EERA
European Energy Research Alliance
BIOENERGY

Biofuel Innovation and Technology Progress

Bio4Fuels Days, Oslo, Norway

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EERA Bioenergy
SPC Thermochemical Platform

EERA Bioenergy

- European Energy Research Alliance (EERA) is the public research pillar of the Strategic Energy Technology Plan (SET-Plan)
- EERA Bioenergy – 37 EU research organisations
- Main objectives
  - Align (public) research activities and research infrastructure
  - Have an advisory role to the SET-Plan and to the industrial sector about biomass and bioenergy research priorities for the middle to long term
  - Boost collaborative research
  - Promote infrastructures sharing and scientist mobility

Outline

Focus on Advanced biofuels

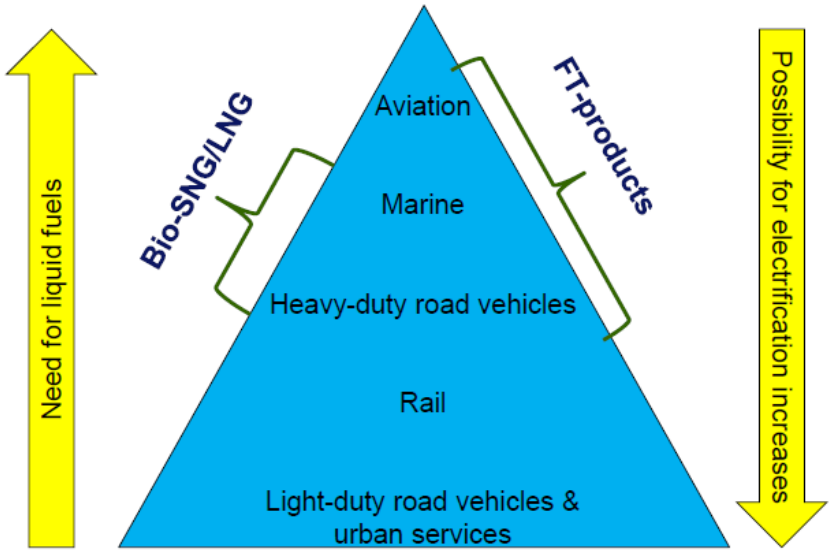
- Changing role of biomass
- EU policy on bioenergy/biofuels (R&D)
- Thermochemical & chemical conversion biofuels value chains
- Biochemical & chemical conversion biofuels value chains
- Main R&D challenges (focus on gasification-based biofuels production)
- Time is of the essence!

Presentation partly based on: Lars Waldheim & Francisco Girio, Bioenergy and biofuels conversion technology developments, ETIP Bioenergy 2018

Changing role biomass towards 2050

Use biomass predominantly in sectors, that cannot be covered (entirely) by other sustainable sources

- High value feedstock for the biobased economy
  - Production of chemicals and materials
  - Connect agro and chemistry sectors
- Sustainable fuel
  - Aviation
  - Shipping
  - Heavy duty road transport
  - High-temperature heat
  - Residential heating (e.g. gas in old cities)
  - Back-up power supply and to cover intermittency problems
  - In combination with CCS enable negative GHG emissions (CO_2 sink)



Source: Nils-Olof Nylund, IMECHE Future Fuels, 2016

EU policy on bioenergy/biofuels (R&D)

- Renewable Energy Directive II (RED II)
  - Target for renewable transport fuels (14% in 2030, of which 3.5% advanced biofuels = 300-400 plants)
- SET plan and Action 8 Implementation Plan
  - 2030 targets on cost reduction, efficiency increase and GHG savings, for advanced biofuels production:
    - Net process efficiency improvement for biomass conversion to end biofuels products of at least 30%
    - At least 60% GHG savings from the use of advanced biofuels (including biomass feedstock contribution)
    - Cost reduction for advanced biofuels to <50 €/MWh in 2020 and <35 €/MWh in 2030, excluding taxes and feedstock cost

32 % overall RES target by 2030

14 % RES in transport by 2030

7% cap of first generation biofuels

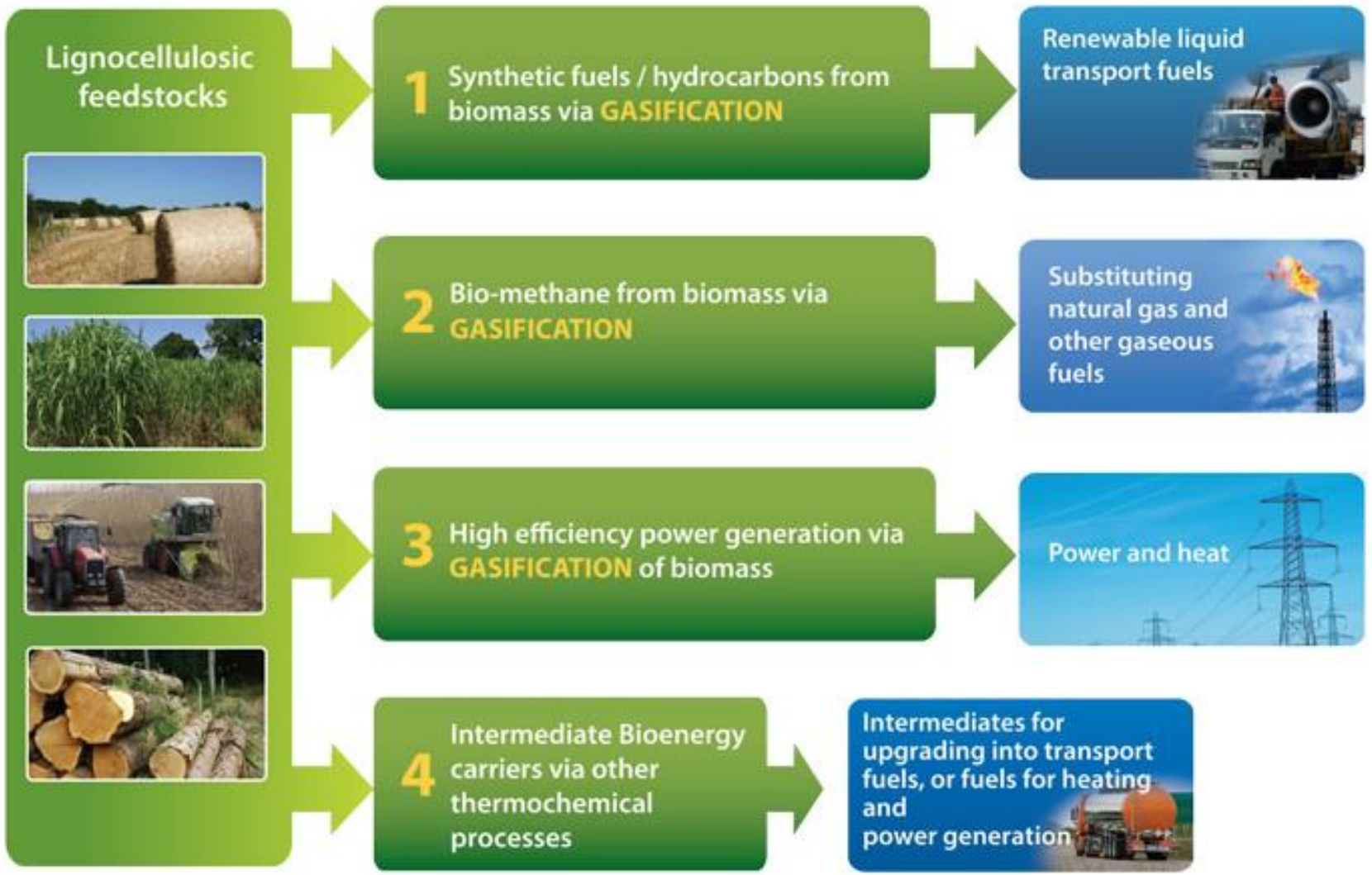
1.3 pp annual increase for RES in heating and cooling

3.5 % advanced biofuels by 2030

SET Plan Implementation Plan

Action 8: Bioenergy and Renewable Fuels for Sustainable Transport

Thermochemical & chemical conversion value chains



Thermal biomass gasification – state of the art

- Biomass gasification commercially available (100 kWth up to 100 - 300 MWth scale)
- Market implementation limited mainly to relatively simple power and heat applications
- Biomass-gasification-based production of transportation fuels or chemicals has not yet had commercial breakthrough
- This is due to both technical challenges and non-technical issues:
  - Syngas cleaning/upgrading/synthesis processes are complex and require rather large scale in order to achieve positive economics
  - Technical uncertainties and availability risks
  - Difficulties in financing the first-of-a-kind industrial plants
  - Binding targets for renewable fuels missing
- Many possibilities for improvement in terms of overall biomass conversion efficiency, complexity, availability, reliability, CAPEX and OPEX

Thermal gasification to biofuels

Developer/project		Feed	Year	Cap. MWth	Type	Status
Ambigo	NL	LC biomass		4 SNG	Demo	Plan.
Bioliq (KIT)	DE	PO+char	2013	5 feed	Demo	Op.
BioTFueL	DE/FR	Torr. agri 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.	Idle
GoGreenGas	UK	RDF	2018	4 SNG	Demo	Constr.
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

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Operating gasification to biofuel plants

30 MWth biomass input
20 MW bio-methane, 5 MW heat output
TUW/Repotec/Valmet, Haldor Topsoe SNG
Operation 2014, 2017-2018 highlights:

- MCR capacity reached
- 1800 uninterrupted hours

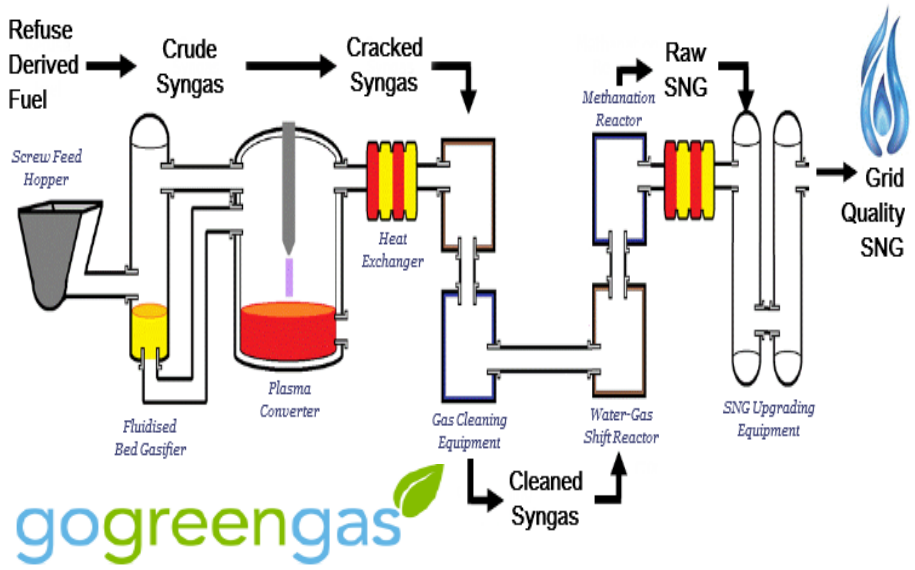
Mothballing decision taken

100 000 tons of RDF input
38 000 m^3 of methanol/ethanol
Univ. Sherbrooke/Enerkem technology
Operation 2014, 2017-2018 highlights:

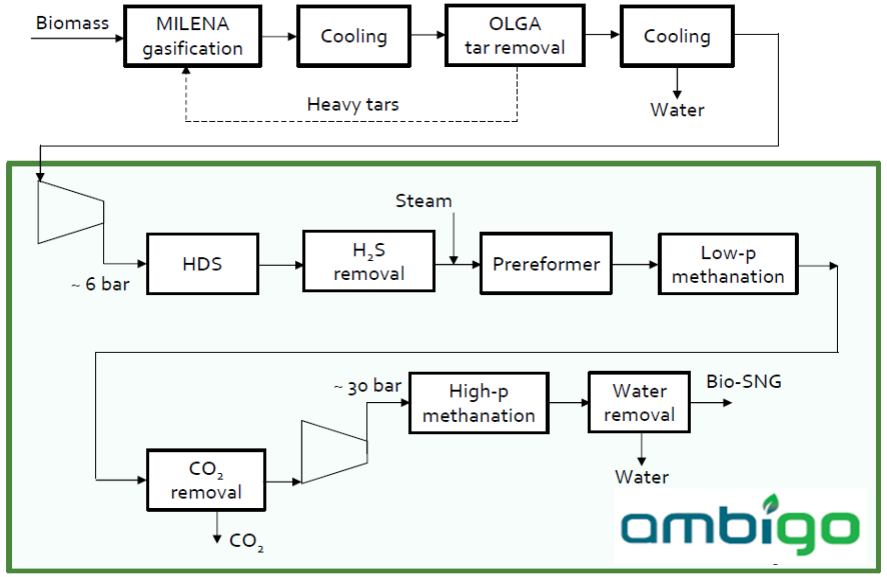
- MeOH to EtOH conv. installed
- Plans for project in Rotterdam
- ~220 M$US from investors

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Short-term operating & planned gasification to SNG plants, EU



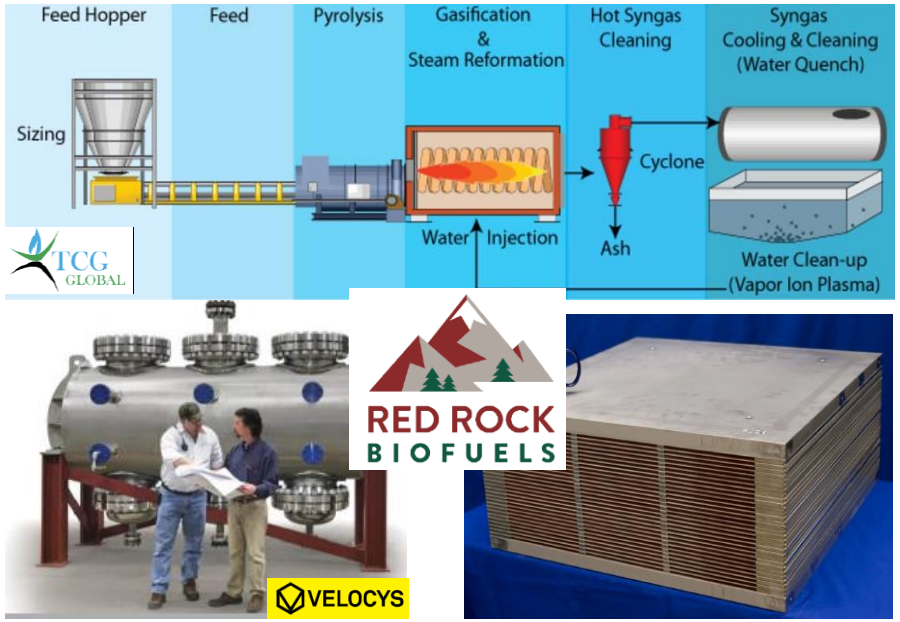
Start-up 2018 RDF feedstock
4 MW bio-methane output
Outotec gasifier, APP plasma
AMEC FW VESTA SNG
27 M£ cost, 11+5 M£ support
Cadent (8.7 M£), APP, Carbotech, Progressive Energy, AMEC FW



Biomass feedstock (demolition wood)
4 MW bio-methane output
ECN Milena gasifier, OLGA, ESME SNG
25 M€, cost, 6.5 M€ support
Engie, Gasunie, ECN p/o TNO, Dahlman Renewable Technologies, Synova, PDENH

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Short-term planned gasification to biofuel plants, USA



150 000 tonnes/year biomass input
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) input
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

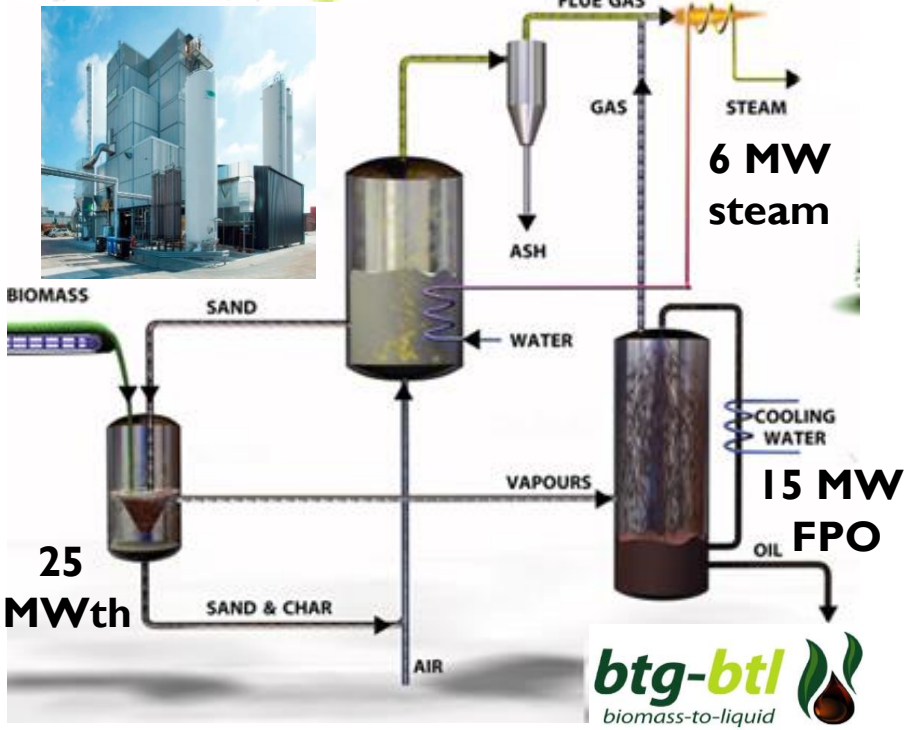
Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Pyrolysis, catalytic pyrolysis and hydropyrolysis to biooils

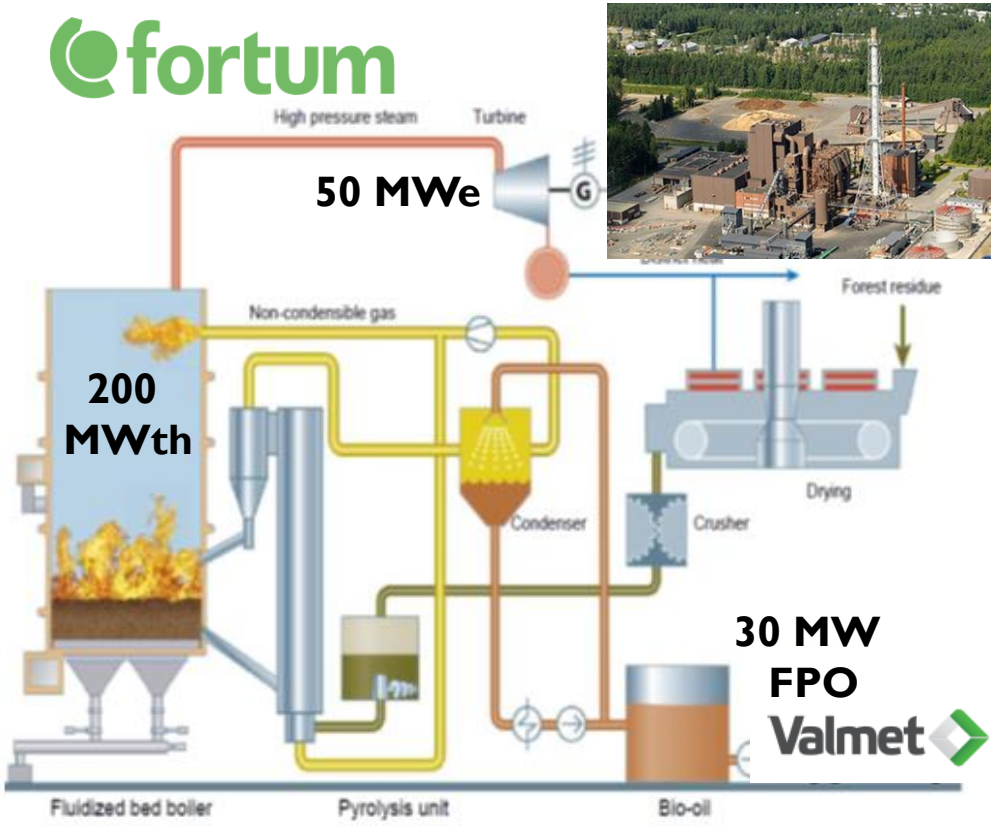
Company	Site	Feed	Year	Cap. ML/yr	Type	Status
Empyro (BTG)	NL	Wood resid.	2015	20	1st ind.	Op.
Ensyn	CA	Wood resid.	2006, 15	20	Com.	Op.
Fortum	FI	Wood resid.	2014	50	1st ind.	Op.
Bioliq (KIT)	DE	Agri resid.	2010	2	Demo	
Metsä	SE	Wood resid.	2022	22	Com.	Plan
Catalytic pyrolysis						
Anellotech	USA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

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

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



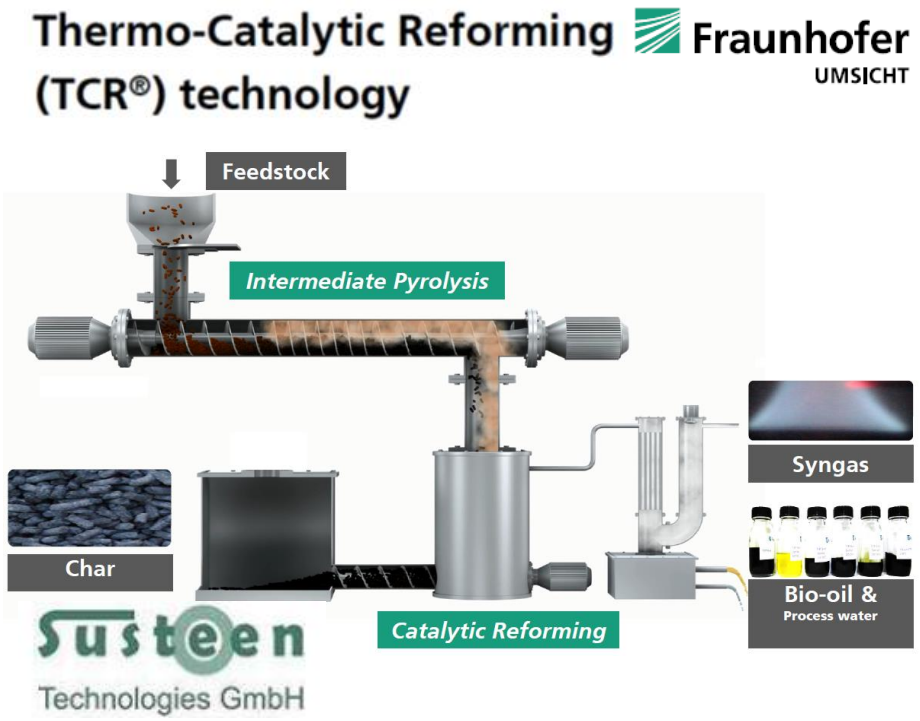
120 tonnes/d woody biomass input
20 000 m^3/y FPO +steam+0.5 MWe
Univ. Twente/BTG rotating cone process
19 M€, support from FP7

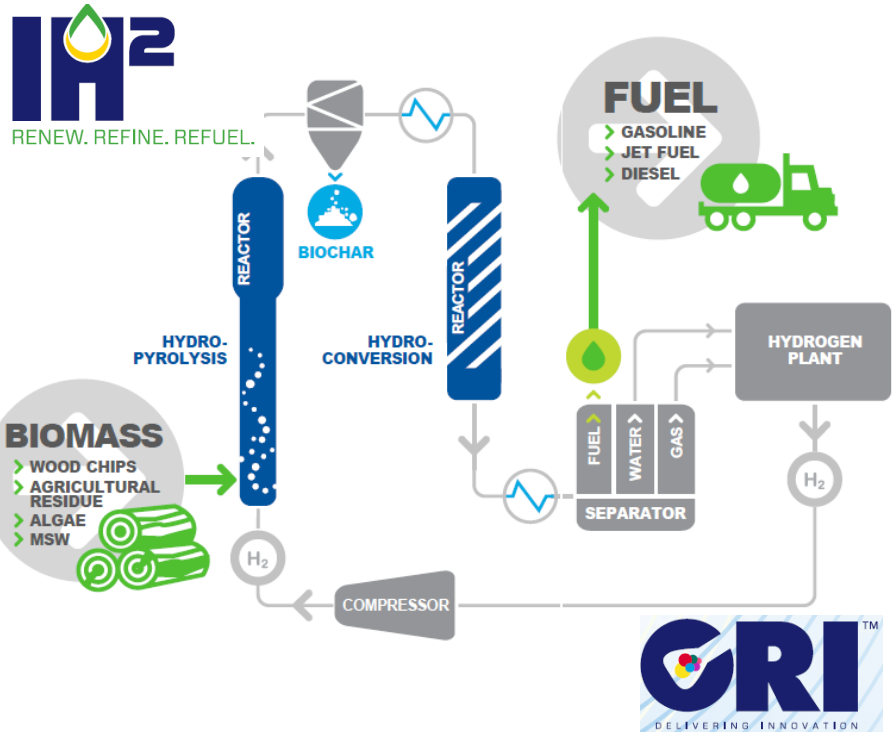


100 000 tonnes/y woody biomass input
50 000 m^3/y of FPO products
VTT/Valmet CFB process. 200 MWth
~ 32 M€ (excl. boiler plant), 8 M€ support

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Catalytic pyrolysis and hydropyrolysis installations





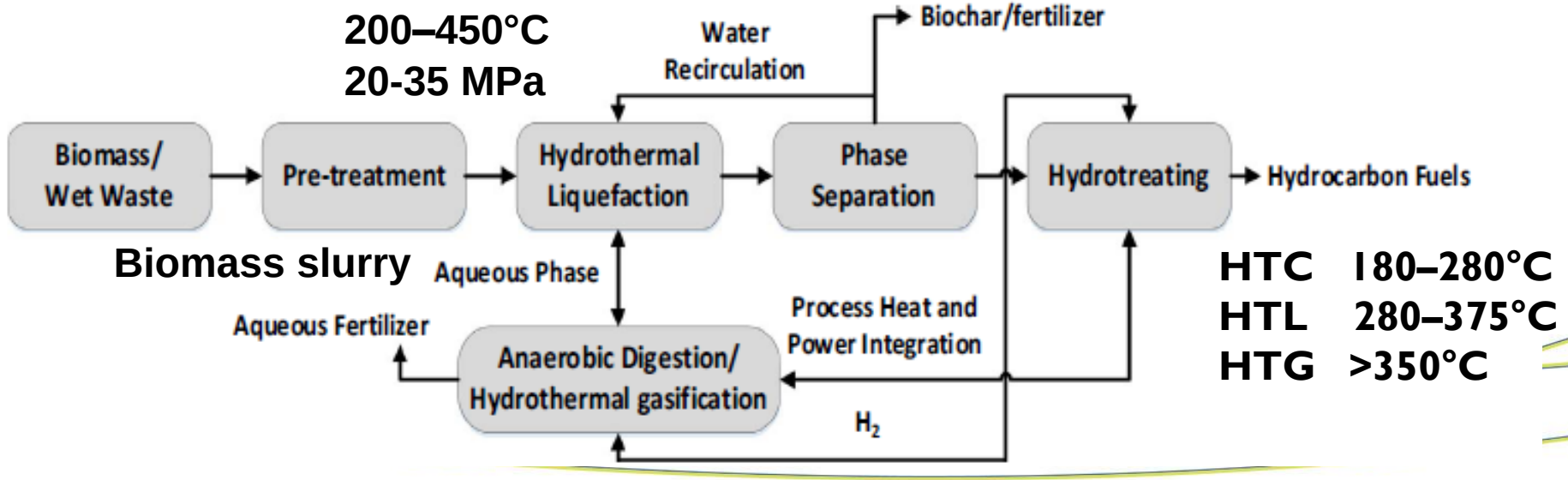
Slow pyrolysis, 4-10 min, at ~ 450°C, catalytic (char) reforming at ~ 750°C
80 kg/h pilot operating, 300 kg/h commis.
H2020 projects 2 SynFuels and FlexJet to establish 500 kg/hr units

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

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

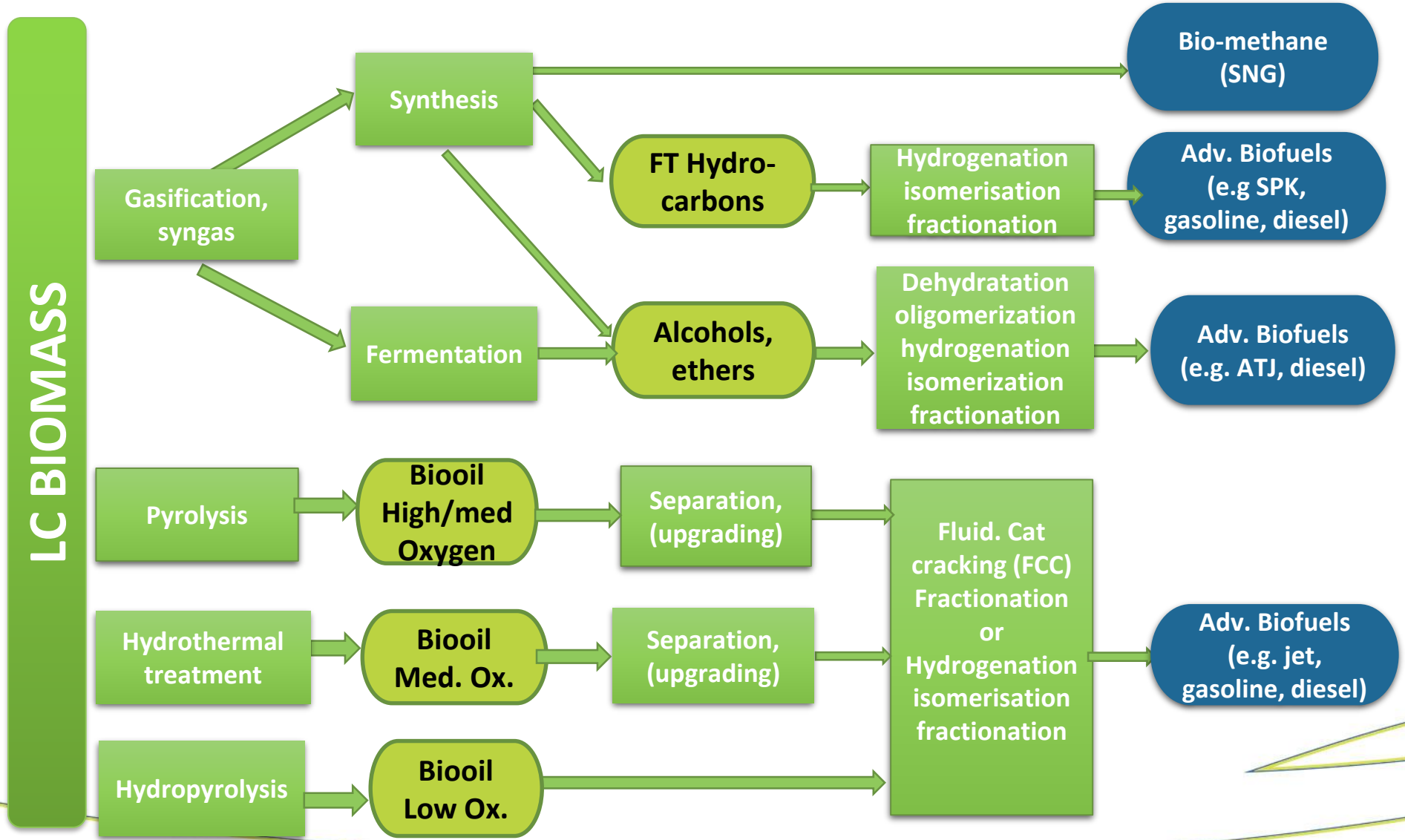
Hydrothermal processing to intermediates and gas

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



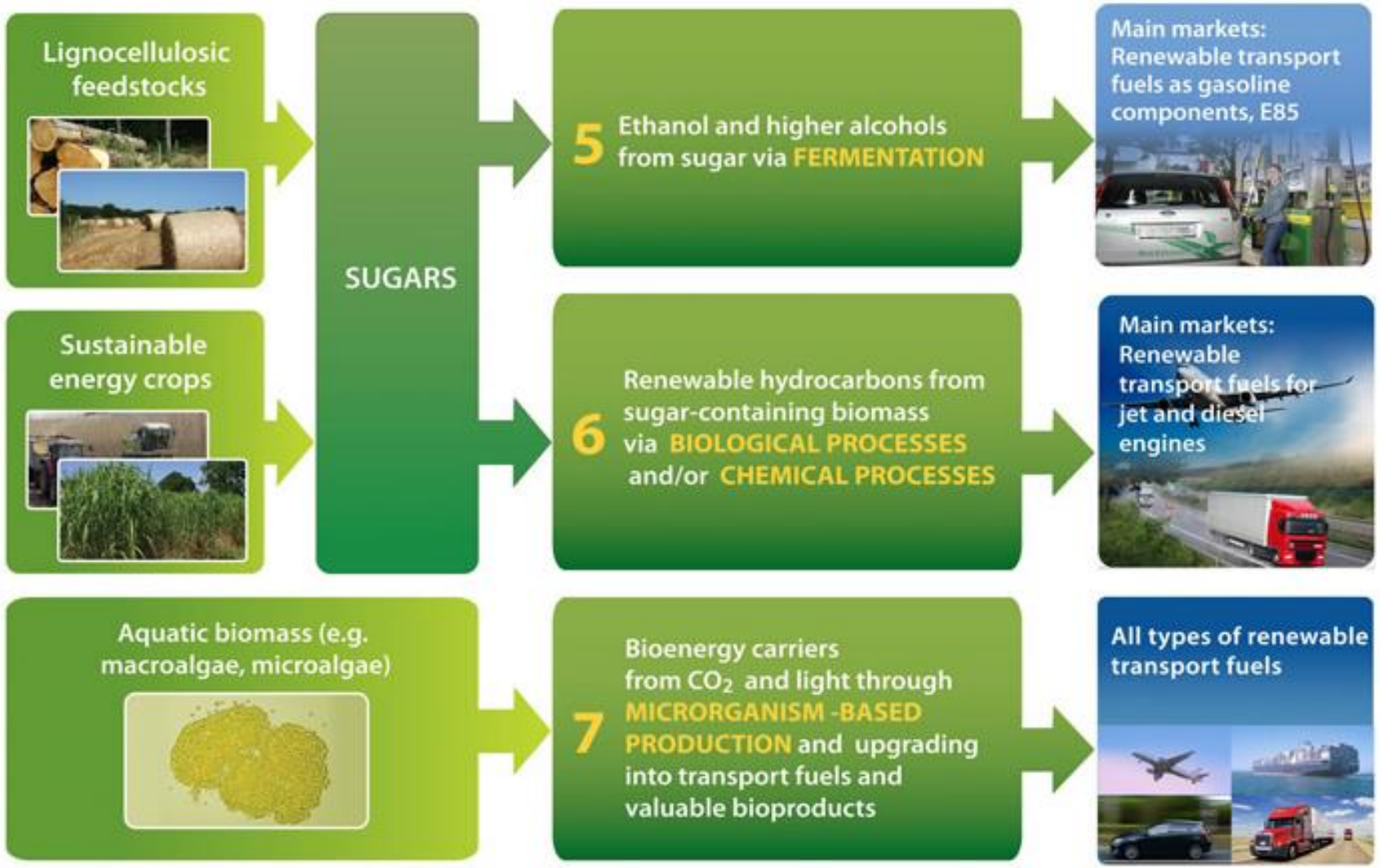
Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Intermediates to hydrocarbons



Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Biochemical & chemical conversion value chains



Lignocellulosic ethanol facilities

Company	Site	Feed	Year	ML/yr	Type	Status
Abengoa	ES	Agri res. MSW	2008	5	Demo	Idle
Beta Renew. Energochemic	IT SL	Agri resid. Agri resid.	2013 2017	76 70	1st ind. Comm	Idle? Constr.
CIMV	FR	Agri resid.	2017	0.9	Demo	Com.
Clariant	DE	Agri resid.	2012	1.2	Demo	Op.
DuPont	USA	Agri resid.	2016	114	1st ind.	Idle
Granbio	BR	Bagasse	2014	82	1st ind.	Com.
Futurol (pre-treatment)	FR	Agri resid.	2011 2016	0.18	Demo Demo	Op. Op.
Inbicon (Ørsted)	DK	Straw	2010	6	Demo	Idle
POET/DSM	USA	Agri resid.	2014	76	1st ind.	Com.
Raizen	BR	Bagasse	2015	40	1st ind.	Com.
Borregaard BALI	NO	Woody biom.	2013	0.14	Demo	Op.
RISE (ex. SEKAB)	SE	Woody biom.	2004	0.15	Pilot	Op.
STI	FI	Woody biom.	2017	10	Demo	Com.
Synata (ex. Abengoa)	USA	Agri resid.	2016	95	1st Ind.	Op.?

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Lignocellulosic ethanol
Beta Renewables, Crescentino, Italy

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

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

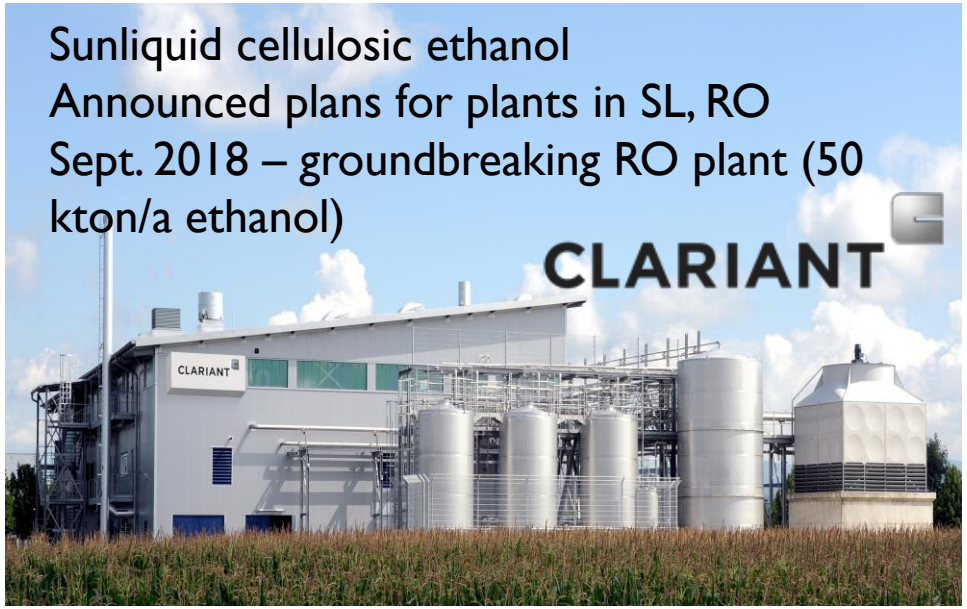
76 000 m3/year of ethanol , 13MWe generated from lignin.

150 M€, FP7 support

Beta Renewables bought by Versalis in Sept. 2018

Developments lignocellulosic ethanol

Sunliquid cellulosic ethanol
Announced plans for plants in SL, RO
Sept. 2018 – groundbreaking RO plant (50 kton/a ethanol)



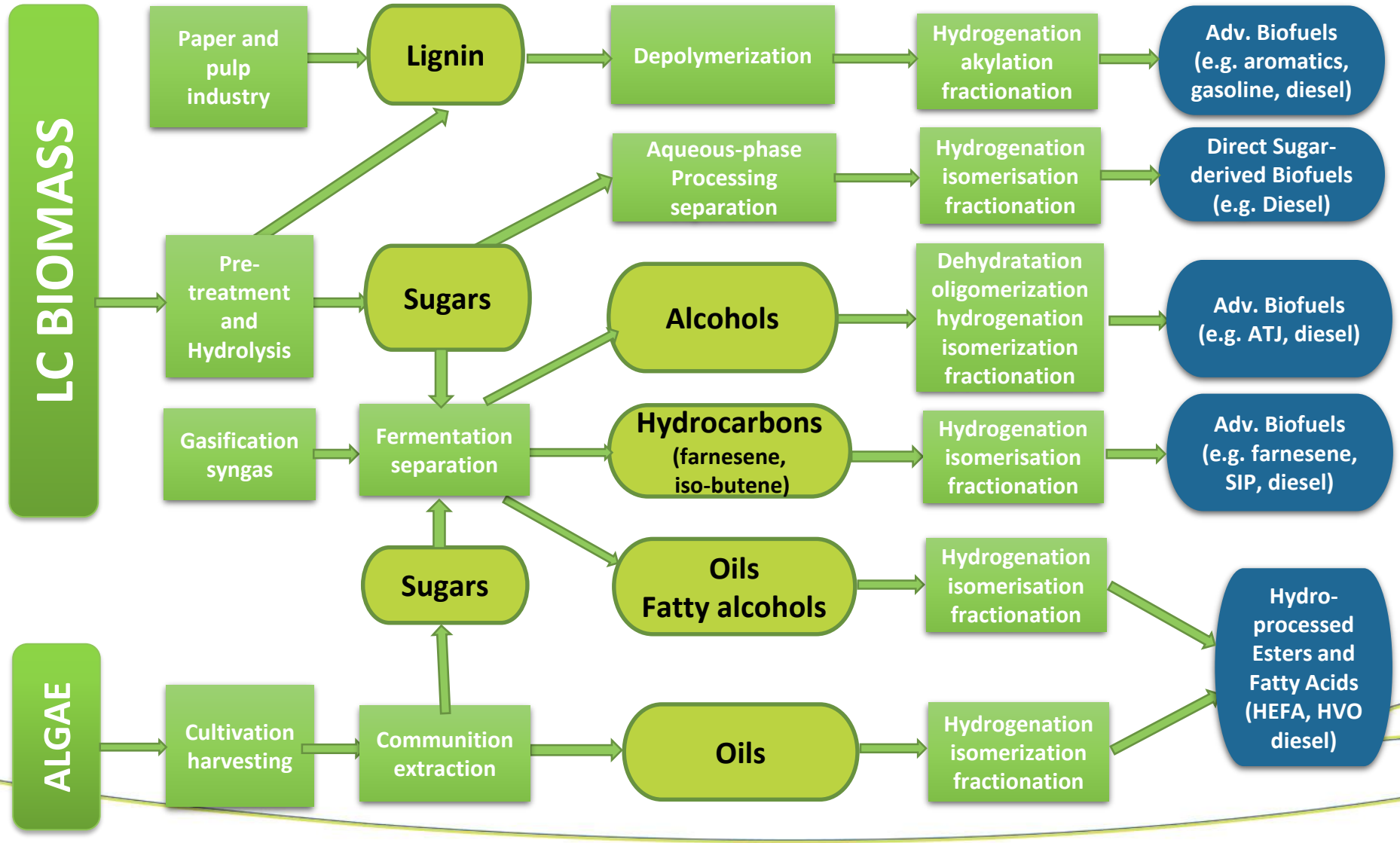
Capacity 10 million liters ethanol from saw mill dust (pine)
Commissioning 2017

Cellunolix® Kajaani, Finland

PRAJ: Capacity 1 million liters ethanol from agro residues
End-to-end integrated demonstration plant
Commissioning 2017

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Intermediates to hydrocarbons



Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

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.

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

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
Topsoe TIGAS	DK	Methanol	2014	90	Com.	2018
Vertimass	USA	Ethanol				

Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

Microalgae to biofuels

	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 have shifted from biofuel to non-fuel products in 2014-2017.
Increasingly promising prospects for macroalgae (seaweed)!

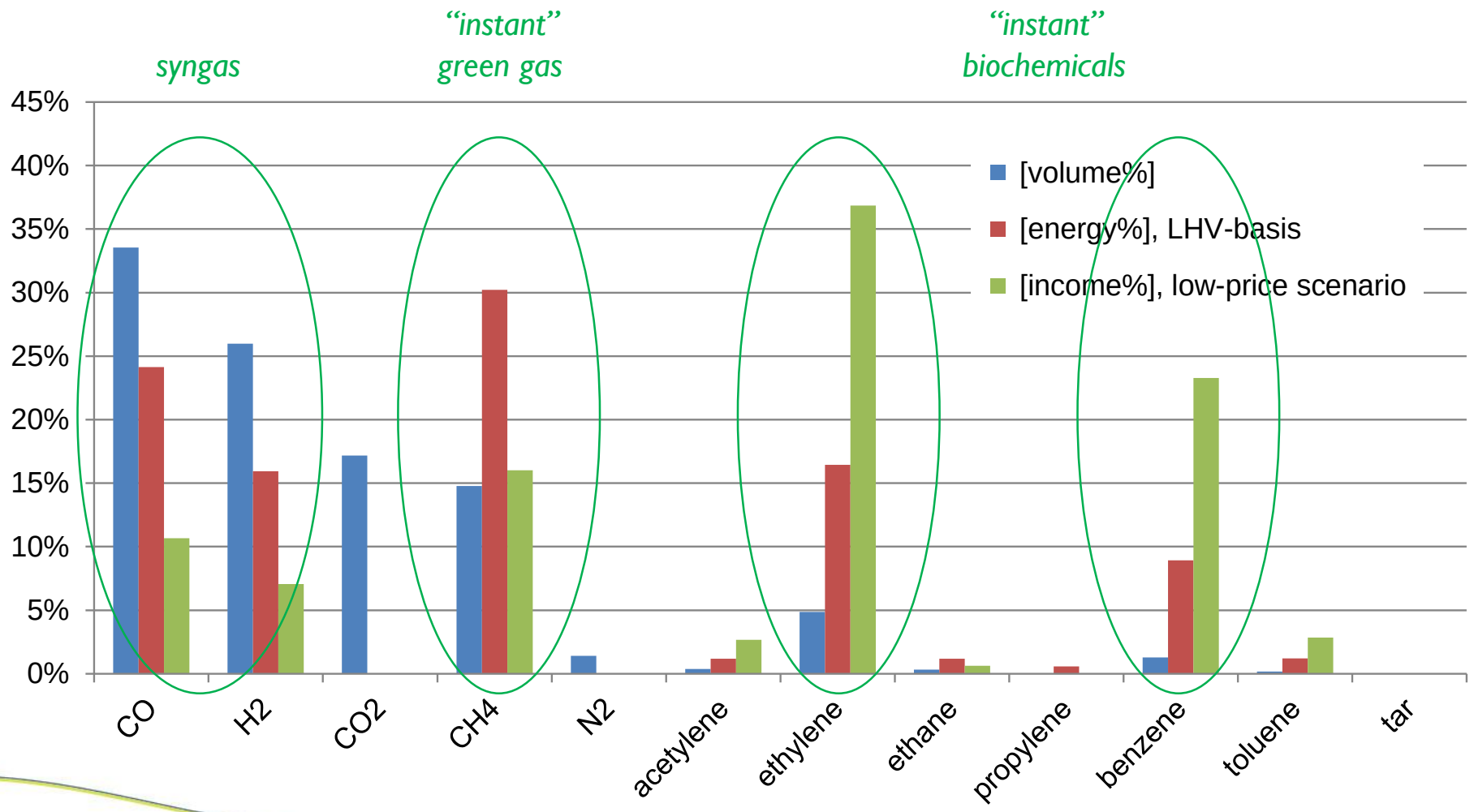
Source: Lars Waldheim & Francisco Girio, ETIP Bioenergy 2018

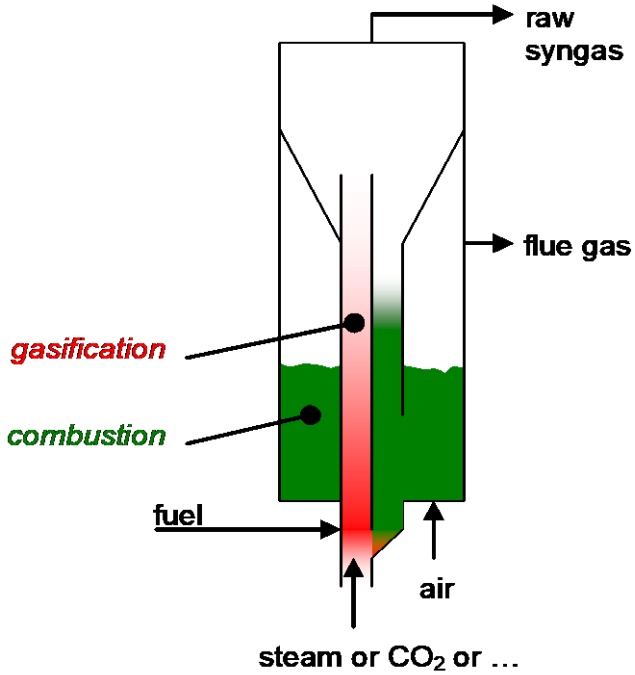
Main directions in biofuels R&D – focus on gasification-based biofuels (taken from the new EERA Bioenergy SRIA)

- Process simplification and intensification
  - Significant cost dimension (CAPEX, OPEX and plant availability, reliability and higher net plant efficiency)
  - Consider smaller scale? (easier financing, more integration options, use of local biomass)
- Increasing feedstock flexibility and allowing application of (cheaper) biomass low-quality feedstock
  - Mainly aiming at cost reduction
- Co-production of chemicals/materials
  - Energy-driven biorefinery; to boost the business case for energy products (with higher added value for chemicals/materials)
- Combining thermochemical and biochemical processing
  - E.g. , thermochemical conversion of residues of biochemical processing (e.g., lignin gasification), biochemical product gas cleaning, syngas fermentation
- Maximizing resource efficiency
  - E.g. by combining biomass processing with other sources like renewable hydrogen produced from solar and wind
- Creating negative GHG emissions
  - Involving concepts like BioEnergy + Carbon Capture & Storage (BECCS) and biochar co-production
- Coupling with other industrial activities (sector coupling)
  - Industrial symbiosis, e.g. exchange of utilities and residues/feedstock, heat integration

Co-production of chemicals/materials – Energy-driven biorefinery

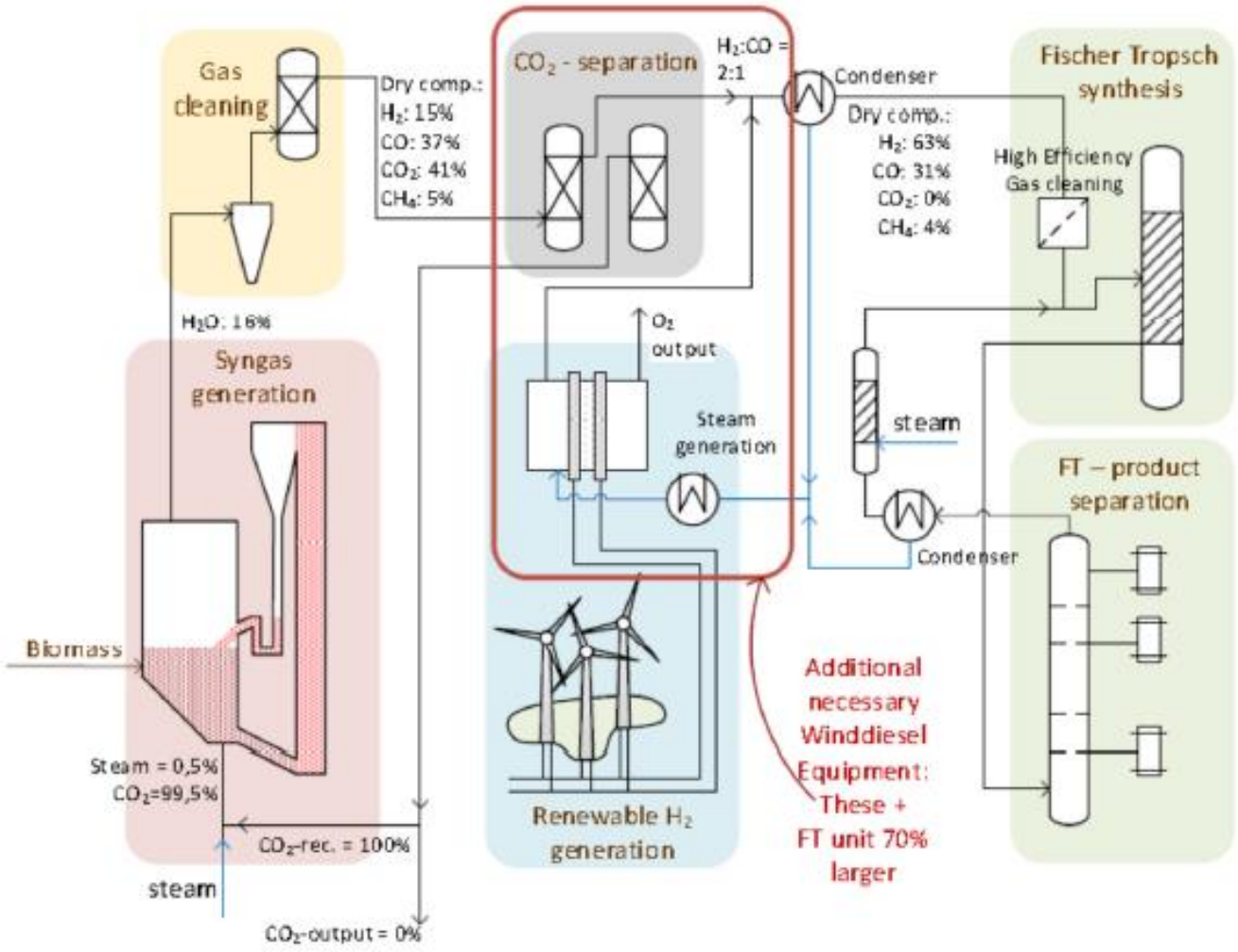
Via gasification to biofuels, biochemicals, heat and power





Tar-free gas from MILENA wood residues gasification

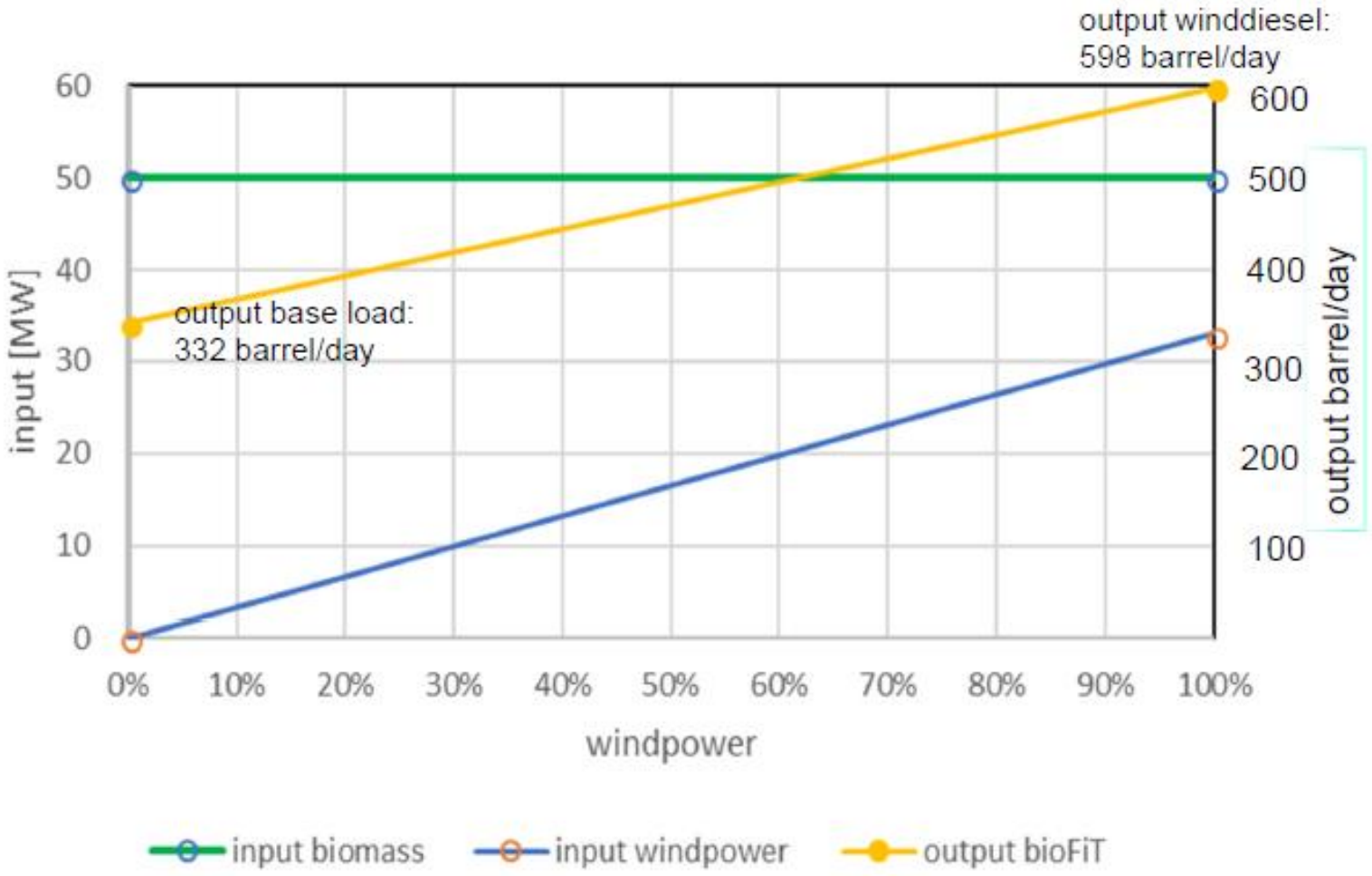
Repotec winddiesel process



www.winddiesel.at

Source: Christian Aichernig, ETIP Bioenergy workshop Emerging Technologies, Brussels, 4 June 2018

Repotec winddiesel process



www.winddiesel.at

Source: Christian Aichernig, ETIP Bioenergy workshop Emerging Technologies, Brussels, 4 June 2018

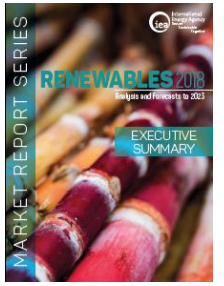
Time is of the essence!

We need to step up biofuels implementation and R&D

- Industrial implementation of R&D requires patience
- The economics of bridging the "development gap" 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
- Also policy must be sustainable over time, not only biofuels

GLOBAL WARMING OF 1.5 °C

INTERGOVERNMENTAL PANEL ON climate change



"Modern bioenergy is the overlooked giant of the renewable energy field," said Dr Fatih Birol, the IEA's Executive Director

- Firm incentives needed to ensure R, D&D up to high TRL and timely wide-scale commercial role out (taking into account required time intervals)

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THANK YOU FOR YOUR ATTENTION

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