Tomorrow's biorefineries in Europe

Paper-mills options for partial conversion: Example of an integrated Biorefinery

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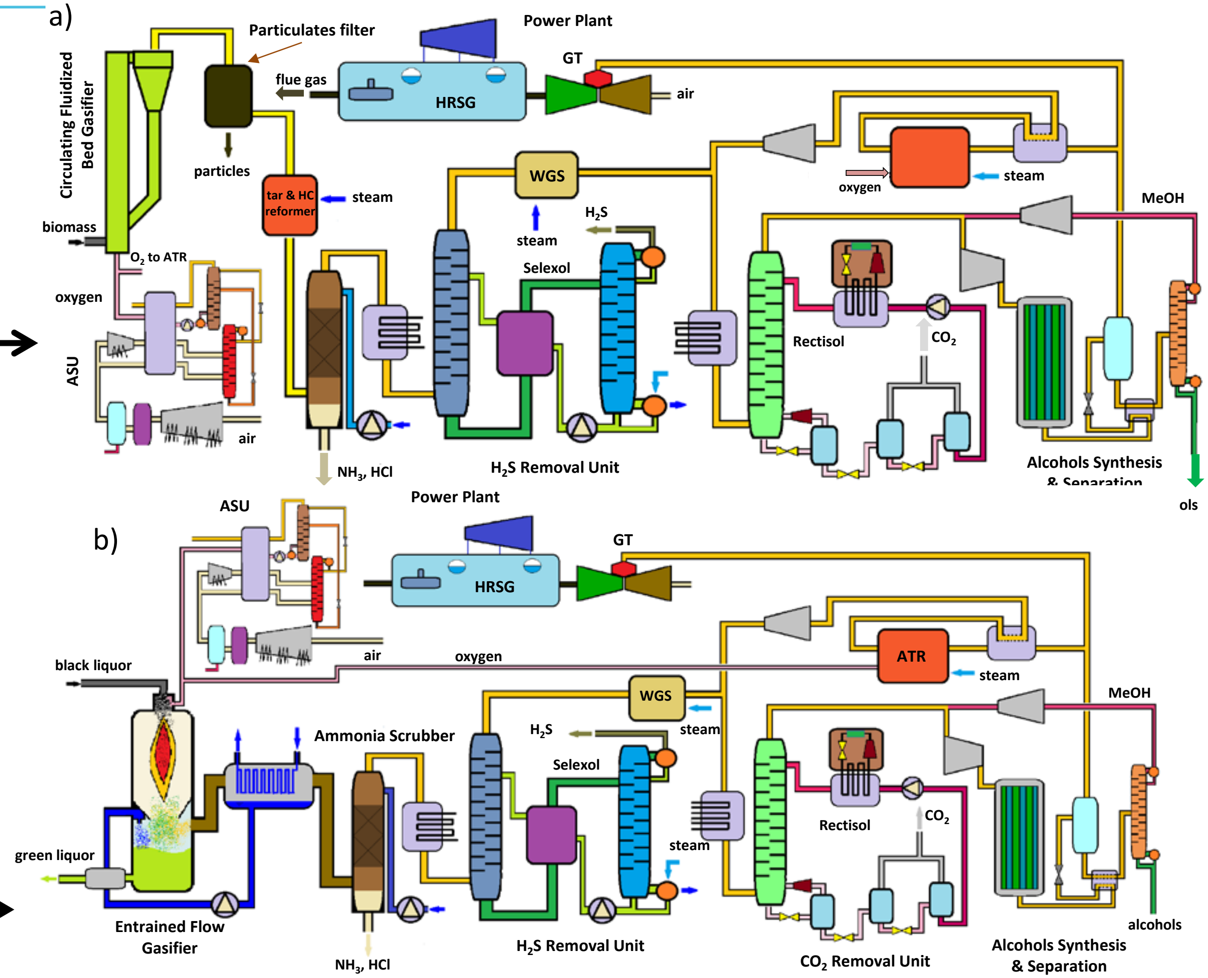
Gasification based biorefinery

Willow / Poland →

Giant Reed / Greece →

Wood / Sweden
↓
Pulp industry
↓
Black Liquor →



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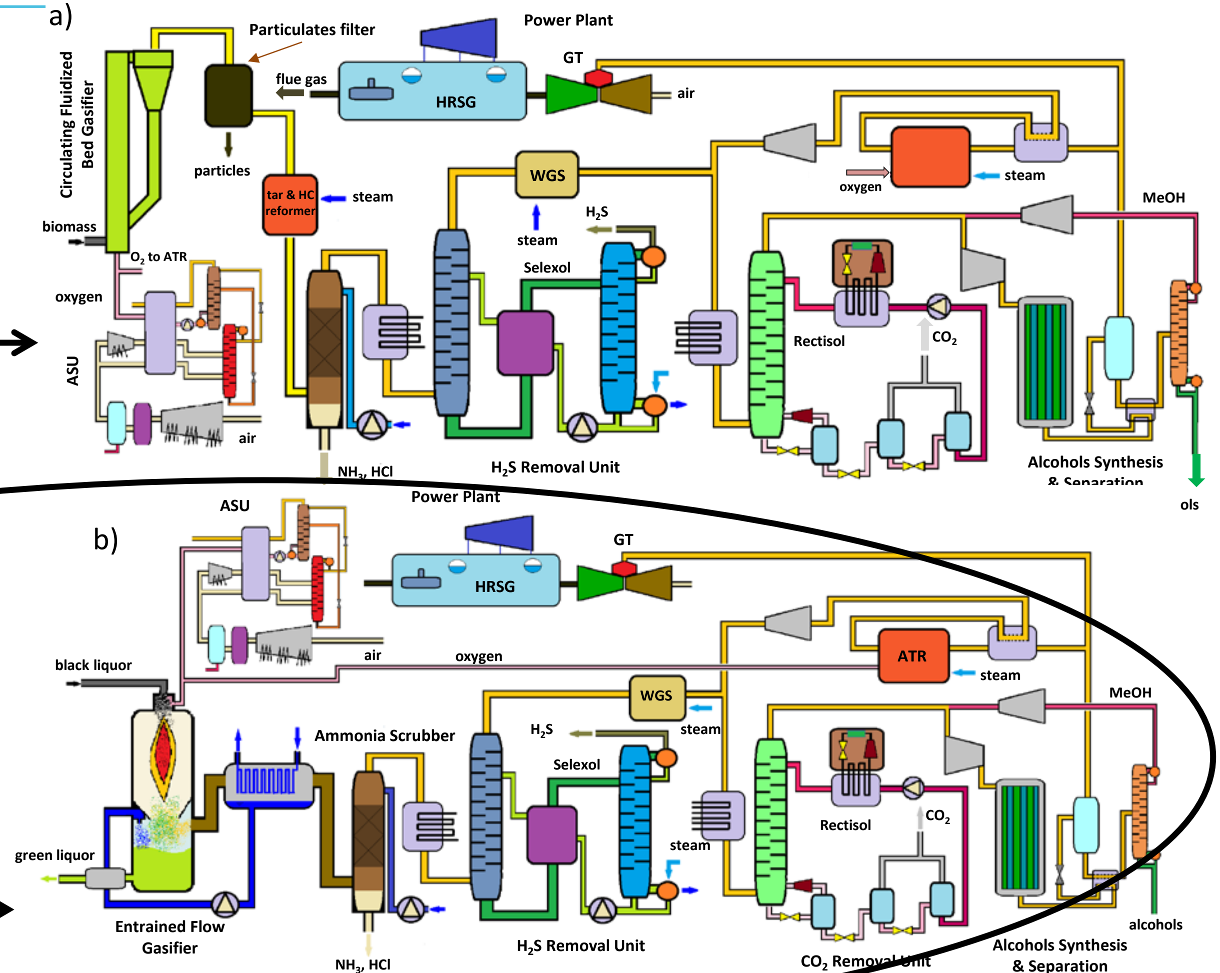
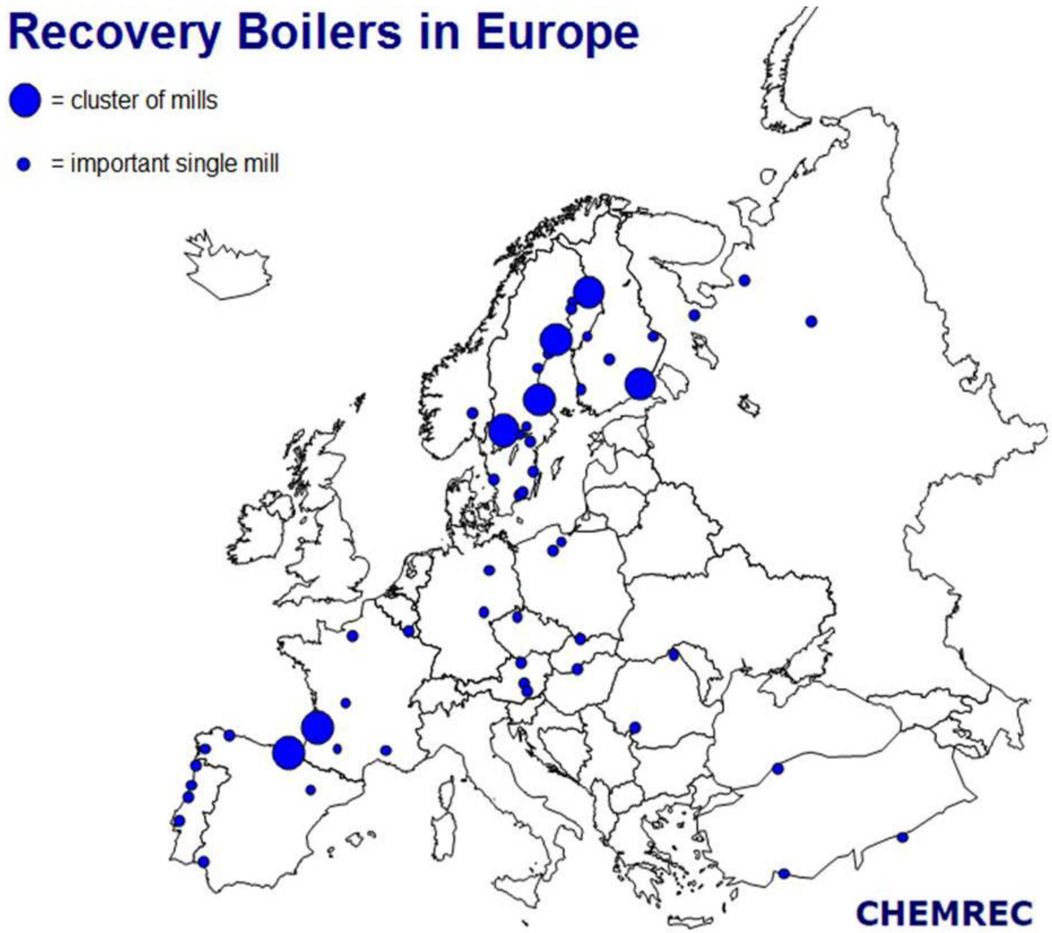


Mapping Production / Consumption



Brief description

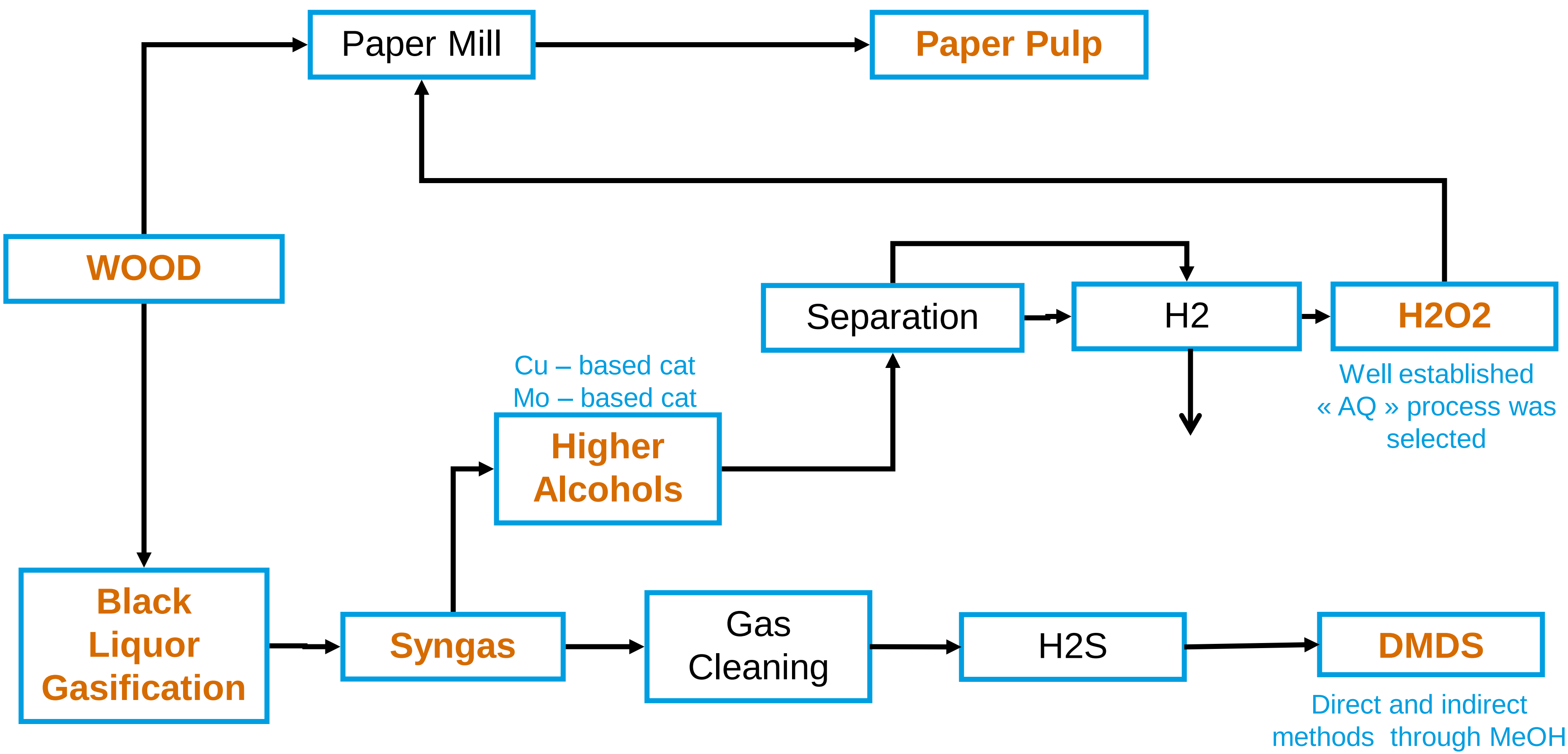
- The primary technology for a Syngas Biorefinery is biomass gasification

- For a fast track to materialization of the Syngas Biorefinery, the Chemrec process is selected. This process gasifies black liquor deriving from the Kraft pulping process.
- A typical mid-size European mill, with a capacity of 1300 ton pulp per day, produces 2000 ton black liquor dry solids per day (2000 tDS/d) corresponding to about 270 MW thermal energy

The novel products identified from this biorefinery are:

- Production of Hydrogen peroxide (H_2O_2)
- Production of Dimethyl disulphide (DMDS)
- Production of higher alcohols (HA)
- Energy production

High Pressure SynGas / H2O2 BIOREFINERY:
Combined production in a Paper Mill. **Specifics: High Pressure Syngas**



Production yields overview

2500 ton /d Biomass → 2000 tons/d Black Liquor → 1057 ton/d syngas → W tons of product D

	Ultimate Analysis (Dry basis %)			Proximate analysis (%)	
	wood	black liquor		wood	black liquor
C	48.75	31.3	moisture	5.1	24.8
H	6.54	3.4	fixed carbon	9.88	12.6
O	44.10	37.3	volatiles	89.8	21.6
S	0.24	5.6	ash	0.32	41.2
N	0.05	0.1			
Na	-	22.4			
HHV (MJ/kg)				18.88	12.57

ton/d	**MeOH**	**EtOH**	**PrOH**	**BuOH**	**PeOH**	**H2O2**	**DMDS**	H2O2 used	**H2O2**
Cu- cat	**399,6**	**22,9**	**69,3**	**8,6**	**1,9**	**45,7**	**30,4**	-11,0	**34,7**
Mo cat	**11**	**235**	**55**	**20**	**10**	**45,7**	**30,4**	-11,0	**34,7**

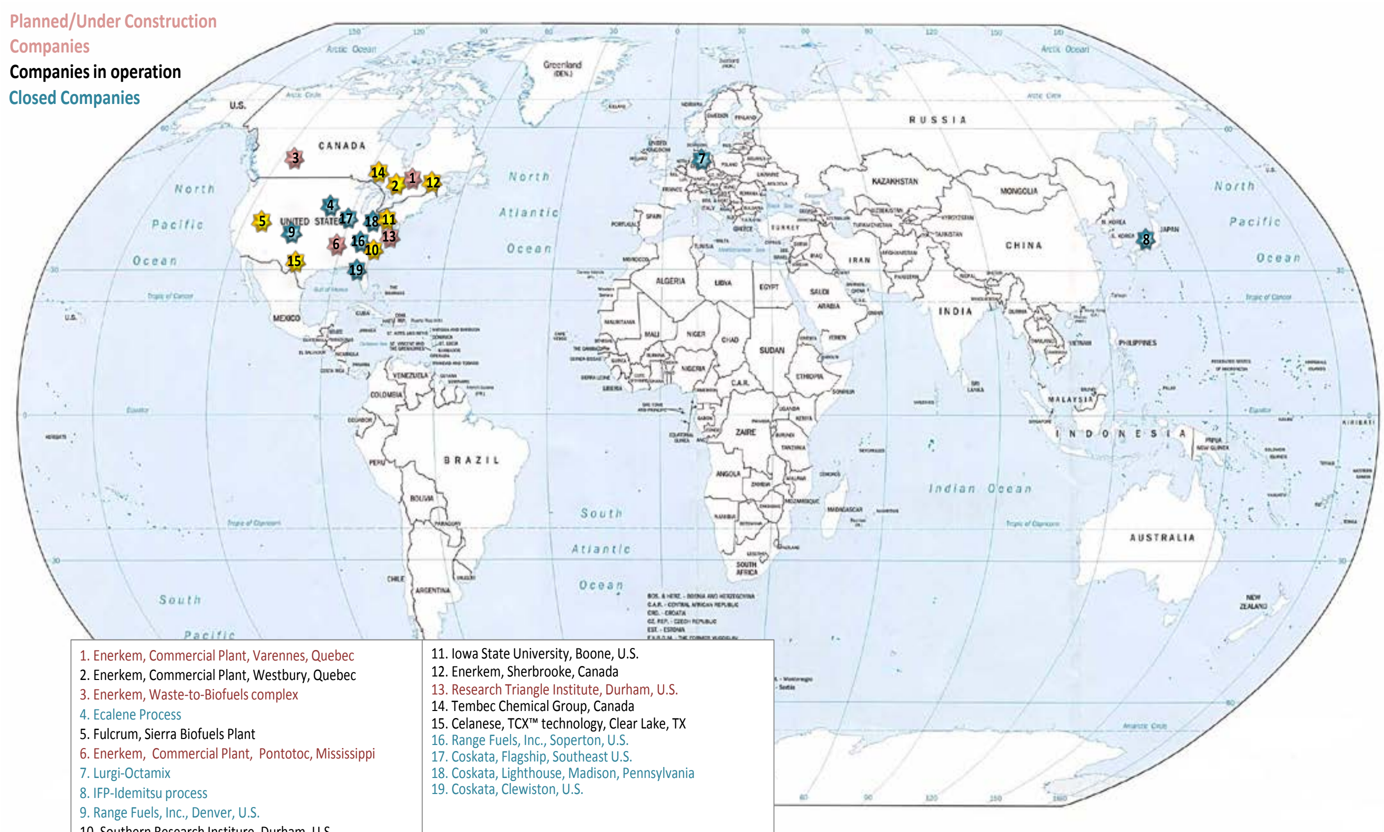
Side Product

Upgrading

Tradable Commodity

Paper Industry Bleaching

Map of commercial and pilot units for higher alcohols production form syngas



1. Enerkem, Commercial Plant, Varennes, Quebec
2. Enerkem, Commercial Plant, Westbury, Quebec
3. Enerkem, Waste-to-Biofuels complex
4. Ecalene Process
5. Fulcrum, Sierra Biofuels Plant
6. Enerkem, Commercial Plant, Pontotoc, Mississippi
7. Lurgi-Octamix
8. IFP-Idemitsu process
9. Range Fuels, Inc., Denver, U.S.
10. Southern Research Institure, Durham, U.S.
11. Iowa State University, Boone, U.S.
12. Enerkem, Sherbrooke, Canada
13. Research Triangle Institute, Durham, U.S.
14. Tembec Chemical Group, Canada
15. Celanese, TCX™ technology, Clear Lake, TX
16. Range Fuels, Inc., Soperton, U.S.
17. Coskata, Flagship, Southeast U.S.
18. Coskata, Lighthouse, Madison, Pennsylvania
19. Coskata, Clewiston, U.S.

SWOT analysis

Strengths

- Diversity of products both chemicals & fuels
- On site H_2O_2 production has increased cost reduction (no need for transportation).
- The target products are high volume
- Existing know-how on process steps
- Sustainable production (LCA).

Weaknesses

- Relatively low selectivity towards HA
- Biofuel market needs to be created in parallel (MeOH and EtOH).
- MeSH production from natural gas is currently far less costly.
- MeSH is a toxic material not easily transported. So an additional step to transform it on site to DMDS or other

Opportunities

- Replacing carbon emitting processes
- Synergy in revenues
- Drawing incentives from both agriculture and New business for European farmers

Threats

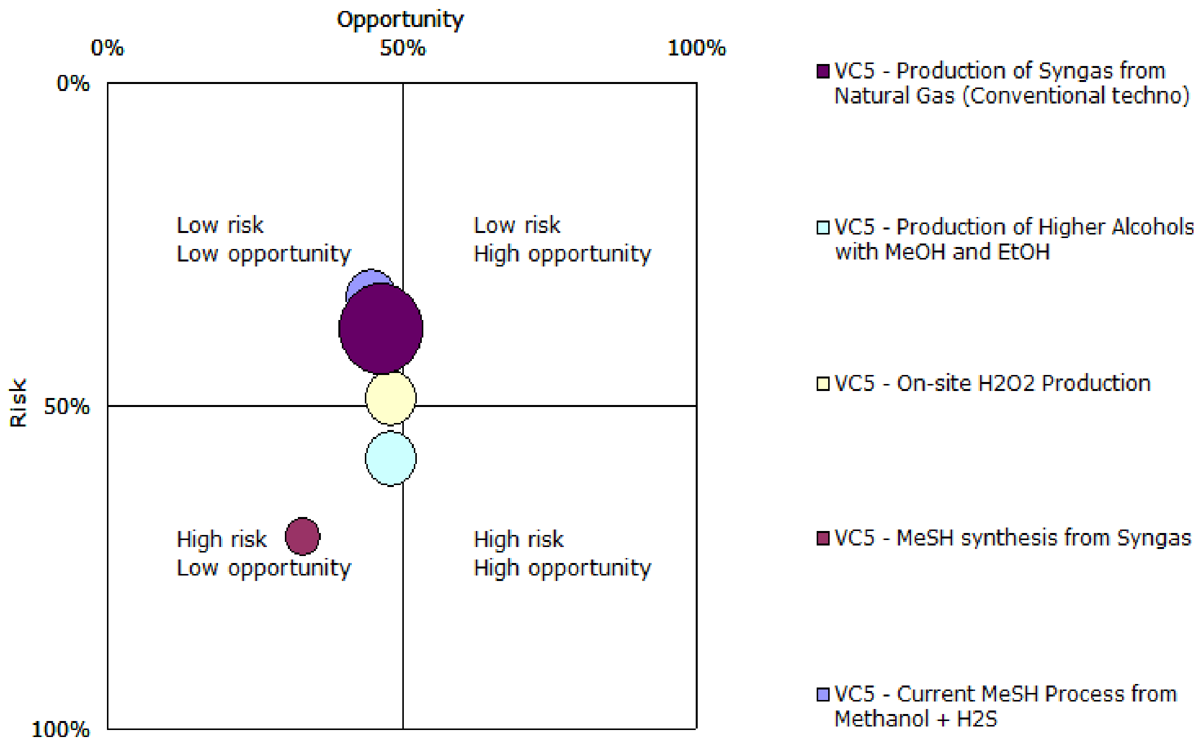
- Capital Costs high
- Opex high compared to Natural Gas.
- Biomass based alternative technologies (FT, NexBTL, Ecofining, Gevo)
- Papermills lack of financial resources

Porter's Six Forces Analysis- Value Chain 5: Value proposition for Paper Mills Black Liquor Gazification, and conversion to Higher Alchohols, H_2O_2, and others

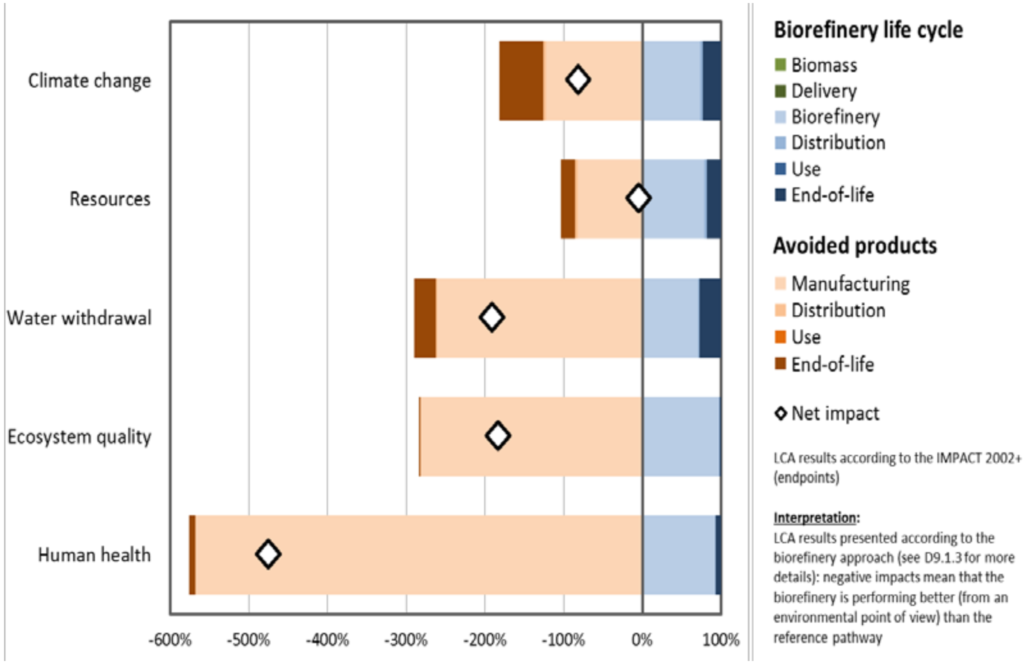
Category	Relative Power	Notes
Bargaining power of Suppliers (of Biomass)	Medium	**Paper Mills** try to find better value secondary products. **Additional biomass or organic** wastes can be used for energy production. Other options include **stand alone gasification plants** - in that case **feedstock capacity building is difficult (logistics)**.
Bargaining Power of Customers (of chemicals & fuels)	Medium	**Paper Mills are also H2O2 consumers.** They can see a value of on-site production in reducing the transportation cost and storage. **Large array of customer industries for higher alcohols.** Customer / producer need to be satisfied with HA mixture composition / efficiency (respectively)
Threat of New Competitors	Low	Absolute cost **(CAPEX + OPEX) remains high** for fuels compared to current market Substituting fossil based chemicals might attract **subsidies** but this will attract also new competitors.
Threat of Substitute Products or services	Medium	H2O2 production sites are far from paper mills and this means transporting 50 % water. Nevertheless NG costs are currently very low (alternative route) Biobased higher alcohols can be produced by other processes as well.
Competitive Rivalry	High	Many Biomass gasification projects **close to demo** phase, **Diverse reactor technologies**: low or high pressure; Fluidized bed, entrained flow etc for **handling different feedstock** (south/north)
Stakeholders: Government / Public	High	Governement can positively favor renewable products (Bio-Preferred) and Biofuels, through subsidies, Existing projects receive **positive public reception** and news coverage

IP score – Competition benchmark

Diagnostic report on risk and potential factors



LCA



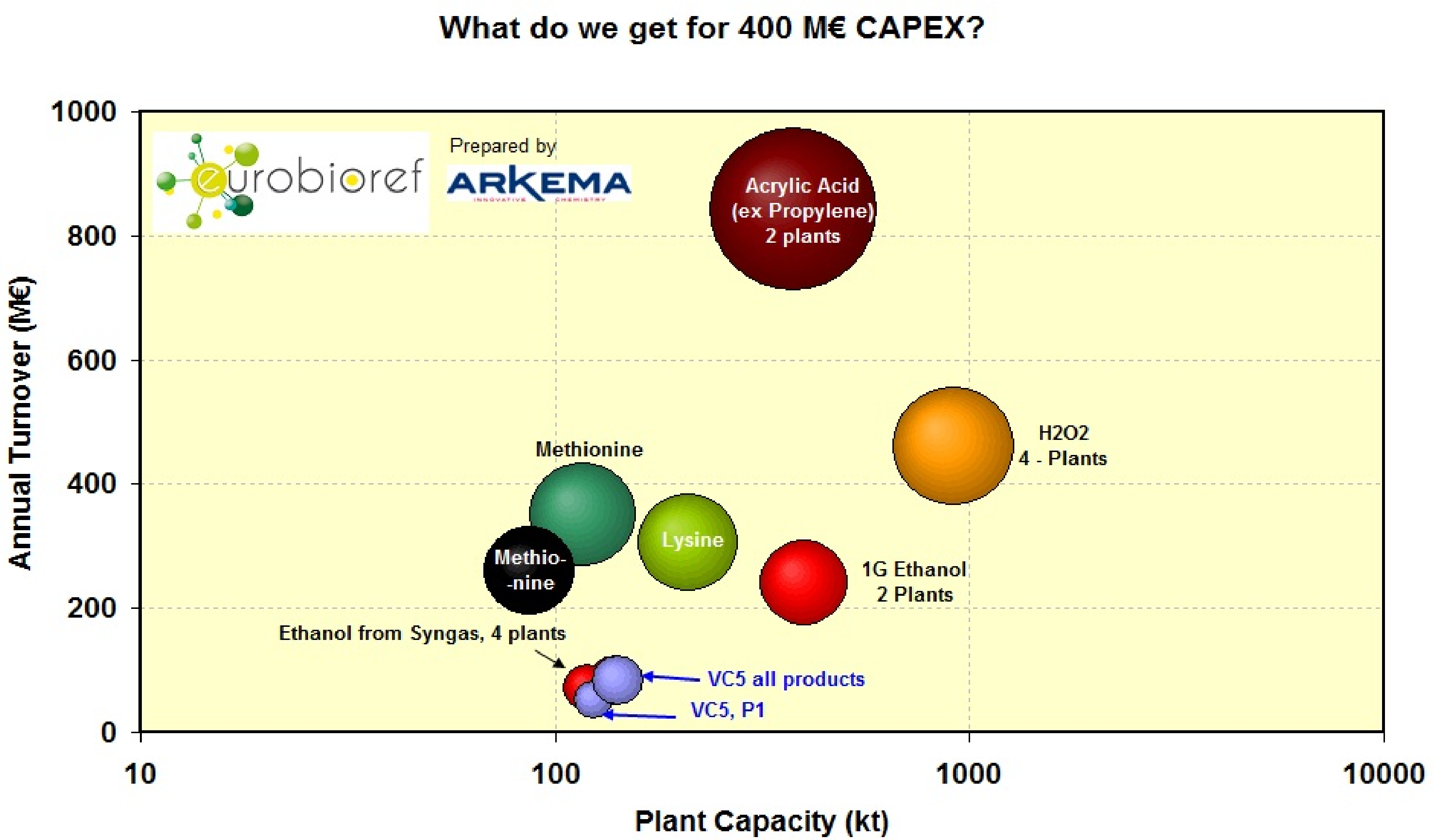
Significant benefit in terms of:

- climate change,
- water withdrawal,
- ecosystem quality and
- human health

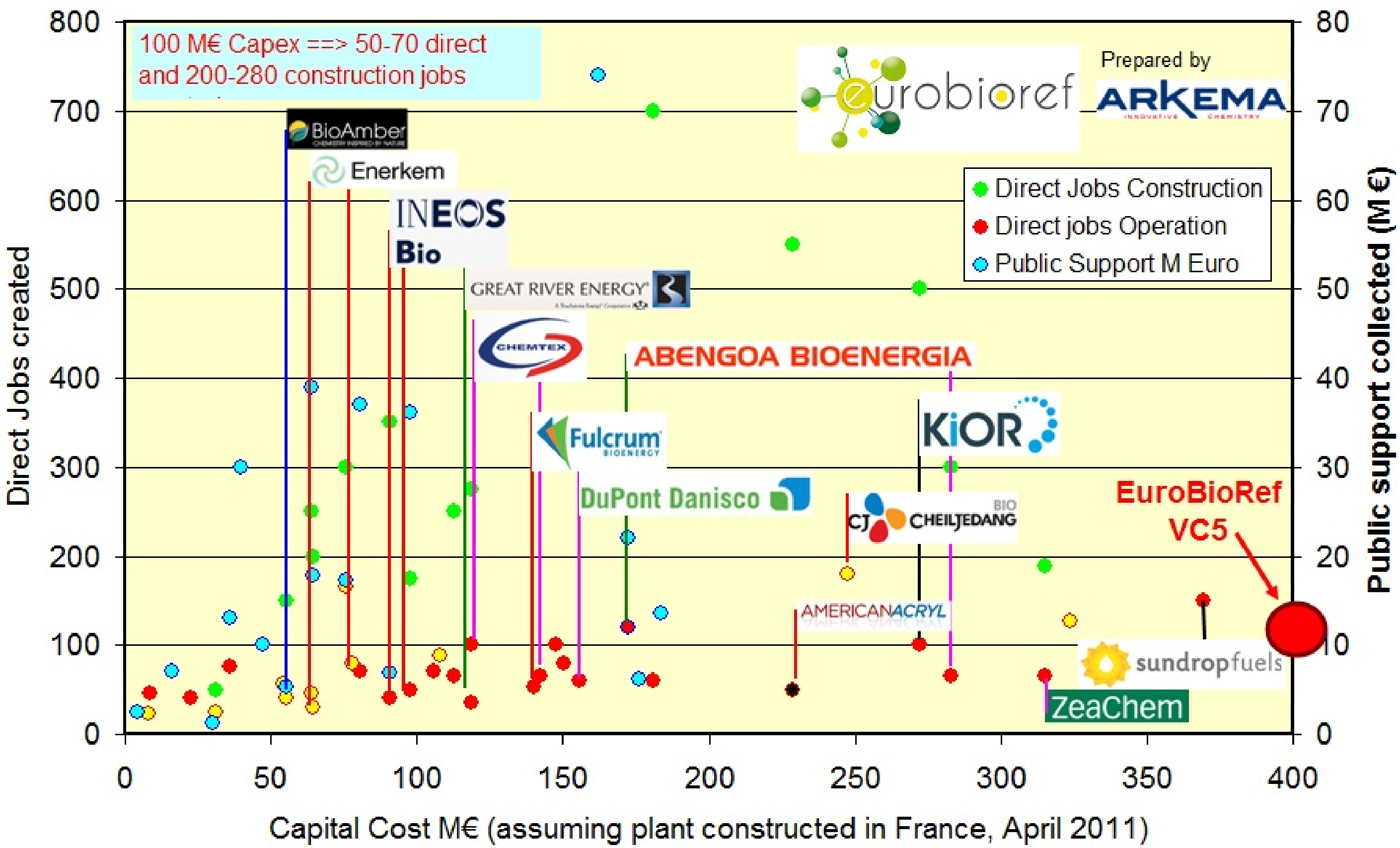
with respect to conventional production routes for the specific set of co-products (incl. alcohols, hydrogen peroxide and di-methyl sulphide).

Ecosystem quality is favourable to the compared to conventional routes. The main reason for this is that the avoided product in this case is considered to be ethanol from biomass (considered as a mix of 40% corn-based from US, 40% sugarcane-based from Brazil, 15% wheat-based from Europe and 5% lignocellulosic).

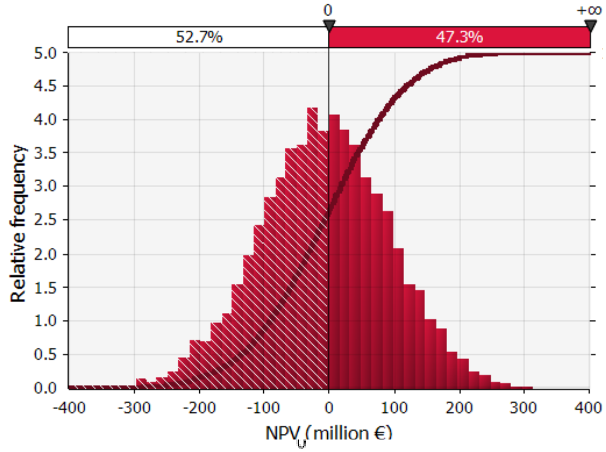
Capital Cost impact



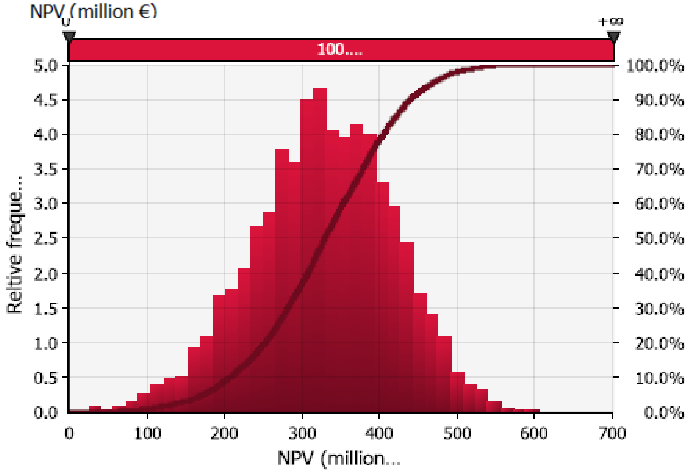
Jobs creation



VC5 cost analysis – Black liquor to H_2O_2, higher alcohols and DMS



Base case



Best case

- Base case: 47% chance of being profitable
- Best case: 100% chance of being profitable but requires
  - very low wood cost
  - 40% of capital cost offset against recovery boiler cost
- Heat integration essential for good economics

Imperial College London

Net present value – Value Chain 5
hydrogen peroxide, higher alcohols and DMS

Summary of Value Chain 5: High pressure Syngas / HA& H_2O_2 Biorefinery

Need, Market Opportunity & Impact

Need: H2O2 is required on site in pulp & paper industries ,
directly as fuels, as fuel additives for octane or cetane enhancement,
as oxygenate fuel additives for environmental reasons, and as intermediates
to form other fuel additives as well as for the production of solvents or
other chemical sub-processes in the chemical industry.

Market Opportunity: There is a growing need for fuels and CO_2 neutral products

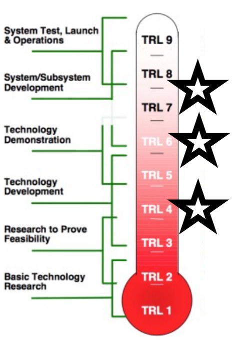
Impact: Gasification can both cover energy and power demands of the total process as well as provide processes routes for intermediate chemicals production.
This important combination is expected to push the gasification technology into diverse application coupled with almost all diverse technology bio-refineries

Technology

Wood → Pulp → Black Liquor → HA → Fuel additives, Chemicals
H_2O_2 → Paper Industry
DMDS → Sulfur Chemicals

Technology Development Milestone (T.R.L.)

Step	TRL	Risk	Measure of Success
Higher alcohols synthesis from Syngas from EuroBioRef technology.	4	medium	Stable catalyst performance
MeSH Synthesis from Methanol	9	low	Already at commercial scale, but not biobased
MeSH synthesis through direct syngas	4	Medium	Stable catalyst performance
H_2O_2 synthesis	7	Low	Stable catalyst performance
Gas cleaning	6	Low	Proper gas cleaning
Solid Biomass Gasification	6	Low	Robust performance **without** downtime due to agglomeration/ defluidizesation as well problems.
Black liquor gasification	7/8	low	In operation in Chemrec at large pilot scale under pressure (level 7 or 8). Would be 9 if at atmospheric pressure and with Air.



Business Model

Pulp & Paper Industry

CHEMREC

ARKEMA

Fuel /Refinery Industry

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Thanks for your attention!