RE·CORD

Politecnico di Torino

Thermochemical Biofuel Conversion processes: overview and innovative approaches

David Chiaramonti

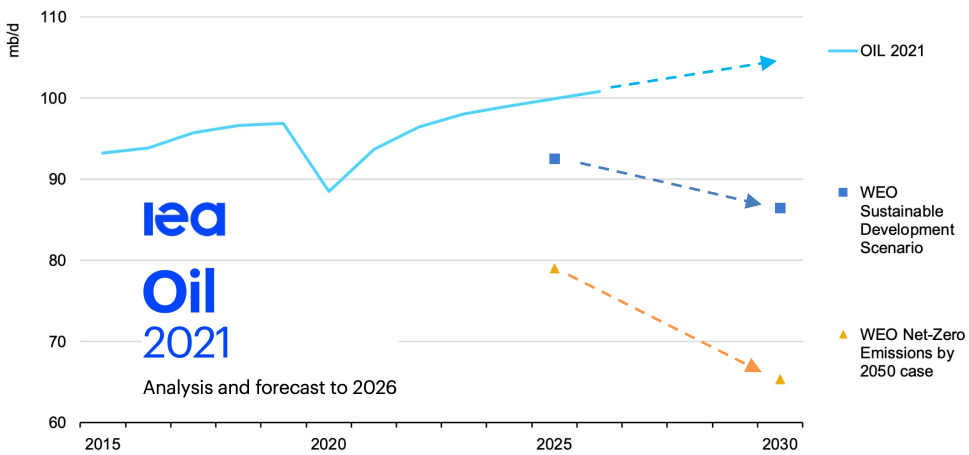
Polytechnic of Turin and RE-CORD

david.chiaramonti@polito.it

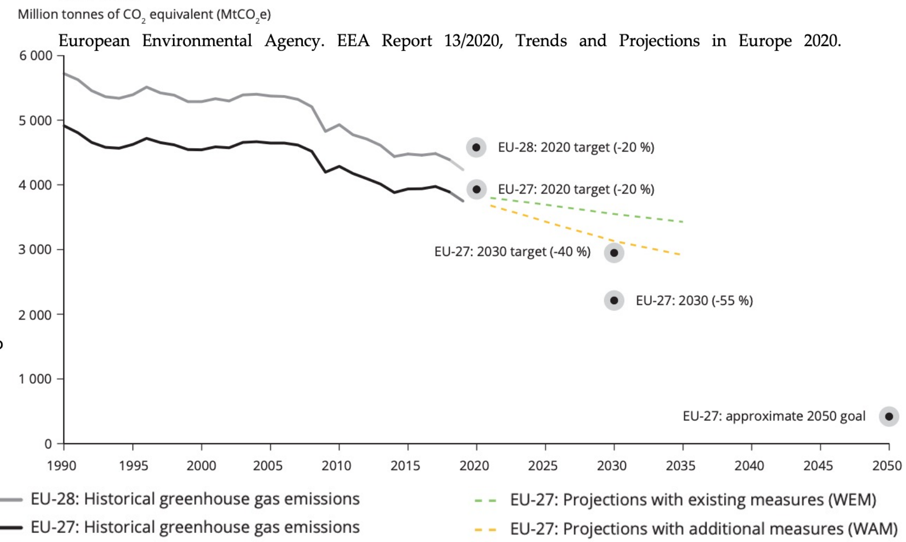
Setting the scene: an unprecedent challenge

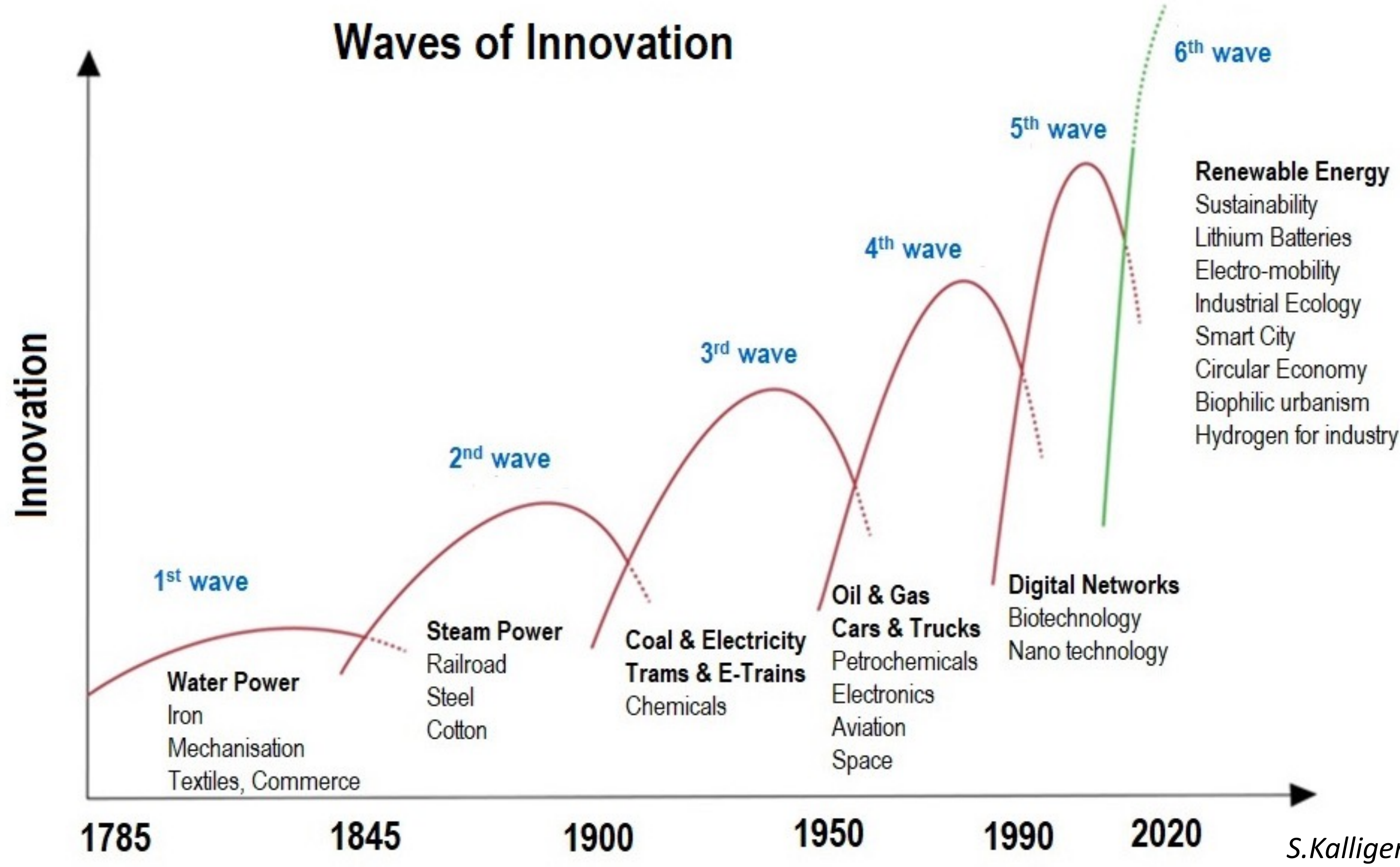
Oil demand off-course to meet sustainable development and net-zero targets

Global oil demand forecast in Oil 2021, Sustainable Developments Scenario and Net-Zero Emissions by 2050 case



Greenhouse gas emission targets, trends, and Member States MMR projections in the EU, 1990-2050

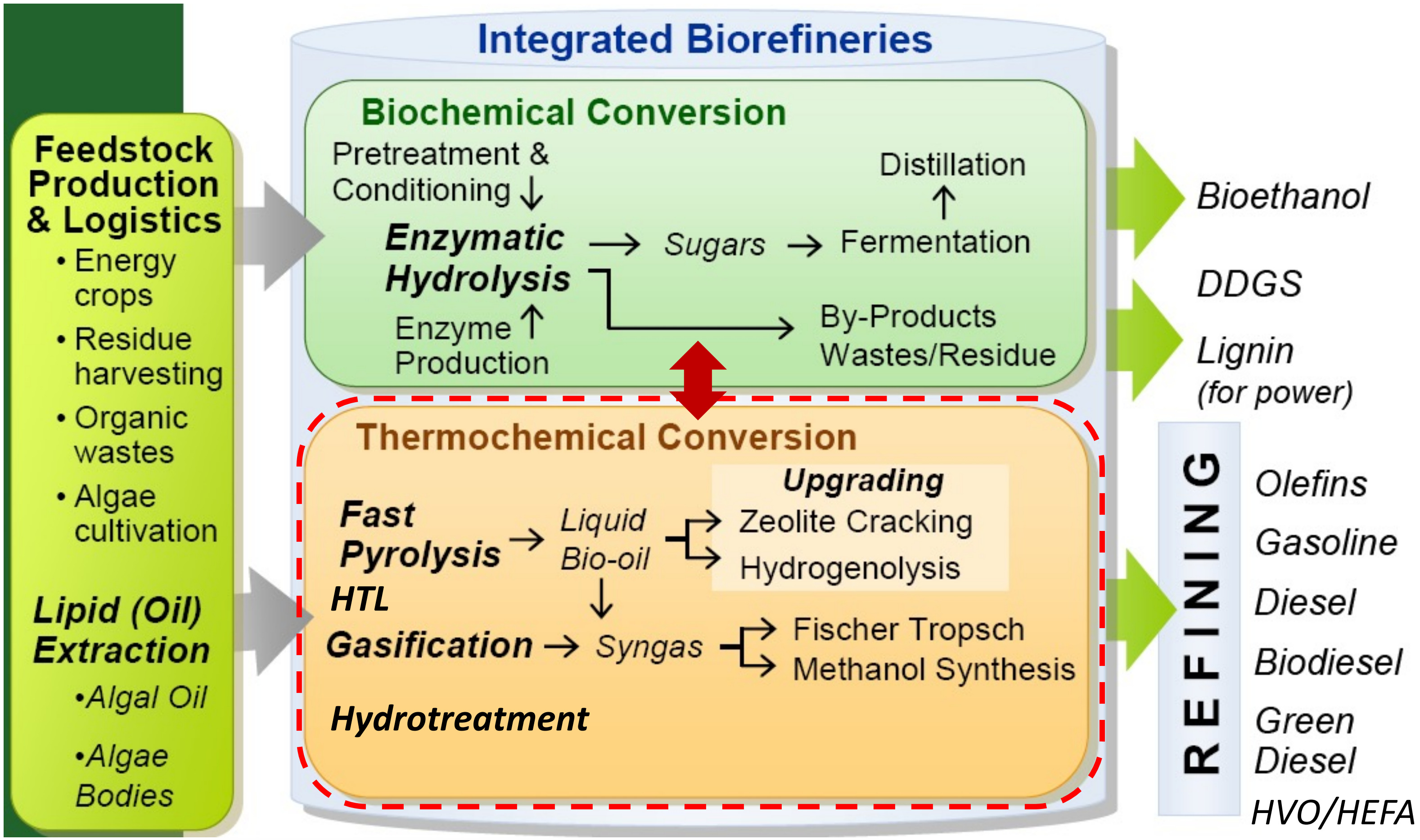




S.Kalligeros, 2020

- **Industrial scale-up & Policy making need to adapt to such fast changes**
- **What is doable in the given timeframe? Do we meet the urgency?**
- **Which socio-economic impacts?**

Biorefining & Thermochemical conversion



NREL Definition of Biorefinery

– "A facility that integrates biomass conversion processes and equipment to produce fuel, power and chemicals from biomass"

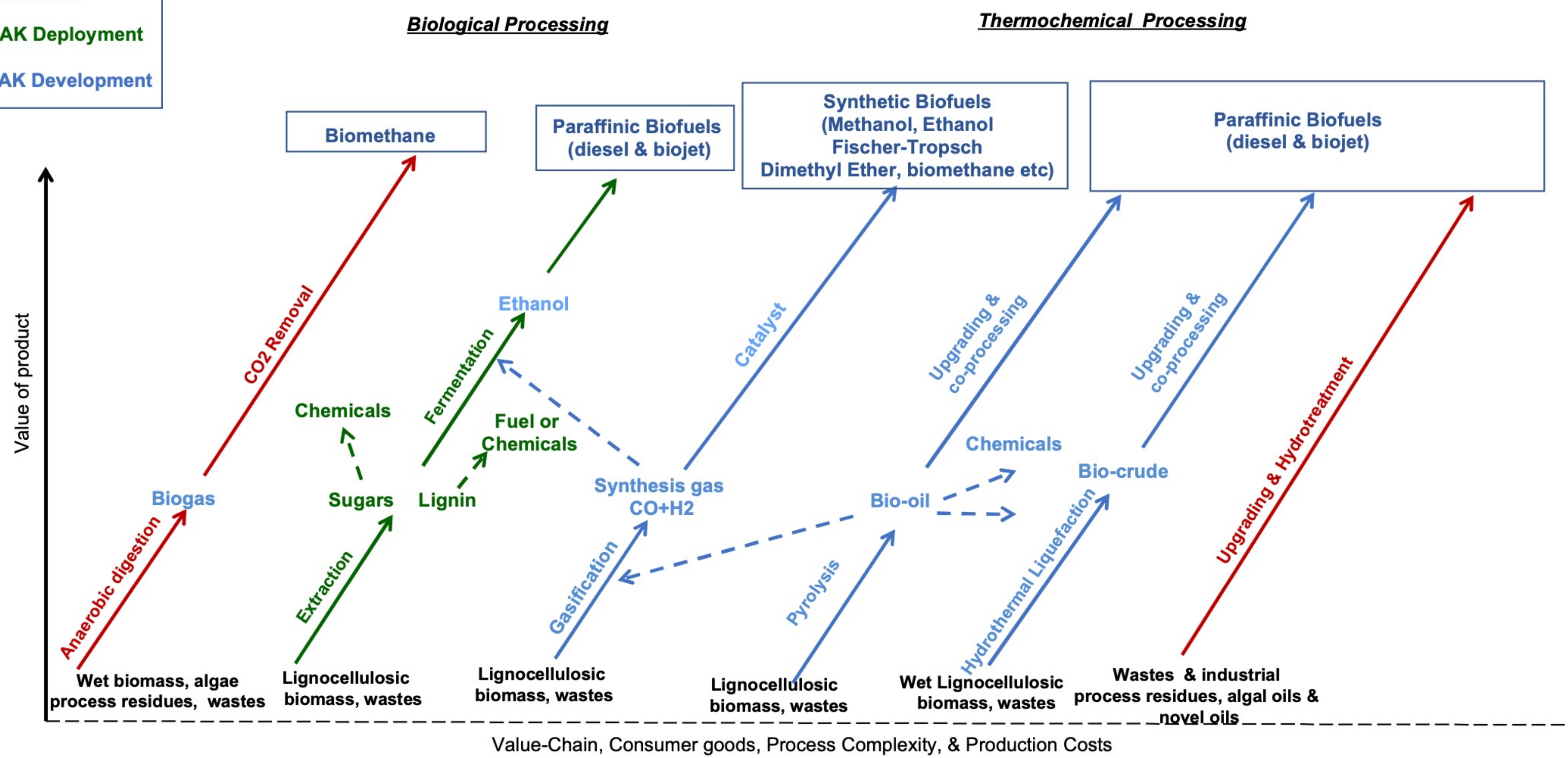
Source: elaborated from IEA-Bioenergy

RE·CORD

POLITECNICO DI TORINO

Key to graph
Commercial
FOAK Deployment
FOAK Development

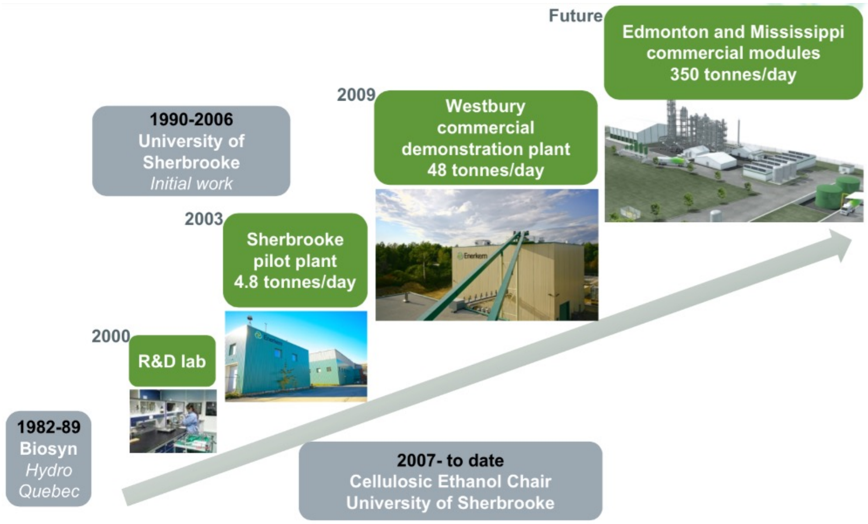
Available technologies for advanced biofuels

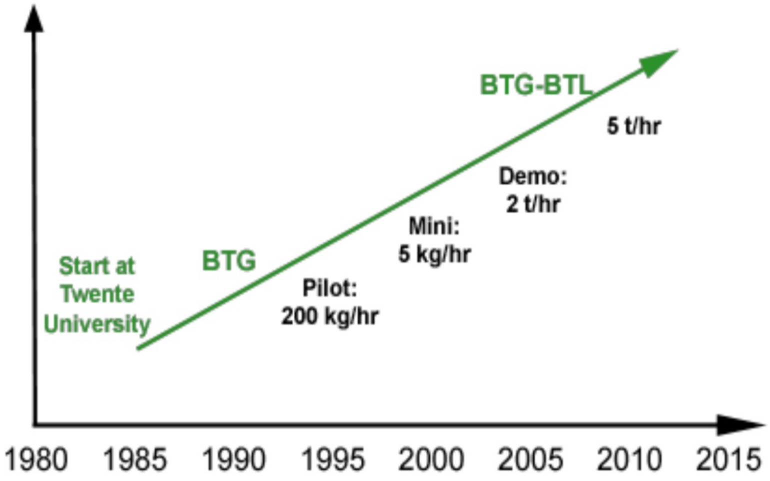


Adding value to biomass by processing to advanced biofuels and to biochemicals

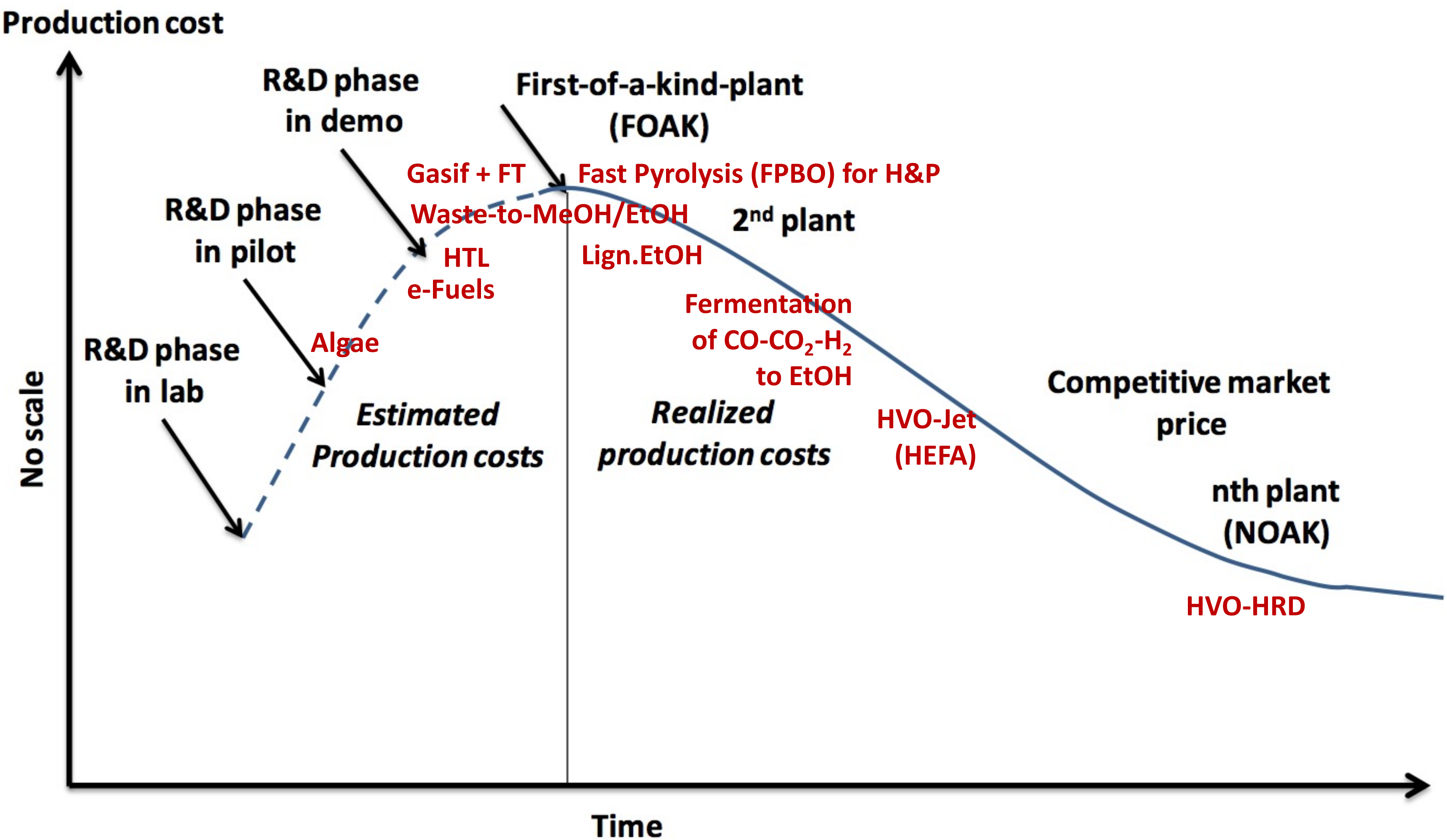
Source: K.Maniatis, 2017 & 2021

- From **Pilot** to Ind.**Demo** to **FOAK** (Mountain of Death) – Time to market





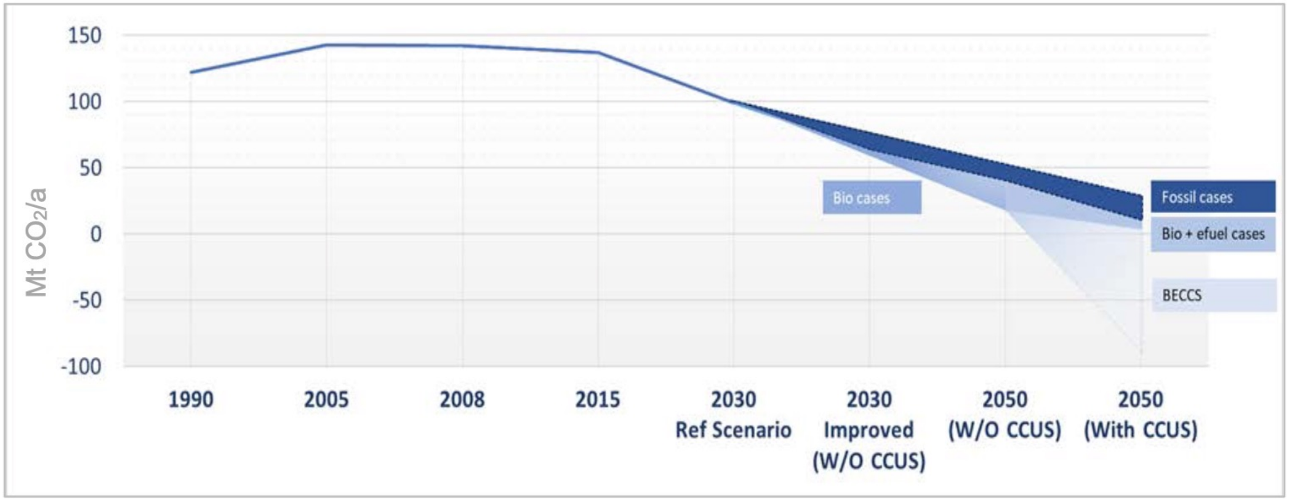
MOUNTAIN OF DEATH



Remark – estimates change with feedstock & application (CHP or Transport)

Author's elaboration from K.Maniatis / SGAB, 2017

Refining industry forecasts

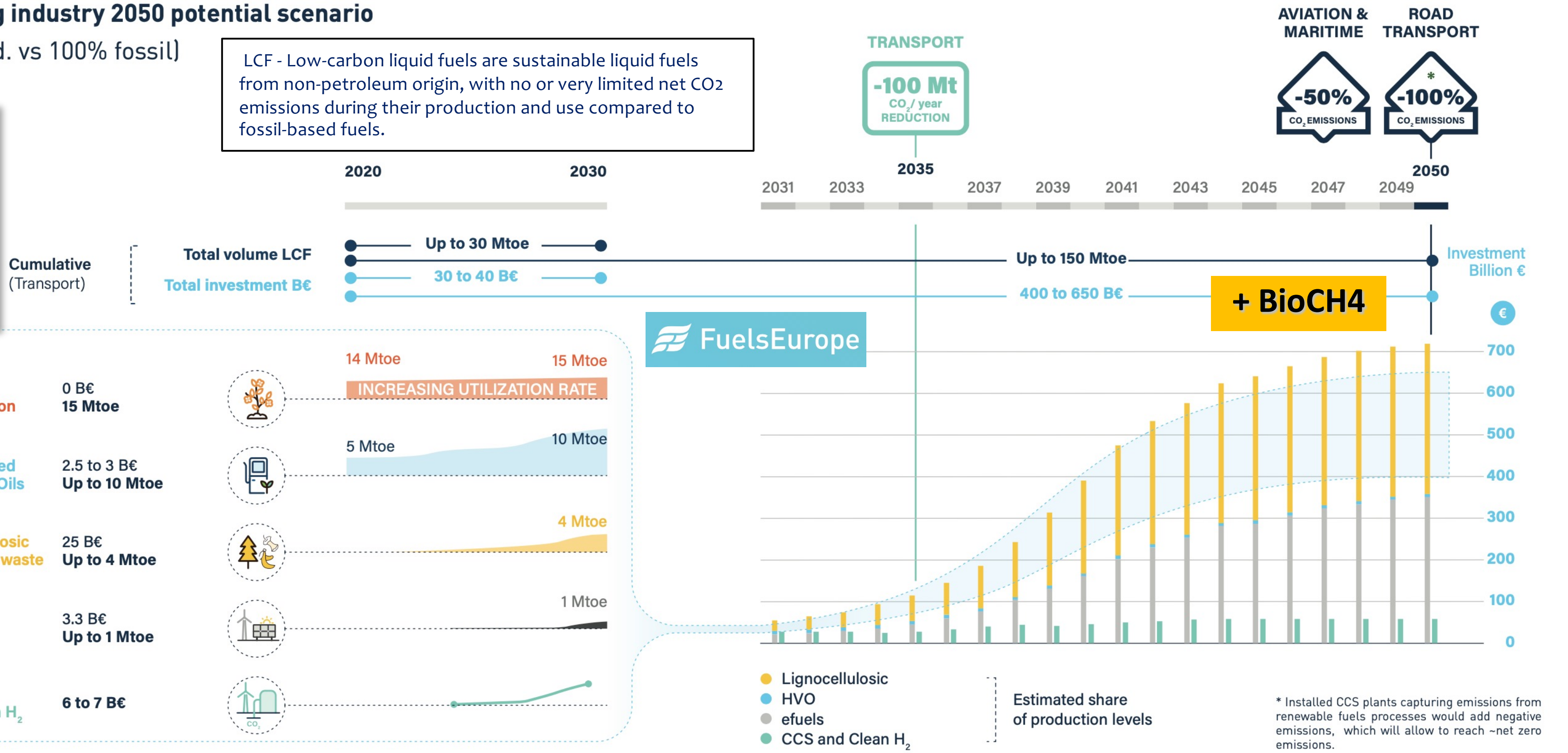


Concawe

EU refining industry 2050 potential scenario

(% GHG red. vs 100% fossil)

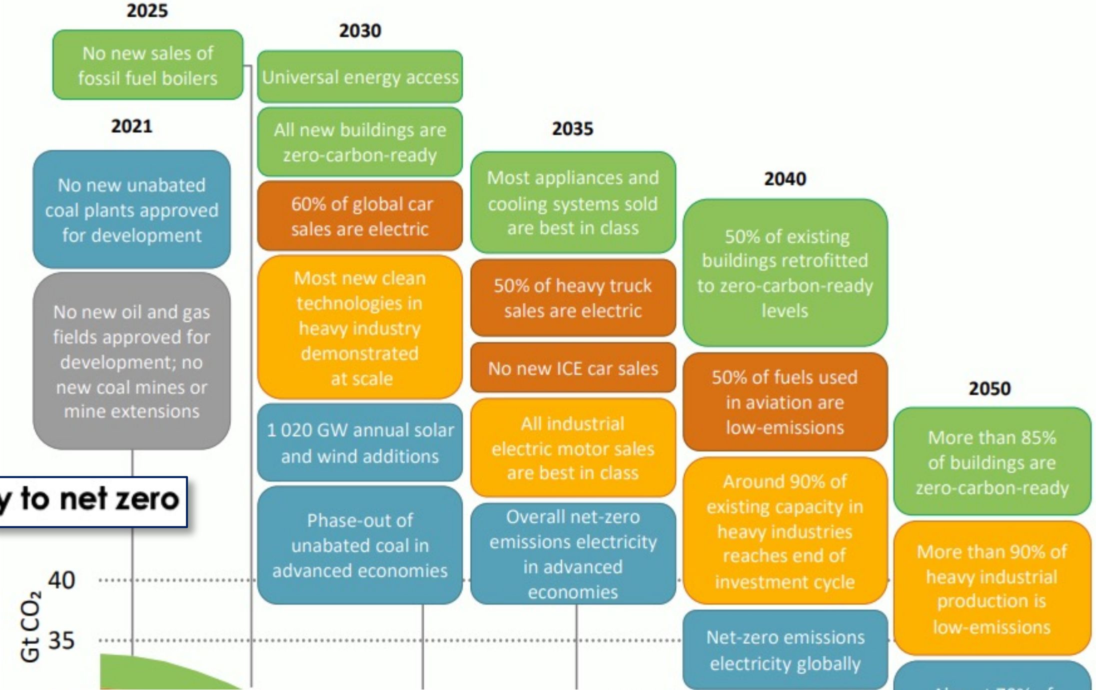
LCF - Low-carbon liquid fuels are sustainable liquid fuels from non-petroleum origin, with no or very limited net CO_2 emissions during their production and use compared to fossil-based fuels.



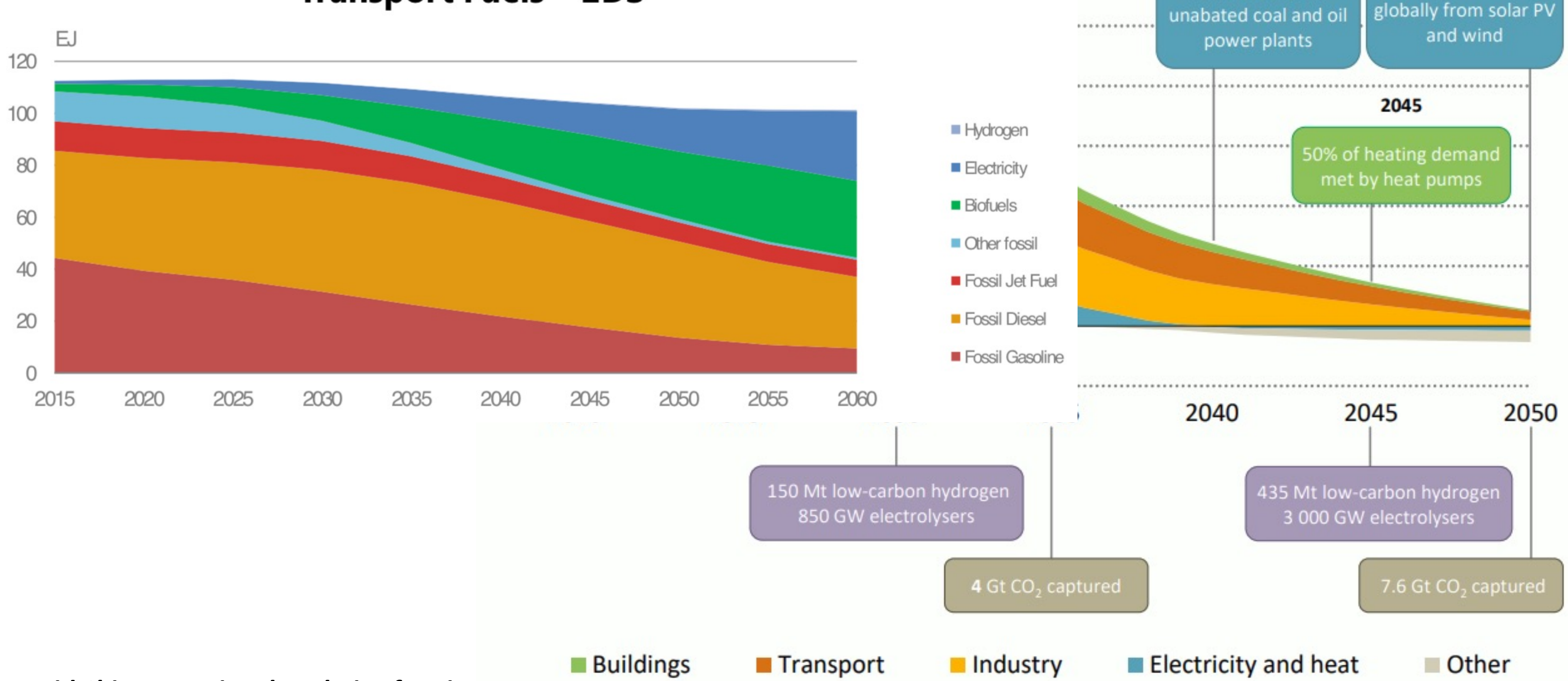
RE·CORD

POLITECNICO DI TORINO

Key milestones in the pathway to net zero



Transport Fuels – 2DS

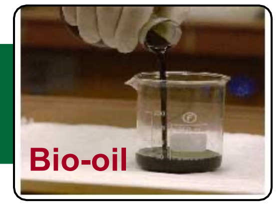


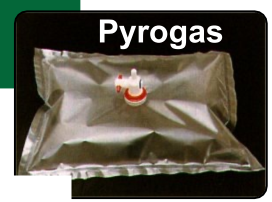
iea

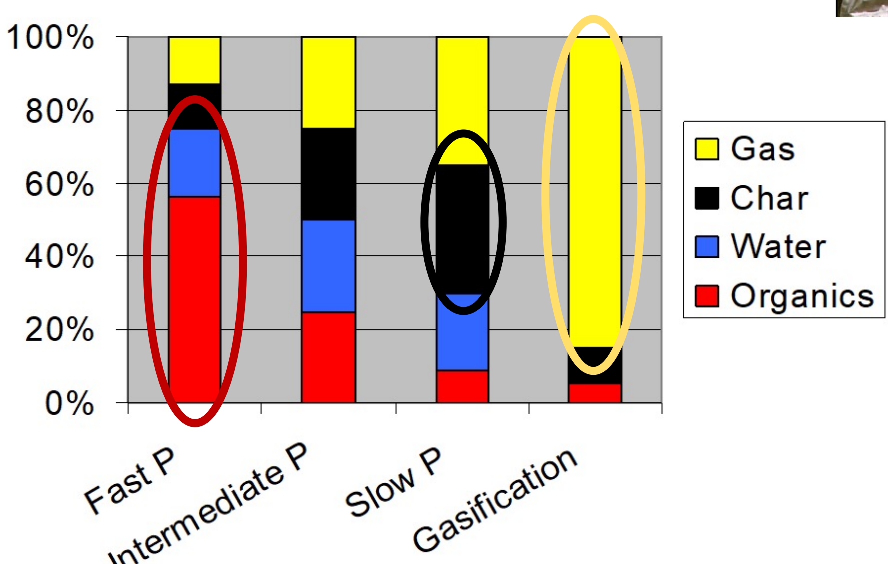
THERMOCHEMICAL CONVERSION PYROLYSIS / GASIFICATION

PRODUCTS OF THERMOCHEMICAL CONVERSION

- **SOLID**
- **LIQUID**
- **GAS**







– ***Pyrolysis*** *(Slow, Intermediate, Fast),* ***Gasification***

- ***Fast Pyrolysis:*** *some full-scale* ***industrial plants.*** *Focus on* ***biocrude. Oil quality*** *sensitive to* ***Feedstock.***
- ***Slow Pyrolysis****: very* ***robust and mature technology****.* ***Many reactor*** *types available at* ***any size****. A* ***Multi-Feedstock*** *technology focused on* ***solids****.*
- ***Gasification****:* ***well-developed and known****.* ***Scale vs feedstock and costs****.* ***Energy*** *oriented, now shifting to* ***Products****. Conversion of gas into product as* ***FT-fuels****,* ***MeOH/EtOH****, etc. Also, FT products conversion in fossil refineries,* ***Co-processing***

– *Pyrolysis, Gasification:* ***DRY feed***

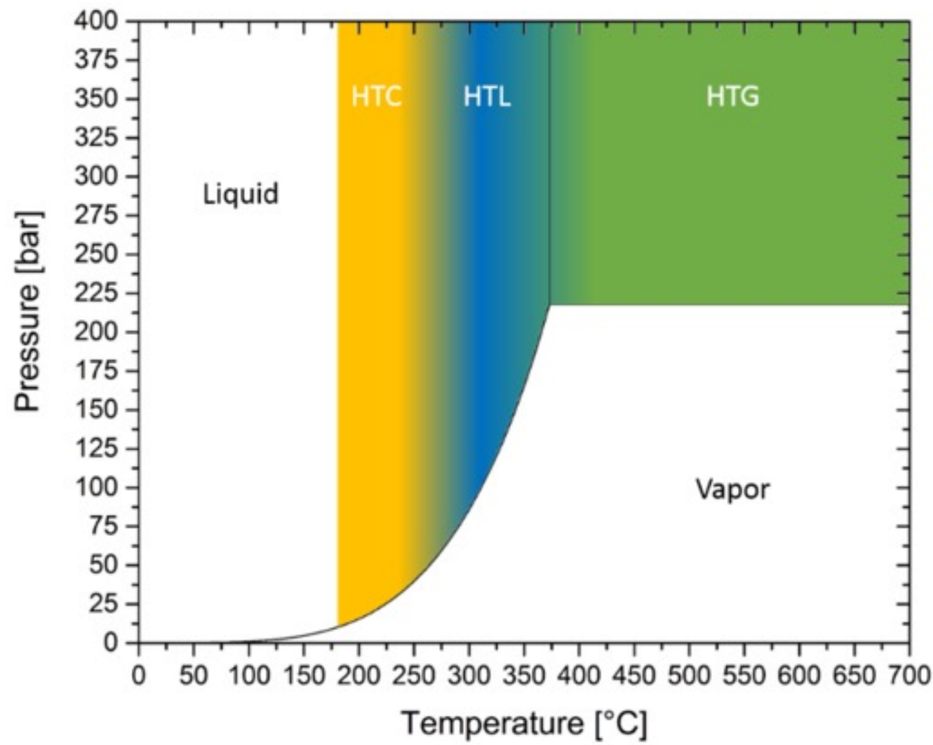
HYDROTHERMAL PROCESSING (HTC, HTL)

HYDROTHERMAL PROCESSING ROUTES

HIGH T

Higher T *Super Crit. Conditions*	**HTG (HydroThermal Gasification)**
High T *~Crit./Sup. Conditions* 280-370 °C	**HTL (HydroThermal Liquefaction)**
180-250 °C	**HTC (HydroThermal Carbonisation)**
140-230 °C	LHW (Liquid How Water pre-treatment)
100-180 °C	PHWE (Pressurised Hot Water Extraction)
< 100 °C	HWE (How Water Extraction)

LOW T



Modified from Peterson et al. Energy Environ. Sci. 1 (2008) 32–65. doi:10.1039/b810100k

✓ *Hydrothermal Processing:* ***WET feed***

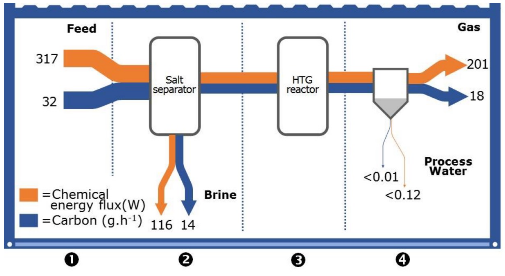
HTL: KEY NEEDS AND SCALE-UP STRATEGIES

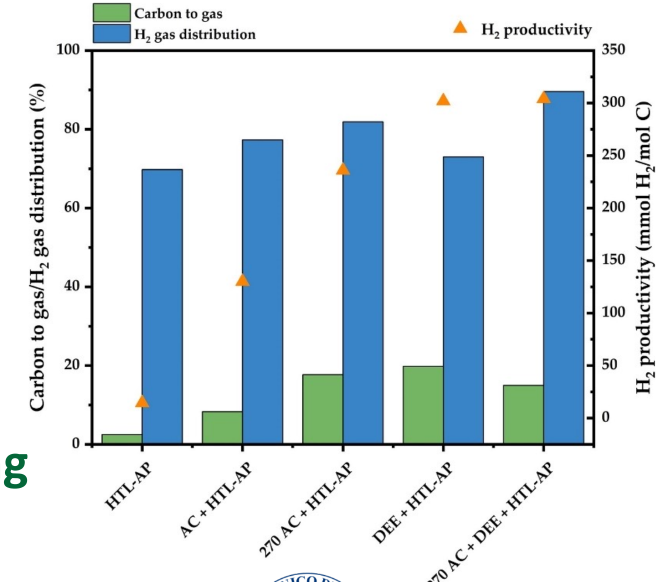
- **<u>Residual/waste feedstocks</u>:** *Genifuels (WWT), Steeper (Forest Residues, Sludges and MSW), ENI (OFMSW), Mura (end-of-life plastics)*
- **<u>Co-Liquefaction</u>:** improved economics by enhanced feedstock availability
  - ✓ Synergistic effects for yield and biocrude quality reported
  - ✓ Wood + Algae, Sewage sludge + Lignocelluloses, Miscanthus + Polyurethane
  - ✓ Wheat straw + Manure, Sewage sludge + Swine manure *(Mix with sewage sludge: No base catalyst, enhanced slurry pumpability)*
- **<u>Water management</u>:** Recycle, Cat HTG (CH_4-rich gas , high p and cat.deactivation), AD (proven, inhibition of MO, recovery of nutrients), LLE+APR (H_2 production)
- **<u>Co-refining</u>**: similar to FPBO (Stabilization + HDO + co-refining), but less oxygenated crude
  - ✓ Waste feedstock → Intensive hydrodenitrogenation (HDN) and hydrodesulphurization (HDS) are often needed to avoid catalyst deactivation
  - ✓ 3 EU projects considering HTL biocrude co-refining: 4refinery, Waste2Road, HyFlexFuel
- **<u>Biocrude sCO_2 fractionation</u>:** extraction yields above 50%, low water&metal content, avg mol.weight, density and viscosity, reduced acidity (shift to carboxylic instead of phenolic), moderate Oxygen content reduction. Longer HT catalyst life, lower hydrogen requirements, and less coking

HTL: Aqueous Phase Management

- One of the main bottleneck for process scale-up. Options:
  - **Recycle**
  - **Catalytic hydrothermal gasification** (PNNL, PSI)
    - CH_4-rich gas
    - High pressure equipment, catalyst deactivation
  - **Anaerobic digestion**
    - Simple and well-proven technology
    - Inhibition of microorganisms
  - **Recovery of nutrients**
  - **Liquid-liquid extraction + Aqueous phase reforming**
    - H_2 production for biocrude upgrading
    - Catalyst deactivation

http://www.besustainablemagazine.com/cms2/wp-content/uploads/2019/12/2019-11-19-HyFlexFuel_Joint_Workshop_Brussels_distribute.pdf





Zoppi et al., (in press), Catal Today 2020. doi:10.1016/j.cattod.2020.08.013

NG INFRASTRUCTURE – (BIO) DECENTRALIZED PRODUCTION + (THERMO) CENTRALIZED PROCESSING

The same Decentralized-Centralized approach can also be adopted for Biocrudes from Fast Pyrolysis or Hydrothermal Liquefaction, as well as for a variety of feedstocks (including wastes)

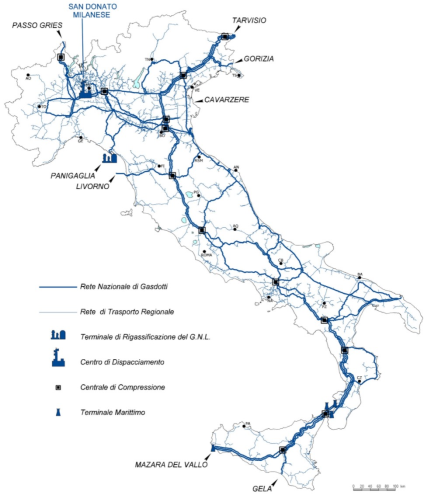
Decentralized Bio-NG

NG grid

Centralized Processing

FT fuels
MeOH
EtOH
Etc..

Guarantee of Origin



Similar to PV/Wind (VREs)

- ✓ ***Guarantee of Origin (GO)*** *as €/Nm³_bio-CH_4*
- ✓ ***Centralized conversion, Mass balance***

LUNGHEZZA DELLA RETE DI TRASPORTO DI SNAM RETE GAS

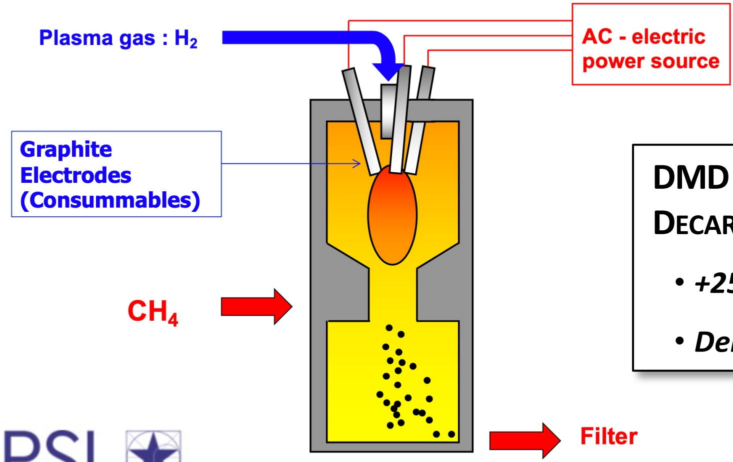
DATI IN CHILOMETRI	2016	2017	2018 (*)	Var. ass. 2018 vs 2017	Var. % 2018 vs 2017
RETE NAZIONALE	9.590	9.620	9.668	48	0,5%
RETE REGIONALE	22.918	22.880	22.918	38	0,2%
TOTALE	**32.508**	**32.500**	**32.586**	**86**	**0,3%**

(*) situazione ad ottobre 2018

(Bio-)Methane Pyrolysis: Grey, Blue, Green, Turquoise

BIOMETHANE → PYROLYSIS → CARBON AND H2

Methane Plasma Technology pyrolysis turquoise H_2

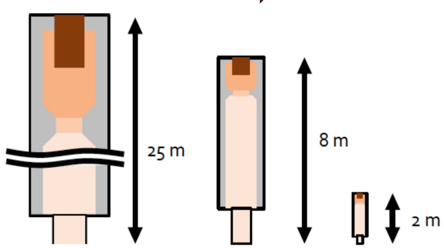


DMD – Direct Methane Decarbonization

- *+25 anni di ricerca*
- *Demo iniziata nel 2012*

PSL RESEARCH UNIVERSITY PARIS

PERSEE MINES ParisTech



	Production Plant (Olive Creek I)	Pilot Plant (Seaport I)	R&D Reactor (MPT)
Carbon Black Production (yearly)	14,000 ton	~1,000 ton	<1 ton

Fonte: Laurent Fulcheri, MINES-Paris Tech EUI Webinar, 2021

MPT – Monolith Materials

5000 t/y H_2

COMPARISON OF H_2 PRODUCTION ROUTES

	kWh/kgH_2	kWh/Nm^3H_2	$kgCO_2/kgH_2$	H_2 and Sustainability	Notes
SMR	8.7	0.725	9.5-12	Grey H_2 **Green H_2** *if from $BioCH_4$*	Heavily exothermic reaction C released in gaseous form as CO_2 Low-C or at best Carbon Neutral only if combined with CCS Carbon Negative only if from combined with CCS and $BioCH_2$
Electrolysis	39.6 *(Theoretical limit)* 53-80 *(Industrial)*	-	-	**Green** *if from RES*	It requires Power *(53 kWh/kg=63% eff)* Power from RES to generate Green H_2
DMD-MPT	10-20 *(kWh_e)*	-	0	**Turquoise**	C separated as solid (C_s) It requires Power Low-C or at best Carbon Neutral Carbon Negative only if from $BioCH_2$
Bio-methane pyrolysis	11-15 *(kWh_e)*	-	0	**Green and Carbon Negative**	C as solid (C_s) Elevated T (1300 °C) without catalyst The Catalyst can be bio-based It could be run without Power Demo needed. Costs to be confirmed and *f*(*catalyst*), but potentially low cost It generates C allowances
H_2 via APR of Bio-residues	Low power demand (low TRL)	-	0	**Green and Carbon Neutral or Negative**	Variable yields depending on soluble organics C released in gaseous form as CO_2. C negative if combined with CCS and biogenic CO_2 (in that case, C allowances are generated)

Sources: Elaborations by PoliTO, Laurent Fulcheri (MINES-Paris Tech) e Bernd Meyer e Roh Pin Lee (EUI Webinar), 2021; Parkinson et al., 2018

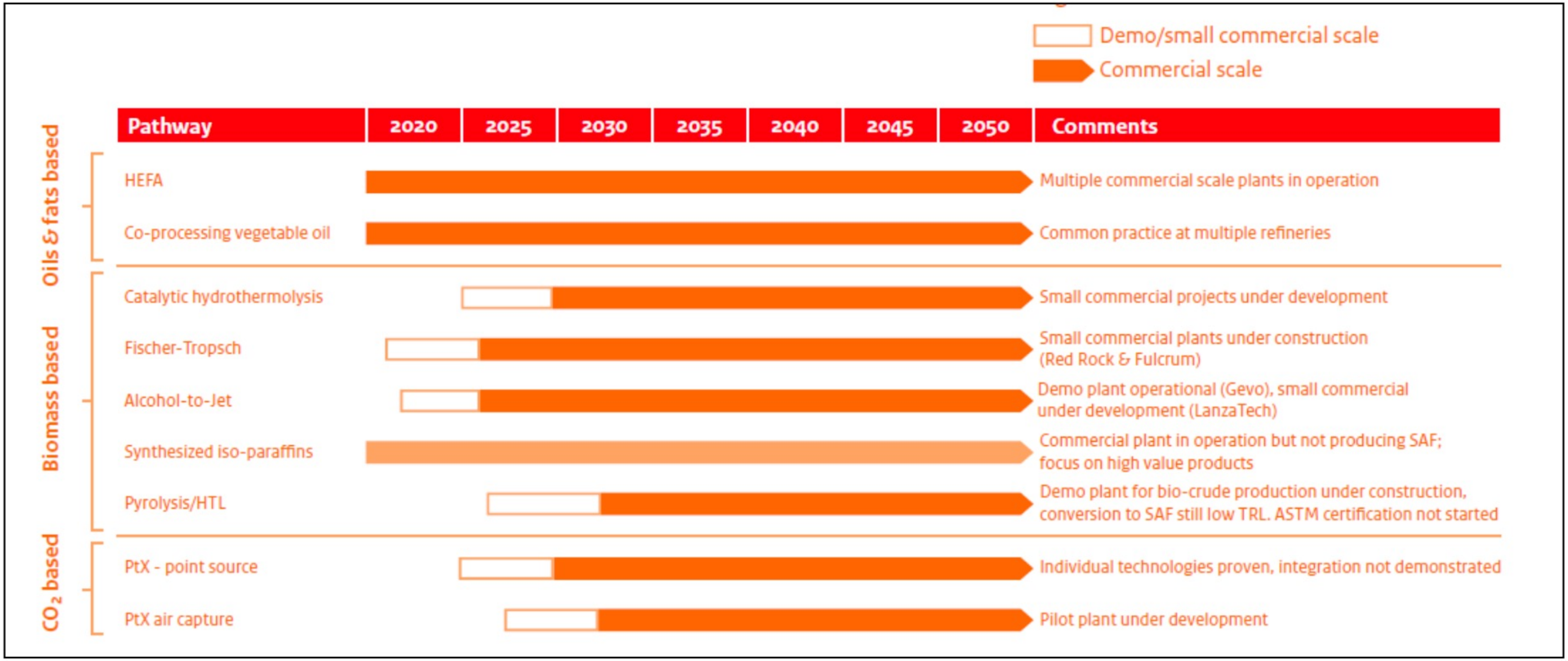
AVIATION: THE CHALLENGE, AND THE NEED FOR AN EU CLEARINGHOUSE FOR NEW PROCESS ROUTES

- **142** Mt CAF at 2010 → 570-**860** Mt at 2050 (International Aviation) + 400-600 % !!
- **100% CAF** substitution (**MAX** scenario) – **170 new biorefineries each year** from **2020 to 2050** (15-60 $B/y) - **MAX** would reduce **CO_2 emission by 63%** *Source: UN-ICAO*

- **Thermochemical processing can well target <u>SAF</u> (the most challenging fuel) and <u>Maritime</u>**

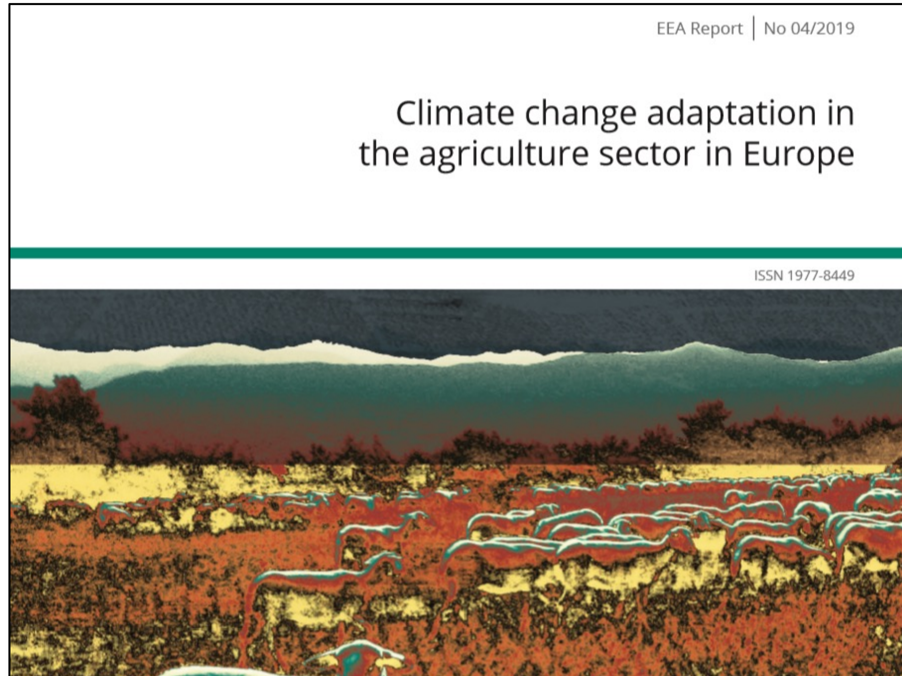
- **The US Clearinghouse supports ASTM certification path of new routes**
- **A similar Clearinghouse should be established in the EU**

STATUS OF CHAINS/FUELS

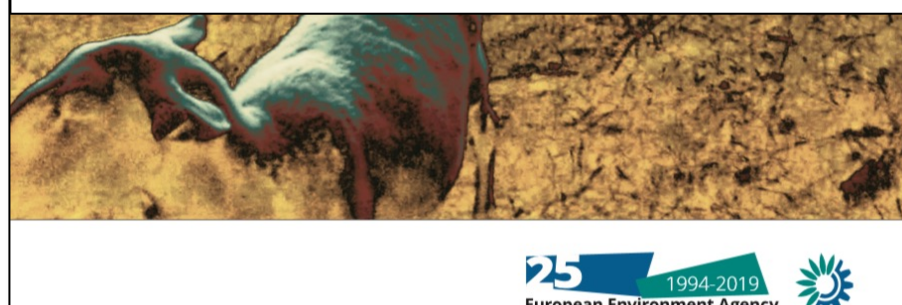


SOIL: THE URGENT NEED TO TAKE ACTION

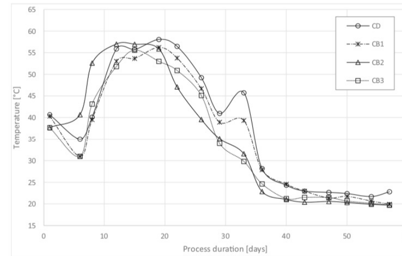
*V. [..] **no EU-level strategy on desertification and land degradation**. Rather, there is a range of strategies, action plans and spending programmes, such as the Common Agricultural Policy, the EU Forest Strategy, or the EU strategy on adaptation to climate change, which are relevant to combating desertification, but which do not focus on it.*
*[…] we make recommendations to the Commission aimed at better understanding land degradation and desertification in the EU; assessing the need to enhance the EU legal framework for soil; and stepping up efforts towards delivering the **commitment** made by the EU and the Member States to achieve **land degradation neutrality in the EU by 2030.***



*While climate change is projected to improve conditions for growing crops in parts of northern Europe, the **opposite** is true for crop productivity in **southern Europe.***
According to projections using a high-end** emission scenario, yields of non-irrigated crops like **wheat, corn and sugar beet are projected to decrease in southern Europe by up to 50 % by 2050.







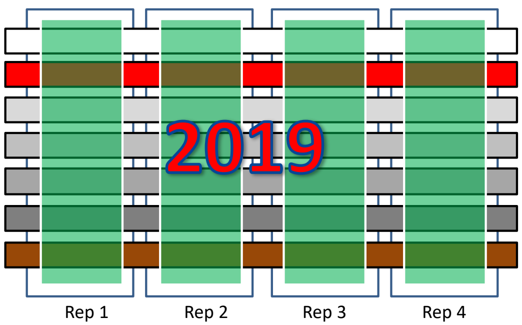
Biochar concentration in the final product: 14.9 - 19.8 - 22.8% w/w d.b.

Table 2 Initial windrows compositions

	U.M.	CD	CB1	CB2	CB3
Windrow	kg d.b.	160.6	156.5	153.0	149.6
Starting moisture	*% w/w* w.b.	61.6	60.0	59.2	58.3
Biochar content	kg w.b.	0.0	12.0	18.0	24.0
Biochar rate	*% w/w* d.b.	0.0	7.3	11.2	15.2
C/N index		36.3	40.4	42.7	45.2

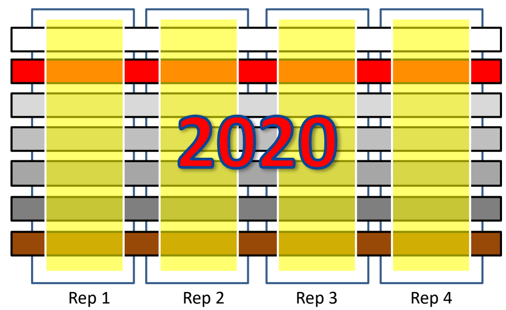
Recovery of Low ILUC REDII marginal land through BIOCHAR and co-composted biomass AD Digestate/biochar (COMBI) for HEFA

No fertilization
Mineral fertilization
10% Biochar + Compost
15% Biochar + Compost
20% Biochar + Compost
Biochar + mineral fert.
100% Compost



Camelina

No fertilization
Mineral fertilization
10% Biochar + Compost
15% Biochar + Compost
20% Biochar + Compost
Biochar + mineral fert.
100% Compost

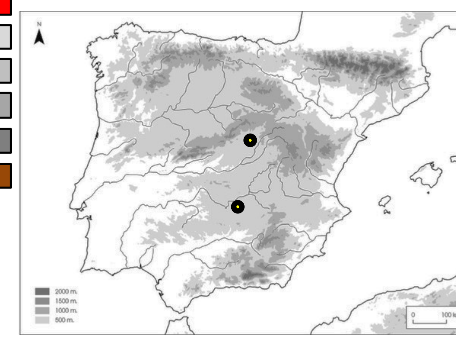


Barley

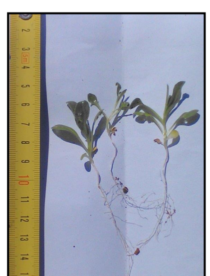
Two sites in very dry and marginal areas in ES →

Finca La Canaleja (**Madrid**) – L1

Finca Entresierras (**Ciudad Real**) – L2



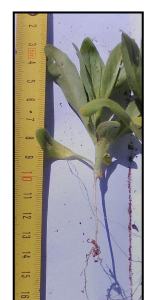
No fertilization



Mineral fertilization

100% Compost

100% Biochar



Biochar+ Compost 10%

Very positive result in experimental plots

- Rotation of energy crops (Camelina for HEFA jet) and food/feed (barley) in recovered soil, otherwise unproductive
- Carbon offsetting
- Improved resilience to Climate Change

Conclusions: Challenges and Opportunities

- *Thermochemical conversion of biomass and waste is expected to play a leading role in the ecological transition*
    - *Multiple products can be obtained from biobased or circular carbon feedstocks*
    - *Scale-up and full replication beyond mountain of death post 2030?*
- *Focus on whole value-chain, not on fuel production step only*
- *This chain will complement Biochemical, eFuels, RCF – all options needed to meet the challenge*
- *Policy-driven markets*
    - *Framed in the Green Deal scheme, Fit-for-55 package and International (ICAO, IMO) regulations*
    - *Stable and doable policy needed to stimulate investments (large CAPEX)*
- *Way for EU economic recovery, supporting domestic chains*

Thanks for your attention

David Chiaramonti

Polytechnic of Turin

david.chiaramonti@polito.it