concerning ILUC) that to avoid situations where measures comply with the targets, but in practice hamper realisation of the goal, criteria for good use of biomass are needed. Targets and measures should be designed in such a way that these criteria are respected. These criteria do not differ for sustainable cascading or sustainable use of biomass in general. Different organisations have already elaborated on such criteria (Projectgroep Duurzame productie van biomassa, 2007; Commissie Duurzaamheidsvraag-stukken Biomassa, 2011; CE, 2010; Stichting Natuur & Milieu, 2008).

Summarized the main criteria entail:
- high reduction of CO_2 emissions (per euro and hectare, including ILUC);
- minimal loss of nutrients;
- no competition with food production or other essential local functions.

These criteria define the boundary conditions of sustainable use of biomass. As such, they are still open to interpretation; ‘high’, ‘minimal’ and ‘essential’ are not absolute terms. Therefore, and as illustrated by the case studies, it is important to evaluate alternatives, take a systems perspective and include secondary effects in impact assessments. This chapter will elaborate on current Dutch and EU policy and how this may influence, or already influences, cascading in the BBE.

4.2 Current policy

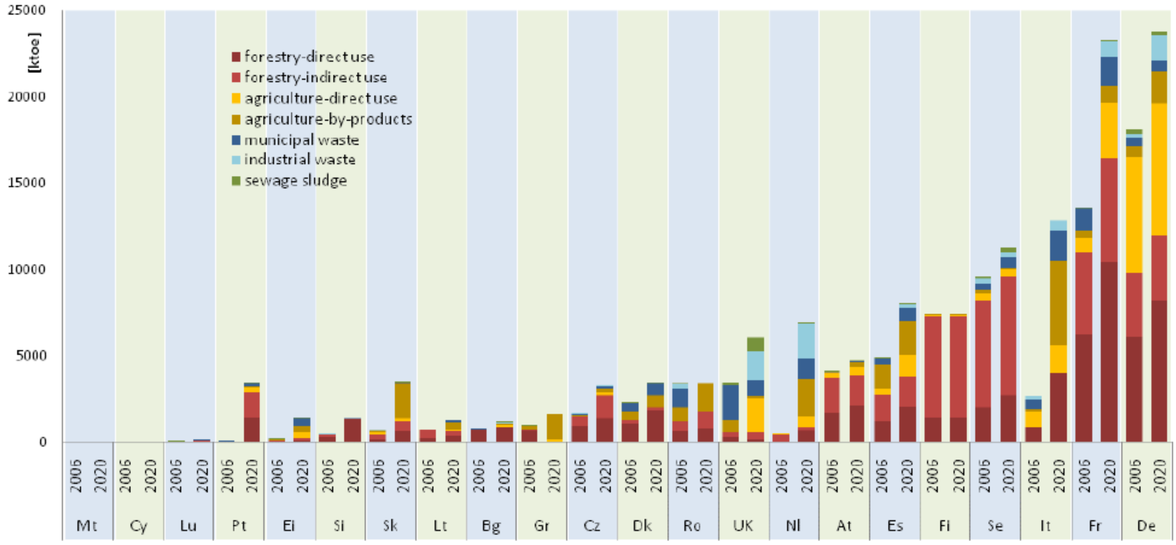
4.2.1 Goals and targets

The Netherlands and the EU have committed to reducing emissions of greenhouse gases by ratifying the Kyoto protocol; in 2012 the emission in the EU-15 should be 8% lower than it was in 1990.

The Renewable Energy Directive (RED) obligates Member States to a 20% renewable energy share in EU energy end uses, and a 10% share of biofuels in automotive transportation. In order to comply to these obligations, all Member States have made National Renewable Energy Action Plans (NREAPs). Other targets related to biomass application are shown in Table 8.

A review of the NREAPs (Figure 23) of individual Member States indicates that more than 50% of the 2020 target should come from biomass or biomass-derived fuels and power. The main biomass application (80%) is expected to be domestic and industrial heat production, and the main type of biomass to be utilized is wood (see Figure 23), primarily from the forestry sector indirect use of forestry refers to shavings, chips and sawdust) and from landscape maintenance.

Figure 23 Projection of applied types of biomass in 2020



Source: ECN, 2011.

4.2.2 Policies

Table 8 lists the EU policies and the national policies relevant to the cascading cases.

Table 8 Overview of EU & Dutch policies that influence biomass application

EU Policies	Type	Target
Renewable Energy Directive (RED)	Law	Obligatory 20% renewable energy share in EU energy end uses 10% obligatory share of renewable energy (includes biofuesl) in automotive transportation + double counting of second generation biofuels and biofuels from waste
European Declaration on Paper Recycling	Covenant	70% recycling rate by 2015
Revised Waste Framework Directive	Law	70% recycling target for construction and demolition waste 50% recycling target for household waste (EEB, 2010) High efficiency energy recovery qualified as comparable with recycling The establishment of a definition of ‘by-products’ that allows some materials currently defined as waste to become non-wastes and be removed from waste regulation, as well as the definition of minimum requirements for ‘end-of-waste

EU Policies	Type	Target
		criteria'
Landfill Directive	Law	No degradable organic material to landfill
Emissions Trading System, zero emissions value for biomass use	Law	Bonus of 8-20 €/ton CO_2 when biomass is used in larger industry which is regulated by ETS
EVOA, rules for trade of waste	Law	Rules for trading of waste from country to country
Rules for manure and the use of digestate	Law	Protect soil against too much nitrogen and phosphorous
National policies	**Type**	**Target**
Subsidies for bioenergy, bio-heat and biogas	Law	
National delivery obligations for renewable electricity and renewable biofuels	Law	Renewable energy in transport, including biofuel: 10% in 2020 and 4,5% in 2012 Overall: 14% renewable energy consumption
National rules for manure treatment and use	Law	Protect soil against too much nitrogen and phosphorous
Green deal co-firing of biomass in coal fired power plants	Covenant	Renewable energy from co-firing of biomass

Subsidies and obligations for biomass to electricity and heat

Biomass for power, heat and transport has been allotted an important role in making the EU energy system less carbon intensive and more renewable. In view of this target, the production of bio-electricity, heat generation from biomass and production of bio-methane are promoted by the individual EU Member States with subsidies per unit of generated energy and by subsidising investments. Also some Member States have obligations to deliver a percentage of renewable energy to businesses and consumers.

As indicated in Annexes A and B, certain biomass by-products are already cascaded and utilised for applications with a high added value, e.g.:
- utilisation of crop residues and food processing by-products as feed;
- utilisation of sawdust and waste wood as a raw material for board.

Current energy policies within the EU actively stimulate or tend to stimulate diversion of these by-products to fuel applications. For example, in The Netherlands the government added sugar beet pulp – a high value and high protein feed – to the so-called white list of co-substrates for anaerobic co-digestion of manure that are eligible for subsidies. At the same time Agentschap NL applauds utilisation of bagasse, from sugarcane based ethanol production, as cattle feed as a way of making sugarcane ethanol ILUC free.

Similarly, on a European scale the energy policies in different Member States are claimed to be promoting redirection of residual wood from an application as raw material for board to application as a fuel for electricity production.

An obligation to use biofuels for transport

Production and application of biofuels in the transport sector is promoted through an obligatory target of a 10% share of biofuels in the automotive transport fuels consumption in the year 2020. In reaching this target use of waste fats is counted twice.

Recycling targets

For some traditional applications, waste treatment and recycling policies or covenants are in place stimulating (re)use of biomass in products. For example for paper, a fourth European Declaration on Paper Recycling (2011-2015) has been launched by Ulrich Höke, European Recovered Paper Council (ERPC) chairman, and Soledad Blanco, Director at the European Commission, DG Environment. Also most European companies have rules for recycling targets for paper. For construction waste and demolition waste and the materials included in it - including waste wood - an overall recycling target of 70% has been defined.

No structural policies for biomass to products and chemistry

For other biomass applications - e.g. application as a raw material for chemicals, consumer products or as a reductant - little to no stimulation policies or obligatory targets have been implemented. This applies to traditional applications of biomass such as wood products. Only for paper recycling targets are in place. Furthermore, no such targets or policies are in place for applications in which bio-based products have additional benefits with respect to toxicity, such as biodegradable lubricants.

Innovation

For development of new applications of biomass, or new conversion technology development, subsidies are provided under e.g. the Framework programs. These include, among others, subsidies for development of technologies for utilisation of lignin and natural fibres in products and for bio-refining.

4.2.3 Lock-in situations due to former policies

There are many examples of lock-in situations in the fossil economy. These will not be discussed here, as such a discussion falls outside the scope of the present study. Because there are many examples were fossil-based industries have an advantage because of former policies, it is a good idea to actively stimulate projects and industries in the bio-based economy. This does not mean lock-in situations do not occur in the bio-based economy. Many installations in the bio-based sector are capital intensive and have a technical life expectancy of between 10 and 40 years. Policies which stimulated such installations which were introduced in the past, still influence the current developments related to cascading of biomass. In the search for cascading options the following lock-in situations were identified.

1. *The co-firing biomass in coal-fired power plants*
   This application of biomass is relatively cheap. Coal-fired power plants were stimulated in the energy diversification policies in the 1970s and 1980s in a number of European countries (e.g. in the Netherlands and in Denmark.
2. *The stimulation of first generation biofuels in Europe*
   The stimulation of first generation biofuels started with a situation in which a significant amount of agricultural land in Europe was left fallow because of over-production. Such policy does not match the current projections which indicate we need more land globally for food and feed. Because investments have, however, not been returned yet, first generation biofuels will be a part of the bio-based economy the coming years.
3. *The focus on stand-alone heat installations in households*
   In the Netherlands heat production for households is based on the use of cheap natural gas, and every household has its own installation. This makes the use of waste heat for district heating much more complicated than in for example Denmark where district heating has been obligatory in many cities for a long time.

4. *The former support for composting installations for bio-waste*
   Many European countries have invested in composting installations for bio-waste to prevent the landfilling of bio-waste. In most cases this bio-waste could now be used more efficiently by producing biogas and bioelectricity but the composting installations, which are already written off, can process the bio-waste cheaper.
5. *The existing municipal waste incinerators*
   In the Netherlands too many waste incinerators were built (partly with public money) for the waste which currently produced in the Netherlands. Together with the restrictions on import of waste from other European countries which still exist, this causes a low price for waste incineration which makes recycling/cascading less interesting.

4.2.4 The influence of current policies on cascading options

Current policies relevant to the case studies were also checked. Table 9 lists the policies that stimulate or hamper the cascading option, and the net effect of policy on the cascading option.

Table 9 Influence of current policy on cascading options and their alternatives

	Option	Policies	
	Cascading vs. alternative	Stimulates the cascading option	Stimulates the alternative
1.	Straw utilisation for ethanol production	Double counting of second generation biofuels (NL/EU)	Subsidies for use of straw for bio- electricity (NL)
2.	Bio-ethanol to chemistry instead of application as a biofuel	-	Double counting of second generation biofuels (NL/EU)
3.	Anaerobic digestion and processing of manure	Subsidies (NL)	Laws which complicates the use of digestate as fertilizer (EU)
4.	Chemicals instead of biofuels from waste fats	Double counting of second generation biofuels, generating a shift from low-efficiency use to biofuels (NL/EU)	No level playing field between chemistry and fuels, making the shift to highly efficient use in biochemistry relatively unattractive (NL/EU)
5.	Grass refinery	Innovation subsidies (NL)	Subsidies for energy sector to use this as energy source (NL)
6.	CO_2 as feedstock in greenhouses	-	Lower gas price for greenhouses (NL)
7.	Bio-cokes for chemistry	-	Subsidies for energy sector to use this biomass for electricity production (NL)
8.	CHP vs. small scale bio-energy production	-	Subsidies are higher for bio-electricity than for bio-heat (NL)
9.	Electricity and heat production from bio-waste instead of landfilling	Landfill bans and taxes (NL/EU)	-
10.	Recycling of bio-plastic instead of incineration	Recycling targets for plastics (NL)	Focus on biodegradability (e.g. Dutch packaging tax) (NL/EU)
11.	Additional recycling of paper	Recycling targets (NL/EU)	

	Option	Policies	
	Cascading vs. alternative	Stimulates the cascading option	Stimulates the alternative
12.	Use of wood for energy instead of paper recycling	Recycling targets (NL/EU)	Subsidies for energy sector to use this as energy source (NL)
13.	Incineration of waste wood instead of production of particleboard	Recycling targets (NL/EU)	Subsidies for energy sector to use this as energy source (NL)

4.3 Conclusions

As summarized in Table 9 above, different policies influence the cascading solutions in different ways. A sufficient level of technological development is a prerequisite for successful market penetration of new technologies. A number of cascading options are, however, hampered by policy; in many cases the subsidies in the energy sector to use biomass for energy are hampering the cascading solution. For example, the cascading option of using waste fats for biofuels is supported by the double counting rule in the biofuels obligation. This will probably result in a shift away from landfilling the material to energy production. It will not, however, stimulate the shift to highly efficient use of this material for biochemistry.

On the other hand, some obligations, targets, taxes and subsidies stimulate the cascading solution. These situations are limited, and policy can be improved in numerous ways to increase sustainable use of biomass in the bio-based economy.

Suggestions for policies for stimulating cascading in the BBE

Cascading of biomass can lead to higher environmental gains from the same amount of biomass. The current policy instruments (stimulation of both biofuels and bioenergy, and waste policies) can be improved to support cascading more. Furthermore, with good policy future undesired lock-in situations can be avoided. These are suggestions for improvement and we suggest further elaboration to enable policymakers in making the best choices.

Changes to existing policies:

1. Create sustainability criteria for biofuels and bio-energy to stimulate cascading of biomass.

Criteria could be introduced, in the regulations for bioenergy subsidies or in the regulation for a delivery obligation, which state that only biomass can be used that is not suitable for products or for cascading of biomass. Such policy could be supported with a list of allowed biomass types, which should be updated regularly.

2. Include ILUC in the sustainability criteria.

An ILUC factor in the GHG calculation can be introduced for biomass which is not a waste product or which is not produced on degraded land. Only biomass which reaches the minimum GHG reduction level including the ILUC factor is allowed to receive subsidy or is included in the biofuel obligation. This policy stimulates the use of degraded land and waste.

3. Create an option for cascading options to be included in the biofuel or bio-energy obligations.

The shift from the current situation in which bio-support is given per sector to an integrated bio-based stimulation programme could be stimulated by this policy option. As a start 0.5% or 1% of the biofuel obligation for petrol companies could be delivered by biochemistry companies, the steel industry or the aluminium industry which (could) use biomass to produce their products. This means that part of the biofuel obligation for transport can be fulfilled by companies in other sectors, which would sell biomass rights to companies in the transport fuel sector (without a governmental support programme). This option may be used a first step to a bio-obligation for other sectors.

4. Change the European laws on manure so that digestate can be used to replace synthetic fertilizers.

The use of manure for simultaneously producing biogas and fertilizer is an interesting cascading option for minerals like phosphate and potassium which are mined from finite sources. Policy stimulation use of digestate as fertilizer stimulates cycling of nutrients.

5. Support the use of heat from bio electricity plants.

Introduce minimum GHG reduction standards for bio-electricity which stimulates the use of heat, as was suggested in e.g. England (EA, 2009). Furthermore, the subsidy scheme should focus more on CHP projects, so that overall efficiencies are increased.

6. Introduce/strengthen recycling obligations for paper.

Paper recycling is an important cascading route already in place. The recycling of paper from households and offices can be increased by smart stimulation and obligations, for instance by differential tariffs (diftar), education, and improving recycling infrastructure. Furthermore, recyclable paper could be excluded from bio-energy subsidy schemes.

7. Introduce recycling schemes for bio-plastics.

Some bio-plastics are used in applications were degradation is important (e.g. as bags for collection of bio-waste). In many cases recycling of the plastic is more attractive from an environmental point of view than composting. For fossil-based plastic most European countries have introduced separation and collection schemes. Most of the current recycling schemes in Europe are only focussing on recycling of LDPE, HDPE, PP and PET. Bio-plastics like PLA are not recycled in most cases because the separation does not recognize these materials. Recognition and separation of the main bio-plastic is an option in these schemes and can make cascading of this bio-material possible. An option could be that separation of the main bio-plastics becomes obligatory for recycling schemes in Europe.

8. Withdraw the possibility of receiving subsidies for co-substrates to co-digestion of manure which have valuable other applications.

Criteria could be introduced in the regulations for subsidy for biogas that state that only biomass that is not suitable for products or cascading of biomass may be used.

New policies to stimulate cascading options:

9. Introduce a sector-neutral bio-support scheme which focusses on maximum performance.

There is a large difference in the performance of bio-options. In the report Good use of biomass (CE, 2010) we calculated that the annual GHG emission reduction of bio-options based on crops differs from 3 ton CO_2 per hectare per year (ethanol from wheat) to 28 ton CO_2 per hectare per year (steal produced with bio-cokes). Also the use of ethanol in chemistry performs 1.5 times better than the use of ethanol as a biofuel. Replacing the current sector specific support schemes by an integrated scheme with competition between sectors would improve the performance of the bio-based initiatives and probably also reduce costs.

a) Develop a support scheme (subsidies or obligations) for biochemistry and related products besides the support scheme for bioenergy and biofuels. An integrated support scheme for all bio-options is the preferred option to introduce a level playing field. However, if such an approach is too complicated because of the sectorial organisation of policies a second-best option would be the introduction of a bio-products supports scheme which would be in place besides the schemes for biofuels and bio-electricity. Because the chemistry sector is an international sector and there are many chemical products on the market, which are in many cases ingredients in other products, an obligation for a certain percentage of biochemistry in chemical products will be complicated. A subsidy scheme is therefore deemed more suitable. If governments who still subsidize bioelectricity change to obligations for this sector, this subsidy budget could be used for biochemistry and products. Another option is that the biochemistry and products sector could tender in the existing bioelectricity and biofuel support schemes (option 3).
b) Develop a support scheme for products from bio-refineries. Policies similar to former policies for combined heat and power production could be introduced to stimulate bio-refineries which co-produce food ingredients, bio-products and energy carriers. This could be in the form of a premium for all installations which reach a certain CO_2 reduction target per kg of biomass.
c) Develop a support scheme for use of waste wood in products instead of using virgin wood. Recycling of wood (and paper) is an important cascading option. In the current policy situation energy production from waste wood is stimulated more than recycling of waste wood in products. This could be corrected by:

- Making it possible for companies who produce products from waste wood and reduce CO_2 emission doing this to tender in the support scheme for electricity and heat from waste wood (SDE++).
- Asking for recycled wood in public procurement sustainability rules.

General policies which support cascading of biomass:

10. Strengthen the ETS system in which GHG emissions - not only energy related emissions, but also industrial process emissions, waste processing emissions and emissions related to changes in carbon stocks in vegetation and soils - get a penalty.

With a higher CO_2 price in the economy cascading of biomass is automatically stimulated because these options reduce CO_2 more. This policy option only works significantly when the CO_2 price reaches the current stimulation bonuses for bio-electricity (50-100€/ton CO_2) and for biofuel (200-600 €/ton CO_2).

11. Introduce a uniform CO_2 tax on all types of energy possibly implemented through an emission trading system.

A general CO_2 tax on fossil energy works similar to the former option; because cascading options reduce CO_2 to a higher extent, a CO_2 tax will favour cascading options.

As was shown in Chapter 3, cascading of biomass can contribute significantly to the CO_2 emission reduction targets. Of course, cascading is also possible in the fossil economy, which could also have significant benefits. As the analysis of the influence of policy on cascading options and the presentation of policy adjustments and new policies has shown, policy currently in place, which attempts to stimulate the bio-based economy, does not create a level playing field. Sectors other than the energy sector, such as the chemistry or the food sector, can contribute significantly to the bio-based economy and these sectors deserve fair play. The policy options presented above include those sectors and will therefore help stimulate cascading of biomass in a broad and diverse bio-based economy and will provide a sound basis for reaching the emission targets in 2030.

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Annex A Agricultural and Processing Residues

A.1 Introduction

Part of the agricultural by-products find use in high(er) value applications in animal husbandry, such as feed (crop residues, straw) and bedding material (straw). For these applications the alternative would be growing dedicated feed crops or crops providing bedding material, which would require (additional) arable land. The total amount produced on an European scale, however, is higher than the requirements for these high(er) value applications. The part that is not utilised as feed or bedding material is usually left in the field and provides nutrients and carbon to the soil. In addition, according to EU Commission (2010) CAP (Common Agricultural Policy) induced livestock reductions can potentially generating a large surplus of grass. By-products from the food industry find high value applications, mostly as feed. Here too, the alternative for the utilisation of these by-products as feed would be growing dedicated feed crops, which may require additional arable land.

Table 10 Overview of amounts of agricultural residues released in the EU

	Competing function	Functionality combinable?	ILUC risk at functionality loss?	Availability (PJ/year ILUC free)
Agricultural by-products				
- straw	Bedding	No	Yes (hay, peat)	0
	Feed		Yes (roughage)	0
	SOC + nutrients	Yes	No	3,224
- crop residues	Feed		Yes (roughage)	0
	SOC + nutrients	Yes	No	4
- prunings	SOC + nutrients	Yes	No	392
- manure	SOC + nutrients	Yes		1,456
By-products food-industry	Feed	No	Yes (feed crop)	63

Sources: ECBREC, 2006; EEA, 2006; Elbersen, 2010.

Crop residues and manure utilized as humus and nutrients sources can be cascaded by separating the humus forming components and nutrients from the other components and utilize the latter as raw materials in other product chains. In a similar way, grass could be separated by bio-refining into individual components, which could next be used in high value applications as a raw material or as feed. Food processing is another source of biomass residues. A lot of these residues are currently also used as feed.

Several examples have been elaborated in following paragraphs.

A.2 Straw utilisation for ethanol production

Options for cascading?

Straw is a by-product of cereals cultivation and oil seeds cultivation. As indicated in Annex A, straw which is not utilised in animal husbandry is primarily used as a green manure and is left on the field to supply nutrients and carbon to the soil of the arable land.
In this application a significant part of the straw is not utilised as it does not contribute to the build-up of soil organic matter through the formation of humus. As only lignin - and to a lesser degree cellulose - contributes to the formation of humus, the hemicelluloses, starch and part of the cellulose present in the straw are 'wasted'. Additionally, the nutrients and especially the nitrogen in the straw are utilised with a low efficiency. Most of the nitrogen is released by straw decomposition outside of the growing season.

The utilisation of straw could be optimised by utilisation of these otherwise 'wasted' components:
- The hemicelluloses and other hydrocarbons could be utilised as a feedstock for simple sugars, which could be used as a feedstock for e.g. ethanol. The ethanol (or other secondary products) could be utilised for substituting fossil fuels in road transport or plastics production.
- The nutrients could be isolated as a concentrate and could subsequently be applied with high efficiency as a fertiliser substitute.

Optimisation would be realised if these additional functionalities would be achieved while maintaining the functionality of straw for humus formation.

Technological options for isolating underutilized fractions

The so-called second generation ethanol production technology currently under development would allow for the above-described optimisation of utilisation.

In this technology (as also shown in Figure 6):
- straw is first treated with a dilute acid at increasing temperatures (150–200°C) and pressure (5–10 bar), resulting in decomposition of hemicelluloses into simple C5 xylose and arabinose sugars;
- the cellulose is decomposed in simple C6 glucose by enzymatic hydrolysis;
- in a third process step the C5 and C6 sugars are fermented into ethanol (and CO_2);
- the lignin fraction remains as a solid and is separated;
- the nitrogen and phosphorus nutrients present in the straw remain in the lignin rich fraction, while potassium is concentrated in a waste water stream;
- the CO_2 produced during fermentation could be utilized in e.g. horticulture or calcium carbonate production.

In this specific example the isolated sugars are converted into ethanol. This technology is currently under development by different companies. The sugars could also be used as a raw material for other platform chemicals such as lactic acid or 1.3 propanediol.

The optimised utilisation of straw - in which its original function is retained - would be realised if the lignin rich fraction would be returned to the field. The lignin rich fraction could alternatively possibly be applied as a substitute for peat in potting soil.

Potential cascades

Based on ethanol a very large number of chemicals can be produced, starting with ethylene and propylene and butadiene produced on the basis of ethylene. The number of production routes is too large to include in this report, but interested readers may want to visit APPE's website and study its flowchart (Appe, 2012).

Figure 24 Production of ethanol from straw

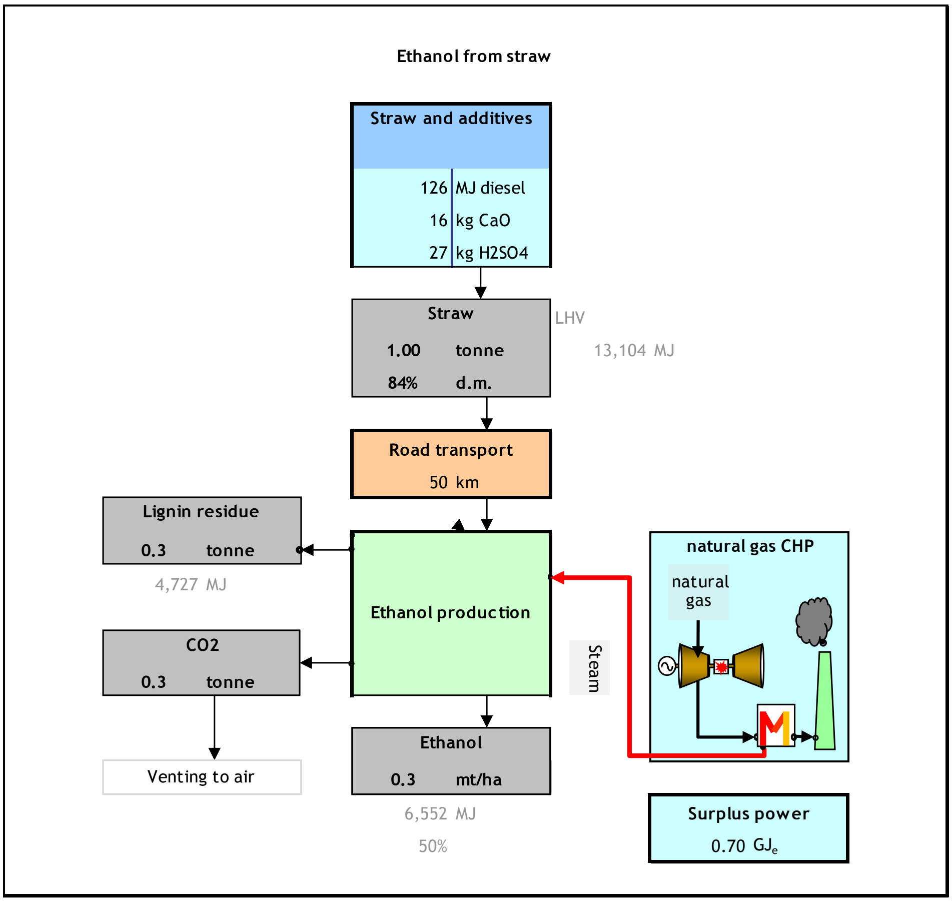
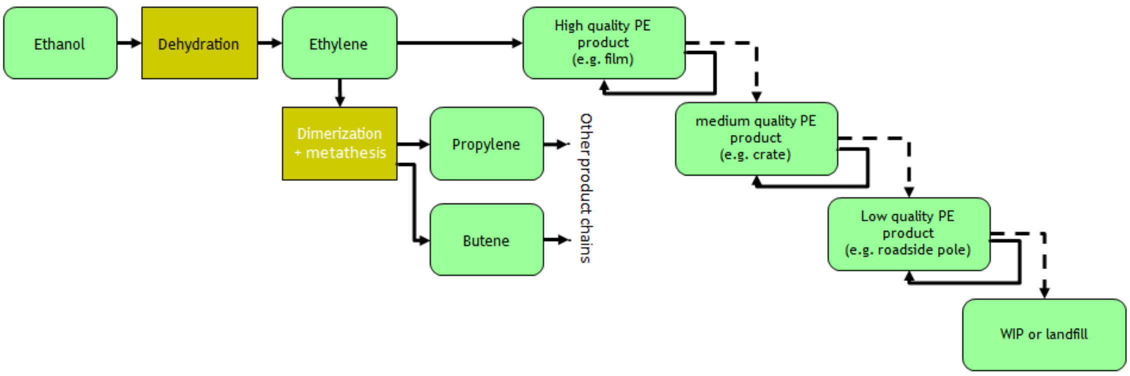


Figure 25 Ethanol to platform chemicals and beyond



Bio-propylene could be produced on the basis of bio-ethylene (as shown in Figure 8). Production of bio-ethylene can be achieved by dehydrogenation of bio-ethanol. Dehydrogenation of bio-ethanol is a commercially offered technology.

The production chain would require dimerization of part of the ethylene into butenes (see Figure 25) and subsequent reaction of ethylene and formed butenes by a metathesis reaction.
A recent world scale example is the 725 ktons/a of propylene combination of dimerization and metathesis being build for Borouge in the United Arab Emirates[4]. The unit, which will convert ethylene into propylene to feed two new Borstar® technology polypropylene plants, will be the world's largest using ABB Lummus licensed technology. Total annual output from the metathesis plant will be 752 kilotons of propylene plus 39 kilotons of butene-1 – totalling 791 kilotons.

Returning the lignin-rich fraction to the field and utilising natural gas for generation of the heat and power required for the process would give a net reduction in greenhouse gas emissions of 34 kg CO_2 eq./GJ_{straw} or 68 kg CO_2 eq./$GJ_{ethanol}$, compared to the emissions of transport fuels according to the RED (83.8 kg CO_2 eq./GJ). Straw currently used as green manure in the EU amounts to 3,224 PJ/year, which translates to around 190 Mton straw per year[5]. With a conversion efficiency of straw to ethanol of 30%[6], the maximum ethanol production from straw is around 1,688 PJ per year[7], which is around 11% of the transport fuel consumption in 2020 (transport fuel consumption in 2020: around 15,000 PJ (CE, 2010a).

This 1.7 EJ could also be used in the European chemistry sector which used 2 EJ of fossil sources as source mainly for plastics and 1 EJ as fossil energy as energy source (CE, 2012b).

The CO_2 produced as a co-product in fermentation could be utilised for example in horticulture or as a raw material in high purity carbonates.

No extra land would be involved and nutrients would be available and applicable with at least the same efficiency as in the case of unprocessed straw. The risk that straw applied in livestock husbandry is rerouted to ethanol production will depend on subsidies provided to ethanol producers and on the pressure that is put on the market by policies.

A.3 Anaerobic digestion and processing of manure

Options for cascading?

Comparable to straw, manure is applied in agriculture as a source of nutrients and carbon for the soil. As with straw, in this application part of the substances in the manure - hydrocarbons not contributing to humus formation - are 'wasted'. Therefore, the opportunities for optimising manure utilisation are similar to those for straw.

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4 Borouge is a joint venture between the Abu Dhabi National Oil Company (ADNOC) and Austria based Borealis.

5 17 MJ/kg straw; 3,224*10^9 MJ / 17 MJ/kg / 10^9 = 190 Mton.

6 Weight basis, thus 190 / 3 = 63 Mton ethanol.

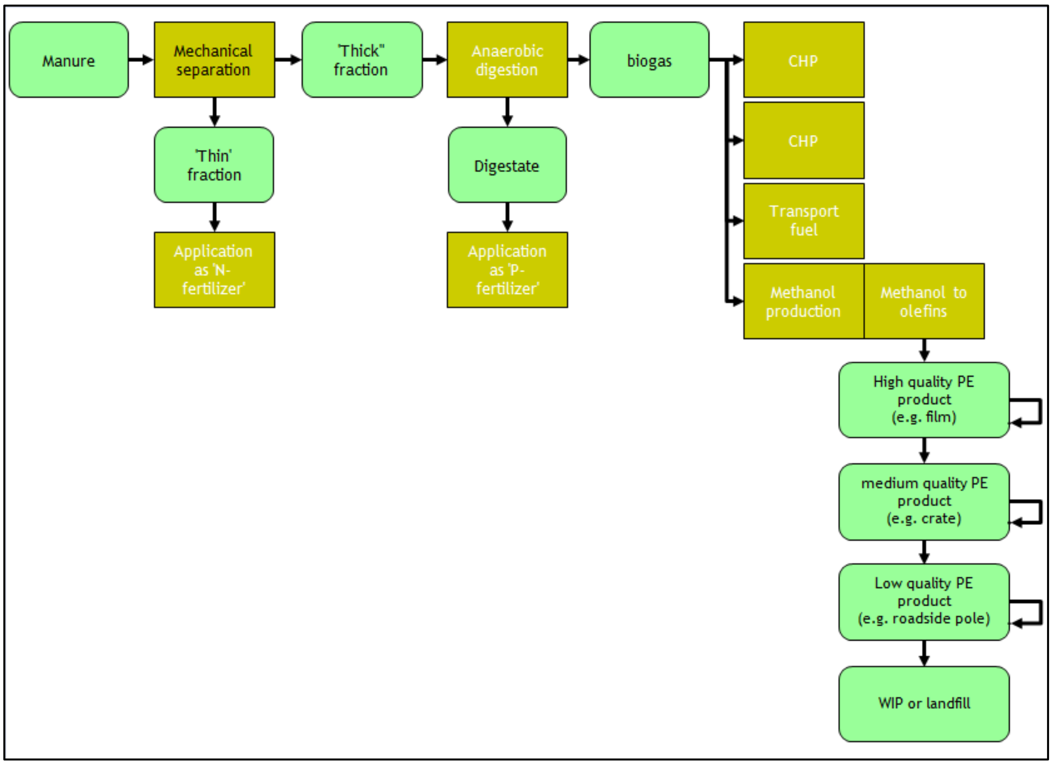
7 63 Mton * 10^9 * 26.8 MJ/kg / 10^9 = 1,688 PJ.

For manure, optimisation could be achieved by anaerobic digestion and subsequent separation of the residual digestate in a wet and a dry fraction. During digestion decomposable organic components are converted into biogas, a mixture of CO_2 and CH_4. This biogas could be utilised for:
- heat and/or power generation;
- natural gas substitution, by separating the methane and injecting it in the natural gas pipeline system;
- diesel substitution in automotive applications;
- feedstock for e.g. methanol or ammonia.

Nutrients in digested manure are better available to plants, hence can substitute fertilisers to a higher degree. Residual digestate separation allows for separately managing the nitrogen (liquid fraction) and phosphorus (solid fraction) present in the manure.

Technological route for cascading
For economic reasons, liquid manure is probably best separated at the farm yard into a 'thin' and a 'thick' fraction (as also shown in Figure 9). The 'thick' fraction contains almost all the organic components and almost all of the phosphorus present in the manure (LTO, 2011). The 'thick' fraction is digested at a central anaerobic digestion facility. This avoids the transportation of large amounts of water. Digesting manure has the beneficial effect that methane emissions (and ammonia and N_2O emissions) from storage and application are largely avoided.

Figure 26 Flowsheet for manure based CBG production



Benefits from cascading
Digesting liquid manure and applying the produced biogas as compressed gas in transport would save approximately 70 kg CO_2 eq./GJ_{CNG} or 35 kg CO_2 eq./GJ_{manure}, compared with the emissions of transport fuels, according to the RED (83.8 kg CO_2 eq./GJ). In these figures greenhouse gas emission savings by avoidance of methane and N_2O emissions from manure

storage have not yet been discounted. No extra land would be involved and nutrients would be available and applicable with at least the same efficiency as in the case of unprocessed manure.
Availability of manure amounts to 1,456 PJ/year in the EU, savings amount to 35 kg CO_2 eq./$GJ_{manure.}$ Use of all available manure would lead to an avoided CO_2 emission of 50,960 kton CO_2 per year in Europe. Conversion of the currently available manure into green gas which could be a substitution for natural gas (efficiency of 10% from manure to biogas, and of 75-91% from biogas to green gas (SNM, 2011) could cover around 0.5% of the current (2007) European gas demand (of 19 EJ in 2007).

A.4 Chemicals from waste fats/oils

Options for cascading

Low quality or high risk waste fats from consumers and meat processing industries are currently mostly combusted in coal fired power stations (high risk material) or combusted as integral part of domestic waste.

The recent introduction of the EU Renewable Energy Directive has initiated another application: conversion into biodiesel. This application is further stimulated because biodiesel produced from both types of waste fats is double counted in terms of contribution to the RED target for biofuels. Because of this valuation the price of both commodities has boomed and biodiesel produced from waste fats is more expensive than conventional diesel.

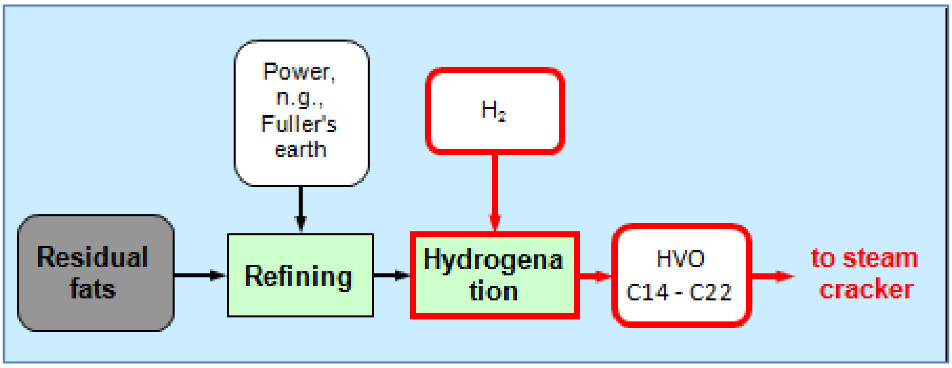
In both cases – combustion/co-firing and biodiesel – the application is ‘once through’ and the carbon and energy content of the waste fats is lost. An alternative application could be production of hydrogenated oil, which is subsequently processed in a steam cracker for production of platform chemicals. These chemicals - olefins and aromatics - can be further processed into e.g. plastics and solvents.

Technological route for cascading

In this cascade the waste fats are purified as would be done for biodiesel production. They are next treated with hydrogen in a process as for example applied by Neste at Maasvlakte.

In this hydrogenation process (shown in Figure 9), the purified waste fats are treated with hydrogen, which reacts with the oxygen in the fats forming water. The products are diesel, propane and small fractions of fuel gas and naphtha. The diesel, propane and naphtha can all be utilized as a feed for steam cracking, in which these feeds are converted into olefins (ethylene, propylene) and aromatics. Diesel is for example processed in a steam cracker at Sabic in Zuid-Limburg.

Figure 27 Flowsheet for production of hydrogenated oil from waste fats



Benefits from cascading

This application ensures use short-cycle carbon in high-tech products, which then can still be co-fired or processed into a transport fuel. Benefits differ slightly between application as biodiesel and platform chemicals. Total supply is around 100 PJ/ year. The avoided CO_2 emissions are a little over 6.5 Mton CO_2 when all the waste fats in the EU are used to substitute naphtha (2.5 ton CO_2/ton waste fats), and 351 kton when substituting biodiesel from waste fats (130 kg CO_2/ton waste fats in case of substitution of naphta for biodiesel). Application as biodiesel thus also has a significant benefit relative to landfilling; 6.4 Mton CO_2 when all waste fats are applied as biodiesel instead of being combusted. The naphtha-route has a small benefit compared with biodiesel production or co-firing in terms of costs or direct greenhouse gas emission reduction. Therefore, it is likely that more money can be earned producing biodiesel.

A.5 Grass refinery

Options for cascading?

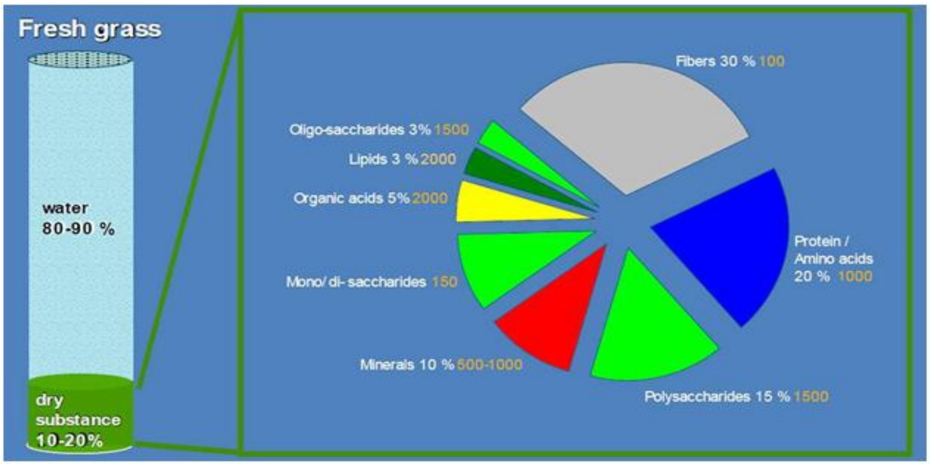
In regions with intensive dairy cattle and other bovine husbandry, part of the grass cultivated for feeding these animals is lost because it is too wet. Especially in spring and wet summers a lot of grass can be lost. Indications of the size of the surplus range from 7 to 15% of annual grass yield of 7 metric tons of dry matter per hectare. With ± 39 Mha fertilized grassland (current area in the EU) a surplus of 15% would give a total availability of 15 Mton grass/yr. Next to this an indicated amount of 15-20 Mton of grass from natural sources and unfertilized lands is said to be available annually (Eska Graphic Board, 2012).

An alternative may be to refine the grass and isolate and separate its components for further utilization as high value raw materials and ingredients (Courage2025).

Technological route for cascading

The idea of grass refining is to bruise the grass stalks and press them to separate fibres and juices. Figure 28 shows the average composition of grass from fertilized lands.

Figure 28 Average composition of grass from fertilized grasslands



Source: Eska Graphic Board, 2012.

Next, proteins can be separated by heating and addition of rennet. The resulting protein flakes can be isolated by filtration and applied as high quality, high-protein concentrate. The concentrate has qualities comparable to soy meal and can be used for:

- pigs feeders especially piglets and sows feed;
- in general poultry food;
- fish food;
- pet food.

The fibres can be applied as an intermediate layer in graphic board. Graphic board producer Eska is one of the partners in the Dutch Grassa! Grass refining initiative. (Minerals, sugars, acids and other soluble components remain in the treated juices). These could be digested for biogas production as is currently under investigation. The technology has been demonstrated at industrial scale with a mobile installation, allowing surplus grass processing at the point where it is released.

Figure 29 Mobile press for grass refining

A major drawback of grass as a raw material is its seasonality in availability. This could be overcome by ensilaging the grass. However, if and what kind of impacts of ensilaging on protein and fibre quality may be expected are not yet known.

Benefits from cascading

Assuming an availability of 30 Mton (dry matter) grass in the EU per year, grass refinery could potentially produce 6 Mton protein, 9 Mton fibre, 1 Mton fat, 14 Mton sugars.

Assuming the protein and part of the sugar replace feed, the remaining sugars and fat are used to produce biogas and fibre is used as fuel in coal fired power plats, a rough estimate yields the following benefits:

- The high-protein concentrate substitutes soy (45% protein, VEM value of 1,326 per kg dry weight) as animal feed, part of the sugars are added to realize an appropriate VEM[8]-value. Production of soy results in a CO_2 emission of 0.425 Mton/Mton (JRC, 2008). Based on protein content and VEM value, substitution of soy could avoid around 5.8 Mton CO_2 eq. (6 Mton grass protein and 6.2 Mton sugar from grass substitutes 13.8 Mton soy-cake).
- The remaining sugars (7.8 Mton, 16 PJ/Mton) and fat (1 Mton, 36 Mton/PJ), around 161 PJ/year, are used to produce biogas, around 136 PJ/year. Substituting for natural gas, would result in avoided emission of 8.85 Mton CO_2 eq.
- Because market volume for cardboard filler which could be substituted for grass fibres is small, the fibres will more likely be used as fuel in coal fired power plants, with associated avoided emissions of 17 Mton CO_2[9].

These three applications together amount to a total CO_2 benefit of 31.1 Mton per year.
Benefits could be even larger if the grass protein is used to produce meat alternatives. With a CO_2 benefit of 5 kg CO_2/kg meat alternative[10] the CO_2 benefit could increase from 5.8 Mton when soy-cake is replaced to 29.8 Mton when protein substitutes food (30+5.5-5.8[11]).

A.6 CO_2 as feedstock in greenhouses

CO_2 fertilization or enrichment is only possible in so-called high technology greenhouses. CO_2 fertilization in The Netherlands amounts to approximately 125 tonnes/ha/year, normally produced by natural gas combustion. The alternative, as currently already applied in The Netherlands, is CO_2 captured from industrial processes (as is done by e.g. Shell Pernis refinery) and power plants (RoCa III power plant).

Total area in the Mediterranean and in The Netherlands amounts to an estimated 25,000 hectares. Assuming that fertilization levels for The Netherlands are generally representative and that CO_2 enrichment in the

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8 VEM = Voeder Eenheid Melk.

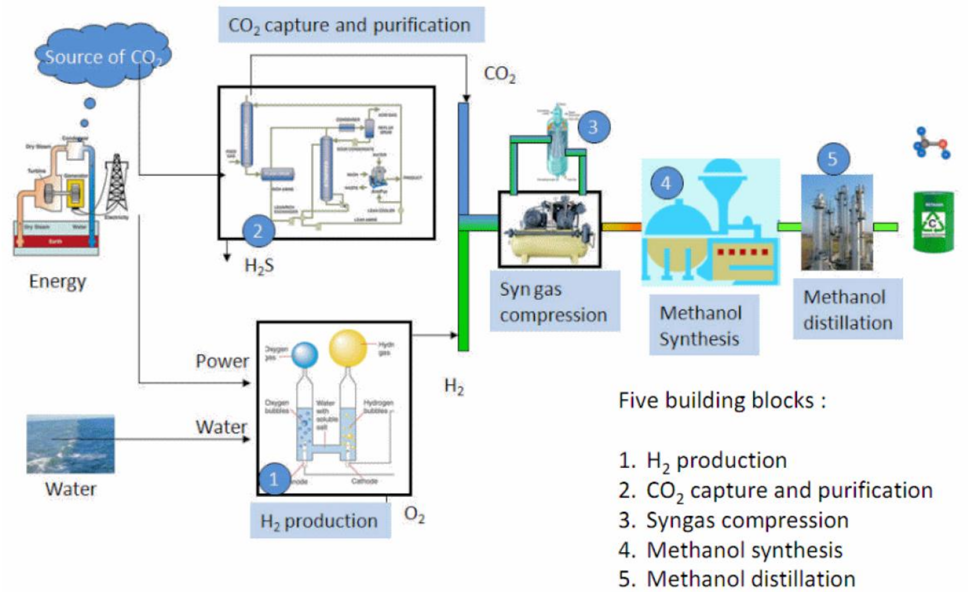
9 9 Mton fibre (18 MJ/kg, ECN, 2012a) x 0.105 (ton CO_2/GJ steenkool, Agentschap NL, 2011) = 17 Mton CO_2.

10 The estimate of the potential effects of using grass to produce vegetable protein foods is based on average greenhouse gas emissions of meats and of meat alternatives, as calculated in (CE, 2011).

11 Protein to food = 5 kg CO_2/kg * 6 Mton protein = 30 Mton CO_2; additional biogas from sugar: 6.2 Mton sugar * 16 PJ/Mton * 0.85 efficiency * 0.065 Mton CO_2/Mton biogas.

Mediterranean would also be achieved by natural gas combustion a maximum of a little over 3 million tonnes of captured CO_2 could be utilized.
Another option for reusing CO_2 is its utilization as a feedstock for methanol by letting it react with H_2 (e.g. ThinkGeoEnergy, 2012). This process has recently been implemented commercially with the opening of a first-of-a-kind commercial production facility - George Olah Plant - in Iceland owned and operated by Carbon Recycling International (CRI). The plant uses power generated by the Svartsengi geothermal power plant at Reykjanes peninsula and CO_2 captured from the power plant's steam vapour.

Figure 30 Methanol production from CO_2



Source: http://www.starch.dk/methanol/energy/img/TM01-02e.pdf.

Methanol production from captured CO_2 and H_2 produced with renewable power could be an outlet for surplus renewable power, e.g. excess wind power.

We did not, however, include this option for three reasons:
- As indicated in the SRREN UNFCCC report on renewable energy (IPCC, 2011) potentials, the potential of competitive renewable energy is limited to 250–450 EJ/year, compared with a total anticipated primary energy consumption of some 1,000 EJ/year. This eliminates CO_2 from hydrogen on baseline renewable power surplus as an option and leaves only temporary and regional surpluses as a relevant power source.
- Production of hydrogen by water electrolysis has an efficiency of 60% - 70%, while future efficiencies are estimated at 75% (CE, 2012d). Such efficiencies are lower than that of pumped storage reservoirs (85% - Ummels, 2009) and flywheels (80-90%, see [12]) and are comparable with that of compressed air storage in e.g. salt caverns, three other options for storage of surplus power. If the aim is utilization of the limited potentials of renewable energy with optimum efficiency, storage in reservoirs should be preferred.
- Hydrogen from surplus power could also be applied for production of ammonia, which could subsequently be applied as a fertilizer (see CE,

[12] See: http://en.wikipedia.org/wiki/Flywheel_energy_storage#Grid_energy_storage.

2012d). N-fertilizer is a necessity in food and biomass for bio-based economy cultivation.

A.7 Use of waste heat from bio-electricity production

Biomass based systems will – according to the National Renewable Action Plans of the individual EU Member States – generate a total of 20 Mtoe of power and 90 Mtoe[13] of heat in 2020 (ECN, 2011).
Though Combined Heat and Power (CHP) facilities will produce a significant share of both power and heat still a large part of biomass based heat will be produced with other technologies. At least 27 Mtoe of the biomass-based heat will be generated in individual households and another estimated 30 Mtoe will probably be produced in industrial boilers without a steam turbine. These latter technologies are less efficient than CHP facilities.
Assuming a maximum efficiency of 85% for heat generation in a residential environment and of 90% for industrial boilers, the heat generated requires utilization of 64 Mtoe. With this amount a total of 39 Mtoe of heat and 13 Mtoe of power could be generated in biomass fired CHP plants. The 13 Mtoe of power will avoid or substitute fossil fuel based power production with – according to the Biograce CO_2 tool – a carbon footprint of 130 g CO_2 eq./MJ. The associated avoided greenhouse gas emission amounts to 70 million tonne CO_2 eq. per year.
However, assuming that no additional biomass can be mobilized to cover the gap between the heat demand of 57 Mtoe and the heat production of 39 Mtoe, an additional 19 Mtoe of natural gas (η = 95%) with a specific carbon footprint of 68 g CO_2 eq./MJ has to be consumed in order to cover the total heat demand of 57 Mtoe of heat. The associated CO_2 emission amounts to 53 million tonnes of CO_2 eq. per year. Therefore, utilizing the biomass in CHP plants instead of, as is planned, in boilers in residential and industrial environments would give a net reduction of 17 million tonnes of CO_2 eq.

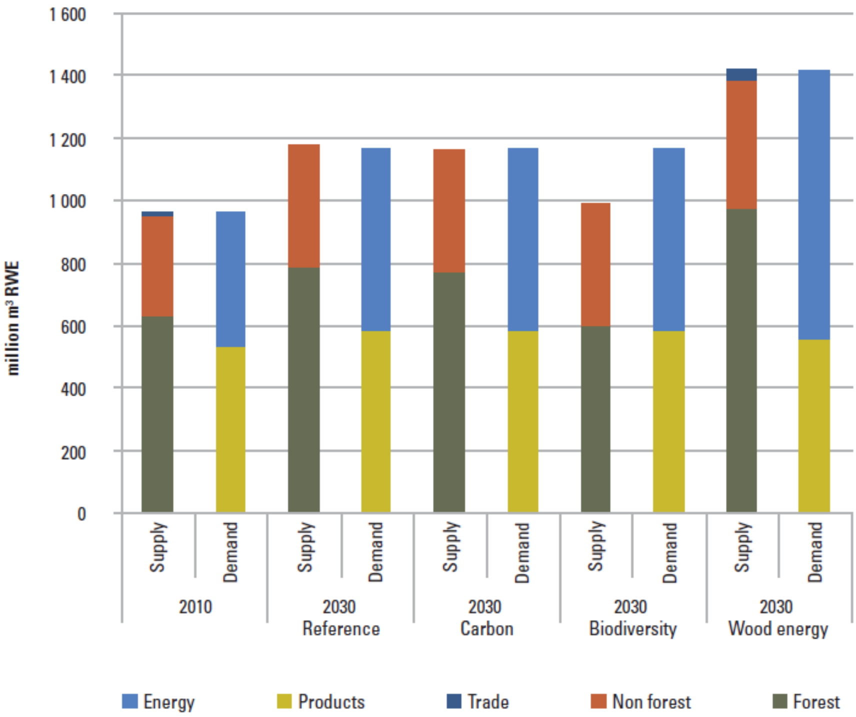
13 Mtoe = Megatonne oil equivalent = 41.87 PJ.

Annex B Woody Biomass

B.1 Introduction

Current demand and supply of woody biomass in the EU amounts to 950 million m^3 per year, of which approximately 40% is utilised for energy applications. As shown in Figure 31, in most scenarios the demand for woody biomass will increase (UNECE, 2011). The wood market is interesting because some extra cascading options can improve this sector of the bio-based economy, but some existing cascades can be jeopardized by stimulating to strongly the use of these sources for bioenergy. Both theses aspects are in the following chapter.

Figure 31 Supply/demand balance in the quantified scenarios, 2010 and 2030



Source: UNECE, 2011.

Potential availability of wood in the EU

There are different categories of woody biomass, which will be elaborated on below. Table 11 shows the amounts of woody biomass by-products released in the EU.

Table 11 Overview of amounts of woody biomass by-products released in the EU

	Competing function	Functionality combinable?	ILUC risk at functionality loss?	Availability (PJ/year ILUC free)
By-products pulp-industry				
- paper sludge	Landfill, WIP			65
By-products forestry-industry + wood industry				
- landscape care	Compost	Yes		380
- additional felling	C-storage	No		1,529
- felling residues (twigs, stump)	C-storage	No		1,002
- saw mill residues	Board	No	Partly (additional felling)	687
- consumer waste wood	Particle board	No	Partly (additional felling)	371

Sources: Mantau, 2010; UNECE, 2011; ECBREC, 2006; EEA, 2006; Elbersen, 2010; JRC, 2011; Monier et al., 2011; VTT, 2011.

Pruning wood
Landscape care pruning wood is often mulched or used in composting to give structure to the compost heap.

Felling residues
Felling residues such as tree tops, branches and stumps in general are left in the forest and contribute to carbon stocks and nutrient concentrations in the soil, while at the same time help maintaining biodiversity and providing protection against erosion.

Additional felling
Next to these different categories of by-products and residues in forestry, there is at least a theoretic potential for producing an additional amount of wood from European forests.
One definition of 'sustainable forestry' is that annual felling should not exceed net annual increments in standing wood volumes (trees). This would give no changes in sequestered amounts of carbon. In a number of European countries annually felled volumes of wood are smaller than net annual increment. So theoretically more wood could be produced and made available for applications, such as for example fuels.
However, the effects of additional felling can have very significant impacts on forest biodiversity and the availability of providing ecosystem services, depending on the type and maturity of forest in which the additional felling is done and how felling is done:
- additional felling in mature and unmanaged forests that are still sequestering carbon will have a significant negative impact on biodiversity and carbon stocks and should be avoided;
- in managed forests, increased wood production should be realized carefully, rather by increased thinning than by clear felling of the neglected forest;
- restoration management in neglected and overstocked tree stands on the other hand is considered to provide many benefits apart from serving as a source of biomass (for example, through improving the general quality of woodlands, improving access for recreation, potentially meeting biodiversity objectives through changes to stand structure and light regime) (AE, 2011; Joanneum Research, 2010).

As indicated in the EFSOS II report, a sharp increase in wood supply is probably not attainable in a sustainable way (UNECE, 2011):
"The main concern is for biodiversity, as increased harvest pressure in all scenarios, except for the "Priority to biodiversity" scenario, lowers the amount of deadwood and reduces the share of old stands. The "Promoting wood energy scenario" shows a decline in sustainability with regards to forest resources and carbon, due to the heavy pressure of increased wood extraction to meet the renewable energy targets".

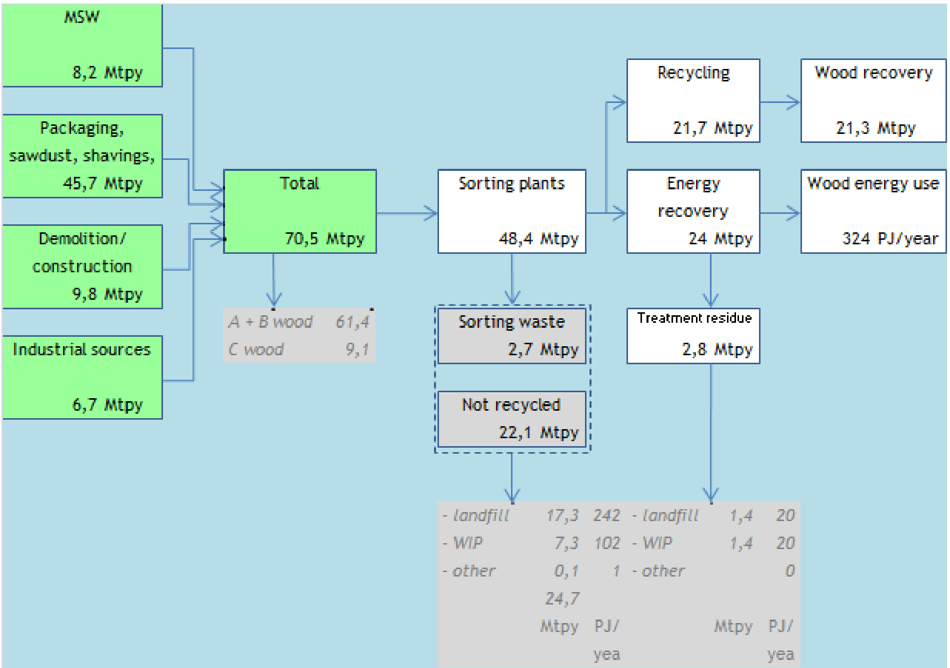
How much biomass can be produced in a sustainable way from neglected tree stands is not completely clear. The potentials mentioned in consulted literature may serve as a first indication, but further research in this matter is necessary.

Sawmill residues
During processing of wood part of the processed material is converted into by-products or residues, e.g. sawdust, bark and shavings. Such by-products from wood processing are already partly applied as raw material for board production or are utilized as a fuel, substituting fossil fuels.

In case of utilization of by-products as a raw material for e.g. board production there is a risk of ILUC occurring when these raw materials are redirected to biofuels production. This risk depends on the total demand and availability for wood on the EU market and will become a fact when demand requires felling of additional wood from pristine forests or felling more wood than the net annual increment (see also the subparagraph on additional felling).

Consumer waste wood
Consumer waste wood includes both bulky refuse and waste wood from industrial sources, such as demolition and construction (see Figure 32). Approximately 60% of the produced waste wood is collected and sorted for application as fuel or raw material for panels. As with chips and shavings from saw mills and other wood processing industries there is a competition between the subsidised energy sector and board producers for high quality waste wood.

Figure 32 Waste wood flows in the EU



B.2 Paper and particleboard: Wood and associated fibres in cascades

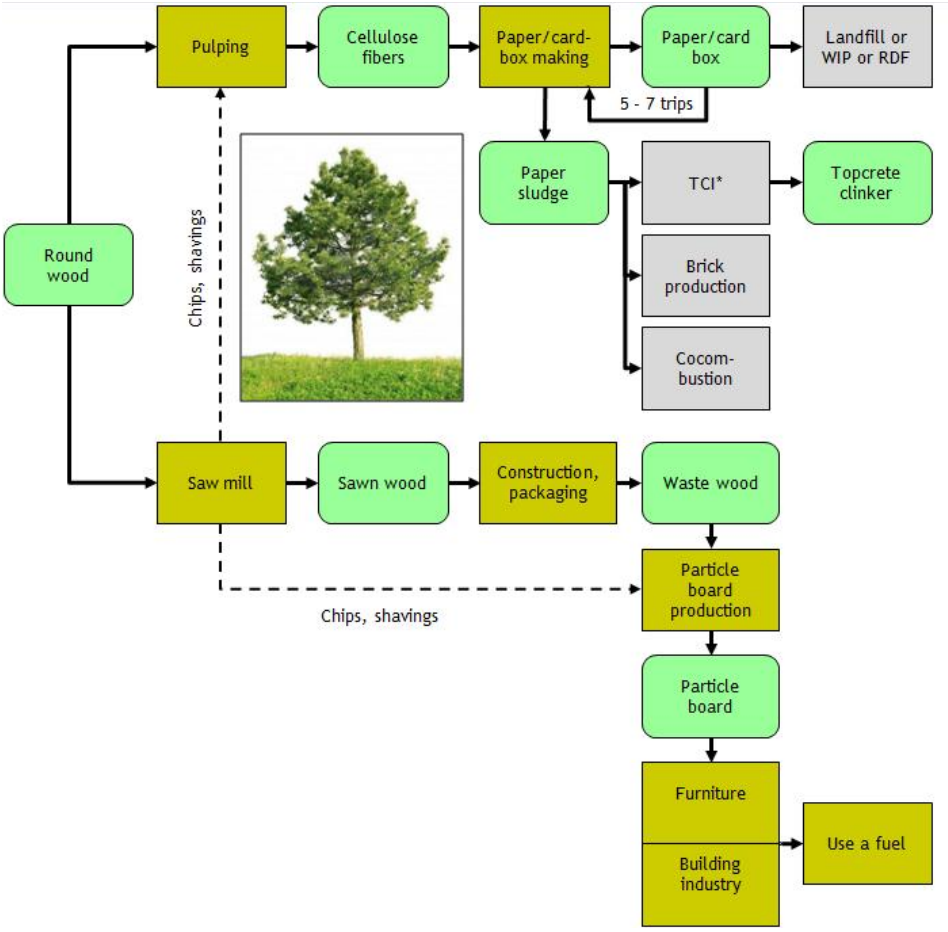
Existing cascades and bio-refinery concepts for wood cascades

Wood is already widely applied in cascades, such as:

- round wood/chips → paper → building materials (Topcrete, pore former in brick production (N+P Recycling Group, 2012));
- sawn wood → construction products → particleboard → utilization as a fuel.

Both cascades are illustrated in Figure 33.

Figure 33 Flowsheet for existing wood based cascades



Especially in Northwest Europe the paper cascade has been optimized nearly to up to the optimum with:

- high recovery rates for waste paper and cardboard (up to 70%);
- maximisation of application of secondary fibres in paper and cardboard with fibres making 5–7 trips before being disposed of (because of having become too short);
- optimisation of paper sludge applications as a secondary raw material or a fuel.

Recycling of fibres means less production forest area is required and/or means existing production forests can be allowed to sequester more carbon and to become more bio-diverse. For each ton of secondary fibre which is not recycled, 2 tons of CO_2 is not sequestered. There is still potential for increased recycling of paper. Current average EU recycling rate stands at 55%, while the maximum attainable recycling rate amounts to approximately 80% (CEPI, 2012). This means an additional 50 Mton of CO_2 could be stored in vegetation.

Taking a pine production forest out of the production system by increasing recycling rates could double the amount of carbon sequestered in standing vegetation from an average 55 metric tons per hectare to 110 metric tons per hectare. The freed-up production forest could also be utilized for production of raw materials for other products cascades.

The cascade for residual wood products from construction and demolition, and from packaging and has not been fully optimised, with approximately 40% of the produced waste wood still being landfilled or burned in waste incineration plants with no or an inefficient energy recovery system. Furthermore, this cascade is under pressure from the energy sector, which uses residual wood as a fuel. High demand for waste wood in the energy sector and subsidies for waste wood utilisation as a fuel has resulted in increased prices for this commodity. This has put pressure on the margin of chipboard producers and has let to a decrease in the availability of this raw materials for particleboard production.

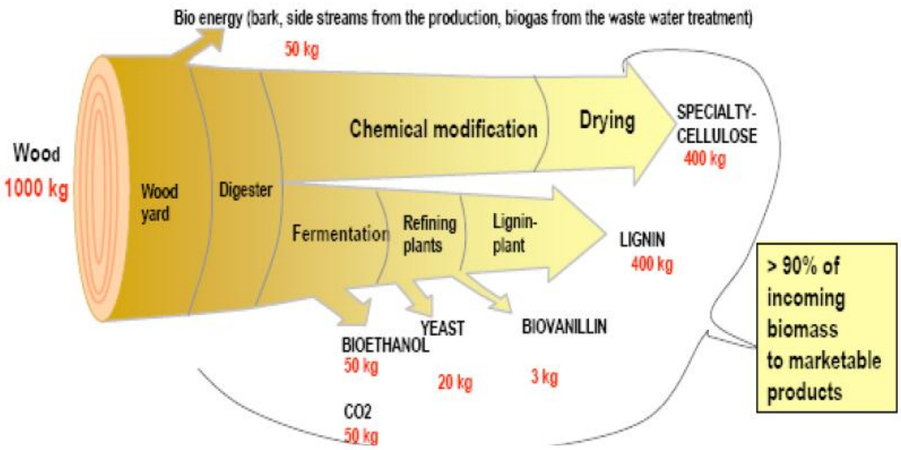
In some countries the percentage of secondary wood utilized in panel board is far higher than the average of 25% applied in the EU. In Belgium 50-60% of the feedstock for panel boards consists of secondary wood. Gruppo Saviola in Italy produces a 100% secondary based panel board (Gruppo Mauro Saviola, 2012). However, there are different panel board qualities and it is not clear from available literature if panel board for all applications can be produced for 100% from secondary wood. Therefore, the possible extra potential is unclear.

Existing wood-based bio-refinery concepts

Sulfate pulping of wood for isolation of the cellulose fibres in itself is one of most widely applied bio-refinery concepts for biomass utilized today. Next to cellulose production, added value is created in sulfate pulping by isolation of valuable by-products, such as turpentine and tall oil components. Some trees such as Pinus Elliottii mainly cultivated for wood and fibre are also exploited for resins tapping.

A range of specialties are produced by Borregaard in Norway and Domsjö in Sweden, utilizing the sulfate pulping process.

Figure 34 **Wood sulphite pulping products yields**



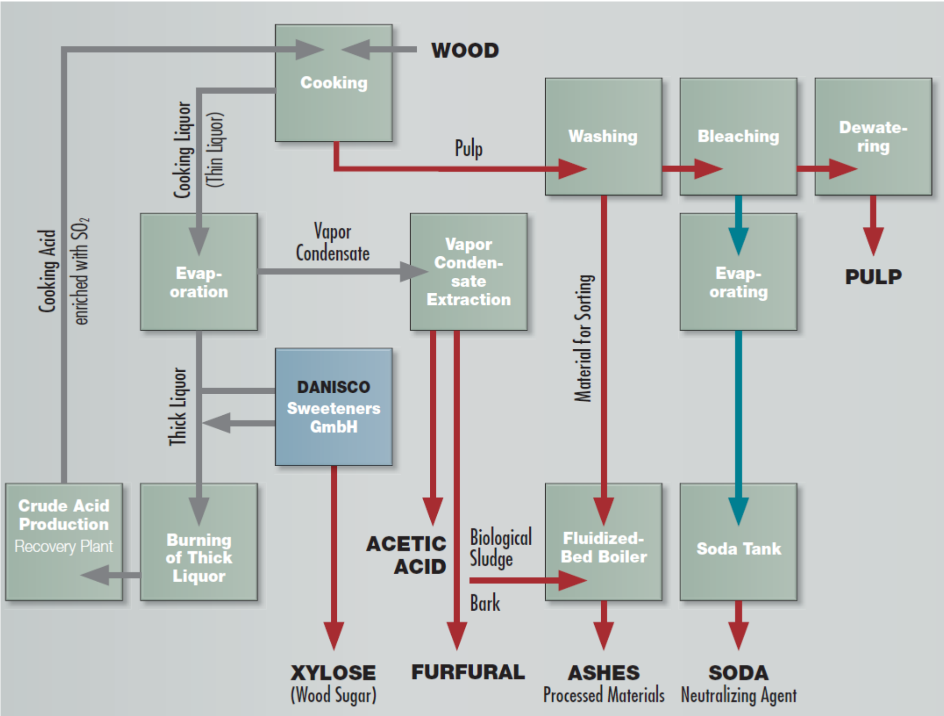
Source: http://www.biomasseverband.at/uploads/tx_osfopage/PS_V_7_Maekinen.pdf.

The high purity specialty cellulose is applied as a textile fibre for clothing and similar products and as a feedstock for cellophane. It also has a high market potential for utilization as a reinforcement fibre in plastics and concrete. Lignin is converted into lignosulfonates, which are applied as an additive in production of concrete and plasterboard and as dispersants in oil drilling mud and in utilization of pesticides, dyes and carbon black.
In addition or alternatively to yeast and ethanol, the C5 sugars could also be converted into high value xylitol and furfural. All these products enter their

own production chain, which often concerns a one stop application, without cascading.

Lenzing's production units in the EU (Austria, Czech Republic and UK) and in North America and Asia utilize caustic soda pulping and produce more or less the same array of products as Borregaard and Domsjö. The pulp is converted into viscose or similar fibres, which are applied in non-woven applications such as wadding.

Figure 35 **Caustic soda pulping of wood**



Source: http://www.lenzing.com/sites/nh/english/images/pdf/english/prozesse_e.pdf.

B.3 Potential additional future wood refining concepts within existing cascades

Two new separation technologies for isolation of by-products from wood are currently being demonstrated at commercial sulfate pulping plants:

- gasification of black liquor by-product of sulfate pulping with the Chemrec process for production of olefins;
- Ligno boost process for isolation of lignin from sulfate pulping produced black liquor for utilisation of lignin in e.g. resins.

In both cases the innovation as aimed at extending the existing conventional sulfate pulping bio-refinery concept. The gasification process has no obvious advantages compared with integral gasification of wood other than that the process combines well with the pulping process and that because of the integration with the pulp plant biomass feedstock is readily available. On the other hand, gasification for chemicals production results in reduced availability of fuel for the pulp plant, requiring additional fuels to be utilized. The same applies to the Ligno boost process. The Ligno Boost technology is mainly aimed at the production of fuel pellets as no high value application for this type and quality of lignin has been developed yet.

B.4 Bio-cokes for chemistry

Why is this cascading?

In the EU, wood is commonly and widely applied as a fuel for direct firing of boilers and furnaces for power, process heat and domestic heating. Wood could however also be converted and refined into charcoal, power and chemical feedstock by means of slow carbonisation – in other words: it could be a feedstock to both chemicals and other raw materials and power and/or heat.

The slow carbonisation process of charcoal production is nowadays a continuous shaft furnace or rotary furnace-based process at a size of scale of up to 10–15 kilotons (metric) per year per kilo. The produced charcoal is primarily applied as an industrial reductant or can be converted into activated carbon. A number of examples of utilisation of charcoal as a reductant have been included below.

Valuable by-products include acetic acid, alcohols, acetals, smoke flavours and tars. For example, Chemviron Carbon in Bodenfelde, Germany produces acetic acid as a by-product (Sintef) and Lambiotte in Wallonia supplies wood-based acetals as specialty products. Pyrolysis gases can be utilised for power production, as is utilised by e.g. Norit AC in Klazienaveen (Agentschap NL, 2012).

Examples of charcoal production for industrial uses

Examples of utilisation of charcoal as a reductant include:

1. Charcoal in pig iron production

In Brazil, wood is applied at an industrial scale for the production of bio-cokes, which are subsequently applied as a reductant in pig iron production (see textbox). According to a recent press release ArcelorMittal is planning to double charcoal utilisation in its Brazilian operations and to improve the energy efficiency of charcoal production by using off-gases for power production (Nielsen, 2011).

Charcoal utilisation in pig iron production (adopted from (IEA, 2007)

The use of significant amounts of charcoal for reducing iron ore is one special characteristic of the Brazilian iron and steel industry. In 2004, about one-third of all pig iron -1.4 Mt of integrated steelworks and 10.1 Mt of independent pig iron production - was based on charcoal. Arcelor Brasil and Acesita are the main integrated steelworks th**at use charcoal.**

The independent producers operate 153 blast furnaces that use charcoal with capacities ranging from 18 to 180 kilotons of pig iron per year.

The average energy efficiency of charcoal production was 53% in 2005. Just over half of the charcoal came from planted forests, the remainder from native forest. The current specific consumption in the blast furnaces of integrated mills in Brazil is about 330 kg coke and 170 kg coal per ton of pig iron, which corresponds to 15.5 GJ/t. The independent producers use on average 25.6 GJ charcoal/t pig iron. The most efficient charcoal-fired blast furnace at Acesita used 16.2 GJ charcoal/t pig iron in 2004. This is close to the figure for coke - fired furnaces.

2. Charcoal in silicon production

In Australia, charcoal is utilised by the SIMCOA company as a raw material for the production of high purity silicon (Si) (Simcoa, 2012). Charcoal is produced on site in a 27 kilotons/year Lurgi charcoal plant. The wood used to manufacture charcoal is a mixture of forest residues (from commercial logging for sawn timber), and sawmill offcuts. The high grade silicon is utilised as:

– an alloying agent in aluminium;

– a raw material for optical glass, silicon chips for electronic products and photovoltaic cells.

An additional application could be the use of calcined charcoal as a substitute for calcined petrocokes in the production of TiO_2 (as a reductant) and SiC (as a raw material). Examples of producers of these products are e.g. Tronox (e.g. Tronox Botlek, Rotterdam) and Kollo (Farnsum).

The possibility of producing calcined charcoal from e.g. residual wood from pallets and wooden boxes has been demonstrated at the 90 kg/hour BlackCarbon CHP and carbon black unit unit at Barritskov in Denmark (Black Carbon A/S, 2012). This installation was designed as a utility unit producing heat, power and carbon black for soil improvement for an agricultural horticulture facility. Another large scale example is production of activated coal from biomass at Notir AC in Klazienaveen.

Gross benefits of wood bio-refining for charcoal production

Production of calcined charcoal from residual would yield approximately 25% of carbon black, containing approximately 50% of the energy content of the processed wood. The remainder of the energy content is largely contained by the volatile and incondensable pyrolysis product gases. In most installations these gases are burned for providing process heat. The combustion gases' heat capacity remaining after process heat supply can be utilised for power and/or heat generation. Losses would amount to 5-10%.

Figure 36 SIMCOA's charcoal production facility

Figure 37 **BlackCarbon CHP and carbon black unit unit at Barritskov in Denmark**

Source: Steiner, 2012.

Substitution of calcined petrocokes would avoid a gross chain emission of approximately 145 kg CO_2 eq./GJ of petrocokes (net avoidance: 135 kg CO_2 eq./GJ), while utilisation the remainder of the energy for CHP would avoid approximately 70 kg CO_2 eq./GJ of remaining energy. The total gross greenhouse gas emission avoided would amount to 105–110 kg CO_2 eq./GJ residual wood[14], or 4.5 ton CO_2/ton calcined petcokes. The avoided greenhouse gas emission may be increased by isolation of high value chemicals as by-products.

In the Netherlands, with around 400 kton of petcokes used per year in (amongst others) the aluminium industry, total avoided emissions could amount to 1.8 Mton CO_2 per year in The Netherlands alone.
For the entire EU petcokes consumption, for e.g. TiO2 production, SIC production and anodes, production amounts to approximately 2 Mtonnes/year (OECD,2010) and total avoided emissions could be as high as 9 Mtonnes of CO_2/year.

[14] 50% x 145 + 50% x 70.

Annex C Consumer Waste

C.1 Introduction

EU citizens produce a total of almost 60 million tonnes of organic waste (MSW + green waste) of which more than 60% is still landfilled or burned in a low energy efficiency waste incineration plant (WIP) annually.
A part of this total concerns products from bio-plastics, such as starch-derived film and bottles made of PLA.

Part of the produced food products is lost in wholesale, in retail or at the consumer end. Wood-based products, such as paper and construction materials are disposed of at their end-of-life.

Part of the produced waste is collected as a separate fraction for recycling. The rest ends up in municipal waste and is landfilled or burned. The landfill gas and heat produced during these processing operations is partly utilised for generation of heat and power.

Figure 38 Waste processing in the EU

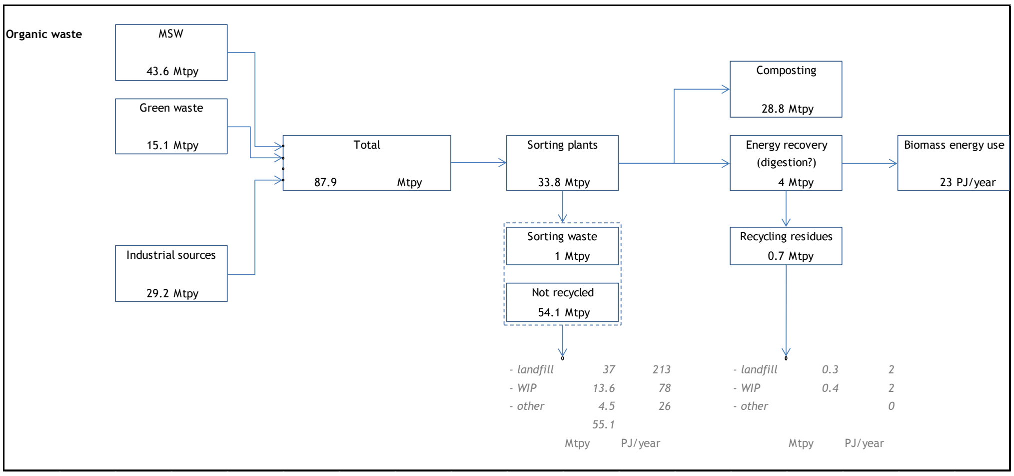


Table 12 in the paragraphs below options to optimise utilisation of organic consumer waste by way of cascading are discussed.

Table 12 Overview of amounts of consumer wastes released in the EU

	Competing function	Functionality combinable?	ILUC risk at functionality loss?	Availability (PJ/year ILUC free)
Consumer waste, ex wood-based products				
- sep. collected green waste	Compost, A.D.	Yes	No	166
- mixed MSW	Landfill gas, WIP	No	No	776
- verge grass	Compost	Yes	No	46
- C1 fats	Co-combustion	No	No	11
- used cooking oil	Co-combustion	No	No	88

Sources: ECBREC, 2006; EEA, 2006; Elbersen, 2010.

C.2 Incineration with energy recovery instead of landfilling of MSW

Why is it cascading?

If wastes cannot be reused or recycled, incineration with energy recovery (power, heat or both) or landfilling are the final options for waste treatment. Waste that is currently landfilled is assumed to have no other useful application; incineration with energy recovery ensures maximum use. In the EU-27, part (21%) of the municipal solid waste (MSW) is incinerated (EC, 2012). Energy is recovered from around 80% of the incinerated MSW. Combined Heat and Power (CHP) is the co-generation of power and heat. Heat is a by-product of power generation and, when put to good use in for example urban heating systems, increases efficiency of electricity generation.

Benefits from cascading

The environmental benefit of incineration of wastes with energy recovery is the avoidance of use of virgin fossils to produce energy. Table 13 shows the energy recovery potential from bio-MSW in the EU-27. Calculations are based on the waste quantities in the year 2008.

Table 13 Potential contribution of incineration with energy recovery of bio-MSW

MSW in EU-27 [15]		% of EU economy in 2030[16]	
Total in 2008	**Bio (EJ)**	**FEFC**	**Electricity**
Landfilled (Mton)	49.755		
Landfilled[17]	0.485		
Potential for energy recovery			
Dutch average (13.7%$_e$)	0.066	0.08%	0.22%
Dutch average (15.9%$_t$)	0.077	0.0%	
Potential in 2030			
Option 1: 30%$_e$ efficiency	0.145	0.17%	0.49%
Option 2: 20%$_e$+40%$_t$ efficiency	0.291	0.33%	

Note: value %$_e$ = electric efficiency, %$_t$ = thermal efficiency.

Based on EC, 2012.

PBL estimates that the European final energy and feedstock consumption (FEFC) in 2030 will amount to 87 EJ. Table 13 shows the (additional) potential contribution of incineration with energy recovery of bio-MSW. Energy content of bio-waste was assumed to be a little lower (± 0.5 GJ/ton less) than fossil waste. With a potential electric efficiency of 30%, 0.17% of the Final Energy and Feedstock Consumption (FEFC) in the EU in 2030 could be met, which translates to 0.49% of final electricity consumption.

CHP is an additional cascading step in the energy recovery phase; heat which would otherwise be lost is used. When CHP is applied, up to 0.33% of the total FEFC in 2030 could be met. It should be kept in mind that these numbers indicate maximum potential, and that accessibility is not included. If the fossil component of the MSW is also incinerated, which is likely as these streams are mixed in the MSW, the totals double and thus 0.97% of final electricity consumption in the EU-27 in 2030 can be met.

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15 Based on Eurostat data, assumptions: category 'household and similar wastes' consist of 50% bio-waste and 50% fossil waste. The category 'Animal and vegetal wastes (excluding animal faeces, urine and manure)' is added to the bio-wastes category (based on EC, 2012).

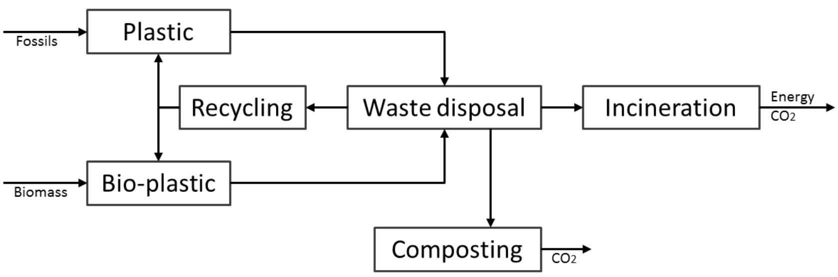
16 Assumed FEFC in the EU in 2030: 87 EJ/a, electricity production: 29,9 EJ/a (PBL and CE, 2012).

17 Assumed energy content: 10 GJ/ton waste for both bio and fossil waste.

C.3 Bio-plastics – biodegradability vs. recyclability

Why is this cascading?
Bio-plastics are made from renewable resources, and may be biodegradable or compostable. Compostability may be a benefit in some cases, while in other cases it may be more advantageous to have plastic be recyclable to extent the life cycle of the biomass. Currently, circa 40% of plastics used for packaging in The Netherlands are recycled (Nedvang, 2012). Bio-plastics should have a valuable end-of-life use in order to be a cascading option. In current practice bioplastics such as starch-based plastics or composites, or PLA are commonly composted or landfilled or burned in a municipal waste incinerator as a fraction of mixed municipal waste. Recycling or incineration with energy recovery would be interesting cascading options for bio-plastics. Recycling avoids production of virgin sources. In case of incineration the use of fossil fuels to produce the recovered energy is avoided.

Figure 39 Bio-plastics recycling scheme



Benefits from cascading
PLA, and probably other bioplastics, can, however, be recycled and significant amounts of CO_2 emissions can be avoided. In (CE, 2011) the recycling of PET is compared with energy production in a MSWI installation. This study concludes that each kilogram of PET in the recycling scheme instead of in the MSWI saves 2.8 kg CO_2. Production of PLA gives a 3.2 kg CO_2 eq./kg PLA greenhouse gas emission. Recycling of a tonne of PLA (assumed to be comparable to PET) requires approximately 1.2 MJe/kg PLA with an equivalent emission of 0.16 kg CO_2 eq. One kilogram of PLA in the recycling scheme therefore instead of in the MSWI therefore has a benefit of 3 kg CO_2 eq. With a current annual consumption in the EU of 100 kilotonnes, the associated saving in greenhouse gas emissions would amount to 300 kilotonnes CO_2 eq./year. If more and more PET is be replaced by bio-materials like PlantPET, it is important that it is compatible with the recycling schemes across Europe.

Annex D Cascading in Sustainability Criteria Schemes

Several sustainability schemes for biomass also mention cascading. Three schemes important to the Dutch situation, are elaborated on below. These schemes provided the input for e.g. the NTA8080 and CEN criteria, which therefore will not be discussed.

D.1 Cramer criteria

In 2006, six sustainability criteria for biomass where established by the project-group 'Sustainable production of biomass', or the 'Cramer Commission'. This commission was lead by the later Minister for the Environment Jacqueline Cramer (minister from February 2007 to February 2010) and developed its criteria in cooperation with industry, science and NGOs. Three of the criteria relate to the environmental performance and are relevant to cascading, as shown in Table 14.

Table 14 Environmental Cramer Criteria and the relationship with use of residues and to cascading

Cramer Criterion	Applies to residues? (According to Cramer Commission)	Relevant to cascading? (CE Delft interpretation)
Reduction of GHG emissions should be 50-70% for electricity applications and at least 30% for bio transport fuels	Yes	Yes: **GHG balance should be better than performance of alternatives**
There should be **no competition** with food or other essential local applications	No	Yes: biomass should be used for the **higher value purposes first**
Production and processing of biomass should improve, or at least maintain, quality of soil, groundwater, surface water and air	**Use of agricultural residues should not compete with essential local functions** such as soil quality enhancer **Residues should be used in the most efficient way** (not unnecessarily burned or discarded)	Yes: **alternative uses of bio-residues should be considered**; the higher value purposes should be considered first.

Source: Based on Projectgroep Duurzame productie van biomassa, 2007.

Distinction is made by the Cramer Commission between primary biomass and residues, which have a value of < 10% of the main product and that have no other valuable purpose. For this latter category a smaller set of criteria applies, as shown in Column 2 of Table 14. In Column 3 the relevance to cascading of the environmental Cramer Criteria is elaborated on. It shows the importance of looking at the alternative uses of the biomass, making sure no competition with essential (local) functions takes place and making sure the cascading option ensures high value use of the biomass.

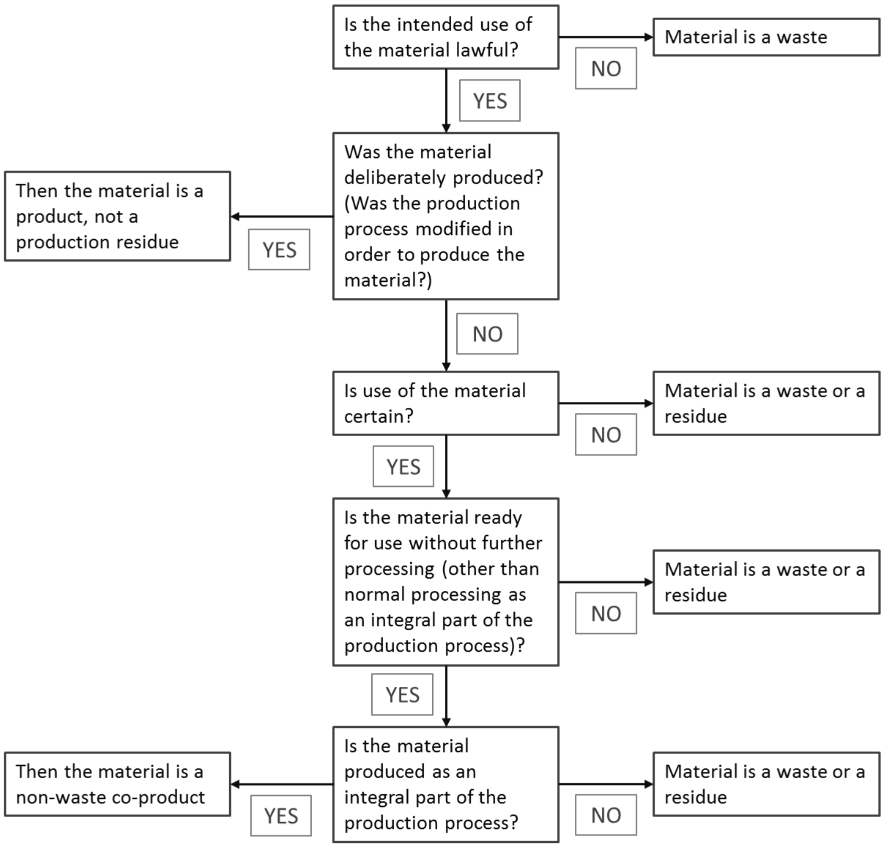
D. 2 Commission Sustainability Issues Biomass

The Commission Sustainability Issues Biomass (Commissie Duurzaamheidsvraag-stukken Biomassa), or the 'Corbey commission', is a follow-up of the Cramer Commission, and was initiated by Minister Cramer in 2009. The commission stresses the importance of (international) regulations concerning sustainable biomass use. In their advice concerning definitions and sustainability criteria of residues they suggest that solid biomass-streams should comply with the RED sustainability criteria, adding that three adjustments should be made (Commissie Duurzaamheidsvraagstukken Biomassa, 2011):

1. A higher CO_2 emission reduction.
2. An additional criterion that ensures maintenance of soil quality.
3. A clear definition for residues.

For the evaluation of cascading options, especially this third topic is important. A distinction is made by the commission between primary residues (from agriculture, aquaculture, fisheries and forestry) and secondary and tertiary residues (residues from processing). They state that for the primary category, all sustainability criteria should be met. To assess whether a material is a co-product or a residue or a waste, they propose using the decision tree used in the CEN-norm, as shown in Figure 40.

Figure 40 Decision tree to differentiate between wastes, residues and co-products



Source: Commissie Duurzaamheidsvraagstukken Biomassa, 2011.

The commission states that using material prices is not a good basis for defining whether biomass streams are by-products or not, because of price volatility and international markets. Therefore, monitoring policy that may encourage premature designation of streams as waste is important (Commissie Duurzaamheidsvraagstukken Biomassa, 2011). Figure 40 helps determine the criteria which streams should comply with.

D. 3 Clear Green Biomass (Heldergroene Biomassa)

The vision of environmental NGOs of ‘good’ and ‘bad’ biomass is summarised in this report, *Clear Green Biomass* (or Heldergroene biomassa in Dutch, SNM, 2008). Ten criteria were developed, of which the first six correspond to the Cramer Criteria. A specific criterion was added concerning cascading; they state that cascading of materials should be encouraged. Because of risks related to use of primary biomass (e.g. ILUC), residues from forestry and agriculture, and residues from the paper industry and food industry should be the preferred biomass streams. From a cascading perspective, residues that already have high value applications, or are used e.g. to increase soil fertility or maintain soil quality, are excluded. Their recommendation to policymakers is that all biomass that can also be used as product should not be subsidised as energy source. Policy should encourage up-cycling or recycling, not down-cycling. Down-cycling is stimulated by subsidies that focus on using biomass as an energy source instead of for a higher value product or function.