'Green carbon' feedstocks for the biobased economy

Quick scan opportunities for Solidaridad

studio Gear Up

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biomass research

Content

1. The question we address

What does the transition to a biobased economy imply for the Solidaridad landscape approach and sustainable supply chains.

Solidaridad would like to understand where are possibilities for increasing sustainable local biomass production and prospects for socio-economic development. It is looking for concrete inspiration and practices for sustainable land use at different levels. Solidaridad is primarily looking for low tech, low cost solutions which can be applied in rural areas and that benefit producers and communities directly.

Specifically:

- Develop a 'knowledge product' which connects the agendas for sustainable agricultural development / sustainable landscape management with the transition towards a biobased economy.

- This knowledge should inspire and inform Solidaridad how to integrate the transition towards a biobased economy in the Solidaridad Landscape Approach.

- The idea is to draw from the wide variety of concrete examples which show current practices and opportunities in diversifying crop production and valorizing biomass streams for food, energy and material purposes on different levels of scale (on farm, in supply chain and landscape level).

2. Introduction

In this quick scan we have looked at the opportunity for bio-feedstocks for two bio-economy sectors as classified by the FAO, that is bio-chemicals and bio-energy, especially biofuels. Biochemicals and biofuels are increasingly interconnected through the bio-refinery.

It is expected that these biobased sectors will be growth markets for both local energy supply and for downstream biobased value chains for biofuels and biobased chemicals. There is a rising demand for bio-based products amongst end users, think of bio-fuels for transport or bio-plastics.

In the international policy arena, organisations like the International Energy Organisation, IEA, and IRENA see an increasing need for biofuels to decarbonize transport. The IPCC (December 2018) has put forward that in most scenario's to remain within either 1.5 or 2 degree scenario's, the use of bioenergy takes an important place in climate change mitigation.

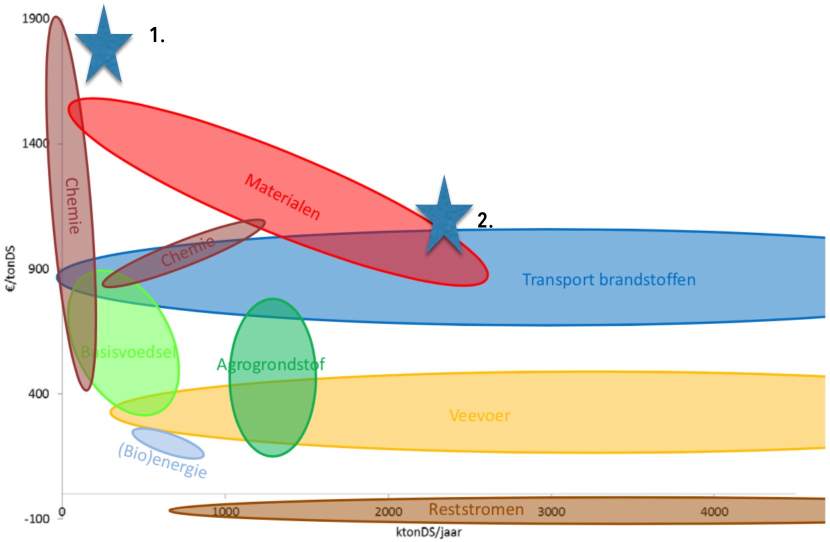
The FAO underlines the potential of food ánd fuel under the condition of sustainability criteria. That's because "biomass supply for energy frequently comes from co-productive systems,[…] in a form of residue or by-product or waste from primary economic activity (furniture, pulp & paper, food production, cattle breeding...) that brings more added value to biomass utilization". See also IEA Bioenergy (2018) 'Sustainable Landscape Management for Bioenergy and the Bioeconomy'

The Bioenergy & Sustainability: Bridging the Gaps report (2015) "affirms that sufficient land is available worldwide for expansion of biomass cultivation, that most of this land is in Latin America and Africa, and that the use of these areas for bioenergy production would not represent a threat to food security and biodiversity under certain conditions. Moreover, they present evidence that soil improvement technologies, production chain integration and use of bioenergy byproducts in poor rural areas could boost economic performance, enhance food quality, reduce pollution and create jobs".

3.1 Feedstocks for biobased chemicals /biofuel markets

Message:

1. Some biobased feedstocks for chemical platform products have a high value and require low volumes of selective crops, but only serve small markets
2. Other biobased chemical platform markets or functions require high (er) volumes of different types of biomass and serve bigger size markets. These are growth markets. It is expected that biofuels will grow to between 5-7 EJ/Year to 16 EJ/Year in 2030 globally for contributing to replacing fossil feedstocks (IRENA 2014).



Source WUR (2014) "De waardepiramide en cascadering in de biobased economy "

Table 1. Main development perspective of biobased products.†

Product	Feedstocks	Market size	Market price	Potential biobased share	Potential biobased production size	Potential impact for local producers	Potential local employment	Prospects for development
Pharmaceuticals	Selective crops	Very small	Very high	Very high	Very low	Very low	–	Very poor
Bulk chemicals	Starch, sugar crops, proteins	Very large	Low	Modest	Very low	Very low	–	Poor to modest
Fine chemicals	Oil, starch, sugar crops, straw	Very small	Average to good	Low	Low	Modest	Very limited	Modest to good
Solvents	Oil, starch, sugar crops, straw	Small	Low	Very low	Very low	Very low	Very limited	Very poor
Surfactants	Various	Small	Low	Modest	Low	Low	Very limited	Poor
Lubricants	Oil crops	Very small	Low	Modest to high	Low	Low	Good	Modest to good
Polymers	Mostly starch & sugar crops	Very large	Very low	Low	Modest	Very low	Very limited	Very limited
Fibers	Lignocellulosic crops, residues, grasses	Modest	Rather low	Low	Modest	Low	Good	Modest to good

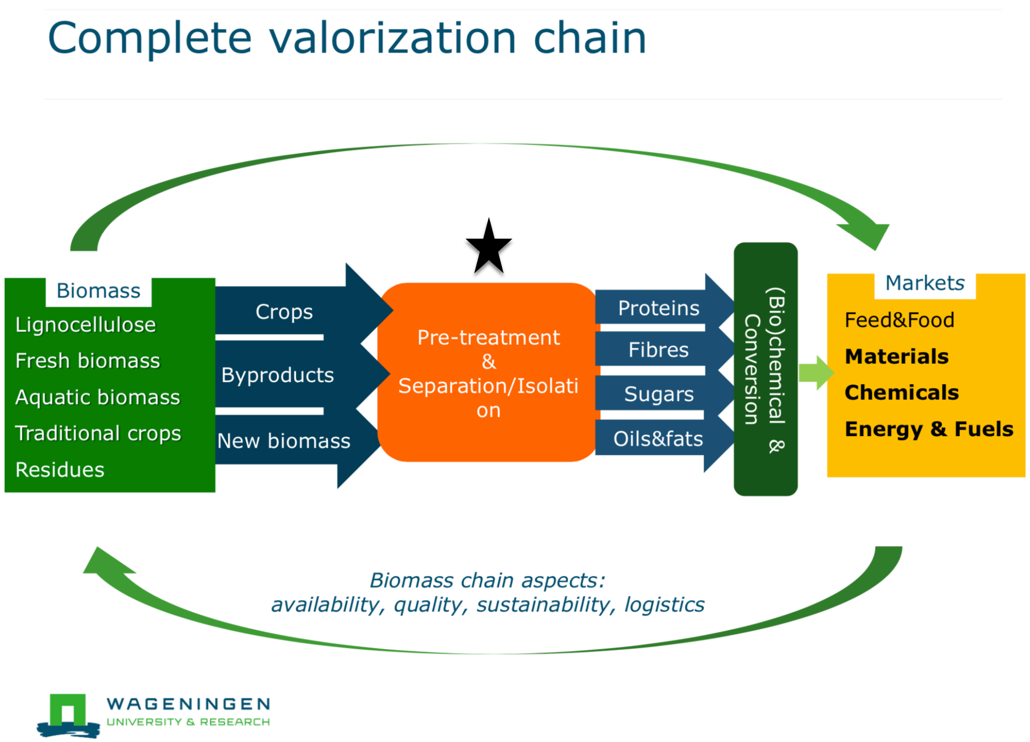
†Source: composed by the authors using data on market size and price and projections of potential market share and size as well as expected perspectives (employment, income) for local biomass producers and laborers.

Source: Langeveld et al. (2010).

3.2 Elements of feedstock strategy for biobased markets

Key insight: each bio-based business needs a solid feedstock strategy to ensure a reliable supply of their biomass raw material.

- long term **supply guarantees** that last at least 10 to 15 years
- Assessing **availability for pre-treatment*** of biomass. Aspects such as low bulk density and avoiding high transport costs and considering greenhouse gas values must be considered.
- Feedstock of **sufficient quality to meet the technical requirements**
- **Pricing and sustainability** of the chosen biomass are equally important

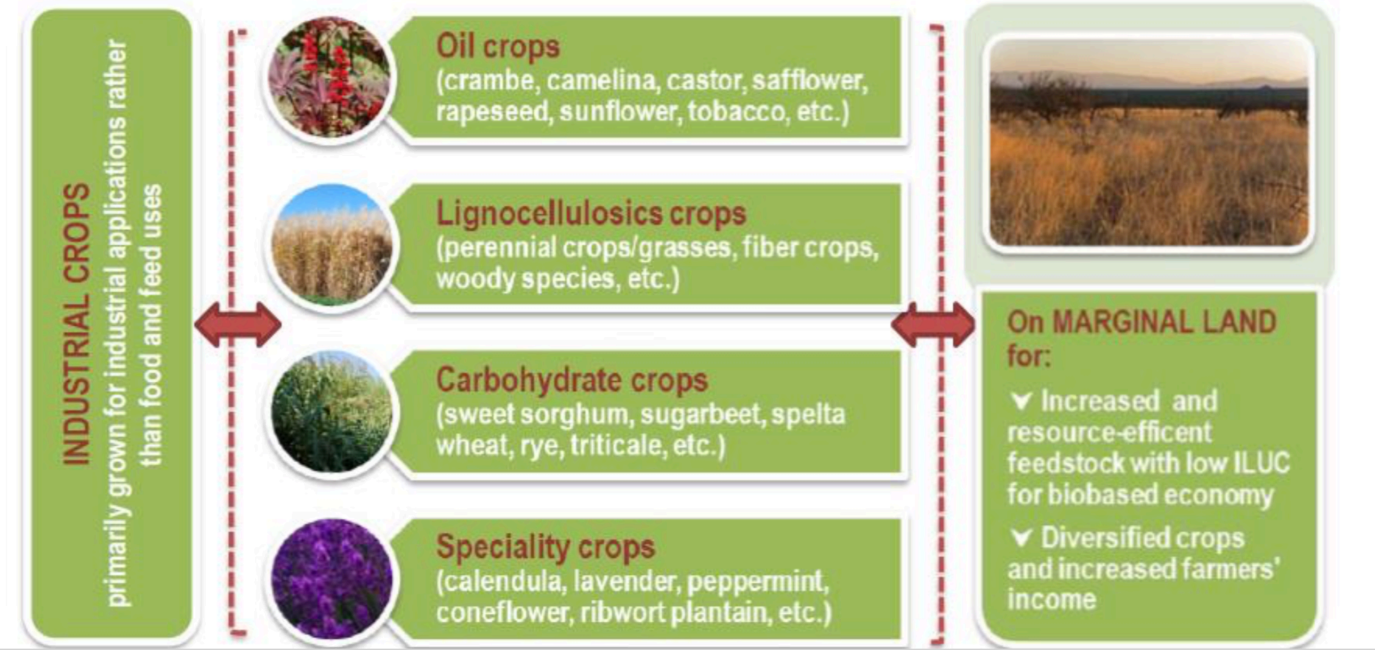


From: bio4products-creating-sustainable-resources-for-processing.pdf

3.3 Interesting biomass value-chains

Top 4 interesting biomass feedstocks:

1. All residues and waste streams – especially for local energy demand
2. Sugars (e.g. sugarbeet, sugarcane) – for ethanol / chemical blocks
3. Lipids (oil crops, oil waste streams) – Renewable diesel (HVO) / Jet Fuel
4. Woody biomass – chemicals / advanced biofuels



4.1 Biomass opportunities in Coffee, Cocoa & Palm oil commodities

Field
Harvesting of shrubs with shade trees

Family
- Kitchen waste
- Manure

Farm
- Food crops
- Livestock

Factory
Depulping, toasting, waste streams (pulp, mucilage, water) → packed coffee for consumers

Field
- Harvesting shrubs with shade trees
- De-podding, fermenting
- Waste: pods

Family
- Kitchen waste
- Manure

Farm
- Food crops
- Livestock

Factory
- waste and residues
- Raw cocoa transport to food factories

Field
- Permanent palm trees
- Waste: field waste

Family
- Kitchen waste
- Manure

Farm
- Food crops
- Livestock

Factory
- Cooking oil
- Waste and residues

4.2 Co-products in selected supply chains at landscape level

Supply chain	Byproducts/co-products	Market demand/uses (FAO)
Cocoa	Pods (in field)	Animal feed, construction materials, soil carbon, biodiversity (shadow trees), bioenergy (pods)
Coffee	Mucilage, pulp, waste water	Biopharmaceuticals (pulp), animal feed, construction materials, soil carbon, biodiversity (shadow trees), biogas (pulp, mucilage, wastewater)
Palm oil	Leaves, male flower-esence (field), Empty Fruit Bunches (EFB), wastewater	Animal feed (kernel meal), construction materials (stems), biogas (EFB, wastewater)

4.3 Threats and opportunities in the supply-chain

Supply-chain	Possible Threats	Opportunities
Cocoa	Nutrient retention	Mulch with pod compost: improve soil quality
Coffee	Shade Water retention Wastewater	Generation of clean energy Cleaning of wastewater (pulp, mucilage)
Palm oil	Wastewater	Generation of clean energy Cleaning of wastewater

4.4 Opportunities

Bio-based option	Waste management	Energy generation	Income diversification	Ecosystem Restoration	Level
Biochar pyrolysis	Field waste of oil palm residues	Produce Pyrolysis oil	• Sell pyrolysis oil • Sell carbon credits	Improve soil carbon Nutrient recovery	Field and factory level
Anaerobic digestion of waste	**Family residues:** sanitation of manure, waste **Factory waste:** POME, coffee pulp	Biogas production	Save on energy costs Save on fertilizer purchase	Prevent pollution Nutrient recovery	Family and factory level
Lignocellulosic crops	Use the unused lignocellulosic parts of food/feed crops	Use biomass to produce energy (e.g. pyrolysis oil) or pellets	Inter cropping Sell pyrolysis oil, sell pellets / biomass for bio-based products (from sugars)	Erosion	Field and Landscape level
Oil crops	Wastes and residues	e.g Esterification - fuels	Inter cropping Sell intermediate products / feedstocks for biobased value chains	Cover crops for nitrogen retention Improve vegetation, shadow cops higher biodiversity	Field/Landscape level

4.5 Technology options

Name	Feedstock	Products	Technology readiness
Anaerobic digestion	Manure, residues Waste water treatment	Biogas and digestate	Ready for full scale deployment
Biochar pyrolysis	Field residues, lignocellulosic crops	Biochar	Commercialization
Fermentation	Sugars, lignocellulose	Polymers, ethanol	Ready for full scale deployment
Esterification	Oil crops	Biodiesel Lubricants	Ready for full scale deployment

5.1 Towards a Solidaridad biomass opportunity scan

The opportunity scan provides a tool for quick analysis for adding / using biomass feedstock to the existing farming system at four levels within a landscape approach:
At the field, the farm or household, the factory and the lanscape level.

It provides another pespective: looking for opportunities for biomass mobilisation.

It is meant to structure the question: could biomass mobilisation improve or will it actually worsen aspects like socio-economic development, biodiversity, water use and land use. Therefore we introduce a **B***etter***W***orse***O***pportunity***T***hreats*-analysis. Simply put: will it create a better or worse outcome. Do we see sufficient improvement and are we able to mitigate side effects?

Part of the analysis takes into account how the business case is made. What is the expected necessary investments and what are investment pathways? Are there pathways to incrementaly improve the financial capacity for larger investments

5.2 Opportunity scan steps

- Step 1 Identify (potential) sources of biomass (volume/price/availability)
- Step 2 Link these to conversion technology and products
- Step 3 Identify markets legislation impacts and by-effects
- Step 4 Evaluate opportunities and risks (B*etter*W*orse*OT)

Step 1. Analytical framework for identifying biomass feedstocks at different levels within a landscape

- Households are often complex with various sources of biomass
  - Crops, residues
  - Animal waste
  - Household waste
- Biomass balance
  - Crop residues can be 100% of the harvest weight
- Potential valorization:
  - compost, biogas
  - Barriers or strips of crops in the landscape
- Reduce soil erosion
- From barriers for animals
- Source of additional valuable biomass
- Check opportunities for construction, fibres, compost, biogas

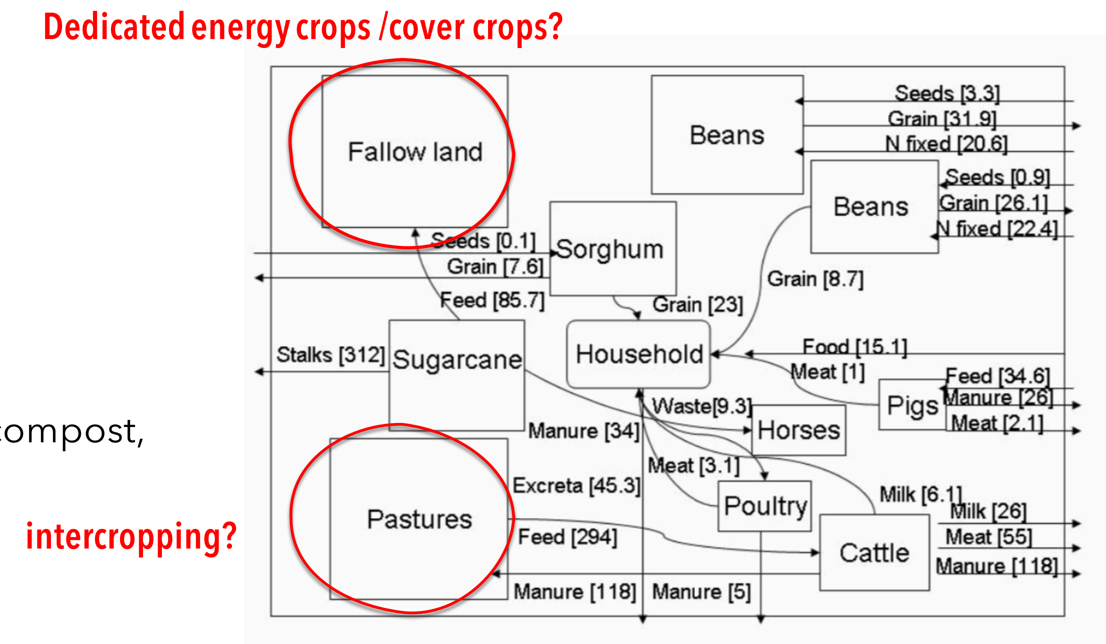


Figure 41 *Nitrogen flows of the livestock farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.*

Source: Langeveld e.a. (2007)

Step 1. Analytical framework for identifying biomass feedstocks at different levels within a landscape

- Large variation of cover crops:
  - Legumes
  - Tropical grasses
  - Tree crops
- Biomass balance
  - Large amounts of dry matter and soil carbon

TABLE 4

Production of biomass (dry matter) and quantity of organic carbon accumulated annually in the above-ground parts of some species of summer and winter green manure/cover crops (average of 3 agricultural periods). Choré Experimental Station.

Green manure/cover crops	Dry Matter (kg/ha)	Organic Carbon	
		% of D.M.[1]	kg/ha
Summer Species[2]			
Pigeon pea	9,153	56.30	5,153
Black-seeded mucuna	7,500	52.15	3,911
Jack bean	7,703	50.15	3,863
Winter Species[3]			
Oilseed radish	4,771	46.52	2,219
White lupine	4,012	47.97	1,925
Black oats	3,680	49.40	1,818
Hairy vetch	2,942	47.43	1,395
Black oats + Hairy vetch	5,440	48.55	2,641
Black oats + White lupine	4,259	48.57	2,069

[1] D.M. = Dry Matter. For summer species, data was taken from tissue analysis from Brazil (Calegari et al., 1991).
[2] Sown in association with corn, and dry matter determined at approximately 7 months.
[3] Sown after cotton, and dry matter determined at approximately 4 months.
Source: Adapted from Derpsch & Florentín, 1992 and Florentín, 2000.

Step 2 How to identify conversion technologies

Criteria for pre-treatment and local bioenergy systems

- Low tech – high tech
- Short term – long term
- Low costs -high costs
- Initiative (at start) and ownership for long term
- Who is investing?

Top 4 interesting technologies * see slide 39

1. Small-scale biomass digesters
2. Pyrolysis/Biochar
3. Fermentation
4. Esterification

Table 1

Techno-economic data for the conversion pathways. Provided here at a normalized annual production capacity of 100 mill. liters.

Product	Technology	Feedstock Input mill. m^3/year	Variable costs/revenue mill. €$^{-year}$|mill. \$$^{-year}$	Fixed costs at normalized capacity mill. €$^{-year}$\|mill. \$$^{-year}$	TPI at normalized capacity mill. €|mill. \$
Ethanol	HYDFERM	0.72–1.41	5.8–32.7| 6.4–36.3	5.5–8.1| 6.1–9.0	158–306| 175–340
Ethanol	MXDALC	0.77–0.84	(−4.5) to (−3.1)| (−5.0) to (−3.4)	9.2–11.2| 10.2–12.4	174–225| 193–250
FT fuels	FTSYN	0.94–1.44	(−17.4)–16.1| (−19.3)–17.9	15.2–19.8| 16.9–22.0	248–294| 275–326
HTL fuels	HTL	0.31–0.59	10.8–11.9| 12.3–13.2	19.0–24.1| 21.1–26.7	173–225| 192–250
Pyrolysis fuels	FASTPYR	0.80–1.31	(−1.4)–14.1| (−1.6) to 15.6	4.5–8.7| 5.0–9.7	102–218| 113–242

Step 3. e.g. Honduras – Policy analysis issues and opportunities

Problems of monoculture oil palm plantations:

- Replacement of tropical forests and other ecosystems
- Loss of biodiversity
- Flooding
- Soil contamination
- Pollution of water courses
- Increase in pests due to breakdown in the ecological balance and to changes in the food chain
- Depletion of water resources
- The use of agrochemicals contaminates workers and local communities
- Coral reef contamination

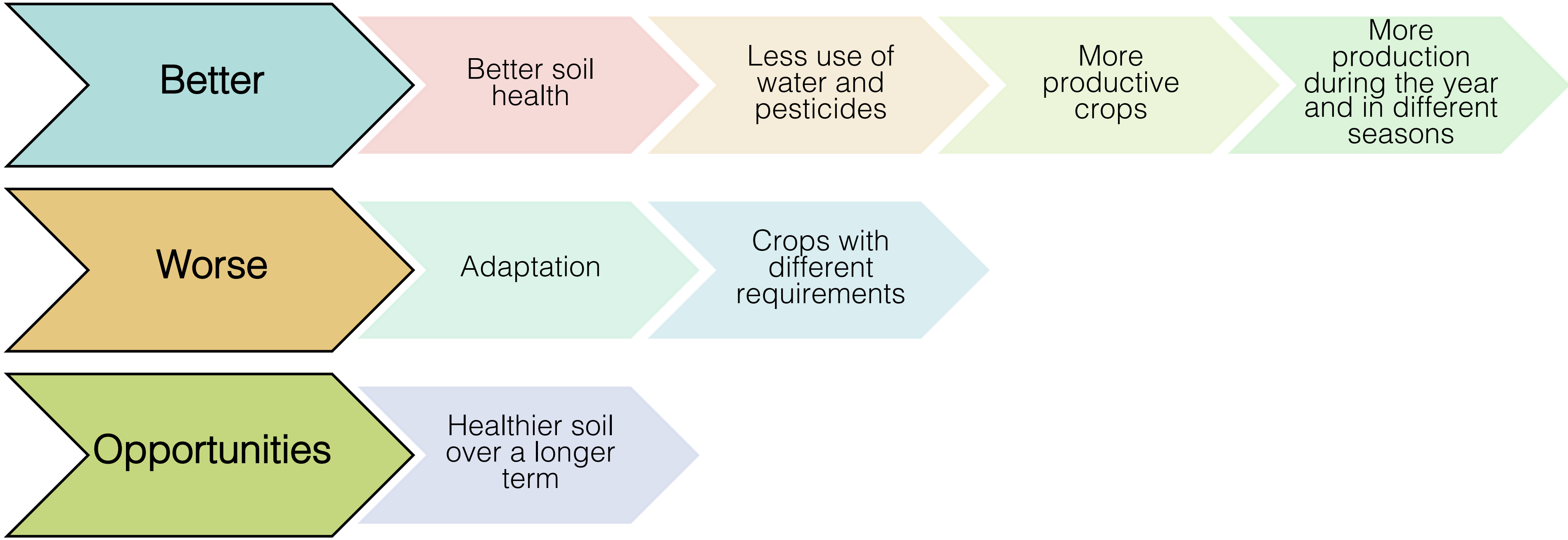
- Deforestation* from logging and clearing of land for agriculture
- Land degradation and soil erosion hastened by uncontrolled development and improper land use practices such as farming of marginal lands; mining activities polluting Lago de Yojoa (the country's largest source of fresh water), and several rivers and streams, with heavy metals.

*Zero deforestation agreement with Solidaridad

Opportunities

- Shift large areas from low-value crops to high-value crops (already happened for some non-traditional export crops)
- Opportunities for diversification and increasing output value
- Smallholders can be more efficient than commercial farms with labour intensive crops

Step 4. Field -BWOT



Family -BWOT

Better

- Diversification of crops
- Access to Energy
- Possibility of more resources for the household
- Cost reductions and increase in profits

Worse

- Getting used to new farming practices
- Finding different markets
- New initial investment
- Highest price does not mean highest value (or profit)

Opportunities

- BioHubs
- New or niche markets
- Minimize waste streams

Threats

- By-products regarded as non-priority materials, not high-potential money makers
- Different treatments & practices for different kinds of crops

Step 4. Factory -BWOT

Better
- Better quality products
- Matchmaking in the value chain, better access to resources
- Wastes and residues
- Nutrient recycling

Worse
- Adaptation to new markets
- Need for new technologies

Opportunities
- New and niche markets
- New investments and business cases

Threats
- Competition with conventional products
- New products will have to compete with the conventional applications/uses of biomass

Landscape -BWOT

Better
- Better water and resource management
- Improve biodiversity
- Restoration of vegetation
- Diversification (Improve resilience)
- Proximity with other actors

Worse
- Needs time and resources, changes in practices
- Need for cooperation along the value chain

Opportunities
- Introduction of new markets and collaboration with new and different sectors
- Improve economy
- Off-farm job opportunities
- Mobilization of underutilized sources
- Better organized logistics

Threats
- Introduction of incompatible species
- Risk that all landscapes will be dealt with in a similar way
- Adapting to new legislation

6.1 Concrete example: opportunity in Palm Oil Production -Factory level

- Palm oil factories are converting a huge amount of biomass
- Most of this is not recovered in the final product
  - Only 20% is recovered
  - Remaining biomass consists of Empty Fruit Bunches (EFB), fibres, kernels, and Palm Oil Mill Effluent (POME)
- EFB, fibres and POME can be converted into pyrolysis oil, biochar, fertilizers, compost or energy

- 1 ton Fresh Fruit Bunches (FFB)
  - 220 kg Crude Palm Oil (CPO)
  - 220 kg Empty Fruit Bunches (EFB)
  - 135 kg Fibres
  - 50 kg Kernels
  - 670 kg POME
- 20-23% oil extraction rate

6.2 Concrete example: opportunity in Palm Oil Production -Field level

- Most of the harvested biomass is residues
  - Only 20-22% is crude palm oil
- Variety in residues and waste streams
- Residues:
  - Empty Fruit Bunches (EFB): 21-22%
  - Fibres: 13-14%
  - Shells: 6-8%
  - Kernels: 5-6%
- Palm Oil Mill Effluent: 35-40%

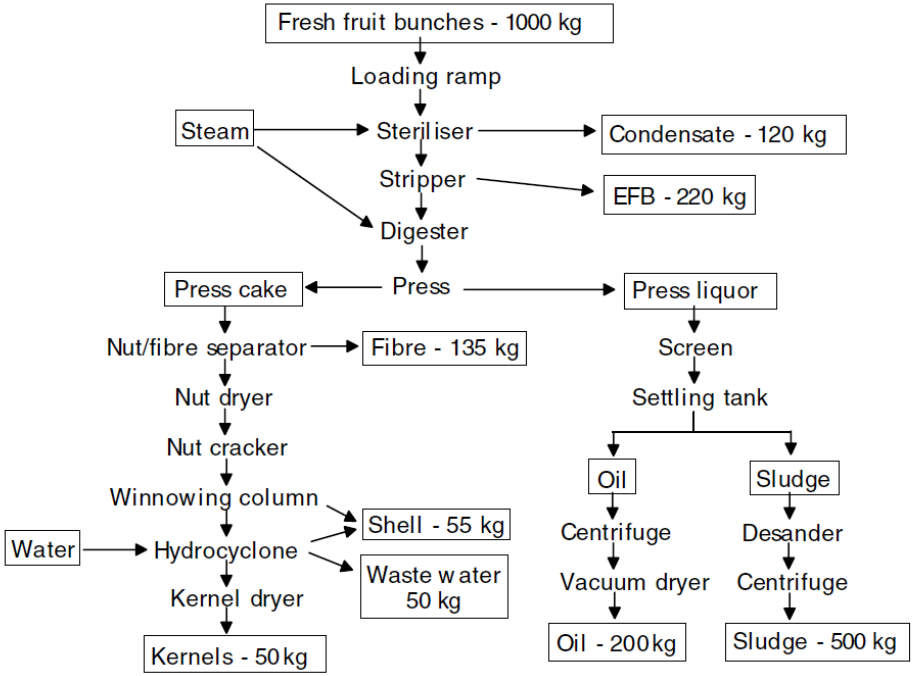
Table 3.1. Outputs of palm oil extraction per 100 tonnes FFB (data based on fresh weight)

Output	Unit	CUE (2012)	Corley and Tinker (2003)	Elbersen *et al.* (2013)
Crude palm oil	tonne	21.4	20.0	21.0
Empty fruit bunches (EFB)	tonne	21.3	22.0	22.0
Kernels	tonne		5	5.6
Kernel oil	tonne	2.0	N.A.	N.A.
Palm kernel meal	tonne	2.9	N.A.	N.A.
Waste water/ POME	tonne	97	67	82
Fibre	tonne	13.2	13.5	14.0
Shell	tonne	7.9	5.5	6.1

N.A. = not available

Source: Corley and Tinker, 2003; CUE, 2012; Elbersen et al., 2013.

6.3 Concrete example: opportunity in Palm Oil Production



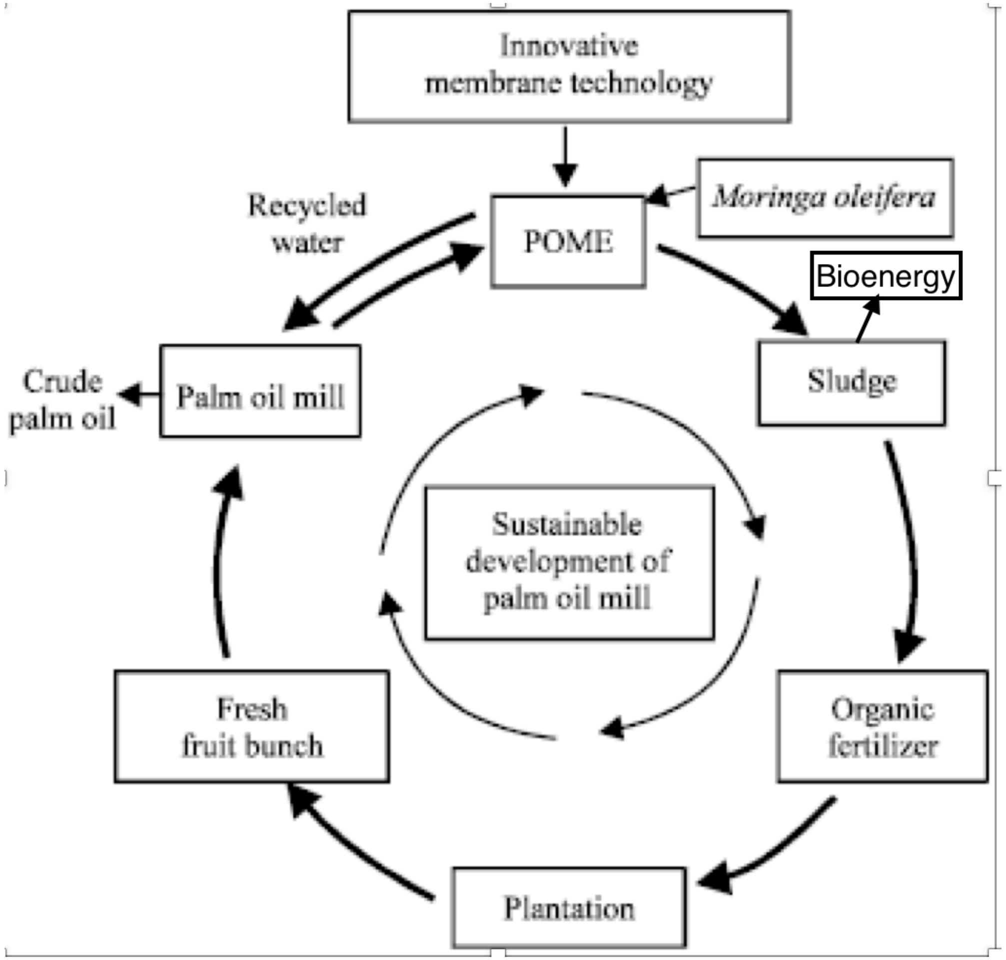
Source: Corley and Tinker (2003). Assuming 20% Oil Extraction Rate (OER) and 5% Kernel Extraction Rate (KER)

6.4 Concrete example: opportunity in Palm Oil Production

- Most of the biomass that is produced each year is recycled
  - Palm leaves are cut
  - Male flowers
  - Roots are renewed each year
- Biomass balance
  - Fruit bunches 16-20 tonne/ha/year
  - Total biomass 60-80 tonne/ha/year
- Potential valorization: pyrolysis oil, biochar, compost, biogas , biofertilizer

6.4 Concrete example: opportunity in Palm Oil Production

Issues in the supply chain: Waste water



6.5 Concrete example: opportunity in Cocoa Production Field-level

- Cocoa pods are not utilised
    - Small amounts at field level
- Shadow: trees source of additional biomass
- Biomass balance
    - check
- Potential valorization: pyrolysis oil, biochar, compost, biogas , biofertilizer

6.6 Concrete example: opportunity in Cocoa Production Field-level

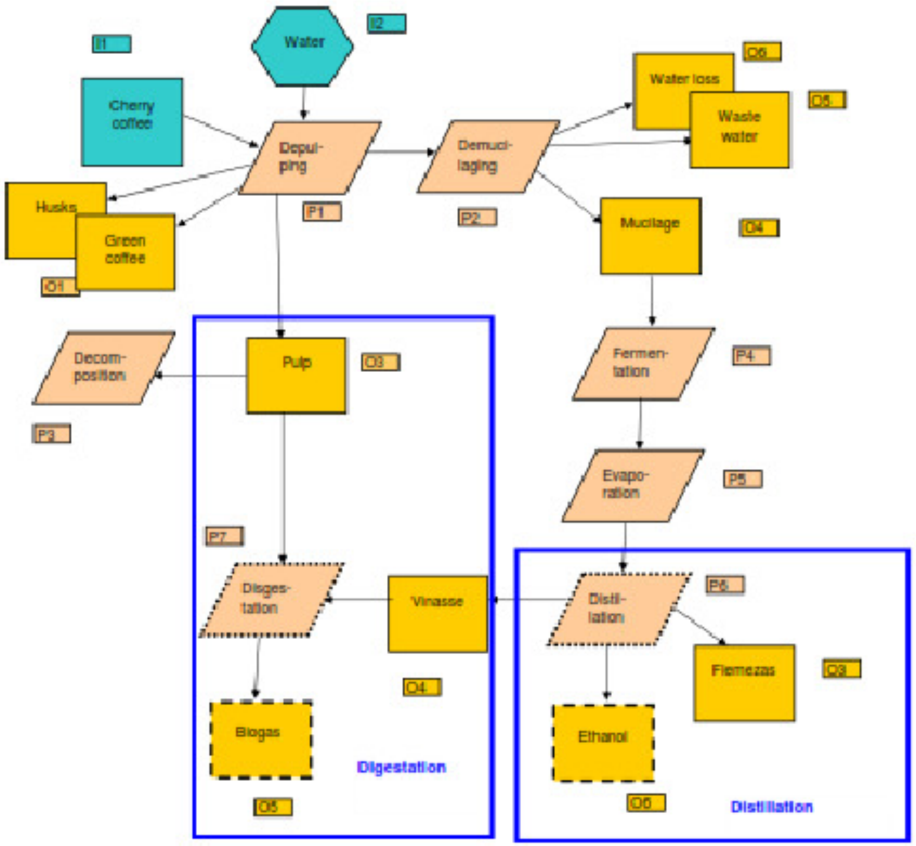
- Shadow crops provide protection to the crop
  - Current species?
  - Alternatives: legume trees, fruit trees, nuts
- Biomass balance
  - 500 – 5,000 kg per ha
- Potential valorization: leaves, wood, animal feed, compost, biogas, biofertilizer
- Legume trees can sequester nitrogen

6.7 Concrete example: opportunity in Coffee Production Factory-level

- Coffee factories generate a lot of residues
  - Coffee pulp
  - Mucilage
  - Waste water
- Biomass balance
  - 40% of coffee berries consists of pulp
  - 16% is mucilage (fatty layer)
  - Water use is 4x coffee weight
- Potential valorization: compost, biogas

6.8 Concrete example: opportunity in Coffee Production

Figura 3. Producción de bioenergía de los desechos del café



Fuente: Wintgens (2009)

7.1 Good Practice Biohub - Concept

It is based on the location of a large scale biorefinery which is provided for by a variety of Biohubs in different local areas (see the figure) . With more Biohubs than needed for one biorefinery, **feedstock supply for the refinery can be secured**.

- Local investments in training and agricultural management aim to secure food supply while excess biomass (e.g. residues) can be prepared for export and local energy supply.

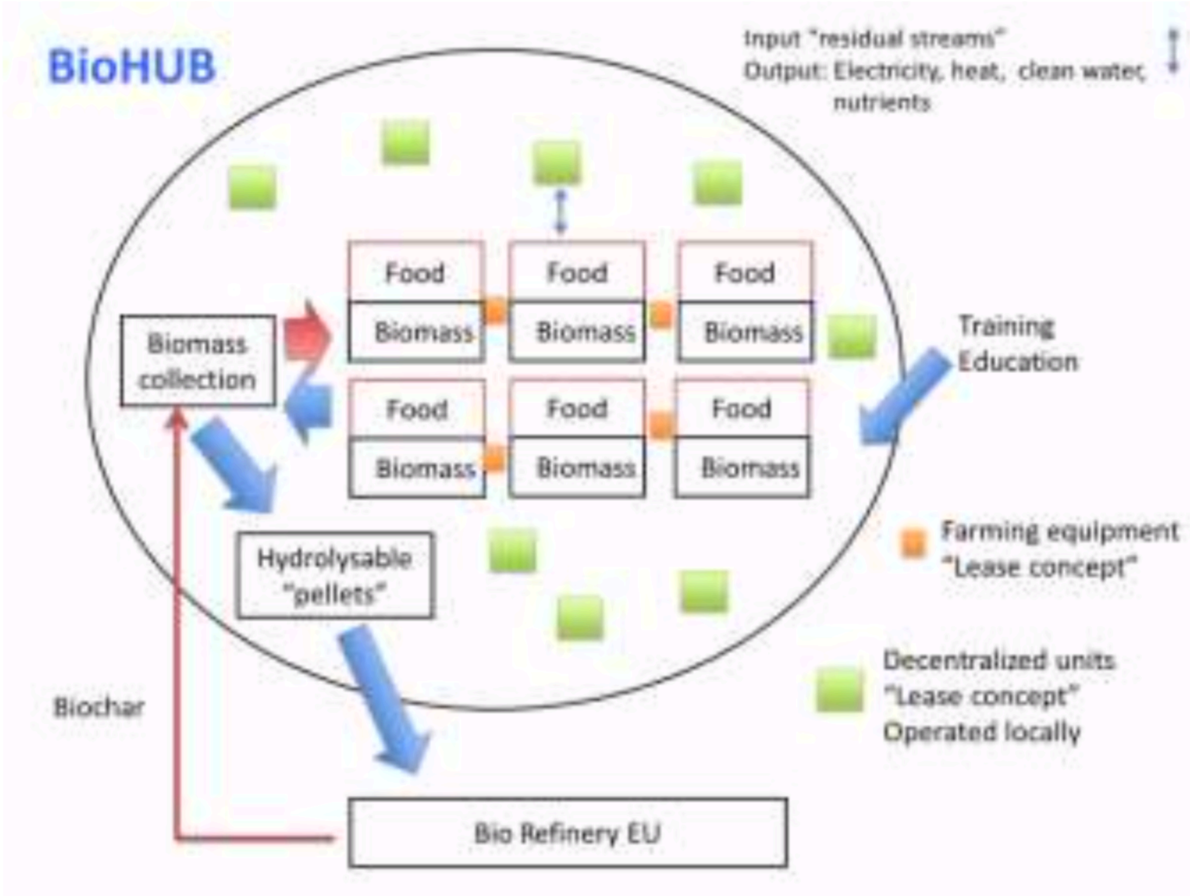


Figure 2. Biohub concept for local social development and feedstock security

7.2 Biohub –Social aspect

- Integrates concepts of a **socially acceptable, profitable and sustainable** bioeconomy

- **Inclusive biobased value chains:** The capabilities of the local people determine what can be achieved
    - It applies sustainable biobased technologies in terms of improving the living conditions of local people (context-sensitive model)

- A robust Biohub will **enable local development and provide growth perspectives** → bring political stability + better options for further investments (including for local biorefineries)

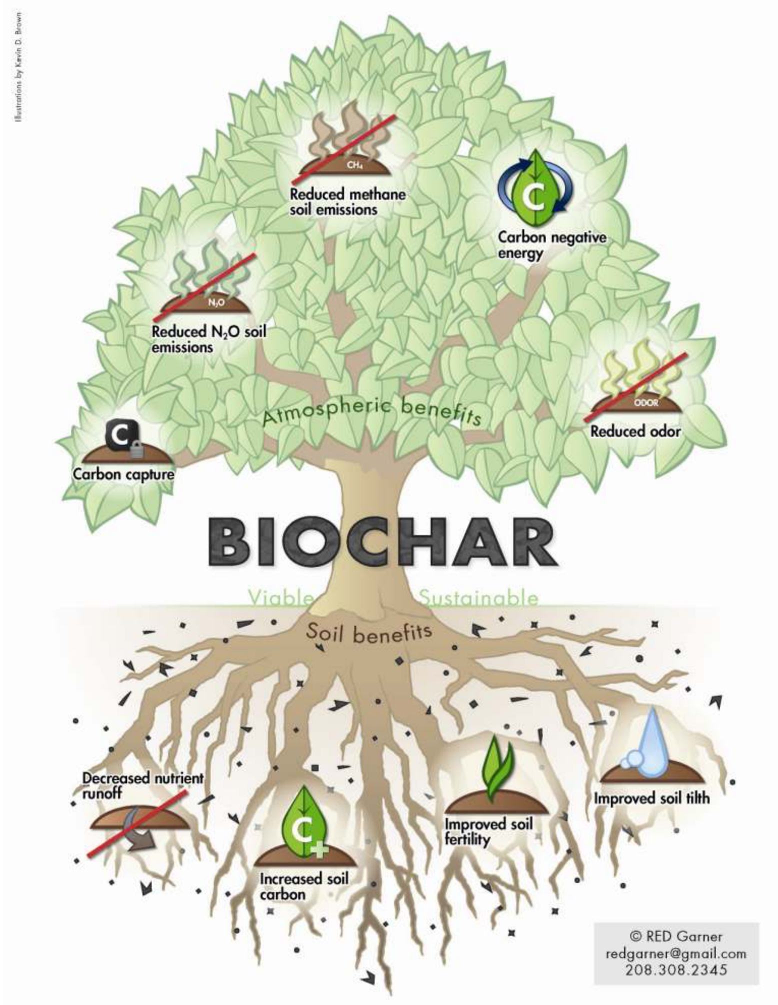
- For end-users: Attain a product that is **attuned with their needs.**

7.3 Biohub + Other practices → No emissions value chains

- A biohub focuses on local food and energy supply **+ nutrient recycling and clean water production**
- A BioHub could ensure:
  - low life cycle GHG emissions
  - continued soil fertility
  - economic feasibility for smallholders providing biomass residues or developing dedicated bioenergy crops.
- Reducing emissions at the beginning of the value chain and along each step using innovative techniques for carbon sequestration like **biochar**
- Reductions at the beginning of the value chain can compensate for emissions in other steps of the chain

7.4. Biochar

- Adding biochars (with a pH of 6-10) to the soil has greater benefits on crop growth in acidic soils (pH<7)
- Opportunities for a better use trade-off: collect manure when it would be treated as waste and represent extra disposal costs → biochar



Conclusion and recommendations

Conclusion

•Building a value system connecting sustainable agricultural development / sustainable landscape management with the biobased economy provides opportunities for:

•Additional income

•Local energy demand

•Environmental services like

- Nutrient recovery and 'green' manure (cover crops)
- Carbon sequestration

Recommendations:

•Monetize added value for carbon sequestration in the consumer market, like introducing the 'carbon negative' chocolate bar concept

•Connect with downstream biobased business

Overview of markets for biochemicals and fuels

Final Product	Intermediate Product	Final Market	Biobased production routes	Input
Biomethane		Grid Transport fuel	Biomethane is produced from anaerobic digestion of biodegradable municipal solid waste (MSW), sewage sludge, manure, wet wastes (farm and food wastes), and macro-algae, followed by a biogas upgrading step. Biomethane can also be produced via gasification of biomass(SNG: Substitute natiral gas) to a product gas, followed by a secondary process consisting of water-gas shift and methanation reactions and methane separation	biodegradable municipal solid waste (MSW), sewage sludge, manure, wet wastes (farm and food wastes), and macro-algae, seaweed, landfill grass, grass, waste water T, sewage tretment, food waste, energy crops, chicken manure, pig manure, cow manure, green waste
Polystyrene, PET (used for soft drink bottles)	BTX: aromatics benzene, toluene and xylene	Chemical industry	1. Reforming of lignocellulosic biomass to fuels, with BTX as a byproduct; 2. Fermentation of carbohydrate-rich streams into isobutanol, followed by conversion to BTX; 3. Production of BTX from lignin.	Biomass: lignin, wood, waste streams
Fuel additives (Toluene)		Transport sector		
Methanol	Methanol	Transport sector	1. reforming, the catalyzed production of syngas from saturated, de-sulphurized natural gas (reformation) 2. methanol synthesis with a Cu/Zn/Alumina catalyst 3. and finally, crude methanol (water containing) purification via distillation.	Mostly natural gas
MTBE		Transport sector		
DME		Transport sector		
FAME		Transport sector		
Formaldehyde		Chemical industry		
Acetic acid		Chemical industry		
Hydrogen, hydrogenates, ammonia, hydrochloric acid	Hydrogen	Transport sector, chemical industry	Syngas production from biomass gasification, followed by water-gas shift reaction and hydrogen separation	
Polyethylene, ethylbenzene, ethylene oxide, ethylene dichloride	Ethylene	Chemical industry	Bioethanol production via biochemical conversion route of lignocellulosic biomass, followed by dehydration of bioethanol to bio-ethylene	
PLA (via lactic acid)	C6 sugars	Food, chemicals		
Butaneidol and THF via succinic acid	C4 sugars	Fibres, solvents, pharmaceuticals		
Nylon and furfural	C5 sugars			
Propane diol	C6 sugars	Bio-plastics, textile fibres, plant industry		
Glycol or ethylene glycol (via xylitol)	C5 sugars			

Source: Table 1: Biomethane Product Market Combination, Source: Table 4: main bulk chemicals produced from sugar platforms, S2Biom deliverable 7.2b, Table 7: BTX Product Market Combination, Source: Table 8: Considered product-market combinations & Table 9: Selected production routes for the considered PMCs, S2Biom D7.2, p. 14, Table 11: Methanol Product market combination, S2Biom D7.2c

Overview of TRL of conversion technologies

Common biomass input	Category	Subcategory	Name	TRL	
Cereals straw, Giant reed (Perennial grass)	Direct combustion of solid biomass	Fixed bed combustion for heat	Grate boiler with straw for heat	9	System ready for full scale deployment
Cereals straw, Giant reed (Perennial grass)	Direct combustion of solid biomass	Fixed bed combustion for CHP (system cycle)	Grate boiler with agrobiomass for CHP	9	System ready for full scale deployment
Cereals straw, Maize stover	Chemical pretreatment	Dilute acid hydrolysis	Dilute acid hydrolysis	9	System ready for full scale deployment
Biowaste as part of integrally collected municipal waste: Biodegradable waste of not separately collected municipal waste (excluding textile and paper), Separately collected biowaste: Biodegradable waste of separately collected municipal waste (excluding textile and paper)	Anaerobic digestion	Plug flow digester	Dry Batch Digestion (MSW)	9	System ready for full scale deployment
Stemwood from final fellings originating from nonconifer trees, Stemwood from final fellings originating from conifer trees, Stemwood from thinnings originating from nonconifer trees, Stemwood from thinnings originating from conifer trees	Direct combustion of solid biomass	Domestic residential batch fired stoves for heat	Batch stove for heat	9	System ready for full scale deployment
Stemwood from final fellings originating from nonconifer trees, Stemwood from final fellings originating from conifer trees, Sawdust from sawmills from nonconifers, Sawdust from sawmills from conifers	Direct combustion of solid biomass	Domestic pellet burners for heat	Pellet boiler for heat	9	System ready for full scale deployment
Hazardous post consumer wood, Non hazardous post consumer wood, Biowaste as part of integrally collected municipal waste: Biodegradable waste of not separately collected municipal waste (excluding textile and paper)	Direct combustion of solid biomass	Waste incinerators with energy recovery	Grate fired waste incinerator	9	System ready for full scale deployment
Sawdust from sawmills from nonconifers, Sawdust from sawmills from conifers, Stemwood from final fellings originating from nonconifer trees, Stemwood from final fellings originating from conifer trees	Direct combustion of solid biomass	Direct co-combustion in coal fired power plants	Co-firing in PC	9	System ready for full scale deployment
Logging residues from final fellings originat	Direct combustion of solid biomass	Fixed bed combustion for CHP (steam cycle)	Grate boiler with wood chips for CHP	9	System ready for full scale deployment

Overview of TRL of conversion technologies

Technology	Products and by products	Applications	TRL
Explosive decompresion	Sugars, digestible products	Heating, electricity, transportation, fuels, and high-value chemicals	9
Torrefaction	Torrefied biomass	Heating, electricity	7
Anaerobic digestion	Biogas, bio-digestate	Heating, electricity, transportation, fuels, and high-value chemicals	9
Fermentation	Liquids and CO2	Additives, high-value chemicals, transportation, heating, and electricity	9
Photofermentation	Hydrogen, carbon dioxide, organic acids	Additives, high-value chemicals, transportation, heating, and electricity	6
Hydrolisis	Cellulose, hemicellulose, and lignite	Additives, high-value chemicals	9
Solvent extaction	Primary and secondary metabolites	Additives, high-value chemicals	9
Supercritical conversion	Chemicals	Wastewater treatment, high-value chemicals, transportation, heating, and electricity	7