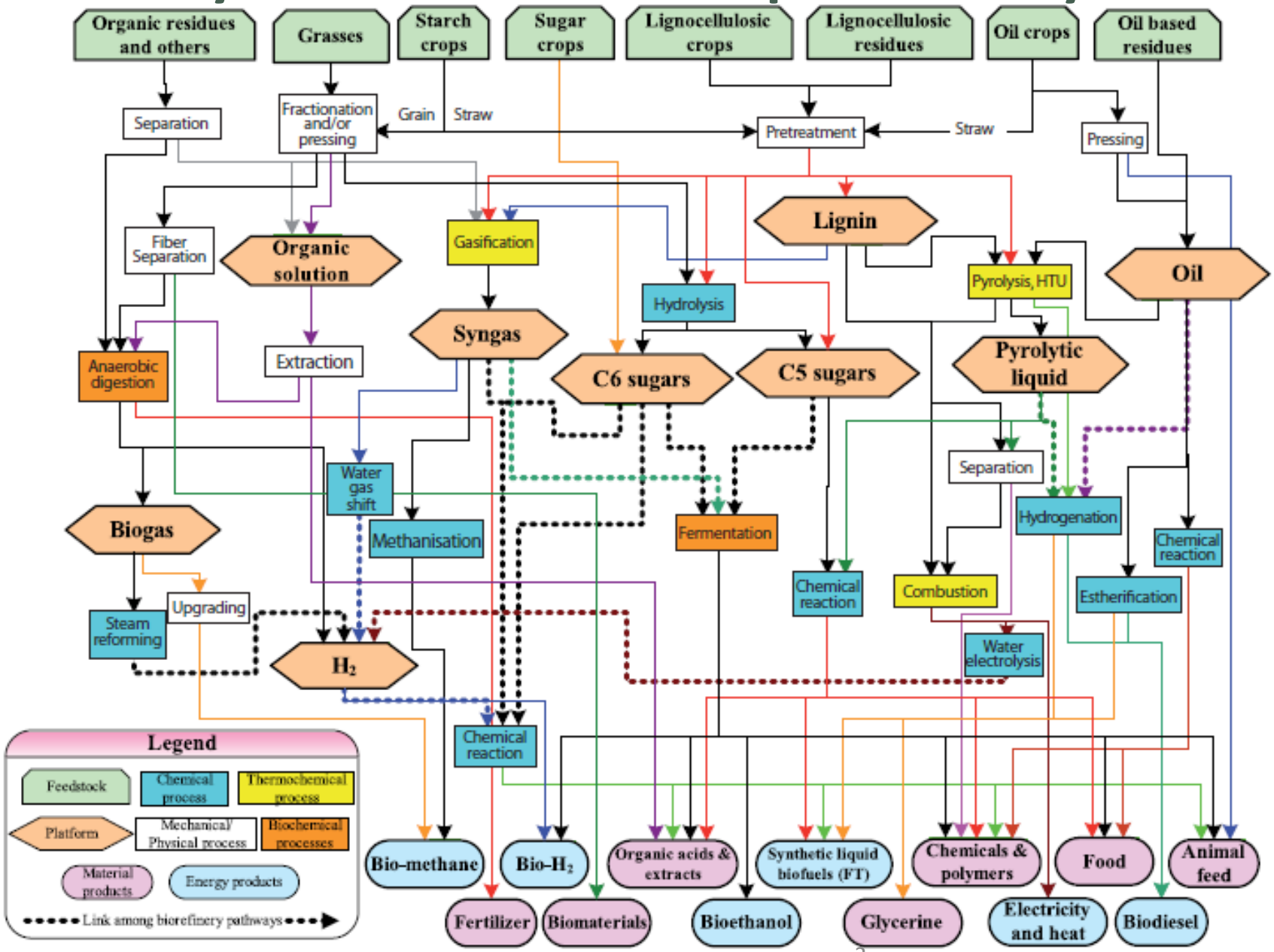
Biorefineries in Europe (and World)

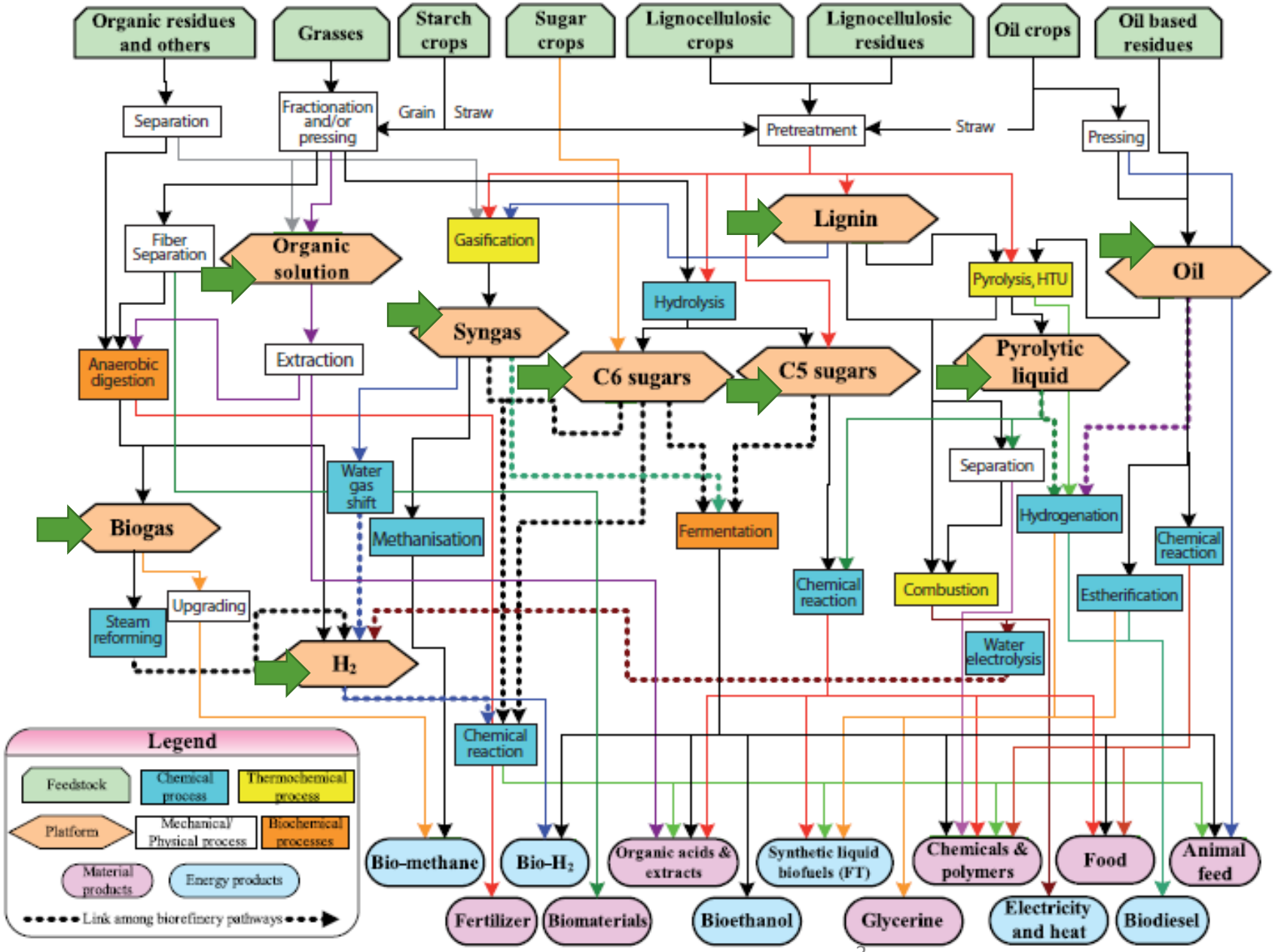
Francisco Gírio
Head of Bioenergy Unit
LNEG - Laboratório Nacional de Energia e Geologia
Lisboa, Portugal

Biorefinery for Biofuels: A Complex Factory?



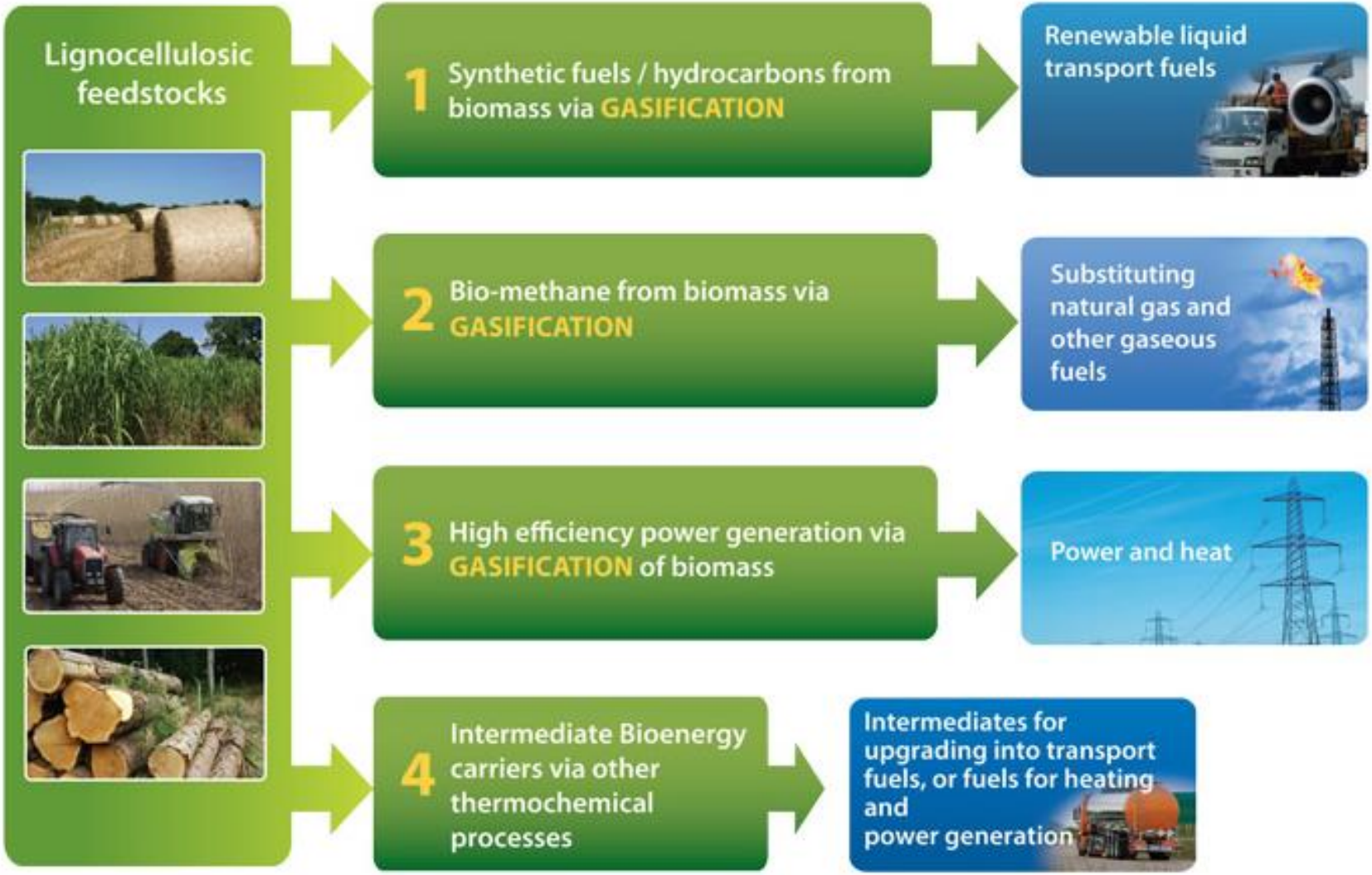
Source: **IEA Bioenergy: Task 42- Biorefineries**

Several Platforms and Multi-Products



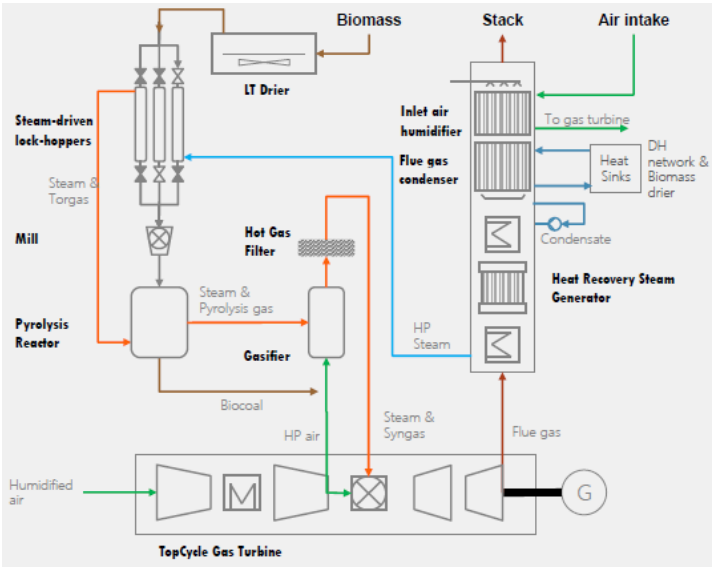
Source: **IEA Bioenergy: Task 42- Biorefineries**

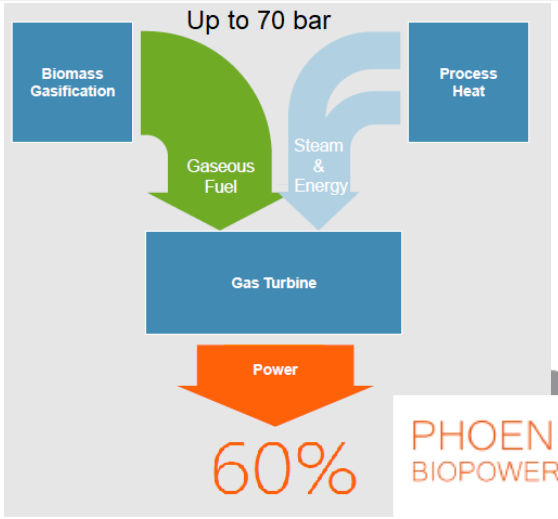
Thermochemical & chemical conversion value chains



Power and heat at high efficiency

SE



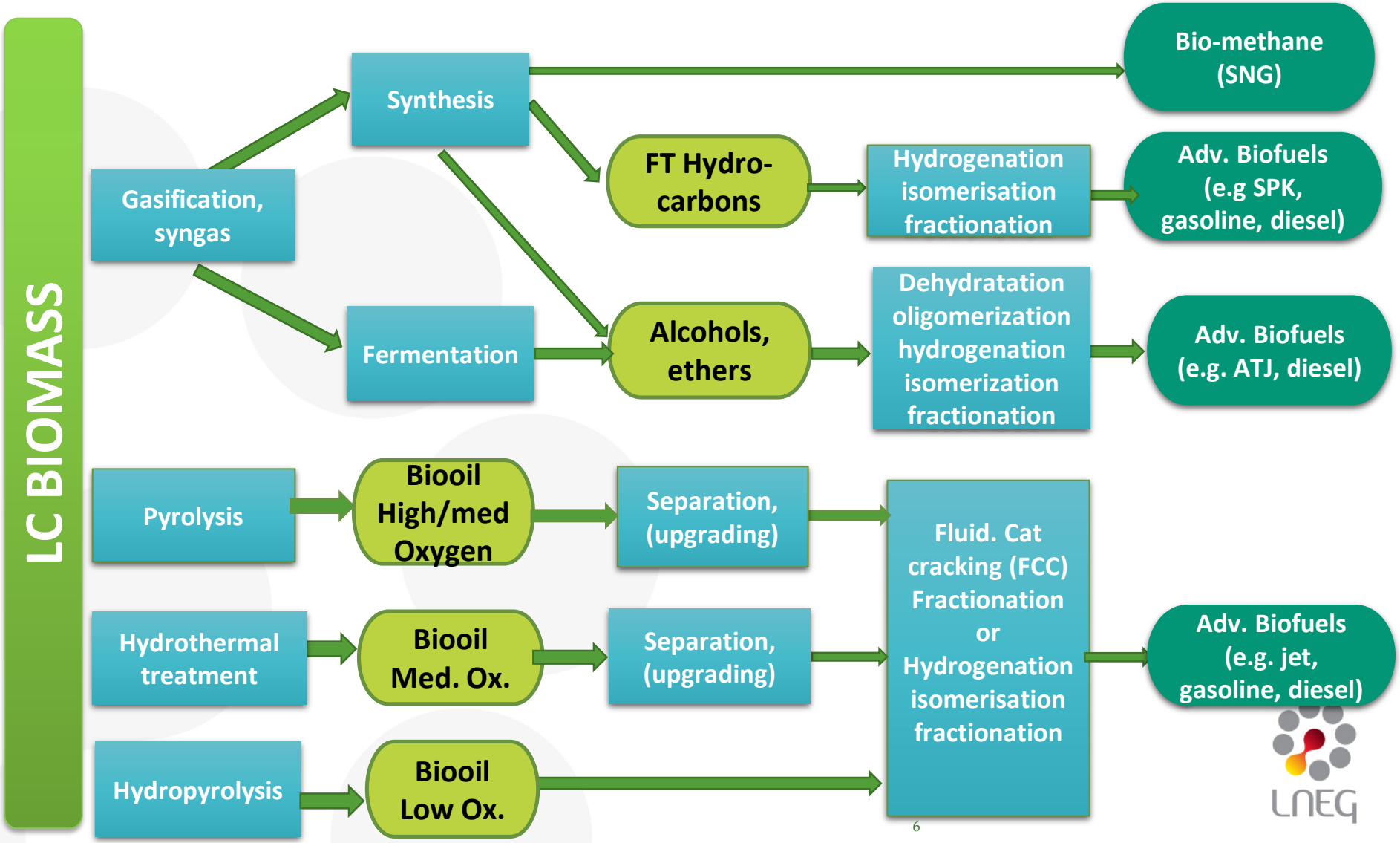


stockholm exergi

2016 KVV8 – Värtaverket
345 MW CFB Steam 140 Bar/560°C
130 MW power gross, 200 MW heat + 80 MW from FG condensing. >100 % efficiency (LHV).
500 M€ investment. Boiler supply by Andritz

PHOENIX BIOPOWER

Intermediates to hydrocarbons



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Thermal gasification to biofuels

Developer/project		Feed	Year	Cap. MWth		Type	Status
Ambigo	NL	LC Biomass		4	SNG	Demo	Plan.
Bioliq	DE	PO+char	2013	5	feed	Demo	Op.
BioTFueL	DE/FR	Torr. ag. resid.	2017	15	feed	Demo	Com.
Enerkem	CA	RDF	2014	30	EtOH	1st ind.	Com.
	NL	Plastic waste		220	MeOH	Comm.	Plan.
EON Bio2G	SE	LC biomass		200	SNG	1st ind.	Plan.
Fulcrum	USA	RDF		50	BTL	1st ind.	Plan
Gobigas	SE	LC biomass	2013	20	SNG	1st ind.	Op.
GoGreenGas	UK	RDF	2018	4	SNG	Demo	Plan.
GTI	USA+	LC biomass	2009	2	BTL	Demo	Op.
Kaidi Ajos	FI/CN	LC biomass		300	BTL	1st ind.	Plan.
LTU Green Fuels	SE	Black liquor, PO	2009	1	DME	Demo	Idle
Red Rock	USA	LC biomass		75	BTL	1st ind.	Plan.
Sekisui/Lanzatech	JP/NZ	MSW	2013	EtOH		Pilot	†2017

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Operating gasification to biofuel plants

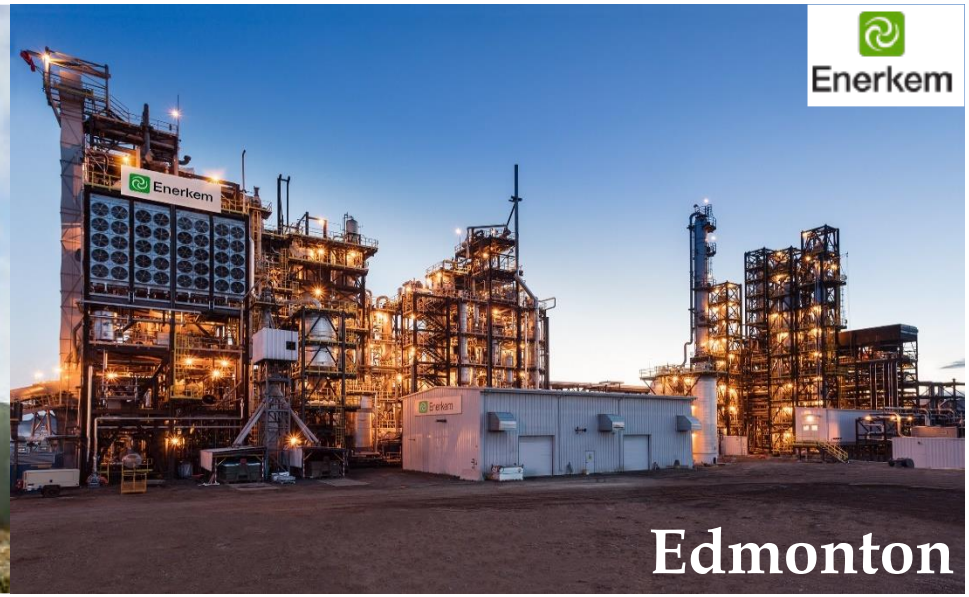
SE

30 MWth biomass in
20 MW bio-methane, 5 MW heat out
TUW/Repotec/Valmet, Topsöe SNG
Operation 2014, 2017-2018 highlights:

- MCR capacity reached
- 1 800 uninterrupted hours

Mothballing decision taken

CA



100 000 tons of RDF in
38 000 m3 of methanol/ethanol
Univ. Sherbrooke/Enerkem technology
Operation 2014, 2017-2018 highlights:

- MeOH to EtOH conv. installed
- Plans for project in Rotterdam
- ~220 M$US from investors

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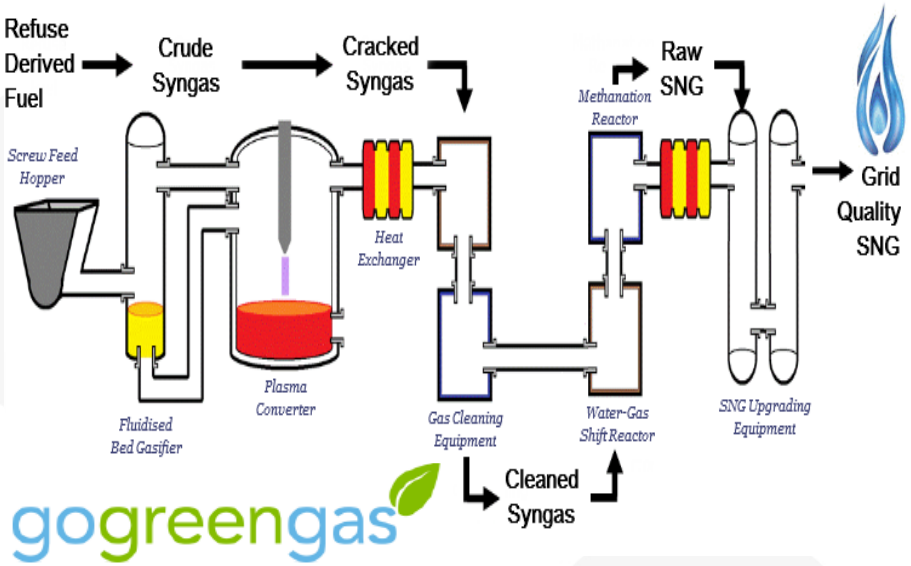
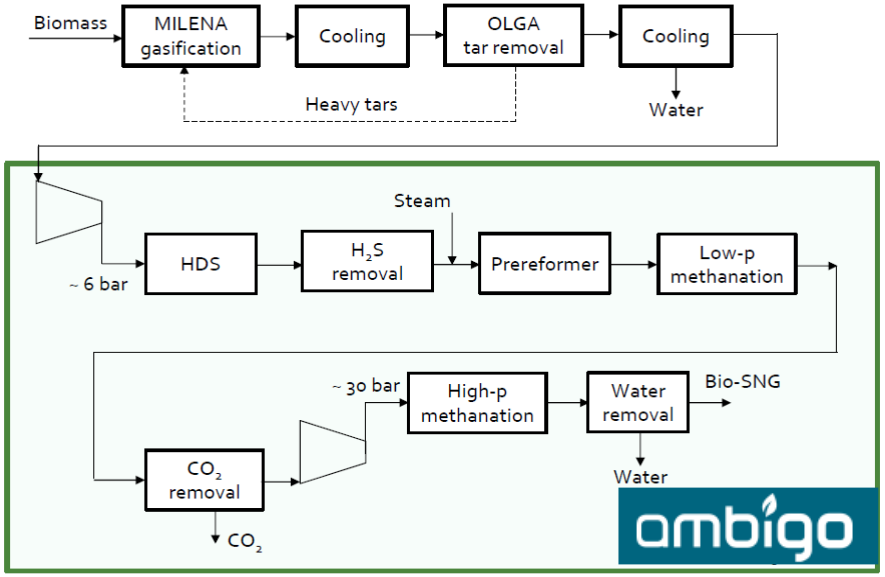
Short-term op. or planned gasification to SNG plants, EU

NL



Start-up 2018 RDF feedstock
4 MW bio-methane output
Outotec gasifier, APP plasma
AMEC FW VESTA SNG
27 M£ cost, 11+5 M£ support
Cadent (8.7 M£), APP, Carbotech, Progressive Energy, AMEC FW.

UK



Biomass feedstock
4 MW bio-methane output
ECN Milena gasifier, OLGA, ESME SNG
25 M€, cost, 6.5 M€ support
Engie, Gasunie, ECN, Royal Dahlman, Synnova , PDENH.

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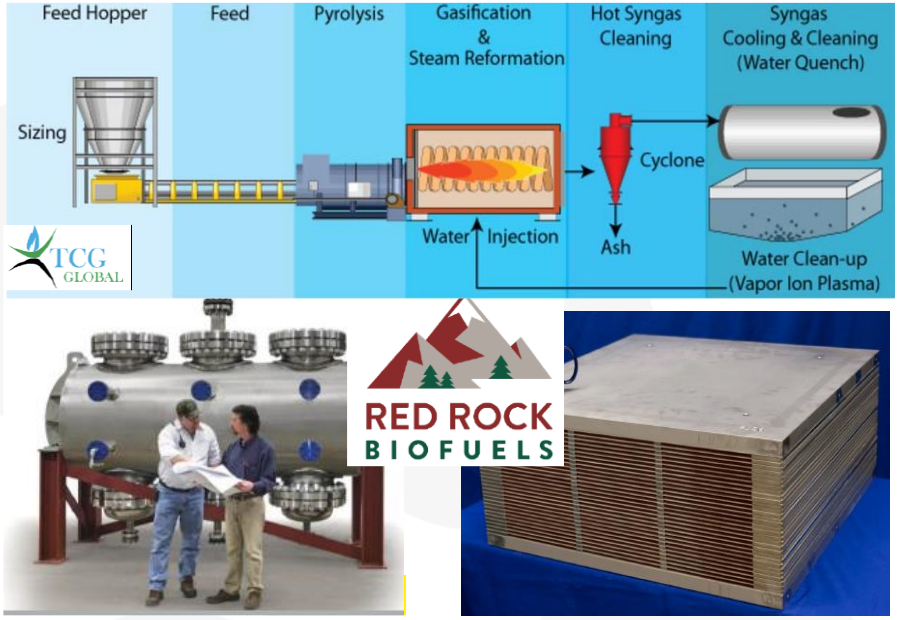
Short-term op. or planned gasification to biofuel plants, USA



150 000 tonnes/year biomass in
57 000 m^3/year of BTL products
TC Global gasifier
Velocys microchannel FT
~ 200 M$, 74 M$ DPA funding (DoD)

160 000 tones/year MSW (before MTP)
40 000 m^3/year of BTL products
Thermochem Recovery Int. gasifier
Emerging Fuels Technology FT
~ 280 M$, 70 M$ DPA funding (DoD),
Air BP and UA invested 30 M$ each.

Pyrolysis, catalytic pyrolysis and hydropyrolysis to bio-oils

Company	Site	Feed	Year	Cap. ML/yr	Type	Status
Empyro (BTG)	NL	Wood resid.	2015	20	1st ind.	Op.
Ensyn	CA	Wood resid.	2006, 15	20	Com.	Op.
Fortum	FI	Wood resid.	2014	50	1st ind.	Op.
KIT	DE	Ag. residue	2010	2	Demo	
Metsä	SE	Wood resid.	2022	22	Com.	Plan
Catalytic pyrolysis						
Anellotech	USA	Wood resid.	2018	n.a.	Pilot	Op.
Fraunhofer Inst.	DE, UK	Various	2015	7 tpd feed	Pilot	Op.
Hydropyrolysis						
IH2	INDIA	Wood resid	2017	5 tpd feed	Demo	Com.
G4 Insights	USA	Wood resid	2017	0.1 tpd feed	Pilot	Op.

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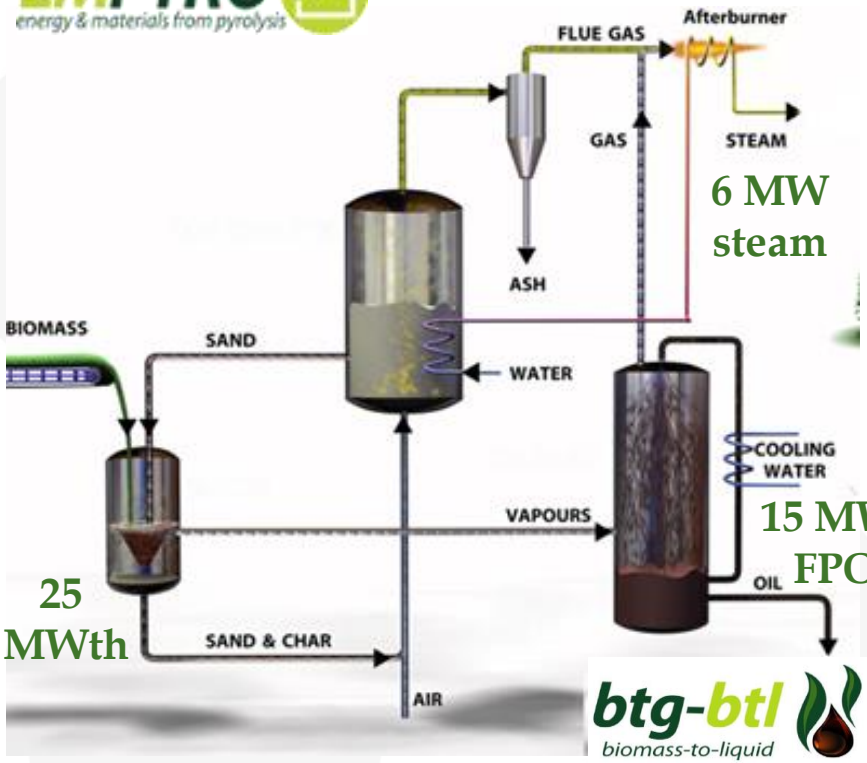
Ensyn	CA	Wood resid.	2006, 15	20	Com.	Op.
Fortum	FI	Wood resid.	2014	50	1st ind.	Op.
KIT	DE	Ag. residue	2010	2	Demo	
Metsä	SE	Wood resid.	2022	22	Com.	Plan
Catalytic pyrolysis						
Anellotech	USA	Wood resid.	2018	n.a.	Pilot	Op.
Fraunhofer Inst.	DE, UK	Various	2015	7 tpd feed	Pilot	Op.
Hydropyrolysis						
IH2	INDIA	Wood resid	2017	5 tpd feed	Demo	Com.
G4 Insights	USA	Wood resid	2017	0.1 tpd feed	Pilot	Op.

Fast pyrolysis (~1-2 s, 450–550°C), op. plants, in EU

NL

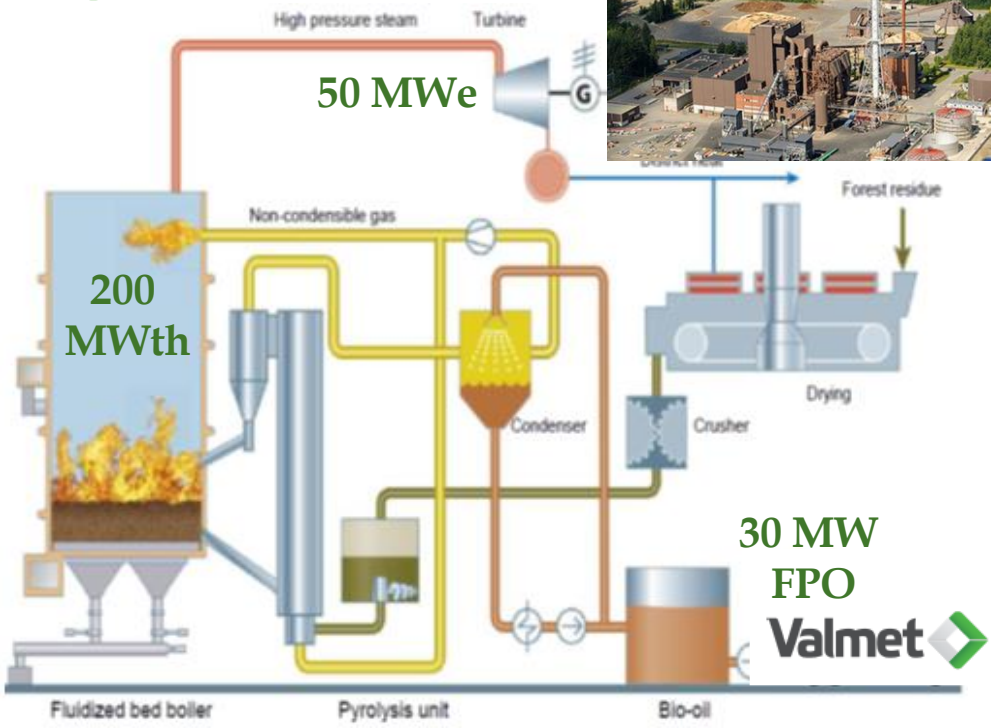
EMPYRO
energy & materials from pyrolysis



120 tonnes/d woody biomass
20 000 m^3/y FPO +steam+0.5 MWe
U. Twente/BTG rotating cone proc.
19 M€, support from FP7

FI

fortum



100 000 tonnes/y woody biomass
50 000 m^3/y of FPO products
VTT/Valmet CFB process. 200 MWth
~ 32 M€ (excl. boiler plant), 8 M€ support

Pyrolysis, catalytic pyrolysis and hydropyrolysis to bio-oils

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Empyro (BTG)	NL	Wood resid.	2015	20	1st ind.	Op.
Ensyn	CA	Wood resid.	2006, 15	20	Com.	Op.
Fortum	FI	Wood resid.	2014	50	1st ind.	Op.
KIT	DE	Ag. residue	2010	2	Demo	
Metsä	SE	Wood resid.	2022	22	Com.	Plan
Catalytic pyrolysis						
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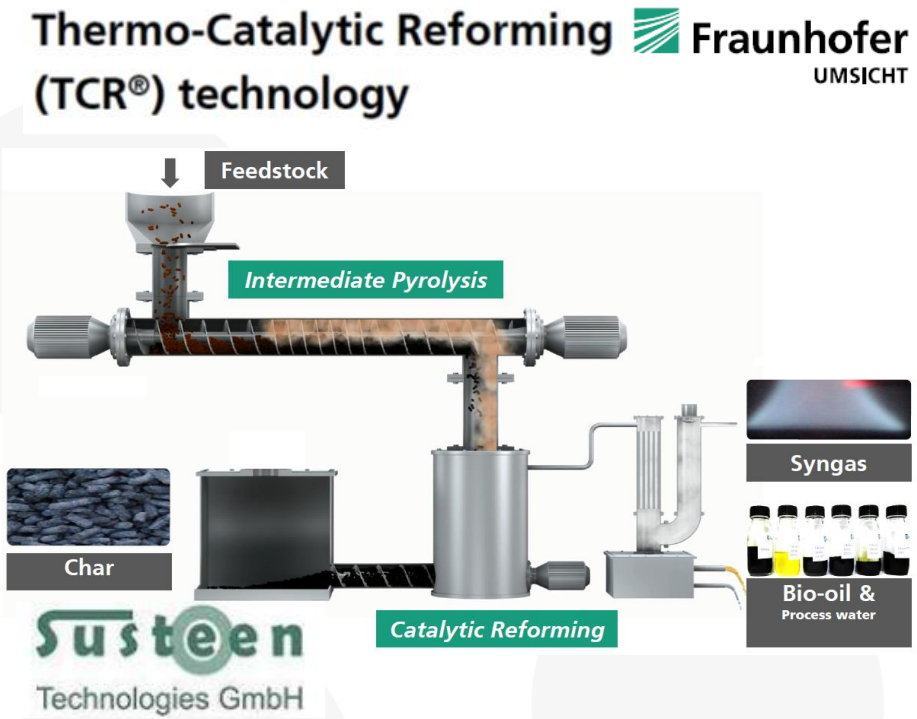
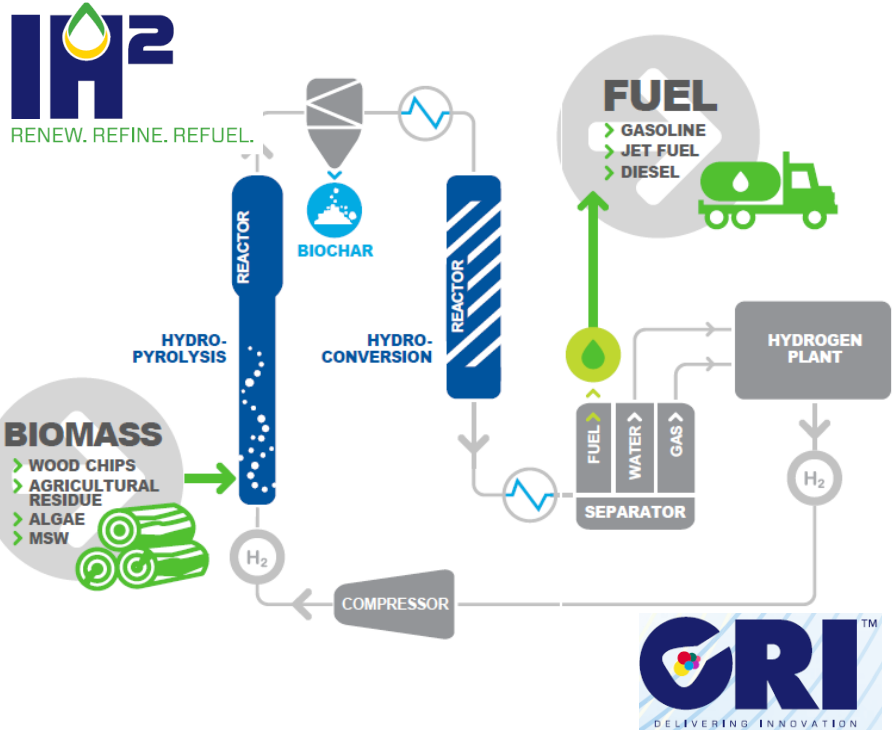
Catalytic pyrolysis and hydropyrolysis installations

DE

INDIA



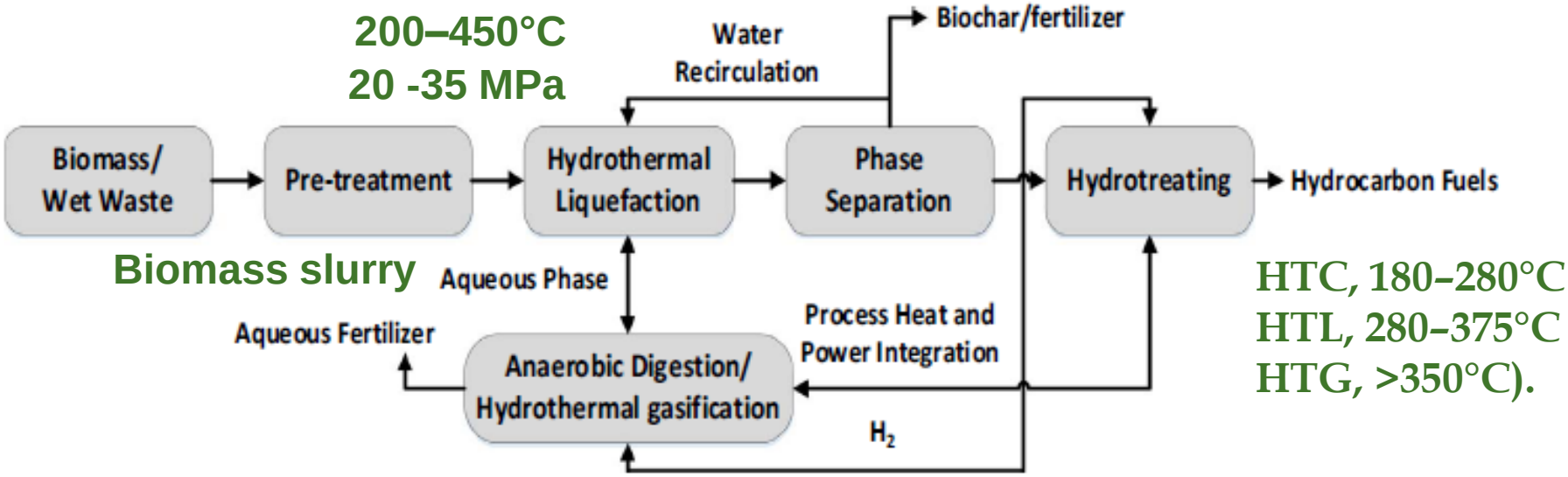


Slow pyrolysis, 4-10 min, at ~ 450°C, catalytic (char) reforming at ~ 750°C
80 kg/h pilot op., 300 kg/h commis.
H2020 projects 2 SynFuels and FlexJet to establish 500 kg/hr units.

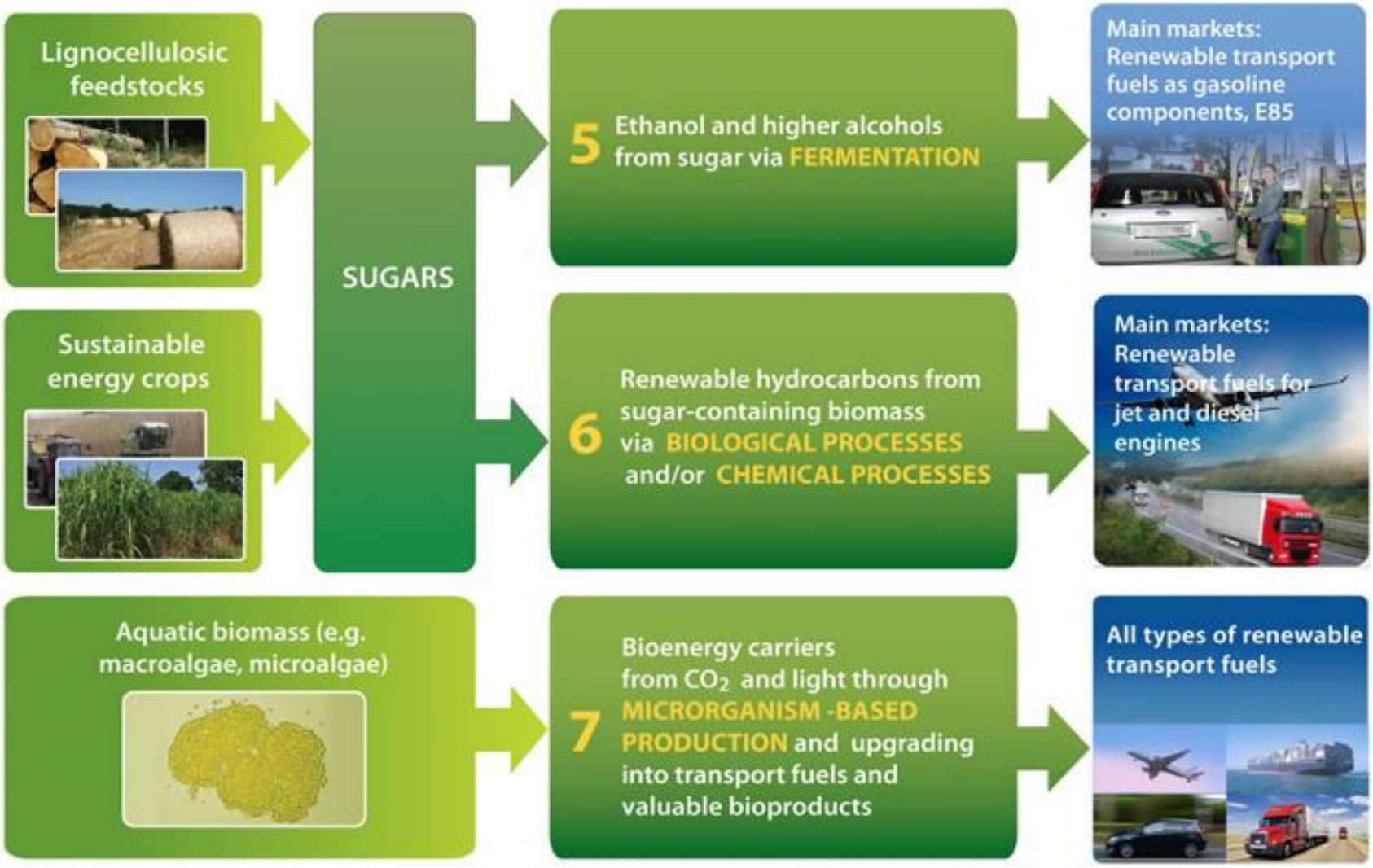
Catalytic hydropyrolysis in hydrogen at 400–550°C, 2-3 MPa pressure.
Demo in India 5 tonnes/d feed 2017
Developed by GTI and licensed to CRI
Studies for 1st ind. plants in NO and IN

Hydrothermal processing to intermediates and gas

Company	Site	Feed	Year	Cap. ML/yr	Type	Status
Licella **(HTL)** Licella/Canfor	AU CA	Various Wood & pulp res.	2012	? ?	Demo 1st ind.	Com. Plan.
Silva Green Fuels Steeper AAU **(HTL)**	NO DK/CA	Wood residues	2019	1.4	Demo	Plan.
SCW systems **(HTG)**	NL	Wet biomass	2017	2 MW 20 MW	Demo 1st ind.	Op. Plan.



Biochemical & chemical conversion value chains



Lignocellulosic ethanol facilities

Company	Site	Feed	Year	ML/yr	Type	Status
Abengoa	ES	Ag. res. MSW	2008	5	Demo	Idle
Beta Renewables	IT	Ag. resid.	2013	76	1st ind.	Idle
Energochemic	SL	Ag. resid.	2017	70	Comm	Constr.
CIMV	FR	Ag. resid.	2017	0.9	Demo	Op.
Clariant	DE	Ag. resid.	2012	1.2	Demo	Op.
DuPont (largest one)	USA	Ag. resid.	2016	114	1st ind.	Idle
Granbio	BR	Bagasse	2014	82	1st ind.	Com.
Futurol	FR	Ag. resid.	2011	0.18	Demo	Op.
Inbicon (Kalundborg)	DK	Straw	2009	6	Demo	Idle
POET/DSM	USA	Ag. resid.	2014	76	1st ind.	Com.
Raizen	BR	Bagasse	2015	40	1st ind.	Com.
Borregaard	NO	Woody bm	2013	0.14	Demo	Op.
RISE (ex-SEKAB)	SE	Woody bm	2004	0.15	Pilot	Op.
ST1	FI	Woody bm	2017	10	Demo	Com.
Synata (ex-Abengoa)	USA	Ag. Resid.	2016	95	1st Ind.	Idle

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BetaRenewables, Crescentino, Italy

First Commercial Cellulosic ethanol industrial scale plant in the world – start up 2013

270,000 ton/yr straw; 60 000 ton/year of ethanol , 13MWe generated from lignin. Production process: uncatalysed steam explosion (Proesa®), EH + Co-Fermentation C5+C6 sugars

BetaRenewables, Crescentino, Italy

MILANO FINANZA 17/10/2017

Mossi Ghisolfi va al concordato

Collateral damage since 2017

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270,000 ton/yr straw, 60,000 ton/year of ethanol , 13MWe generated from lignin. Production process: uncatalysed steam explosion (Proesa ®), EH + Co-Fermentation C5+C6 sugars

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Poet/DSM (Project Liberty)

Local: Emmetsburg, Iowa, USA

Start-up: 2014

Raw material: corn stover (285,000 ton/year); 45-miles radius.

Product: Ethanol (60,000 ton/year) + biogas + CHP (from lignin)

Production process: Two-stage diluted acid pretreatment; C5+C6 fermentation; Co-location with an existing dry mil corn plant

1st Commercial

Raízen (Brazil)

Local: Piracicaba - SP, Brazil

Start-up: 2015

Raw material: sugar cane bagasse and straw.

Product: Ethanol (32,000 ton/year) + electricity. Co-location with an existing 1G bioethanol plant from sugar cane.

Production process: Iogen´s technology – acid-catalysed steam explosion, EH and Fermentation

In operation

Commercial

LNEG

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Synata (ex-Abengoa)	USA	Ag. Resid.	2016	95	1st Ind.	Idle

Clariant (ex- Sud-Chemie)

Local : Straubing (Germany)

Start-up: 2012

Raw material: cereal straw, agricultural waste

Product: Ethanol (1.000 ton/year)

Production process: steam explosion pre-treatment, enzymatic hydrolysis and co-fermentation of C_5 and C_6

Demo

Inbicon/Dong Energy

Local: Kalundborg (Denmark) – Demo plant

Start-up: 2009

Raw material: 30.000 ton/year wheat straw

Product: Ethanol (4.300 ton/year), C_5 molasses, lignin for energy

Production process: Hydrothermal pre-treatment, enzymes from Novozymes, enzymatic hydrolysis and co-fermentation of C_6 (phase 1); C5+C6 co-fermentation (phase 2). Stand-alone plant.

Stop in 2016

Demo

www.inbicon.com

Borregaard Industries AS

Local: Sarpsborg (Norway)

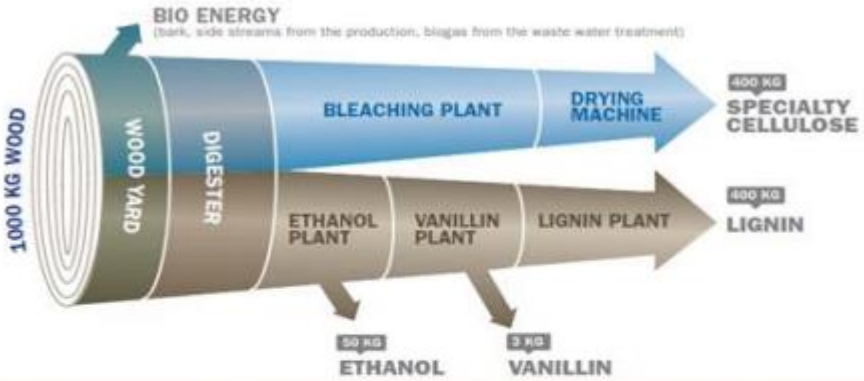
BALI™ technology

Start-up: 2013

Raw material: 50 kg/h; cereal straws, sugarcane bagasse

Product: Ethanol (110 ton ethanol/year or 22º ton sugars C_5/C_6/year; 200 ton/year specialized products of lignin)

Production process: (BALI Technology); Biorefinery concept (chemical pretreatment, HE, Fermentation)



Cellulose	Lignin	Vanillin	Ethanol
Construction materials	Concrete additives	Food	Car care
Cosmetics	Animal feed	Perfumes	Paint/ varnish
Food	Dyestuff	Pharmaceuticals	Pharmaceutical industry
Tablets	Batteries		Bio Fuel
Textiles	Briquetting		
Filters	Mining		
Paint/ varnish			

www.borregard.com

Demo

Short term: Developments on lignocellulosic ethanol

CLARIANT

Announced plans for plants in SL, RO.

Inbicon

April 2017

LoI with Pioneer Point Partners for an investment up to 160 M€ in the MEC plant conditional on political framework and long-term government support is settled .

Capacity 10 million liters ethanol from saw mill dust (pine)

Commissioning 2017

Cellunolix® Kajaani, Finland

PRAJ: Capacity 1 million liters ethanol from ag. residu

End-to-end integrated demonstration plant

Commissioning 2017 –

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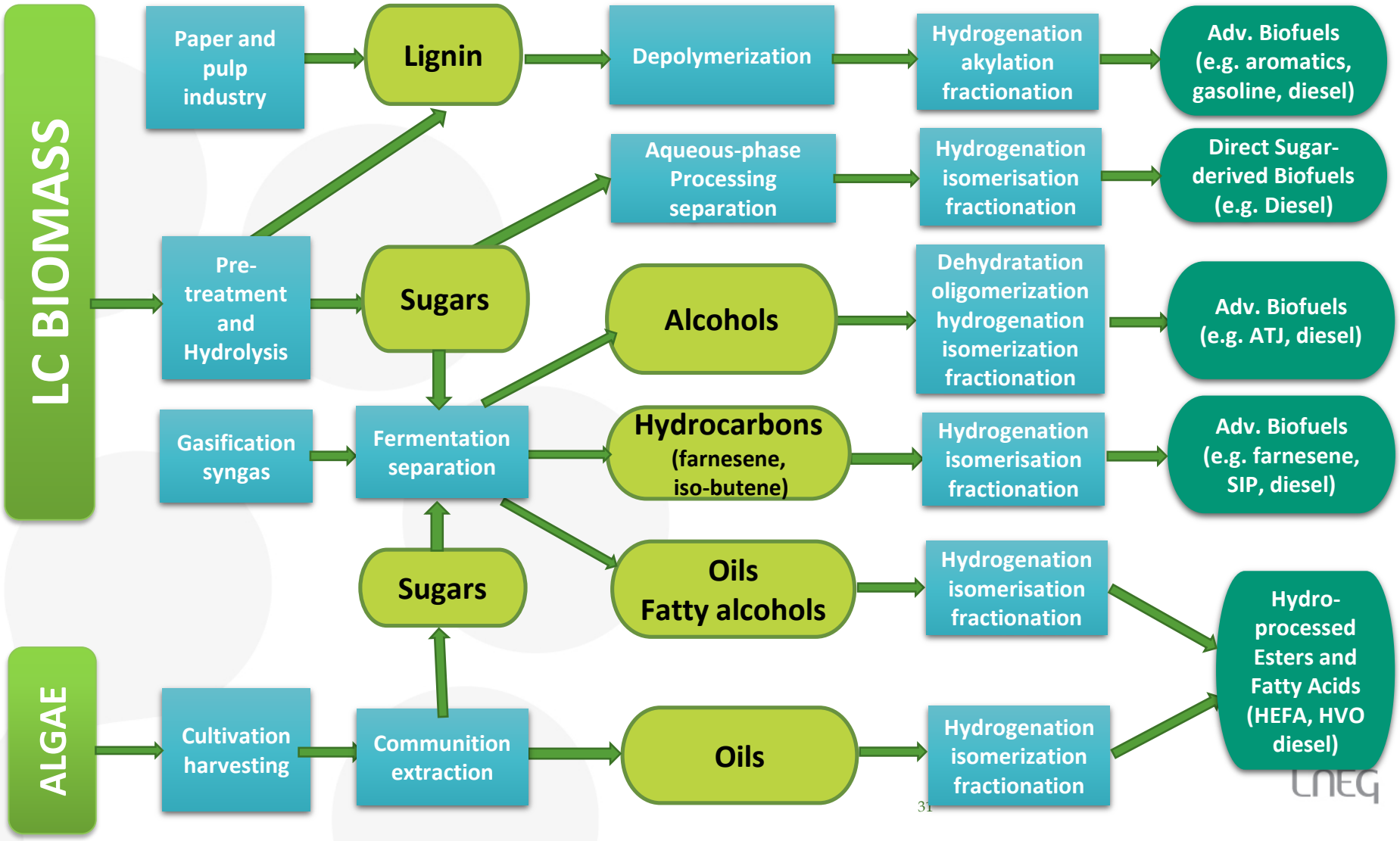
Intermediates to hydrocarbons



Sugars and syngas to higher alcohols and hydrocarbons

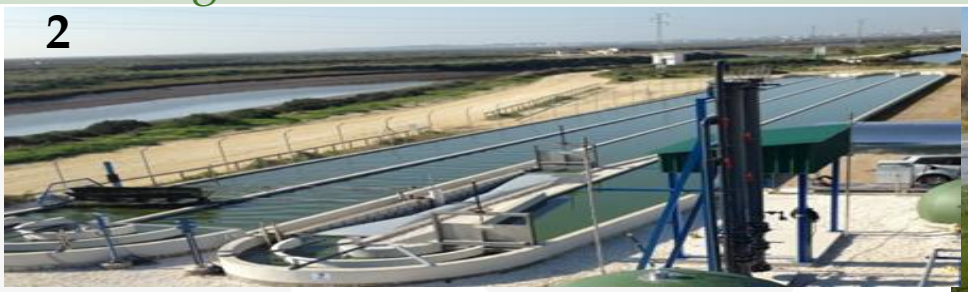
Company	Site	Products	Year	Cap. ML/yr	Type	Status
Amyris	2*NZ KO, AU	Various non-fuel		50 70	Comm. Comm.	Plan Plan.
DSM (ex-Amyris)	BR	Farnesene	2012	40	1st ind.	Op.?
BUTAMAX	UK USA	Iso-butanol	2012	0.2	Demo 1st ind.	Com. Plan.
GEVO	USA	Iso-butanol	2014	6	1st ind.	Com.
Global Bioenergies	FR	Iso-butene	2017	100 tpa	Demo	Op.
REGI (LS9)	USA	Fatty alchols	2012	0.13	Demo	Op.
VIRENT	USA	Various fuel/ non-fuel	2009 2013	~ 0.04 ~ 0.02	Demo Demo	Op. Op.
Syngas (CO+H2) to alcohol						
Lanzatech	USA	Ethanol Fatty alcohols	2018	60	Demo Dev.	Constr.

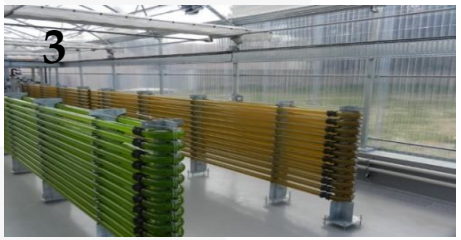
Alcohols to hydrocarbons

Company	Site	Feed	Year	Cap. ML/yr	Type	Status
Main product diesel and jet						
Gevo	USA	Iso-butanol	2011	0.5	Demo	Op.
Byogy	USA	Ethanol	2017		Demo	Op.
Sw. Biofuels	SE	Alcohols	2012	0.01	Pilot	Op.
Lanzatech	NZ(USA)	Ethanol	2015		Pilot	Op.
Main product gasoline						
Enerkem	CA	Methanol	2018		Pilot	Op.
Mobil MTG	USA	Methanol	1985	850	Com.	†1995
KIT	DE	Methanol	2014	0.7	Pilot	Op.
Lurgi MTS	DE	Methanol	2008		Pilot	2011
Topsöe TIGAS	DK	Methanol	2014	90	Com.	2018
Vertimass	USA	Ethanol				

Microalgae – Demo Plants

	Company		Year	Type	Cap. kton dw/y	Product	Future
1	InteSusAl	PT	2015	Microalgae	0.04	Biodiesel	Non-fuel
2	All-Gas	ES	2014	Microalgae	0.014	Biogas	Fuels
3	Algafuel	PT	2014	GE µ-algae	0.001	Ethanol	HTL-oil, non-fuel
4	Algae Tech	AU	2018	Microalgae	Pilot (IN)	Biofuel	
Many e.g. Algenol, Biofat, BuggyPower, Sapphire, Joule, Solazyme, Helliae, Allmicroalgae have shifted from biofuel to non-fuel products in 2014-2017							

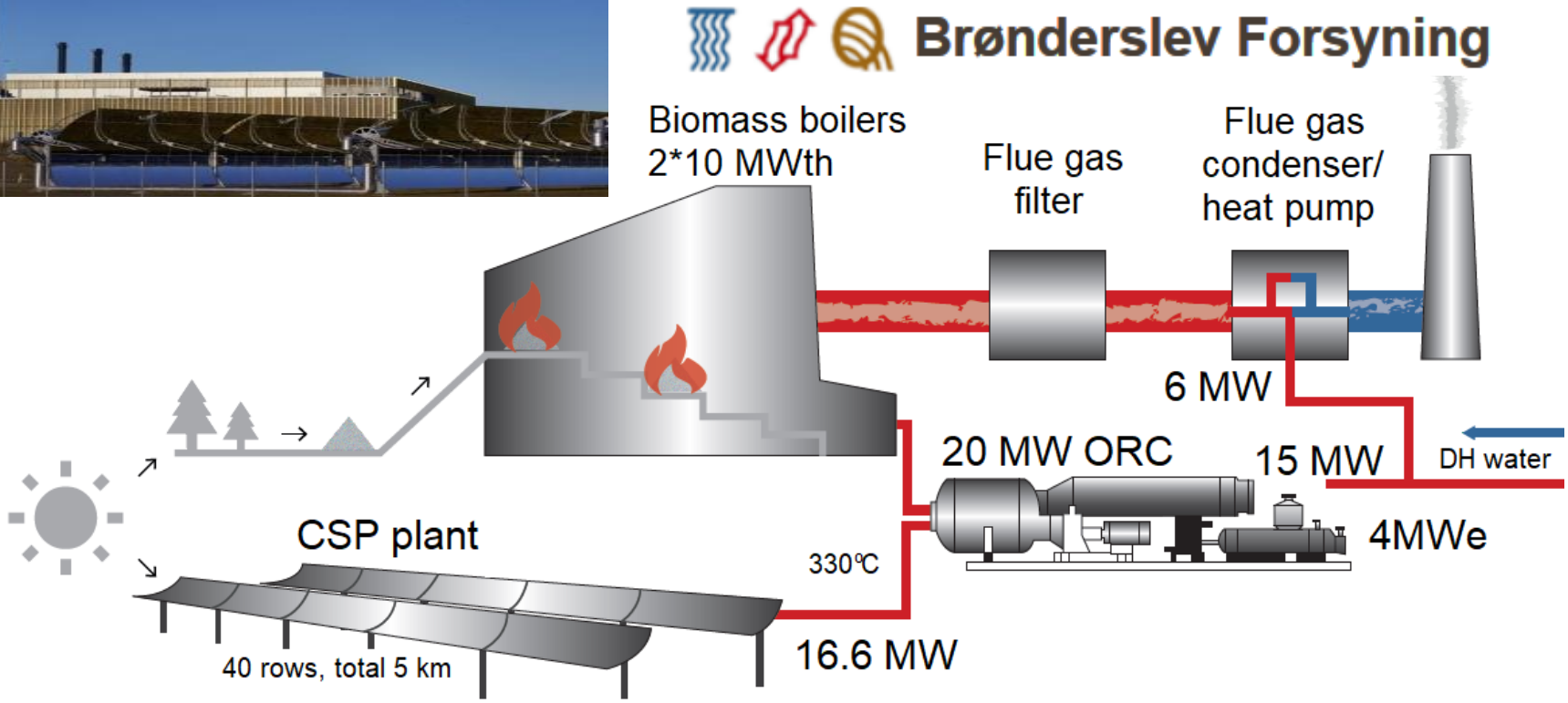




LNEG

Hybrids: Power & heat integration with other RES

Brønderslev DK: First hybrid CSP/biomass ORC CHP Plant



Technology provider: Aalborg CSP A/S. Total cost 35 M€, 2 M€ in support

Power-to-X; some examples

MANY MORE EXAMPLES EXIST

HYDROGEN

ITM POWER
Energy Storage | Clean Fuel

0.2-10 MWE

BUTANOL

EVONIK INDUSTRIES

RHETICUS R&D PROJECT

2018-2020

METHANOL

CARBON RECYCLING INTERNATIONAL

4 000 TPA PLANT

AMMONIA

VATTENFALL

FEASIBILITY STUDY

FT DIESEL

sunfire

150 KWE/ 130 LITER/DAY

METHANE

Audi

*3*2 MWE*

FORMIC ACID

TEAM FAST

R&D PROJECT TU/e

GASOLINE

GLOBAL BIOENERGIES

PILOT 100 TPA ISOBUTENE

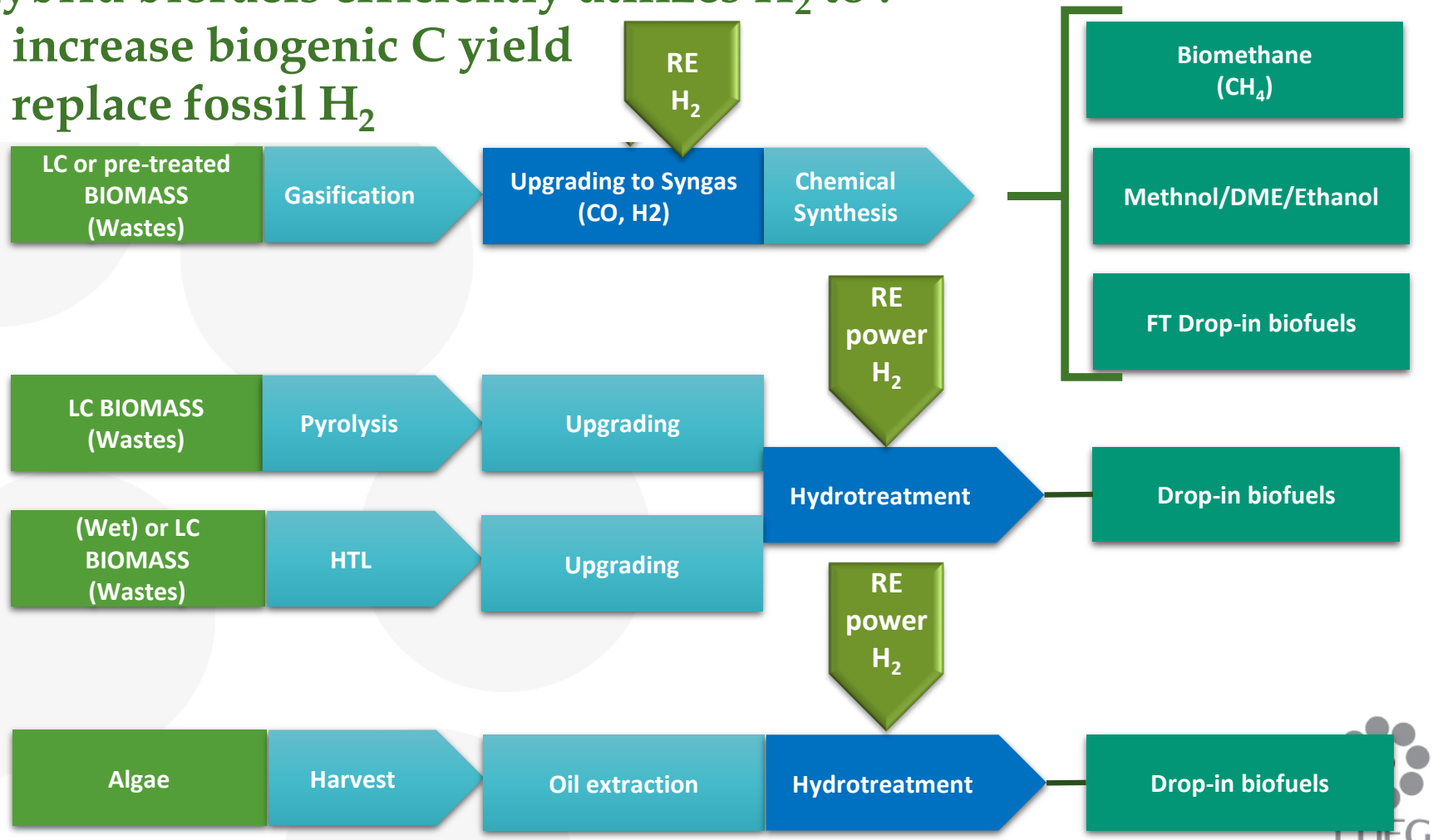
*2*ISOBUTENE +H2=ISOOCTANE*

LNEG

Power-to-biofuels

Hybrid biofuels efficiently utilizes H_2 to :

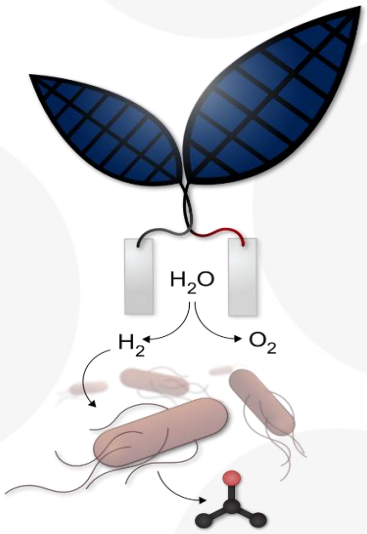
- ✓ increase biogenic C yield
- ✓ replace fossil H_2



Examples of novel ideas in early stage development

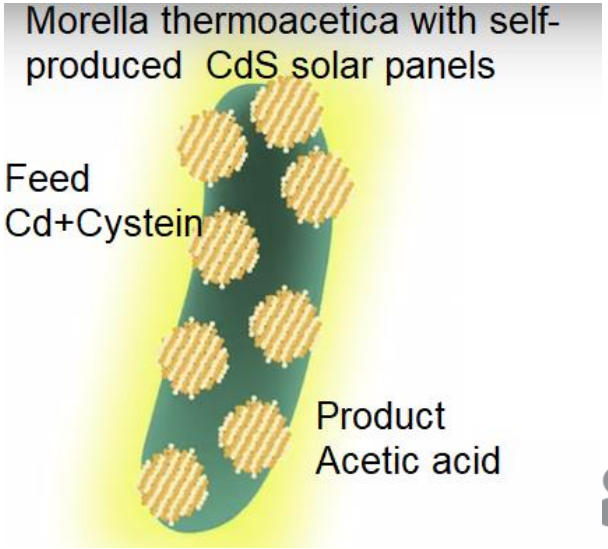
Bionic leafs which uses solar light to split water into hydrogen and oxygen, combined with another microorganism consumes hydrogen and carbon dioxide to produce hydrocarbons, e.g. iso-propanol

Source The Conversation 2015-02-12

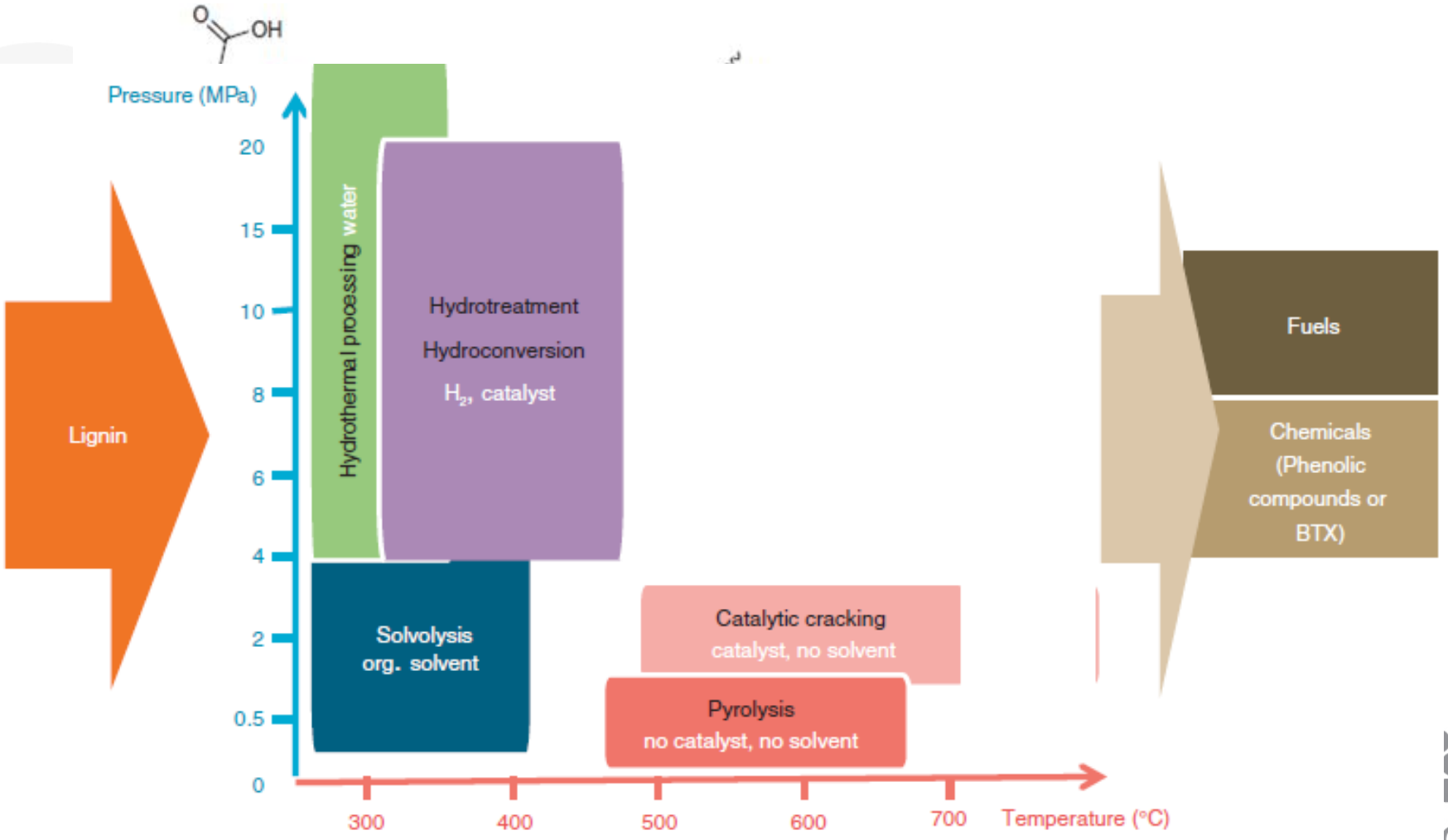


Bio-solar cell factories (BSCF), in which phototrophic micro-organisms (e.g. cyanobacteria, eukaryotic algae) directly catalyze the conversion of CO_2 and H_2O into oxygen and chemical energy, e.g. fuel molecules.

Source CleanTecnica 2017-08-22



Lignin depolymerization



Lignin extraction and upgrading

Company		Feed	Process	BL lignin Prod	Status
Valmet	FI	Black liquor	Precipitation	Lignoboost	Industrial
Suncarbon	SE	Black liquor	Membrane filtr.	Lignin concent.	Pilot
Company		**Feed**	**Process**	**Upgrading**	**Status**
Beta Renew.	IT	Hydrolysis	Hydrogenolysis	Hydrogenation	Pilot
RenFuel,	SE	BL lignin	Thermal	Esterification. Refinery.	Pilot
SCA	SE	Black liquor	n.a.	n.a.	Pilot
Suncarbon	SE	BL lignin	HTL	Refinery	Bench
Licella	AU/CA	Black liquor	HTL	Refinery	Pilot
Lignojet	SE	BL lignin	Hydrogenolysis	Refinery	Bench
Chalmers	SE	Black liquor	Near SC	Refinery	Pilot
Other entities process lignin for non-fuel purposes (resins, phenols, plastics)					

Take-away messsages

- **Industrial implementation of advanced technologies based on Biomass requires patience.**
- **The economics of bridging the "development gap" from pilot R&D to operational 1st industrial plant is a main bottleneck for biofuels, in particular challenging for one-product start-ups.**
- **Support e.g. Investment Fund should be designed with this in mind to be effective in reaching the desired impact (nGeneration Biofuels).**
- **Also policy must be sustainable over time, not only biofuels**

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www.lneg.pt

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MANY THANKS

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