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CRPE

Business unit
energy products

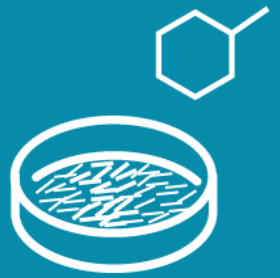
IFP Energies nouvelles

Innovating for a carbon-free and sustainable world

Pathways to SAF production – technology maturity and availability at industrial scale

Bertrand GUICHARD, Héloïse DREUX, Catherine LAROCHE

Project manager for Biofuels production



AGENDA

- IFPEN at a glance
- SAF pathways – presentation 
- Focus on maturity assessment 
  - *HEFA hydroprocessing*
  - *Biomass-To-Liquid*
  - *Ethanol To Jet*
  - *E-fuels (an FT pathway)*
- Final conclusions / Thoughts 

IFPEN AT A GLANCE

Public sector **R&I** institution

Training center

Industrial Group

INTERNATIONAL SCOPE in the field of
ENERGY, MOBILITY and **THE ENVIRONMENT**

1,531 employees

incl. 1,078 R&I engineers & technicians

€ 122 M Budget allocation in 2024

€ 154 M Own resources in 2024

ONE MISSION

Innovating for a **low-carbon** and **sustainable** world

ONE AMBITION

To be a **committed player** in the threefold ecological, energy and digital transition

an **institute open to society**, a creator of value and jobs,

and a **trusted third party** to public authorities

PATENT POSITIONING

Field	World Ranking *	Period	Details	Sources
Low-carbon technologies	**4th**	2000-2019	**1st** in CCUS and Alternative Fuels *3 French organizations in the top 10: CEA 1st, IFPEN 4th, CNRS 7th*	OEB & IEA European Patent Office International Energy Agency
Hydrogen technologies	**2nd**	2011-2020	*The world top 3 are French: CEA, IFPEN, CNRS*	OEB & IEA
Advanced plastics recycling	**1st**	2010-2019 1990-2023	**3rd** in Depolymerization of plastics (all categories combined, including companies)	OEB
Electricity grids	**9th**	2011-2022	**1st** in Stationary Storage	OEB & IEA

* world ranking of public research and higher education institutions

IFPEN SUBSIDIARIES AND SHAREHOLDINGS *

4,000 COLLABORATORS (IFPEN + SUBSIDIARIES)

Eco-energies & mobility

- 75% GreenWITS
- 24% DRIVE QUANT
- 18% la Cie des Mobilités
- 11% K-Ryole carry on
- 11% so sponge
- 6% Tec E Mouv

Processes & products, oil and gas, biomass, water, CO_2, materials recycling

- 99% Axens — Powering integrated solutions — An IFP Group company
- EURECAT
- 16% nacre
- 10% BioTJet

Geosciences consulting & software

- 100% BeicipFranlab
- 50 % CFG GEOTHERMAL
- 100% TECH advantage

Training

- 62% IFP Training

CONSOLIDATED TURNOVER OF €1,100 MILLION

* February 2025

LOW CARBON FUELS AT IFPEN

A LONG STORY FROM 1992 TO NOW

LOW CARBON FUELS TIMELINE

1992 First Biodiesel plant start-up **Esterfip** Technology

1998 Beginning of **Gasel®** development

2001 **Gasel®** demonstration plant start-up

2006 1st **Esterfip-H** start-up

2008 Beginning of **Atol®** and **Jetanol™** development

Beginning of **Futurol®** development

2010 Beginning of **BioTfuel®** development

Gasel® ready for commercialization

2011 **Futurol®** pre-commercial plant start-up

2015 **Futurol®** industrial demo plant start-up

1st **Vegan®** TotalEnergies La Mède Biorefinery project

2018 **Futurol®** ready for commercialization

BioTfuel® demonstration plant start-up

2020 1st industrial reference of **Futurol®** INA Sisak Biorefinery project

2021 **Jetanol™** 1st industrial reference, in collaboration with Gevo

BioTfuel® testing program completed

Vegan® 10 units under construction/design

2022 **BioTfuel®** ready for commercialization

1st **Atol®** plant start-up

2023 **BioTfuel®** 1st industrial reference **(BioTjet)**

LOW CARBON FUELS IFPEN-GROUP TECHNOLOGIES – 4 PATHWAYS COMPLYING ASTM D7566

HVO
Hydrotreated Vegetables Oil

-85% CO_2

Vegetable Oil
Animal Fats
Used Cooking Oil (UCO)

PRETREATMENT

HYDROTREATING

HYDROISOMERISATION

Vegan®

Biofuels and advanced biofuels

BTL and E-BTL
(E-)Biomass to Liquids

-90% CO_2

silvicultural residues
Agricultural wastes

Low carbon electricity

PRETREATMENT

GASIFICATION

O_2

WATER ELECTROLYSIS

H_2

PURIFICATION CONDITIONNING

FISCHER-TROPSCH UPGRADING

BioTfueL

BioTJet

Advances biofuels

EtOH and ETJ
Ethanol & ethanol to jet

-85% CO_2

silvicultural residues
Agricultural wastes

PRETREATMENT

HYDROLYSIS FERMENTATION

PURIFICATION

nacre

FUTUROL

Ethanol 1G

DESHYDRATATION

OLIGO

HYDROGENATION

Jetanol

Biofuels and advanced biofuels

E-FUELS

-95% CO_2

CO2

Low carbon electricity

CAPTURE CO_2

RWGS

H_2

WATER ELECTROLYSIS

O_2

FISCHER-TROPSCH UPGRADING

TAKE KAIR

Renewables biofuels

JET SPECIFICATION

➢ Certified routes

	ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
JET SPK	ASTM D7566 Annex 1	Fisc para		, biomass	50%
	ASTM D7566 Annex 2	Syn hyd		o-oils, animal fat, recycled oils	50%
	ASTM D7566 Annex 3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%
	ASTM D7566 Annex 4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%
	ASTM D7566 Annex 5			Biomass from ethanol, isobutanol or isobuthene	50%
	ASTM D7566 Annex 6	Catalytic hydrothermolysis jet fuel	CHJ	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%
	ASTM D7566 Annex 7	Synthesized paraffinic kerosene from hydrocarbon - hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%
	ASTM D7566 Annex 8	ATJ derivative starting with the mixed alcohols	**ATJ-SKA**		
CO-PROCESSING	ASTM D1655 Annex A1	co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	co-processed HEFA	Fats, oils, and greases (FOG) co-processed with petroleum	5%
	ASTM D1655 Annex A1	co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	co-processed FT	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
	ASTM D1655 Annex A1	co-hydroprocessing of biomass	co-processed biomass		5%

BTL and E-BTL
(E-)Biomass to Liquids

E-FUELS

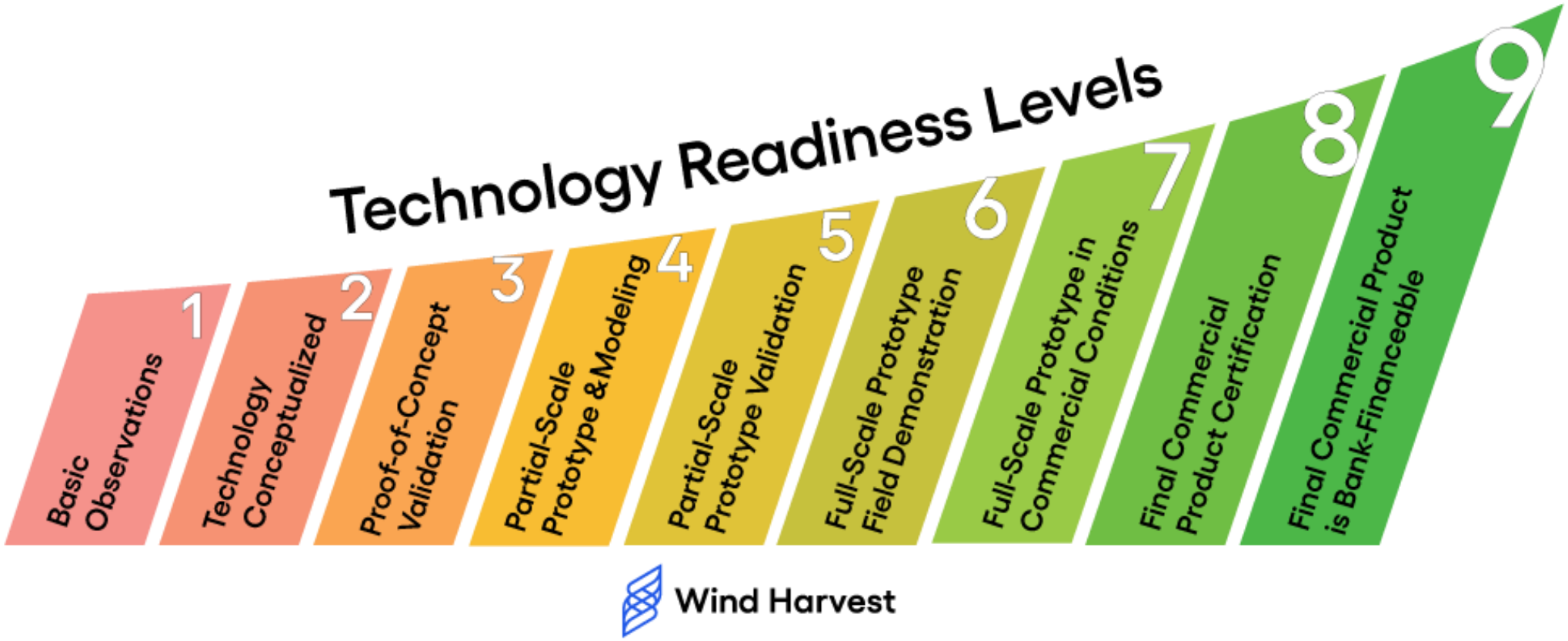
HVO
Hydrotreated Vegetables Oil

EtOH and ETJ
Ethanol & ethanol to jet

➢ Under evaluation

Conversion process under evaluation	Abbreviation	Lead developers
synthesized aromatic kerosene	SAK	Virent
Integrated hydropyrolysis and hydroconversion	IH2	Shell
Alcohol-to-Jet (ATJ) derivative utilising biochemical production of isobutene	-	Global Bioenergies
Single Reactor HEFA (Drop-in Liquid Sustainable Aviation and Automotive Fuel)	DILSAAF	Indian CSIR-IIP
Pyrolysis of non-recyclable plastics	ReOIL	OMV
Co-processing of pyrolysis oil from used tires		
Methanol to jet		ExxonMobil

TECHNOLOGY READINESS LEVEL - COMPARISON METHODOLOGY



HEFA ROUTE

A COMMERCIALIZED TECHNOLOGY

FOCUS HEFA

Renewable lipidic feeds and waste products

UCO

Tall Oil

Animal Fat

triglycerides

Pretreatment *

1st Step : HYDROTREATING

- Olefins Saturation
- Oxygen removal

Inter-stage separation

Bio propane, H_2O, CO, CO_2

n-paraffins

2nd Step : HYDROISOMERISATION

- Cold flow properties improvement

iso-paraffins

Cloud Point, CFPP, Freezing Point to meet commercial fuel specs

Vegan™ process

Drop-in FUELS

Renewable diesel

Renewable Jet fuel SAF

FOCUS HEFA

- Reactor technology close to existing facilities in refinery / use of existing assets
- Renewable ressources accessible : Used cooking oil, Vegetable Oils, animal fat…
- Many units in operation for renewable diesel production
  - Ex: VEGAN Process at La Mède (Rapseed Oil, UCO, Animal fat..)
- Main challenge towards SAF
  - Catalytic optimization especially for HDI stage / cold flow properties improvement and SAF Yield

Shandong Haike Chemical Successfully Starts Up China's First Axens Vegan® SAF Facility

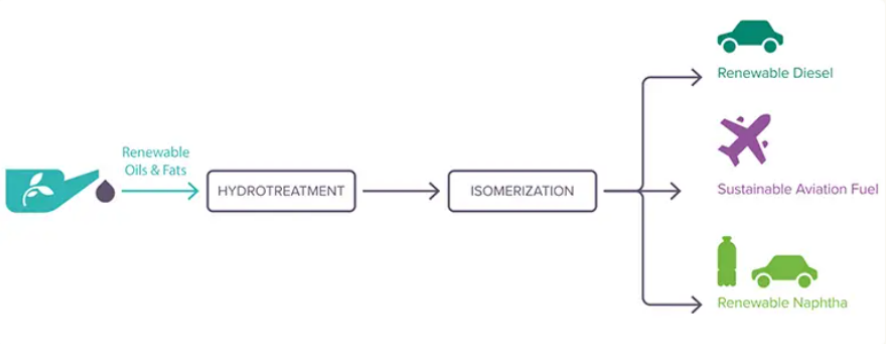
Shandong Haike Chemical Co., Ltd. achieved a major breakthrough in China's sustainable aviation fuel sector with the successful startup of its 500,000 tonnes per year SAF production facility on March 1, 2025. The plant represents the first commercial deployment of Axens Vegan® hydroprocessing technology in Asia and establishes a new benchmark for large-scale

https://bioenergyinternational.com/axens-starts-up-worlds-first-full-saf-vegan-unit-in-asia/

BIOENERGY INTERNATIONAL

Sustainable Aviation Fuel

Axens starts up world's first full-SAF Vegan unit in Asia

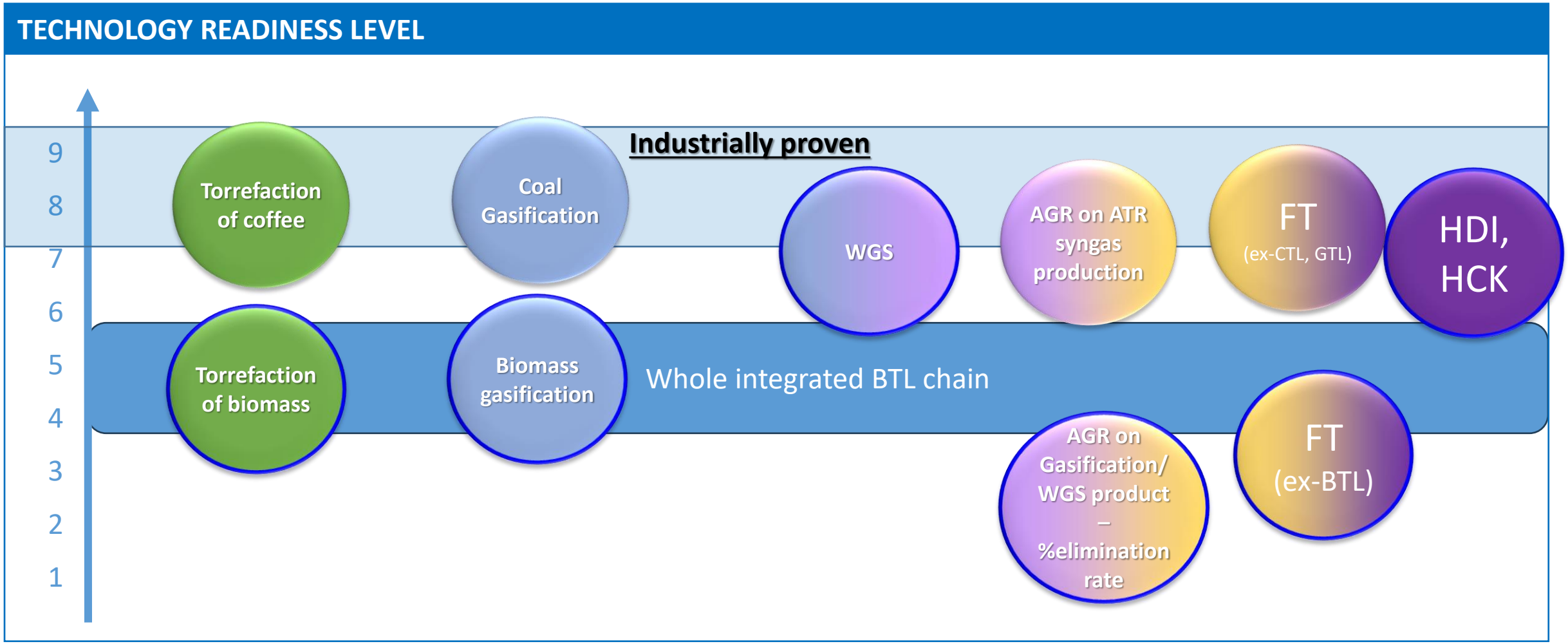


According to Axens, its "Vegan" technology is a second-generation hydrotreated vegetable oil (HVO) solution that processes up to 100 percent of any kind of lipid, including wastes from agriculture and the food industry to produce renewable fuels that are able to reduce greenhouse gas (GHG) emissions by up to 80 percent compared with a conventional jet fuel production scheme (graphic courtesy Axens).

BIOMASS-TO-LIQUID

TRL IMPROVEMENT / SCALE-UP STRATEGY

MATURITY ASSESSMENT ON BTL TECHNOLOGY BUILDING BLOCK EARLY DEVELOPMENT



BIOTFUEL EXAMPLE

BioTfueL

11 years of R&I (2010-2021)
6 partners

Avril · Axens SOLUTIONS · cea · IFP Energies nouvelles · TE · thyssenkrupp

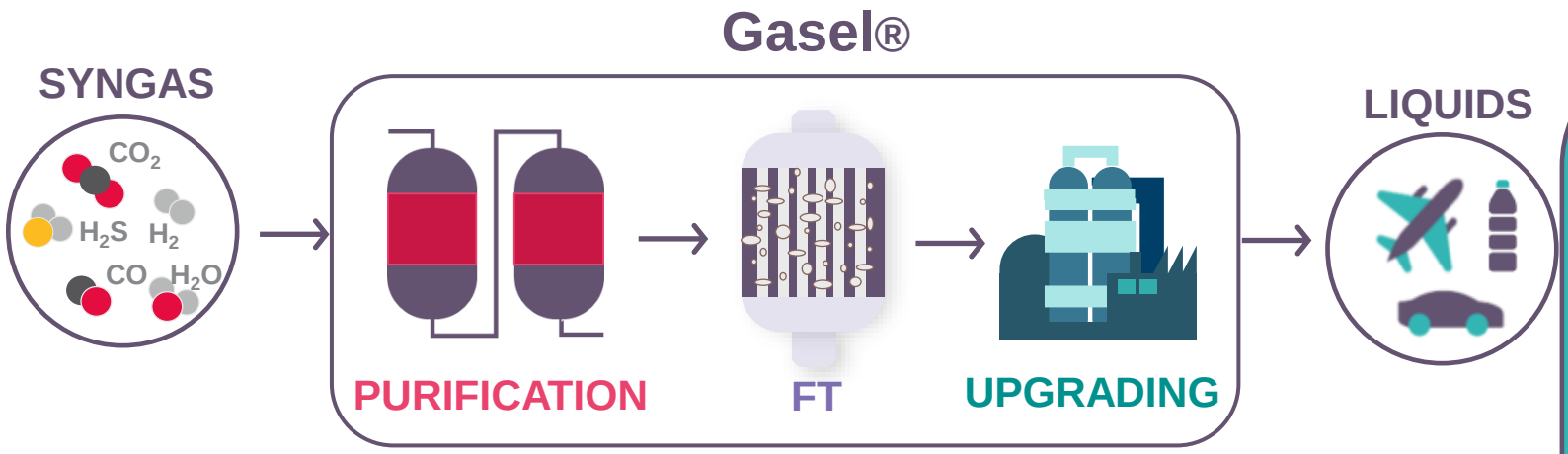
ifpen CRPE Centre de résultats produits énergétiques

1. Biomass Pretreatment
   - Demonstrate the technology at large scale
   - Different operating conditions for different kind of biomass
- Build and operate a demonstration unit

2. Gasification
   - Defined pneumatic transport parameters
   - Determine operating conditions
- Build and operate an **entrained-flow gasifier**

IFP Energies nouvelles

FISCHER-TROPSCH & UPGRADING A PROVEN TECHNOLOGY



FT

Slurry bed reactor - TRL 8-9
➢ pre-commercial demo plant to 25,000h operation Sannazzaro site

UPGRADING

110 industrial references

- **Key Features**
  - Slurry Bubble Column FT Reactor: Maintains product quality and high availability
  - High performance catalysts
  - Flexible Upgrading scheme: Kerosene or Diesel
- **Commercial technology**
  - 5 Designed references (1000 to 32000 BPSD)
  - 25 000 hours of operation of FT pre-commercial demo plant
  - > 110 references worldwide for upgrading
- **Several projects on track**

BIOTFUEL MATURITY : R&D RESULTS

RESULTS

Tests on tools of representative industrial scale making it possible to address design, operational and optimization issues

+ 1000 hrs of Gasification of pure biomass in Dunkirk

(Oak, Spruce, Poplar, Beech, Miscanthus, waste wood …)

+ 1500 hrs of torrefaction in Venette: product quality that meets expectations

Production of Fischer-Tropsch Waxes from Biomass : a global first, which validates the concept of the whole BioTfueL chain

UNIQUE LEARNING/REX from success and troubleshooting

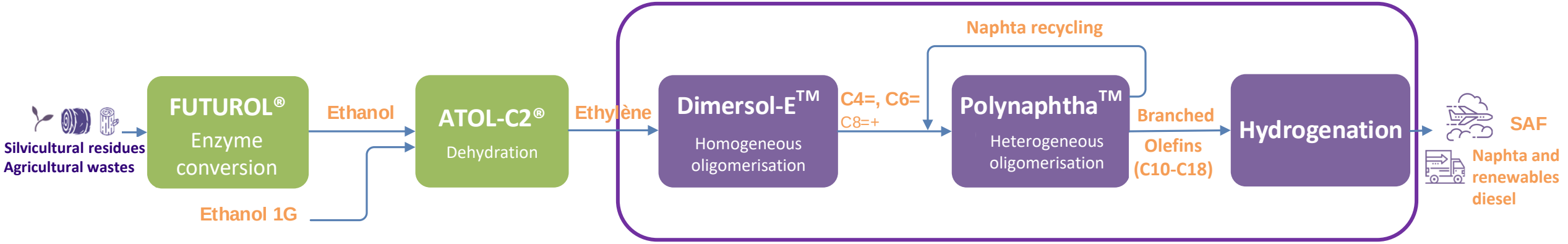
Now ready to commercialization - ex: BioTjet project

ETHANOL TO JET MATURITY

TRL ASSESSMENT

FOCUS ETJ

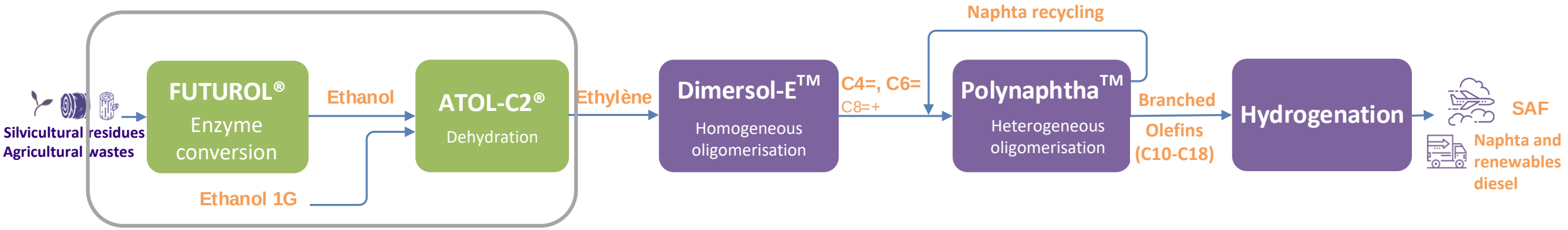
High TRL Processes



- Refining technology proven
- Overpowerd technologies at industrial scale since 70’s-80’
- Adaptation of those technologies to meet the specificities of effluents from ETJ (composition, impurities, feed rates, …)

FOCUS ETJ

Medium TRL processes



- 2 technologies recently developed
- FUTUROL aiming to produce ethanol as transportation fuel
- ATOL C2 aiming to produce high grade ethylene for polymer application

FUTUROL®

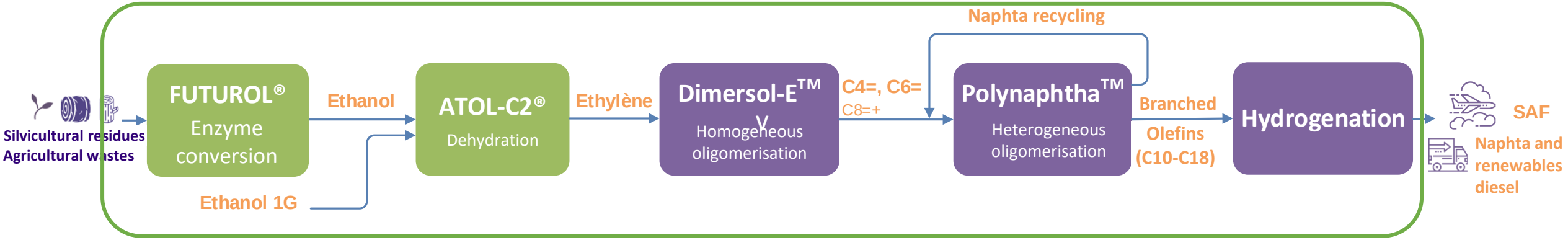
- R&D project launched in 2008
- Demo started in 2015
- Commercialization in 2018
- 1st reference industrial in 2020

ATOL®

- R&D project launched in 2008
- Commercialization in 2013
- Demo started in Japan in 2022

FOCUS ETJ

Increasing the whole chain TRL



R&D study of entire chain

- Maximize the SAF yield
- Energetic efficiency
- Impurities gestion

RESULTS

- 1G / 2G Ethanol compatibility
- Jet SPK with some by-products : gasoline, naphtha, diesel
- Yield SAF competitivity complying ASTM D7566 Annex 5
- Example : commercial reference Jetanol in 2021 – GEVO

GEVO AND AXENS INK ALLIANCE FOR ETHANOL-TO-JET TECHNOLOGY AND SUSTAINABLE AVIATION FUEL COMMERCIAL PROJECT DEVELOPMENT

October 12, 2021 PDF Version

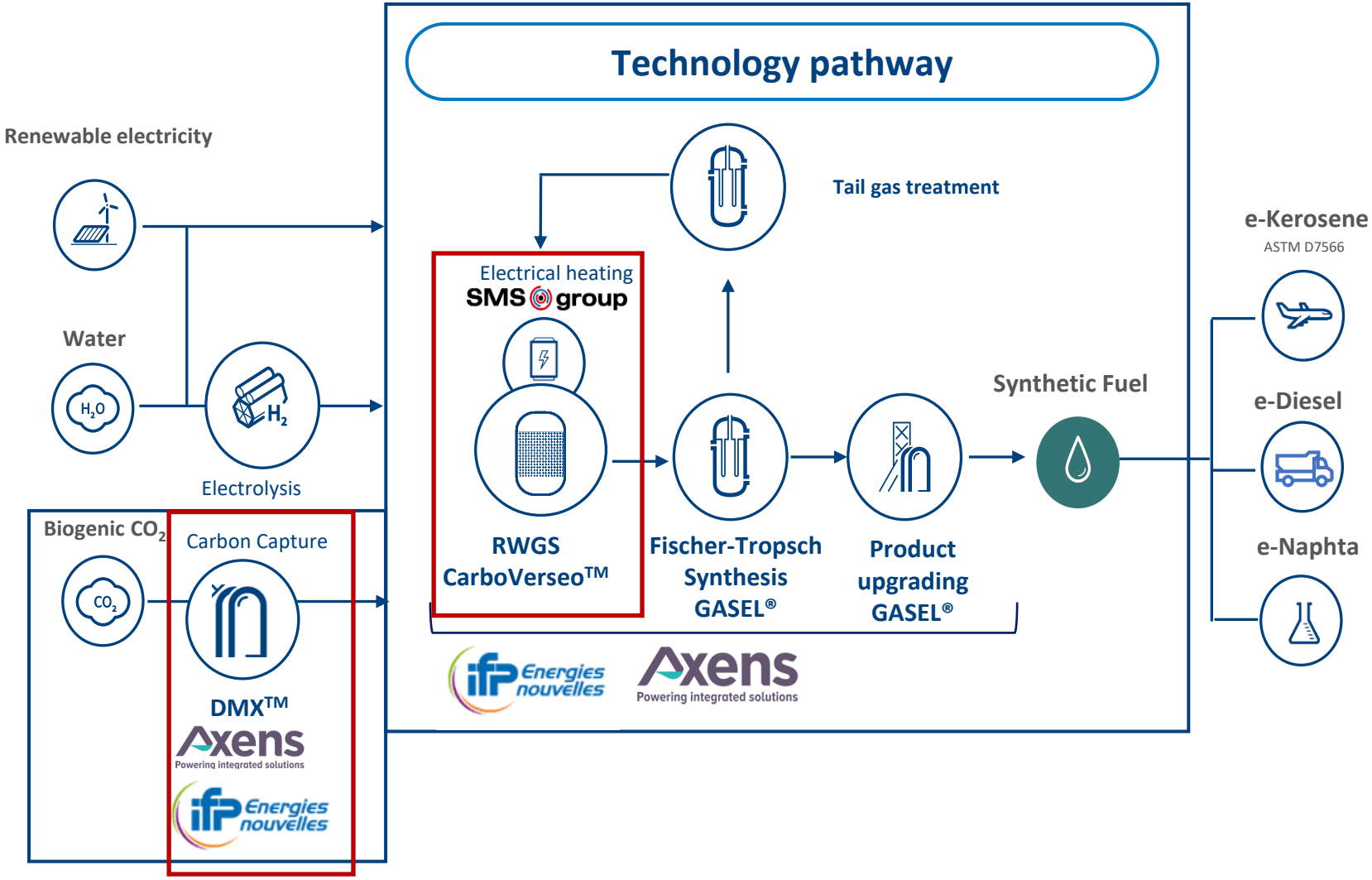
ENGLEWOOD, Colo., Oct. 12, 2021 (GLOBE NEWSWIRE) -- Gevo, Inc. (NASDAQ: GEVO) and Axens North America, Inc. (Axens) have entered into an agreement that establishes a strategic alliance aimed at accelerating the commercialization of sustainable ethanol-to-jet (ETJ) projects in the United States. As part of the alliance, Axens brings technologies with over 60 related patents; engineering packages; proprietary catalysts; and certain proprietary equipment required to convert ethanol into jet fuel. Axens would also provide process guarantees for commercial ETJ projects. Gevo expects to develop, own, and operate ETJ plants to produce sustainable aviation fuel (SAF), utilizing its expertise in renewable alcohol production and technologies; Net-Zero business model, project financing expertise; customer relationships, and contracts.

Axens has a long history of developing and commercializing best in class technology to convert olefins, such as ethylene, propylene, and butylene into hydrocarbon fuels and blend stocks such as gasoline, jet fuel, and diesel fuel.

E-FUEL

TRL ASSESSMENT

DEVELOPMENT OF E-FUELS TECHNOLOGY THROUGH RWGS & FISCHER-TROPSCH PATHWAY



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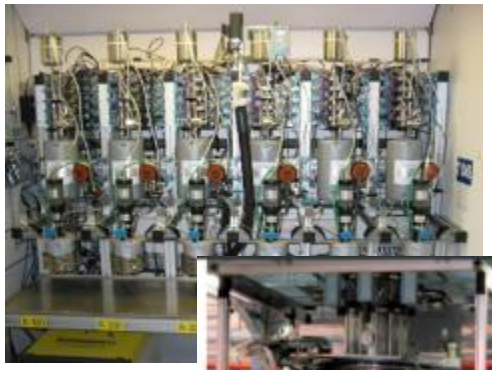
CO_2 CAPTURE FROM FLUE GASES (WITH DMX™)

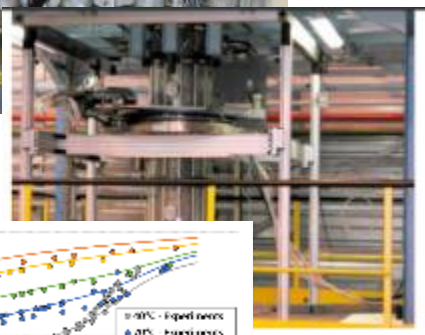
Demonstration to TRL 7-8
- **ready for commercialization**

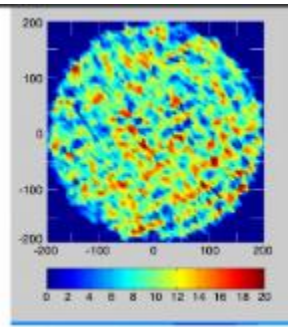
>7500h operation @ ArcelorMittal steel mill in Dunkirk

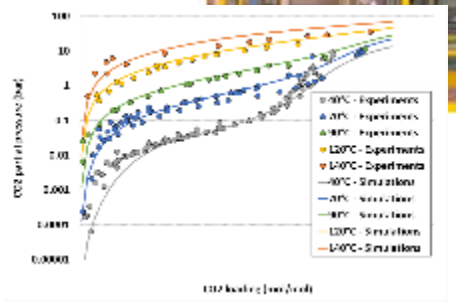
Solvent screening



Cold mock-up
CFD simulations







Process modelling
Thermodynamics, kinetics, physicochemical properties…

Process with strong coupling between hydrodynamics & chemistry

Laboratory scale

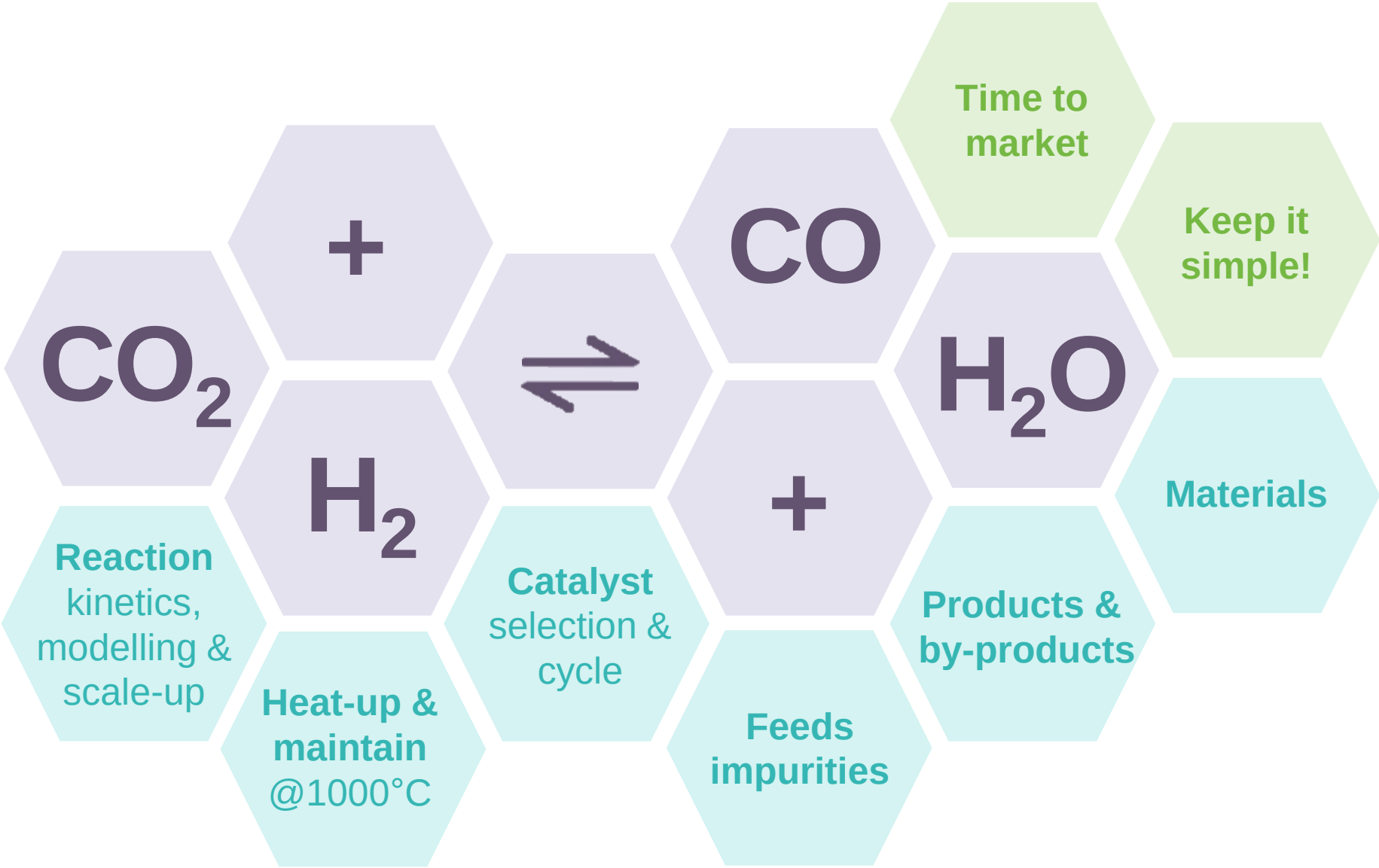
Pilot scale
0.2 kg CO_2/h

Industrial demonstration scale
0.5 tCO_2/h

CO_2 3D DMX DEMONSTRATION DUNKIRK

IFP Energies nouvelles · Axens · ArcelorMittal · TotalEnergies

RWGS: DERISKING STRATEGY



RWGS: DERISKING STRATEGY

SMS group

Heat-up & maintain @1000°C

0.5MW e-heater test stand
Representative of scale 1:1

Technology validation & certification

Potential Feedstock Impurities

- Diatomic gases → N_2, CO, H_2, O_2, Ar
- Sulfur compounds → H_2S, COS, SO_x
- Nitrogen compounds → Amine, NH_3, NO_x, HCN
- Organic compounds → Aldehyde, methanol, …

Kinetic Modeling and Experimentation

Additional purification steps

Reaction kinetics, modelling & scale-up

Products & by-products

Catalyst selection & cycle

Pilot unit testing & reactor modeling

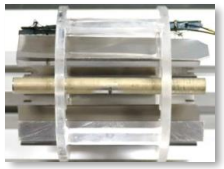
CFD for homogeneous gas mixing & velocity in RWGS reactor

No variation of catalytic performances **over 1000h**

- CO_2 conversion ± 0.07%
- CO selectivity ± 0.03%
- CH_4 selectivity ± 0.03%

Materials

Refractory material tests



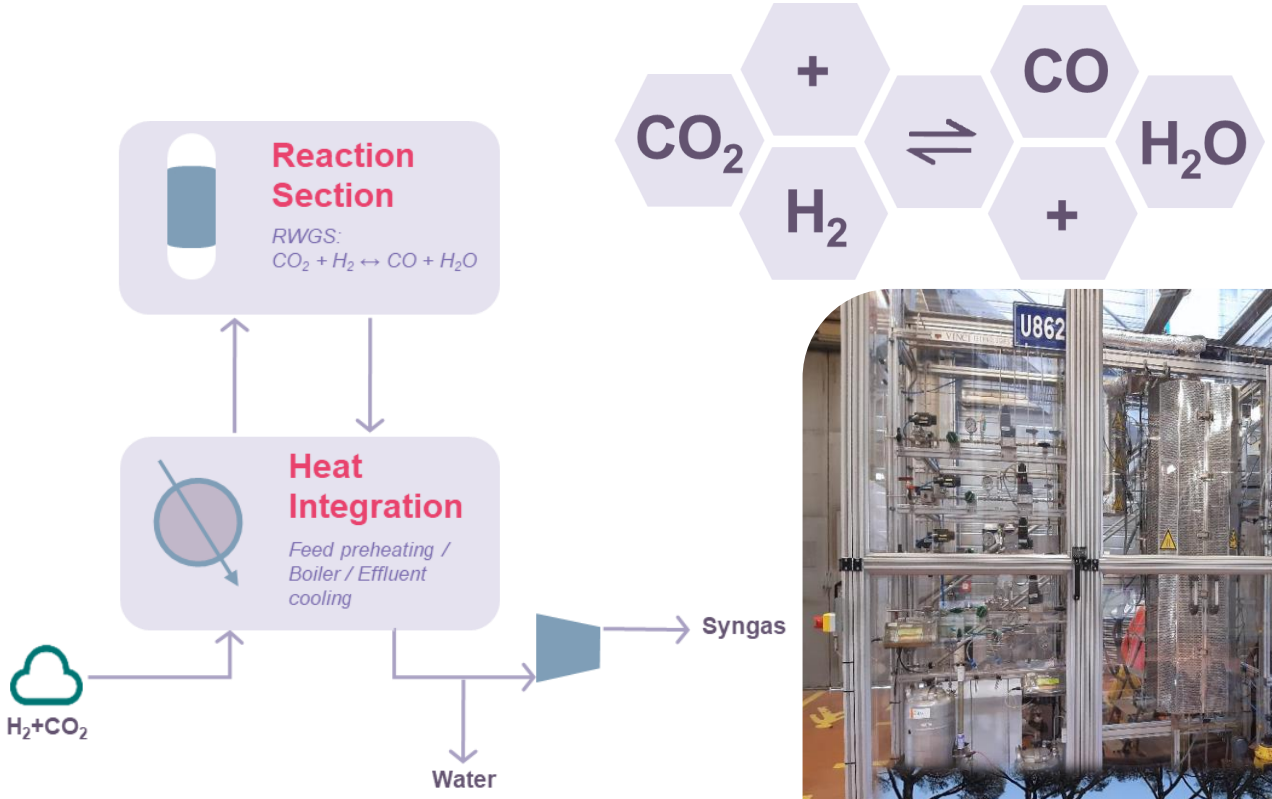
Metal dusting tests

SMS group

Finite Element Method (FEM) for compensation for thermal expansion

Design of refractory heating & drying curves

REVERSE WATER GAS SHIFT SOLUTION



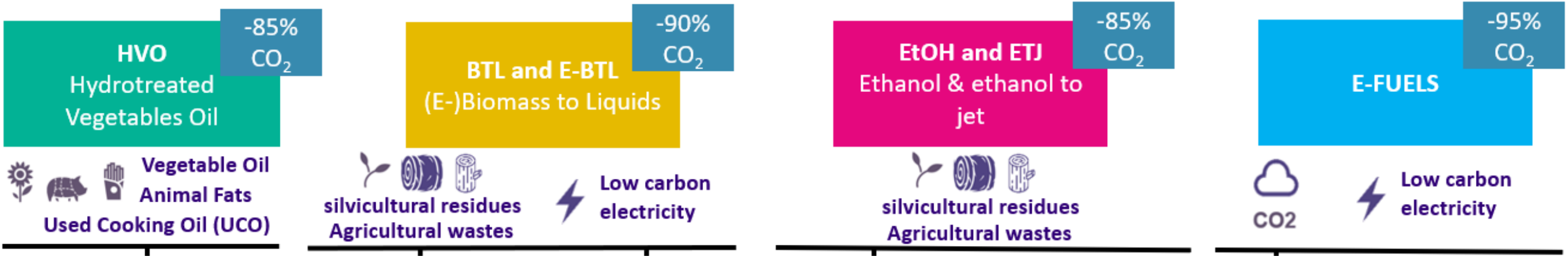
KEY FEATURES

- **Technology commercialized**
- Simple Process scheme
- Optimized conversion & CO selectivity
- Fully electrified
- Robust technology selection
- Industrial ready catalyst

CarboVerseo ™

A new milestone has been reached for the Take Kair project, which is among the winners of the Innovation Fund. The European Union's Climate, Infrastructure and Environment Executive Agency (CINEA) has pre-selected this e-kerosene production project for financial aid. The future plant, located on the Nantes Saint-Nazaire port area in Loire-Atlantique, will produce 37,000 tons of e-kerosene, a synthetic fuel produced from low-carbon and renewable hydrogen. The project, led by Hynamics, the hydrogen subsidiary of the EDF group, and Meridiam, a mission-driven company investing in and managing long-term sustainable public infrastructure, will contribute to the decarbonization of the aviation sector and will be integrated into a favorable regional ecosystem.

TRL SUMMARY



TRL 9

Already industrial
Lower cost and CAPEX
Limited resources in a close future

TRL 7-8

First industrial project in discussion
Various Demo in operation
Larger amount of feeds
FT/upgrading proven technologies

High CAPEX

TRL 7 on 2G Alcohol production stage

TR 8 on Jetanol process highly selective

Medium CAPEX

TRL 6-7

RWGS still under Derisking stages

High CAPEX

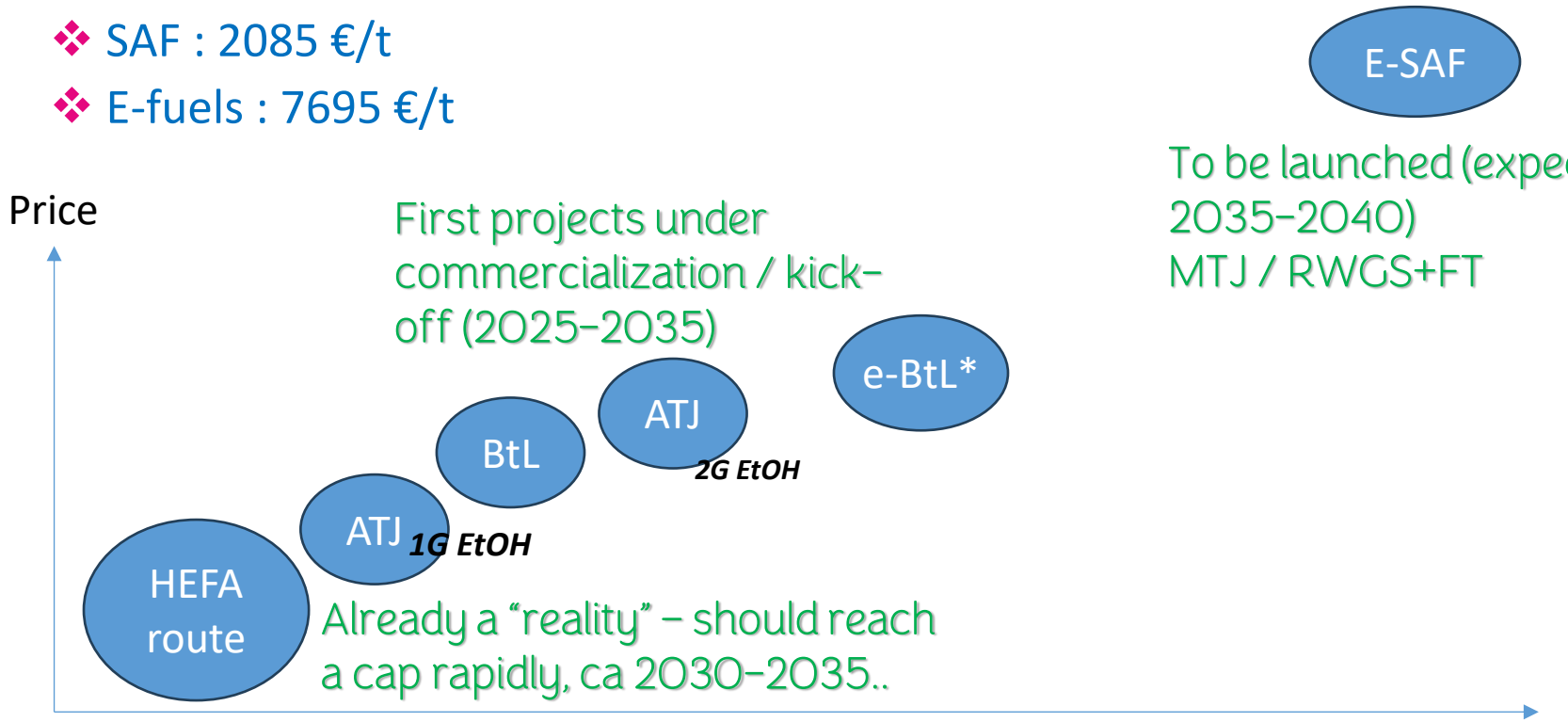
CONCLUSIONS AND FINAL THOUGHTS

MARKET / PRICE / AVAIBILITY

AVAIBILITY OF SAF ACCORDING TO PATHWAYS

https://www.easa.europa.eu/en/downloads/141675/en

- EASA (European Union Aviation Safety Agency) referential of SAF prices (to allow calculation of penalties)
  - HEFA kero approximatively the price of UCO
  - Baseline fossil Kerosene : 734 €/t
  - SAF : 2085 €/t
  - E-fuels : 7695 €/t



SOME R&I PERSPECTIVES

- Hydrogen incorporation to adjust H_2/CO ratio before FT synthesis
  - Suppressing WGS in BtL chains
  - Carbon yield improvement depending on technologies

- RWGS maturity
  - Allow to convert most of the bio-carbon
  - Sensitivity to impurities
  - Integration in productions chains
  - ..

- Improving FT selectivity : catalyst, reactor, process

- Improving catalysts activity in all the routes: minimize catalyst consumption, allow re-use (catalyst regeneration…), maximize cycle length..

- To be continued

Innovating for energy

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