Alcohol based (jet) fuels

Sugar and lignin platform based value chains

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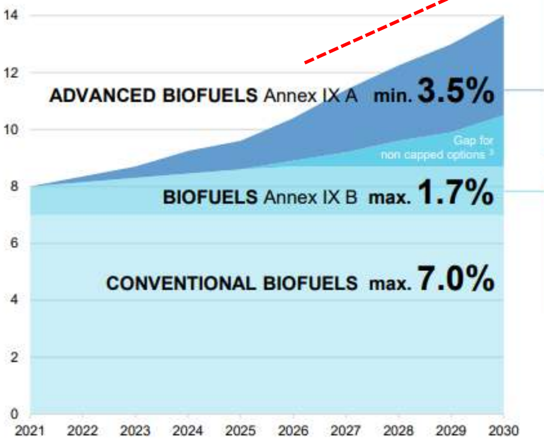
Biofuels for transport – policy goals in a nuttshell

EU market for advanced biofuel under RED II: the supportive path to decarbonize mobility

PROJECTED DEVELOPMENT OF (THEORETICAL) SHARE OF RENEWABLE ENERGY SOURCES IN TRANSPORT
up to 2030 based on RED II provisions



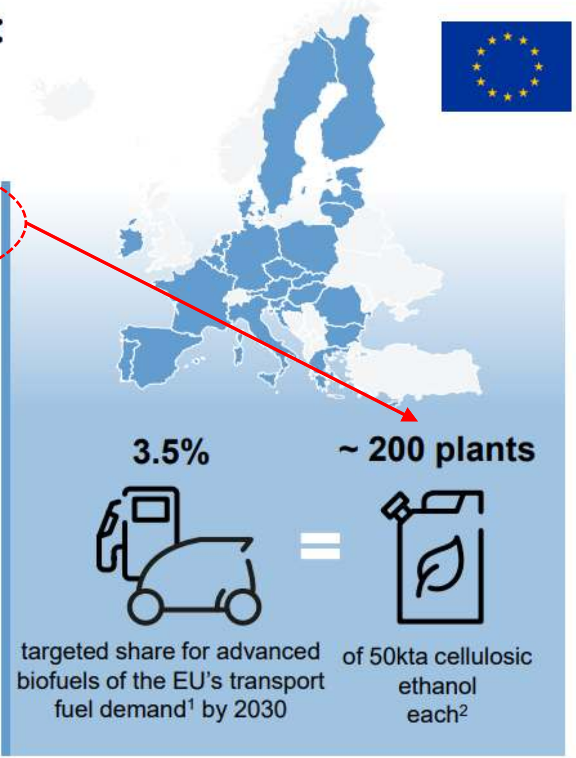
RED II – ANNEX IX

PART A: »advanced« feedstocks and fuels
Targets: 2022: at least 0.2%, 2025: 1%, 2030: 3.5%
Defined feedstocks (excerpt):

- Straw
- Bagasse
- Nut shells
- Cobs cleaned of kernels of corn
- Other non-food cellulosic material
- Other lignocellulosic material

PART B: not considered as »advanced«
Target: capped to 1.7%

- Used cooking oil (UCO)
- Animal fats categories 1 and 2



[1] Source: http://www.etipbioenergy.eu/everyone/advanced-boifuels
[2] Assumption: 50kta sunliquid standard capacity; EU transport fuel demand in 2030 remains at similar levels as in 2016 - Total transport fuel demand (road & rail) in 2016: 306.567 ktoe; Source: Eurostat
[3] Additional advanced fuels from Annex IXA, renewable electricity (used for transport), any other NON capped options (e.g. H2 if not produced neither with FOOD feedstock nor ANNEX IXB feedstock)

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Source: Clariant, Paolo Corvo @ @ ETIP Bioenergy WG2 webinar, 11 Nov 2020

ETIP BIOENERGY – Bioenergy value chains

Priority Value Chains (PVC)

PVC1: Transport fuels via gasification
PVC2: Power and heat via gasification
PVC3: Transport fuels via pyrolytic and thermolytic conversion
PVC4: Intermediate bioenergy carriers for power and heat
PVC5: Alcohol fuels from cellulosic sugars
PVC6: Hydrocarbon fuels from sugars and alcohols

Established Value Chains (EVC)

EVC1: Transesterification to biodiesel
EVC2: Hydrotreatment to HVO
EVC3: Sugar and starch fermentation to ethanol
EVC4: Anaerobic digestion to biogas
EVC5: Small-scale combustion for residential heat
EVC6: Large-scale combustion for heat and power
EVC7: Biomass co-firing for heat and power

Development Pathways (DP)

DP1: Conversion of aquatic biomass

PVC1

PVC3

Sugar and lignin plaform

PVC5

PVC6

Source: ETIP Bioenergy, Current status of Advanced Biofuels demonstrations in Europe, March 2020

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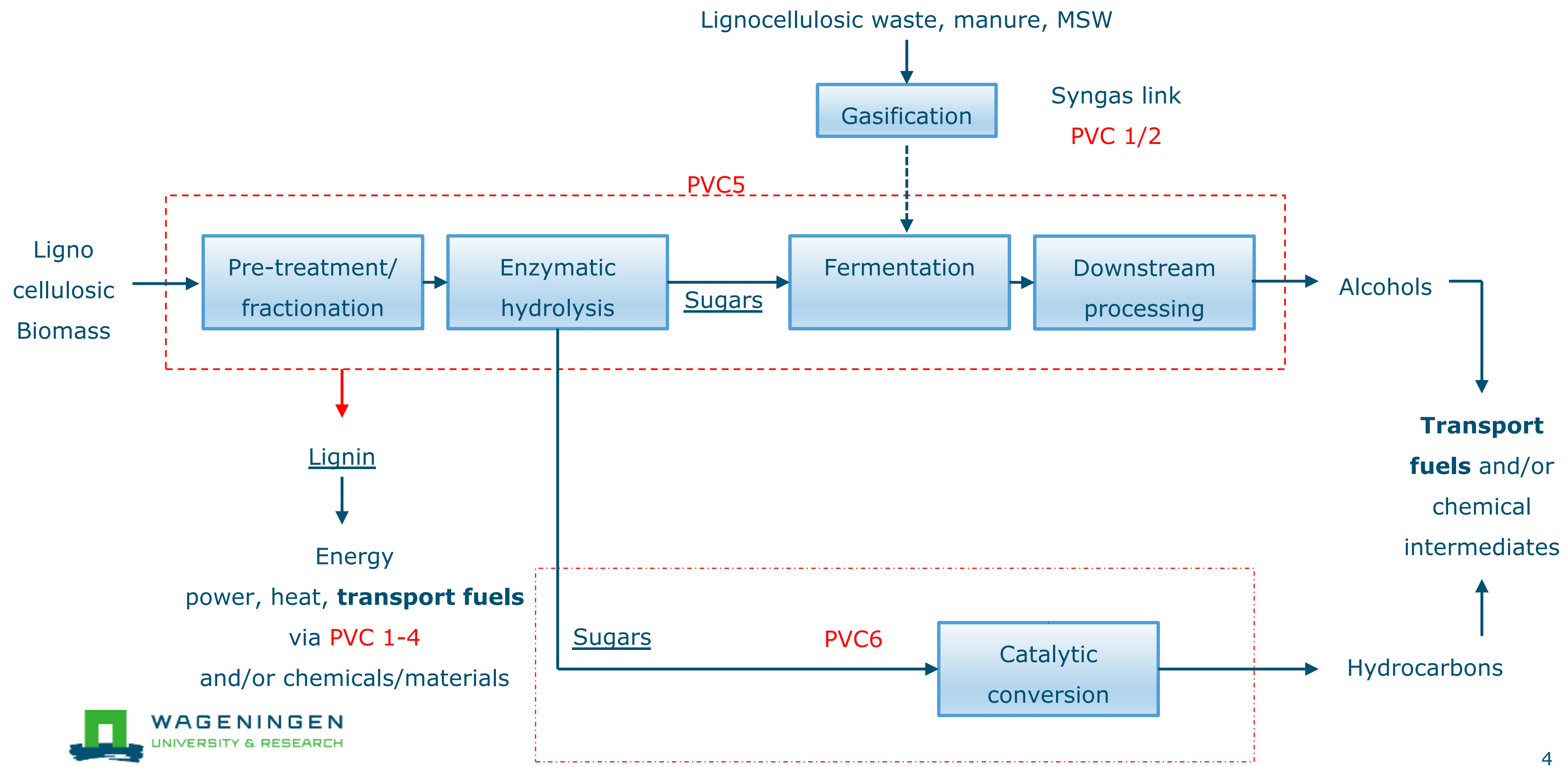
Focus lecture: PVC5 and PVC6 with links to PVC1-PVC4 (syngas fermentation and thermal conversion lignin)

Sugar and lignin platform – general scheme



Alcohol fuels from cellulosic sugars (PVC5): EU

*TRL6-7: demonstration
TRL8: 1st of a kind commercial (flagship)
TRL9: commercial

Company	Country	City	TRL*	Start-up year	Installed capacity (t/a)
Borregaard** (*ChemCell Ethanol)*	Norway	Sarpsborg	9	1938 (operational)	15800
Domsjoe Fabriker	Sweden	Ornskoldsvik	8	1940 (operational)	19000
SEKAB (*Biorefinery Demo Plant)*	Sweden	Ornskoldsvik	8	2004 (operational)	160
Chempolis Ltd. (*Biorefining plant)*	Finland	Oulu	6-7	2008 (operational)	5000
Clariant (*Sunliquid)*	Germany	Straubing	6-7	2012 (operational)	1000
Borregaard (*BALI Biorefinery Demo)*	Norway	Sarpsborg	6-7	2012 (operational)	110
IFP (*Futurol)*	France	Bucy-Le-Long	6-7	2016 (operational)	350
ST1 (*Cellulonix Kajjani)*	Finland	Kajaani	6-7	2017 (operational)	8000
AustroCel Hallein	Austria	Hallein	8	2020 (start-up phase)	30000

Most ethanol from agro-residues; Borregaard/Domsjoe/Austrocel: ethanol from brown liquor wood pulping

Other non-cellulosic sugars based production of alcohols:
ST1 also runs 5 Ethanolix facilities 1000-7000 t/a in FIN (4) and SWE (1) organic wastes to ethanol
BioMCN (Farmsum, NL): methanol from glycerine @ TRL8, 2009 (currently running at lower capacity from biogas)
Arcelor Mittal (Ghent, Belgium) industrial waste gases to ethanol 16000 t/a @ TRL9 using LanzaTech technology; under construction, start-up 2020
Sodra Cell (Monsteras, SWE) upgrading pulping based methanol to fuel/chemical grade methanol 5000 t/a @ TRL9; under construction, start-up 2020

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Source: ETIP Bioenergy, Current status of Advanced Biofuels demonstrations in Europe, March 2020

Alcohol fuels from cellulosic sugars (PVC5): EU

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TRL9: commercial

Company	Country	City	TRL*	Start-up year	Installed capacity (t/a)
Clariant	Romania	Podari	8	2021 (under construction)	50000
Versalis	Italy	Crescentino	8	2020 (re-start)	40000
Sainc Energy Limited (*Cordoba*)	Spain	Villaralto	8	2020 (planned)	25000
Kanteleen Voima (*Northfuel biorefinery, SEKAB techn.*)	Finland	Haapavesi	6-7	2021 (planned)	65000
ST1 (*Cellulonix Kajaani 2*)	Finland	Kaajani	8	2024 (planned)	40000
ST1 (*Cellulonix Pietasari*)	Norway	Pietarsaari	8	2024 (planned)	40000
ST1 (*Cellulonix Follum*)	Norway	Ringerike	8	2024 (planned)	40000
Enviral (*license Clariant's Sunliquid technology*)	Slovakia	Leopoldov	9	Planned	50000
ORLEN Group (*license Clariant's Sunliquid technology)*	Poland	Jedkicze	9	Planned	25000
Eta Bio Ltd. (*license Clariant's Sunliquid technology)*	Bulgaria	Toshevo	9	Planned	50000
INA	Croatia	Sisak	8	Planned	55000

Sources: ETIP Bioenergy, Current status of Advanced Biofuels demonstrations in Europe, March 2020; Clariant, Paolo Corvo @ @ ETIP Bioenergy WG2 webinar, 11 Nov 2020

Hydrocarbon fuels from sugars and alcohols (PVC6): EU

Company	Country	City	TRL*	Start-up year	Installed capacity (t/a)
Global Bioenergies (*isobutene demo*)*	Germany	Leuna	6-7	2017 (operational)	100
Ekobenz (*Bogumilow plant)*	Poland	Kleszczow	8	2019 (operational)	22500
IBN-One (*JV Cristal Union and Global Bioenergies*)	France		8	2017 (?)	50000

*Feedstock beet sugar; H2020 innovation projects to process agricultural residues and softwood

*TRL6-7: demonstration
TRL8: 1st of a kind commercial (flagship)
TRL9: commercial

Source: ETIP Bioenergy, Current status of Advanced Biofuels demonstrations in Europe, March 2020

Lignin to bioliquids (PVC3): EU

Company	Country	City	TRL*	Start-up year	Installed capacity (t/a)
RenFuel**	Sweden	Backhammar	6-7	2016 Operational	3200
RenFuel	Sweden	Vallvik	8	2021 Planned	77000

*TRL6-7: demonstration; TRL8: 1st of a kind commercial (flagship); TRL9: commercial

**RenFuel: lignin depolymerisation to Lignol liquid for upgrading in a refinery, portfolio of fuels

Source: ETIP Bioenergy, Current status of Advanced Biofuels demonstrations in Europe, March 2020

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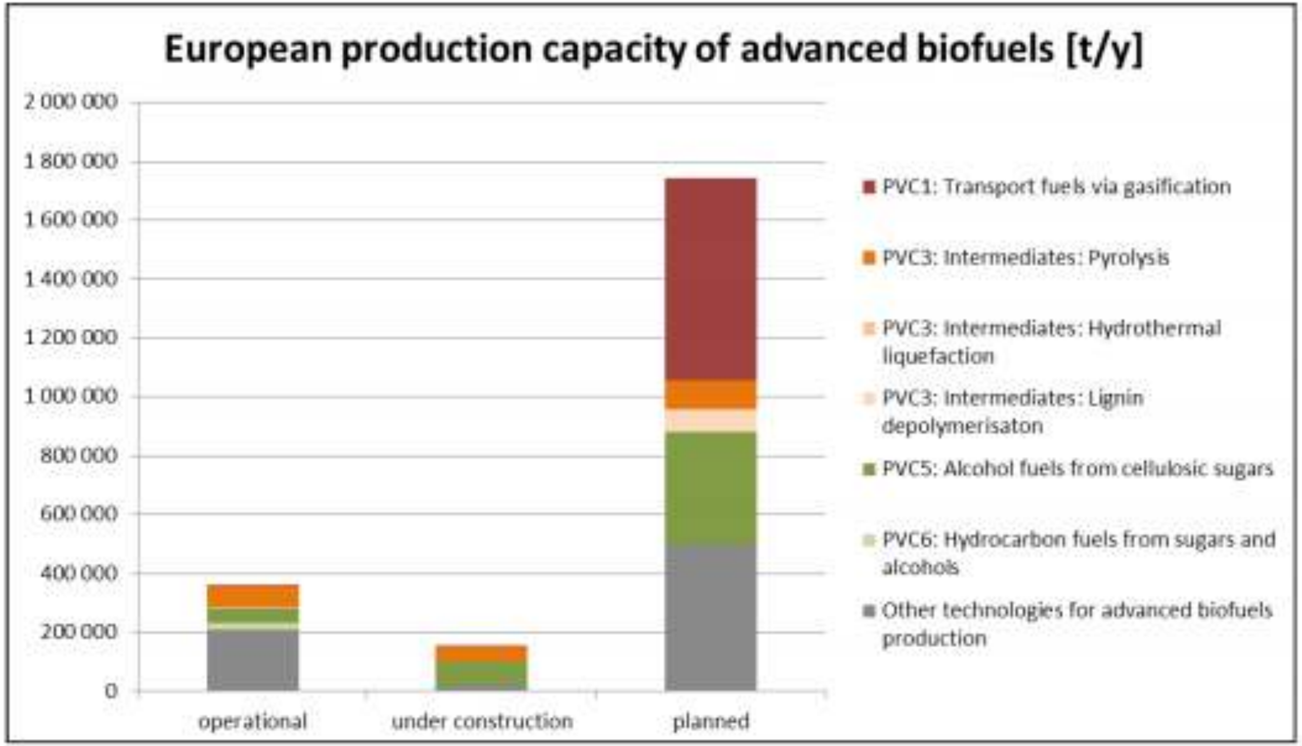
Current EU production capacity advanced biofuels



Production cost cellulosic EtOH*:
EU: about 0.55 €/l
Diesel/gasoline: 0,40 €/l

Need to fulfil EC policy goal: Several hundreds of additional plants necessary to meet 2030 policy goal (approx. 8Mt SAF/y)
Cost reduction is needed

Both innovation and deployment support needed!

Source: ETIP Bioenergy, Current status of Advanced Biofuels demonstrations in Europe, March 2020

Source: LNEG, Franncisco Girio @ ETIP Bioenergy WG2 webinar, 11 Nov 2020

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Sugar and lignin platform – innovations needed for cost reduction

- Cost effective and sustainable feedstock supply (Annex IX RED II)

- Reduction CAPEX and OPEX costs
    - Pre-treatment: more efficient and more sustainable
    - Enzymatic hydrolysis: on-site enzyme production and enzyme recycling
    - Fermentation: High yields/productivity strains, synthetic biology, GMOs, non-sterile systems
    - Lignin valorisation instead of burning for (process) energy
    - Process integration & intensification
    - Catalyst robustness for lignin upgrading and chemical steps

- Valorisation of co-products: process residues (animal feed, soil improver, fertilizers), biobased CO_2 (to negative GHG emission value chains), waste water to biogas, etc.

- For acceleration of developments: Integration of pilots with existing facilities at commercial scale, for example 1st Gen ethanol

Sugar and lignin platform – NL deployment traject

Blue prints potential demonstrations and flagship initiatives sites:

- Harbours (Rotterdam, Amsterdam) or other sites with accessibility to feedstocks (local, imported), chemical industry and for fuel distribution (pipelines)
- Integration conventional and advanced ethanol production (example:C6 to EtOH, C5 to BuOH, lignin to chemicals, fuels)

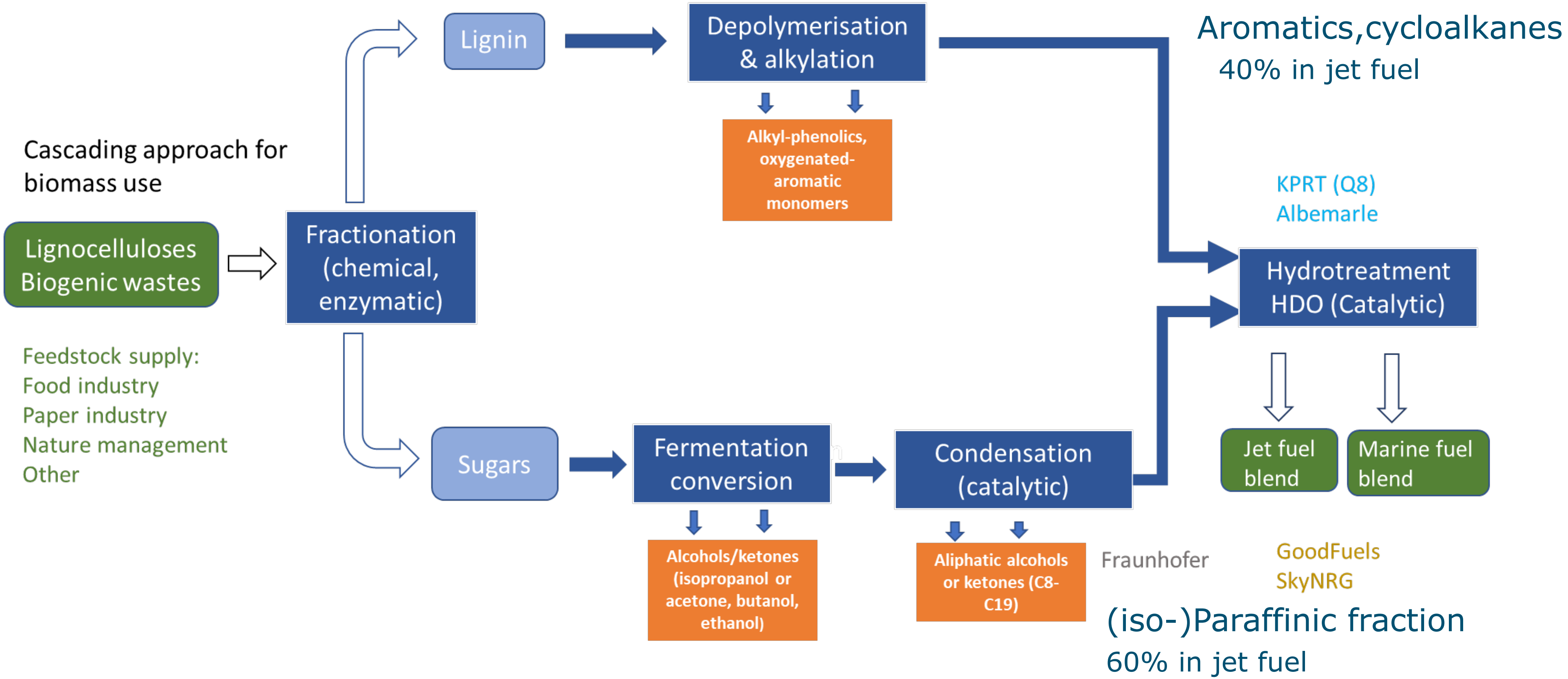
Blue prints supported value chain innovations:

1. Sustainable feedstock/biomass supply
2. Pre-treatment & storage
3. Primary conversion
4. Downstream processing
5. Secondary conversion
6. Product upgrading, incl. co-products (lignin, CO_2, etc.)
7. Product application, incl. co-products
8. Process integration and intensification

Other support measures:

- Sector based roadmapping
- Exchange best-practices (stakerholder platform)
- Solving non-technical deployment bottle-necks
- Education and training

Advanced biofuels: WUR vision



Examples of wet organic wastes in NL

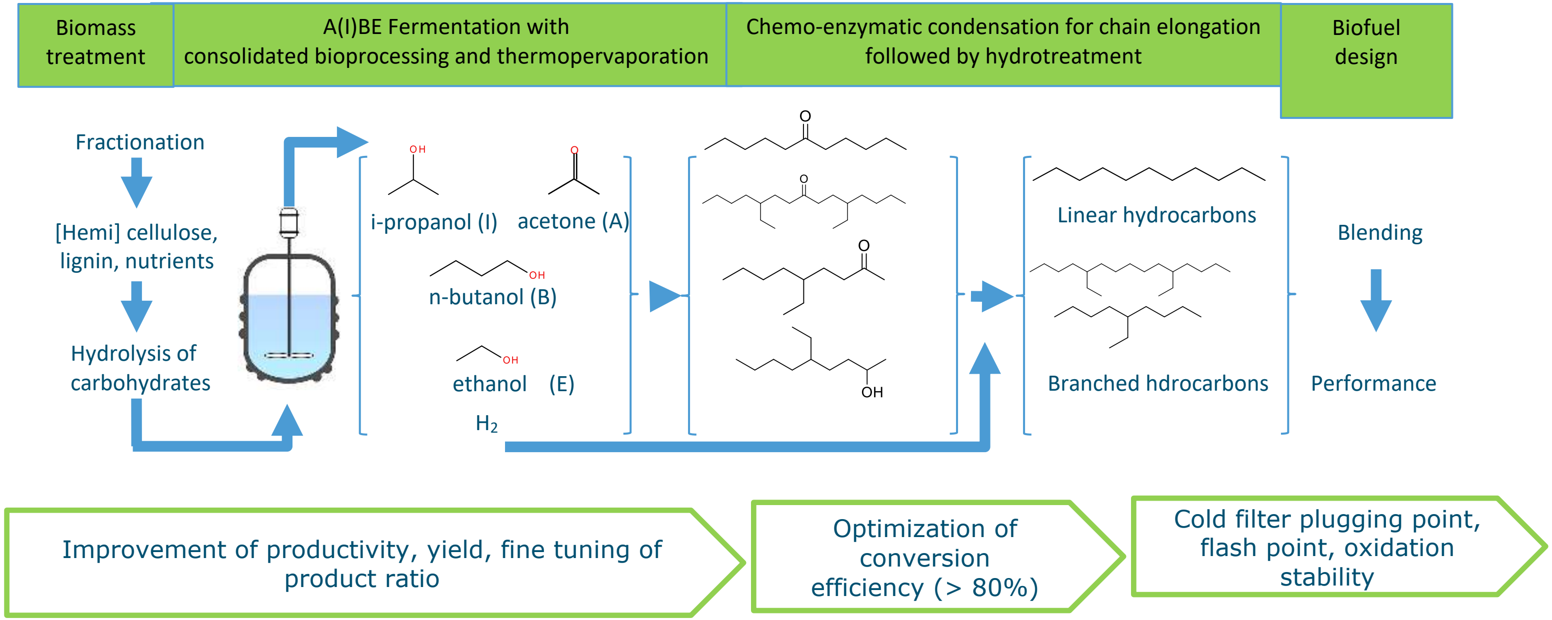
Feedstock		Volume (Ktons d.m.)	Current use
Agriculture			
	Wet streams arable farming	985	Anaerobic digestion
	Wet streams horticulture	356	
Food & Breweries			
	Brewer's spent grains	100	Anaerobic digestion/Feed
	Cereal/potato starch residues	583	
Paper industry			
	Paper residues	256	Combustion
	Paper sludge	531	

Food and beverage industry wastes are estimated at ~8100 kton/y (~2025 kton d.m.). Estimated SAF needs in 2030 are 500-700ktons/y in NL. In EU sufficient lignocellulosic biomass for SAF

Sources:. Koppejan, Elbersen et al. Beschikbaarheid van nederlandse biomassa voor electriciteit en warmte in 2020 (2009) . Senternovem rapport, project nr 200809

Schulze P et al. Biomassapotentieel in Nederland (2017) Gas Unie document GCS.17.R.10032629.2

Alcohols to paraffinic jet-fuel components



- Condensation of A(I)BE in one step to a mixture of C8-C19 aliphatic ketones/alcohols
- Catalytic hydrotreatment in collaboration with industrial partners to produce linear and branched aliphatic jet fuel components

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Butanol (vs ethanol) as transport fuel or intermediate

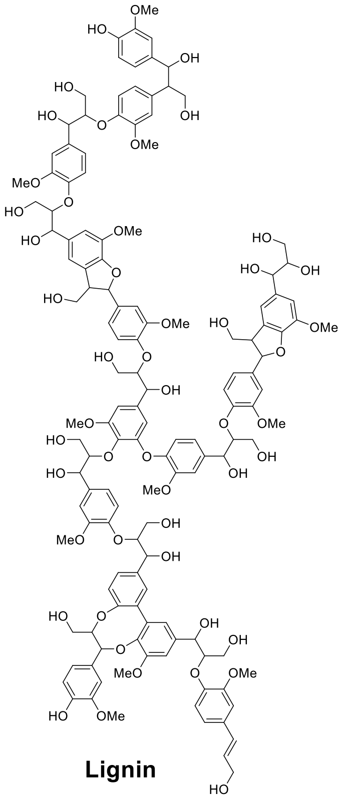
Benefits:

- **Higher energy content:** 36.2 MJ/kg butanol vs 29.7 MJ/kg ethanol, 43.5 MJ/kg gasoline
- **Lower vapor pressure, transport options in pipelines:** 0.8 Kpa butanol vs 7.8 kPa ethanol
- **Increased energy security:** Strains are robust, use C5, C6 sugars and other (glycerol, starch, etc)
- **Fewer emissions, uses in engines as such/blend or small adaptations:** Cleaner fuel, Fewer emissions than fossil fuels. Fuel derived from B/I/A/E mixtures is possible at high yield

Drawbacks:

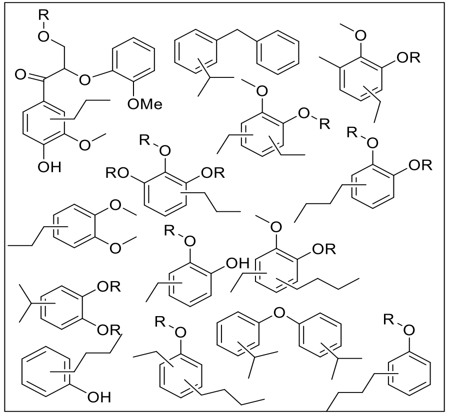
- **Lower yields from substrate:** 0.2 g butanol/g sugar vs 0.5 g ethanol/g sugar
  - Improvement: strains with increased yields by reusing CO2, using GMO
- **Longer fermentation times, lower productivities:** Use advanced reactors with product removal
- **Higher viscosity than ethanol:** maybe adaptations are needed to engines when used pure

Lignin to aromatic/cycloalkane jet-fuel components



Lignin

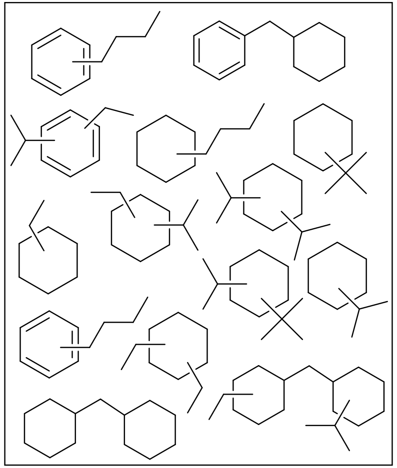
Catalytic depolymerization & C-alkylation



Lignin oil

(R = $-CH_3$, $-CH_2-CH_3$, $-CH(CH_3)_2$, $-CH_2-CH_2-CH_2-CH_3$)

Catalytic hydrotreatment



Jet-fuel components

- Lignin depolymerization and alkylation in fermentation derived alcohols using heterogeneous catalysts
- Catalytic hydrotreatment (hydrodeoxygenation) to produce oxygen free aromatics and alkyl-cycloalkane jet fuel components
- Need for robust catalysts. Process for Marine and jet fuels are different

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Value Chains in WUR

Feedstock	*Conversion*	*Products*	*Comments*	
Potato wastes	**Fermentation to ABE-Condensation-HDO**	**Jet fuel** **By products: feed vitB_{12}, H_2, CO_2**	**Proof of principle** **LCA, TEA completed** **TRL 4-5**	**BioJetFuel**
Paper sludge	**Fermentation to IBE-Enz/chem condensation -HDO**	**Liquid fuels, marine** **By products: feed vitB_{12}, H_2, CO_2**	**In progress** **TRL 2-3**	MOTOR
Lignocellulosics **Wood pellets** **EU-Brazil**	**Fermentation to ABE** **Fermentation to EtOH**	**Alcohols as fuels** **Value chains to be defined**	**C6, C5 streams** **C5 need detox** **In progress, TRL 2-3**	BECOOL Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels
Off gases (CO_2, CO/H_2)	**Fermentation, enzymes, Mixotrophy**	**Alcohols for the chemical market** **Lactic acid, PHB**	**Broad EU project** **In progress** **TRL 1-3**	BIOCON-CO_2

Thank you for your attention!

Questions?/Remarks?