INTERNATIONAL COOPERATION FOR SUSTAINABLE AVIATION BIOFUELS

International Cooperation on Sustainable Aviation Biofuels

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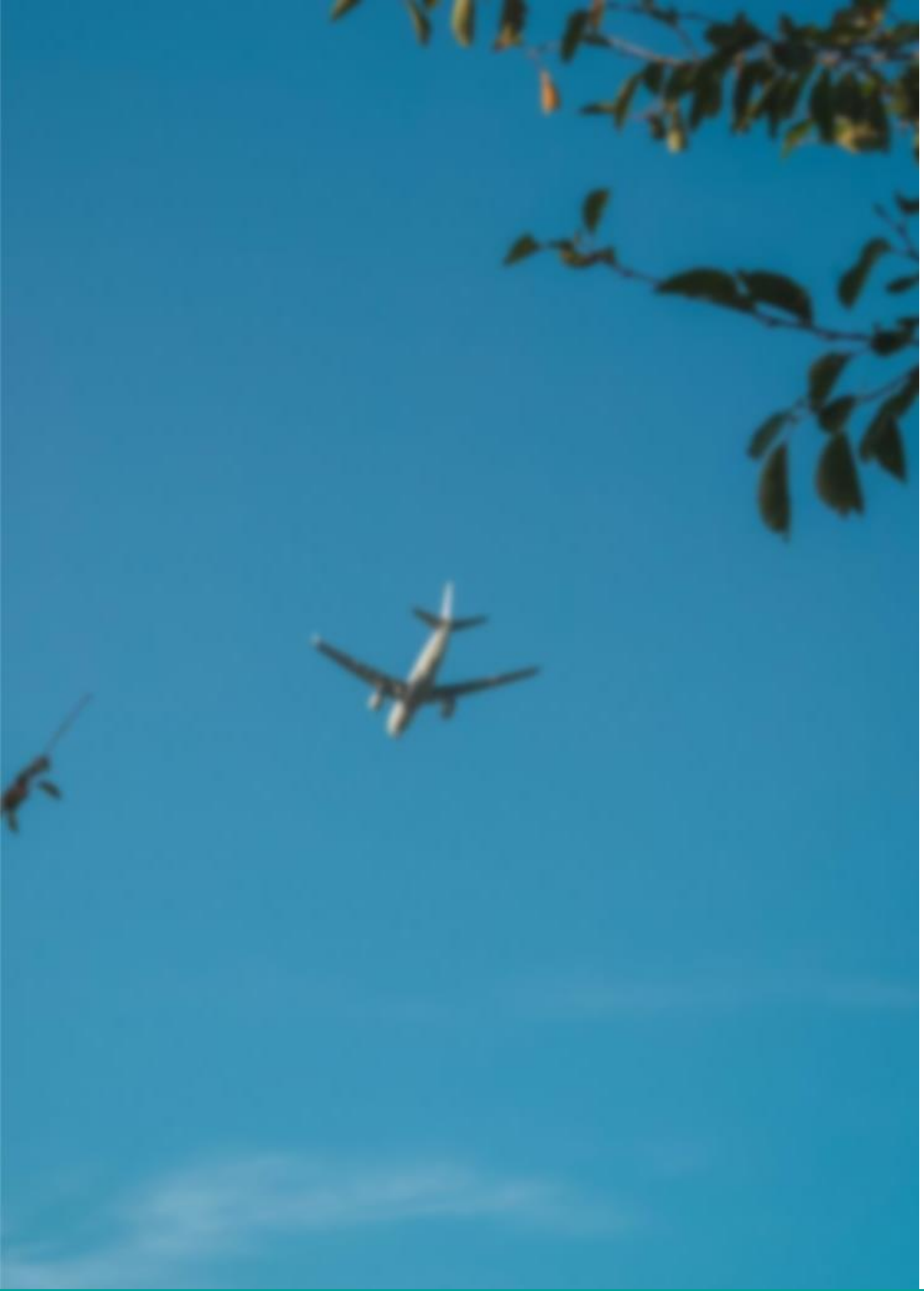

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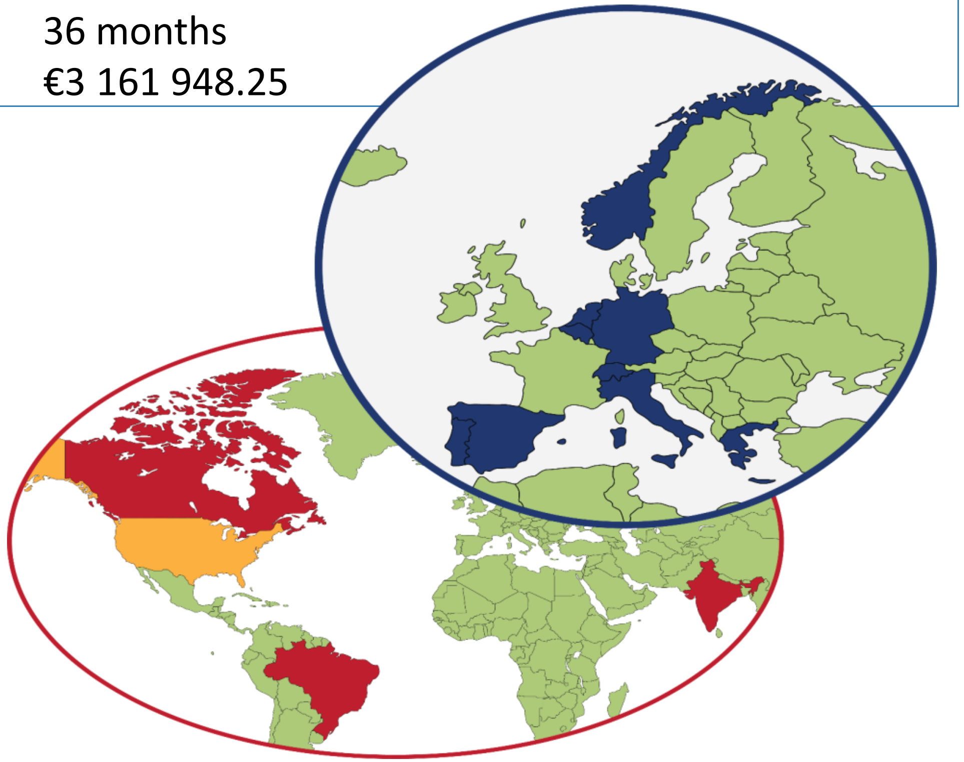
Project Details	
Project:	101122303—ICARUS—HORIZON-CL5-2022-D3-03
	Best international practice for scaling up sustainable biofuels
Service:	CINEA/C/02
Starting date:	1/10/2023
Duration:	36 months
Budget:	€3 161 948.25



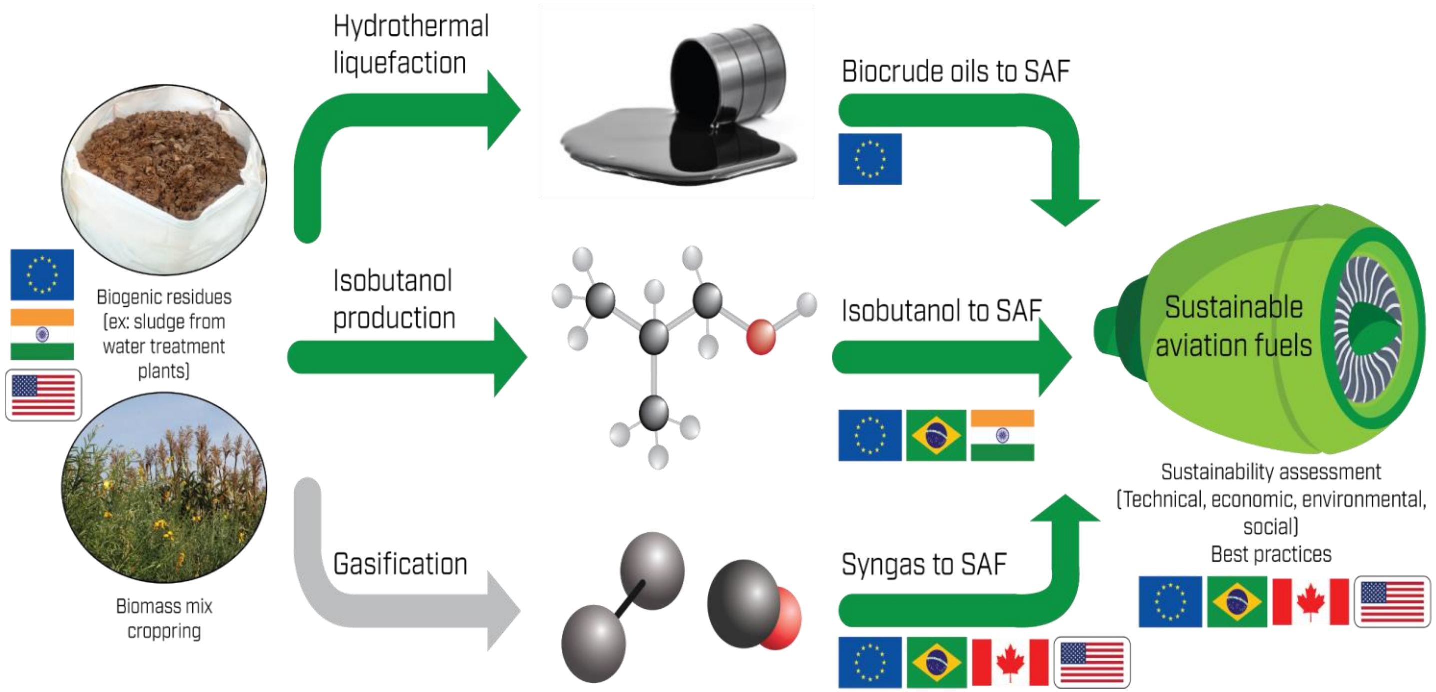
	Participants	Status	Country
1	CRES	RTO	Greece
2	LNEG	RTO	Portugal
3	TNO	RTO	Netherlands
4	NTNU	University	Norway
5	SINTEF	RTO	Norway
6	WIP	SME	Germany
7	DBFZ	RTO	Germany
8	UNIBO	University	Italy
9	BIOREF	RTO	Portugal
10	PETROGAL	IND	Portugal
11	EHU	University	Spain
12	NovelYeast	SME	Belgium
13	NEVIS	SME	Greece
14	KM-IIC	Consultant	Belgium
15 (AP)	RSB	NGO	Switzerland
16 (AP)	UDS	RTO	Canada
17 (AP)	EciEvolv	RTO	India
18 (AP)	AVIONIC	SME	India
19 (AP)	SENAI RN - ISI-ER	RTO	Brazil
20 (AP)	SENAI CIMATEC	RTO	Brazil

External Executive Advisory Board

Members of the External Executive Advisory Board Key expertise	Contribution in the project
Dr Robert Baldwin, NREL Extensive experience in catalysis, reaction engineering, biomass gasification, biomass liquefaction, upgrading of bio-oil, and advanced biofuels.	Innovation in Syngas-SAF Value Chains (WP2)
Dr Marisol Berti, NDSU Expert in forage, cover crops, and bioenergy crops production research. Sustainability and resilience and environmental impact of cropping systems.	Innovation in feedstock (WP2)
Prof. Glaucia Souza, FAPESP Bioenergy Research Program Coordinator University of São Paulo Full Professor, IEA Bioenergy TCP Task 39 Co-Leader on Biofuels to Decarbonize Transport	Capacity building globally (WP5)
Tomas Ekbom, Program Director, BioDriv, Svebio – Swedish Bioenergy Association IEA Bioenergy TCP Task 39 Co-Leader on Biofuels to Decarbonize Transport	
Marco Buffi, JRC Expert in GHG emissions calculations of SAF for both REDIII and ICAO CORSIA' initiative	Sustainability assessments (WP3)
Themistoklis Neokosmidis, Concawe Low Carbon Pathways Science Associate	Coordination with the Oil Sector (WP4)

Objectives

To develop **best practices** (based on improved innovative technologies) **and concepts** (founded on market access knowledge) along **three most promising pathways for SAF development** in both Europe and Mission Innovation Countries, considering their technical feasibility, economic viability, and environmental impact.



Specific objectives

- ✓ **To evaluate the framework conditions for SAF development** in Europe and Mission Innovation Countries, along the three major value chains
- ✓ **To improve scaling up of selected promising technologies** in Europe and MIC, specifically on topics/technological challenges which hinder the market deployment.
- ✓ **To enhance overall cost-effectiveness and sustainability** of large scale production of sustainable biofuels based on Life Cycle Analysis addressing social, economic and environmental aspects for selected value chains.
- ✓ **To develop future best practices and concepts** along the entire values chains, based on experiences and lessons learnt built on European and MIC. To set guidelines for scaling-up and synergies between the private industry and the scientific community at European and global level.
- ✓ **To effectively disseminate and exploit ICARUS activities and results** among important international stakeholders and end users as well as the general public

Overview of WP1 Tasks

- Tasks 1.1-1.5 (under completion)

➢ T1.1 - Overview of biogenic feedstocks (**M6**) - Task Leader: Myrsini Christou

➢ T1.2 - Overview of the VC biocrude oils to SAF (**M6**) - Task Leader: Paula Costa

➢ T1.3 - Overview of the VC isobutanol to SAF (**M6**) Task Leader: Iker Aguirrezabal

➢ T1.4 - Overview of the VC syngas to SAF (**M6**) – Task Leader: Berend Vreugdenhil

➢ T1.5 - Policies overview (**M6**) – Task Leader: Kyriakos Maniatis

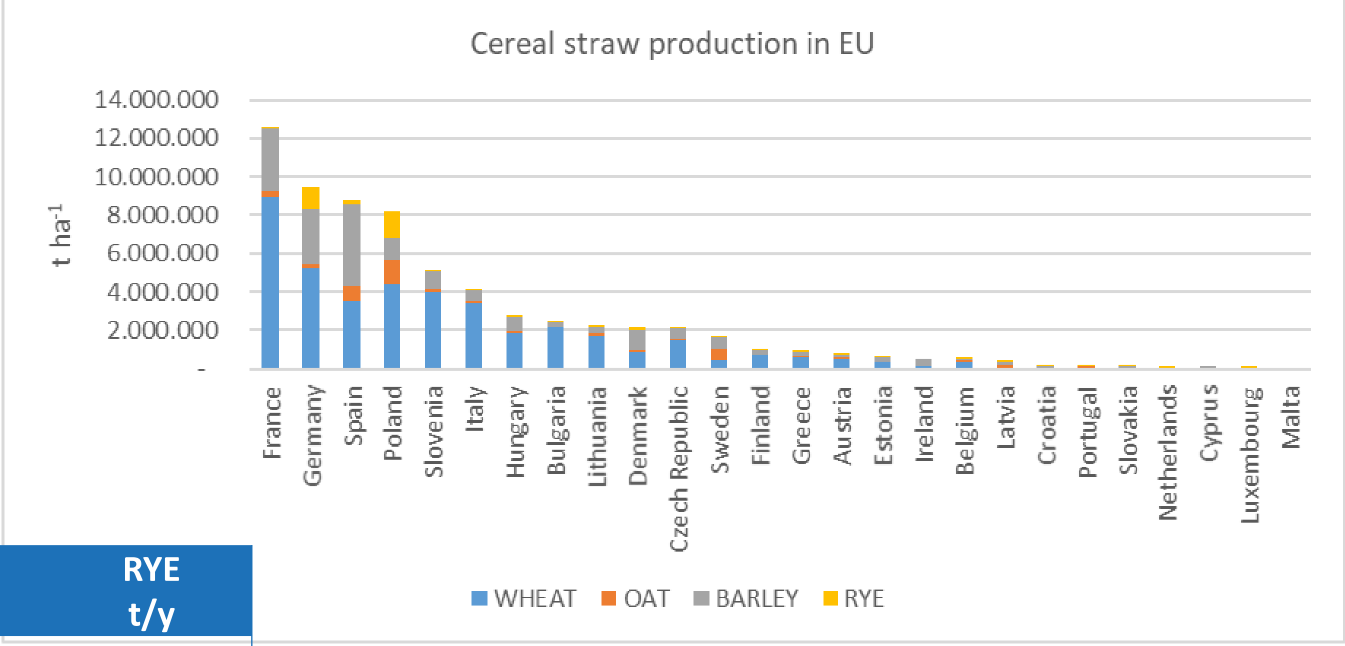
- Task 1.6 and T1.7 (in progressing)

➢ T1.6 - Systemic constrains (M12) – Task Leader: Alda Rodrigues (BIOREF)

➢ T1.7 (T1.5) – Policies update (M18) – Task Leader: Kyriakos Maniatis (KM-IIC)

Agricultural residues

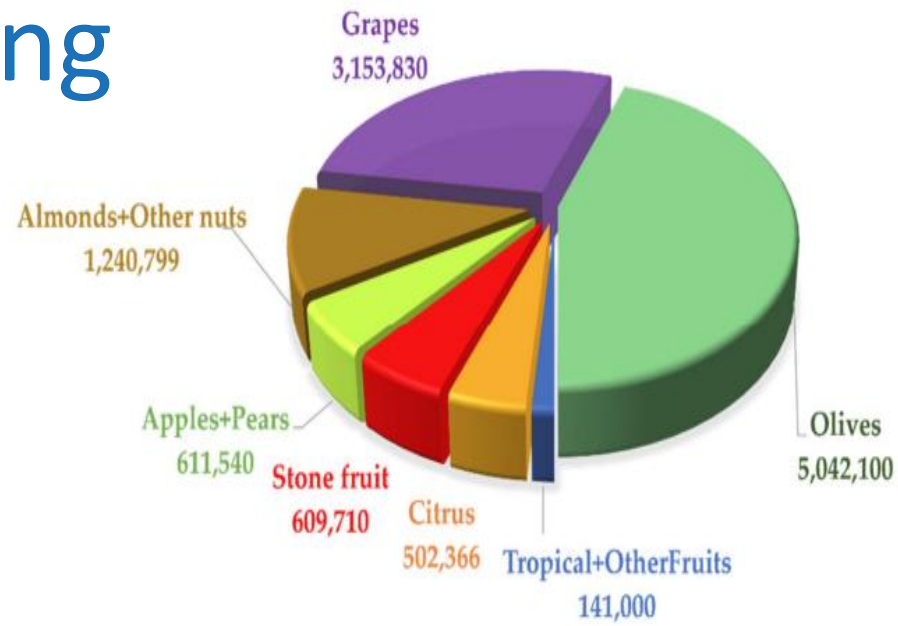
- Agricultural residues are available
- The challenge lie in the competition with other markets and feed

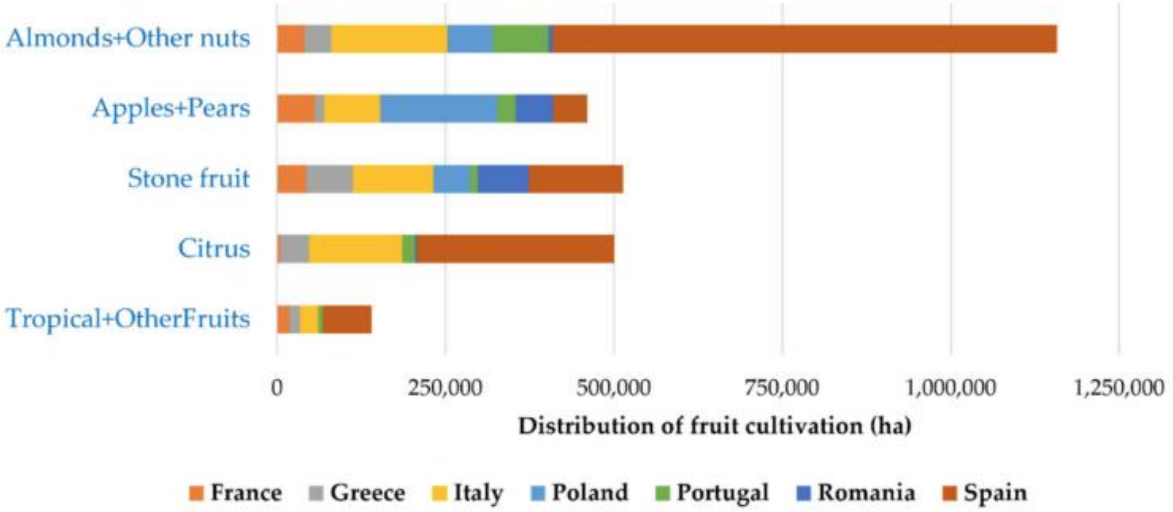


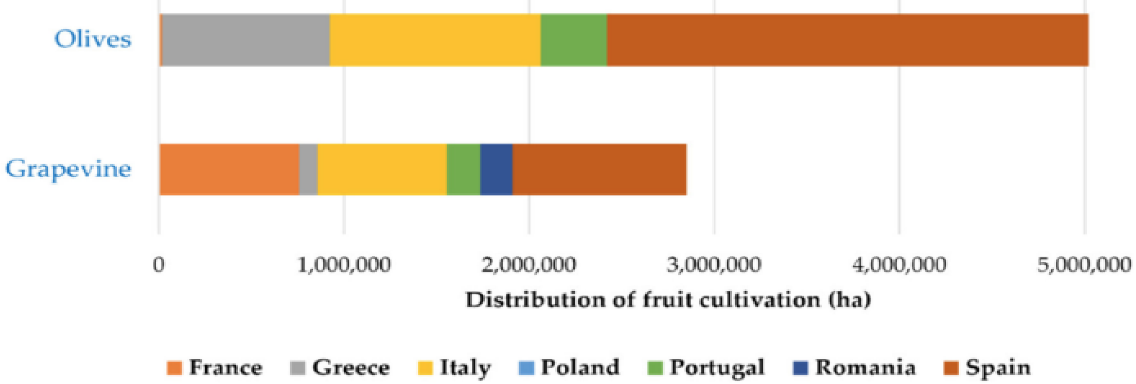
	WHEAT t/y	OAT t/y	BARLEY t/y	RYE t/y
EU- 27 (2020)	**41,604,876**	**4,764,366**	**18,599,832**	**3,511,260**

Feedstock	Mois-ture	Ash Content	Volatile matter, daf	Fixed C daf	C	H	O	N	S	H	LHV	HHV
	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	mg/kg	Mj/kg	Mj/kg
CEREALS												
Barley	11,53	5,20	80,85	19,15	49,09	6,06	44,14	0,64	0,08	2.908,00	18,52	19,85
Corn Stover	6,06	4,75	85,17	14,83	49,31	6,04	43,56	0,70	0,11	2.803,00	17,75	19,06
Rice	11,73	17,79	82,18	17,82	49,15	6,23	42,13	1,59	0,13	7.803,60	17,11	18,47
Rye					49,64	5,85	44,16	0,25	0,04	624,90	18,49	19,78

Pruning







- Pruning is still challenging
- Innovations lie in improving the logistics, mainly in the collection of the harvestable material from the fields

Pruning	Mois-ture	Ash Content	Volatile matter, daf	Fixed C, daf	C	H	O	N	Sulphur	Halides	LHV	HHV
	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	mg/kg	Mj/kg	Mj/kg
TREES												
Olive tree	6,30	5,43	86,52	13,48	51,91	6,26	46,82	1,06	0,10	859,90	19,75	20,15
Vineyard pruning	9,13	8,61	73,51	26,49	50,31	5,56		1,17	0,09	348,30		20,13
Orange tree	31,09	3,02	84,66	15,34	48,58	5,53	44,72	1,08	0,06		17,70	18,91
Almond tree	11,40	1,67	80,52	19,48	50,11	6,03	43,22	0,63	<0,05		19,84	18,53

Municipal solid wastes

- High environmental burden - profitable use for SAF
- Increasing trend in MSW generation, that justifies the importance of this source.

BIO FOOD WASTE		Total	Food waste - bio, household and similar waste
GEO (Labels)	Capita	kg per capita	t
European Union - 27 countries (from 2020)		130	55.820.322
Belgium	11.629.213	250	2.907.303
Bulgaria	6.520.314	108	704.194
Czechia	10.524.167	91	957.699
Denmark	5.873.420	221	1.298.026
Germany	84.432.670	131	11.060.680
Estonia	1.328.439	125	166.055
Ireland	5.011.500	154	771.771
Greece	10.678.639	191	2.039.620
Spain	47.326.687	90	4.259.402
France	68.128.000	129	8.788.512
Croatia	4.036.355	71	286.581
Italy	58.929.360	136	8.014.393
Cyprus	888.000	397	352.536
Latvia	2.003.000	145	290.435
Lithuania	2.860.002	137	391.820
Luxembourg	645.397	147	94.873
Hungary	9.730.772	93	904.962
Malta	516.100	154	79.479
Netherlands	17.641.147	161	2.840.225
Austria	9.027.999	136	1.227.808
Poland	38.039.000	112	4.260.368
Portugal	10.344.802	176	1.820.685
Slovenia	2.120.937	68	144.224
Slovakia	5.447.000	106	577.382
Finland	5.541.000	116	642.756
Sweden	10.545.310	89	938.533

Energy crops

- ✓ Oilseed crops:
  - ✓ Carinata, camelina, castor, solaris energy tobacco, salicornia, pennycress, jatropha
- ✓ Sugar/starch crops;
  - ✓ Sweet sorghum
- ✓ Lignocellulosic crops
  - ✓ Switchgrass, Miscanthus, Giant reed, Reed canary grass

- ➢ Low TRL
- ➢ Innovations in cropping systems

Non-food oil crops	Seed yields t/ha	Oil content %	Oil yields t/ha
Carinata	2.7	42-52%	1.1-1.4
Camelina	1.3-2.5	39-41%	0.5-1.0
Castor	4.3-4.8	42-55%	2.0
Solaris energy tobacco	1.1-1.8	30-40%	0.4-0.7
Salicornia	2.0	30%	0.6
Pennycress	1.5-2-5	36%	0.5-0.9
Jatropha	4.0-5.0	40-60%	1.6-2.9

Lignocellulosic crops	Yields (t/ha)	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Switchgrass	8-13	45	31	12
Miscanthus	10-30	38-40	18-24	24-25
Giant reed	10-30	30-32	32-38	18-19
Grass Esparto	8-10	33-38	27-32	17-19
Sugarcane whole		25	17	12

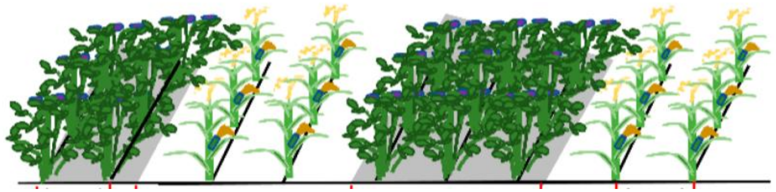
Feedstock– Technical novelties

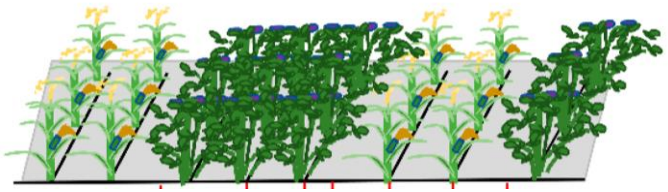
Feedstock

Assure sustainable, affordable and diversified biomass feedstock

Innovations

- Biomass sorghum mix cropped with legumes and cover crops
- Managing the species combination ratios in the mixed cropping system, the lignocellulosic, oil and mineral composition of blended feedstocks can be somehow regulated.
- Mix cropping systems, integrated within a conventional food crop rotations will increase biomass availability by 3 to 4 times, contribute to a more efficient use of land resources and reduce GHG emissions.





Feedstock – Current status

Tasks

T2.1.1: Preliminary trial in growth chamber

Current Status

- Pot trial in greenhouse (spring-summer 2024). Intercropping is not being tested; rather, the interaction between the 4 different crops and the PGPR (plant growth-promoting rhizobacteria) is being individually assessed

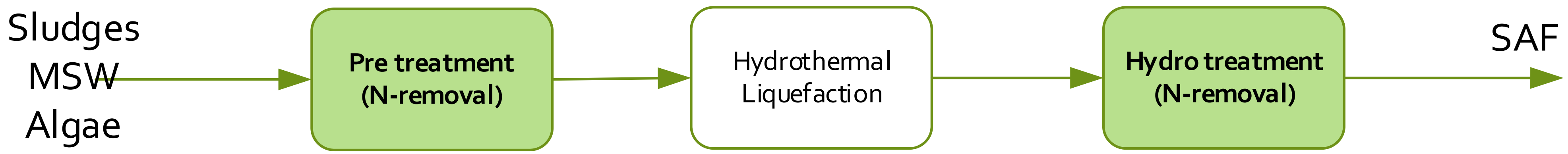
Value chain 1 – Technical novelties

1 **Biocrude Oils to SAF**

Evaluating and analyzing innovative and promising catalytic hydrotreatment approaches for biocrudes produced through Hydrothermal Liquefaction (HTL).

Innovations

- Improvement of feedstock pretreatment and HTL processing to reduce the nitrogen in the biocrude prior hydrotreating.
- Creation of an innovative catalyst bed with blends of strategical catalysts to simplify the hydrotreatment process by decreasing the steps, energy/H2 consumption and materials applied.



Value chain 1 – Current status

Tasks

T2.2.1: Efficient HTL for high quality biocrude

T2.2.2: Bio-oil upgrading processes in a single step

T2.2.3: Kinetic studies in batch operational system

Current Status

- Best performance: 1M H_2SO_4 with additional heat treatment
- pH adjustment after acid treatment seems promising and no permanent gelling is observed

- The oxygen removal was efficient
- N removal wasn´t complete

- Commissioning of the system, implementing of process automation
- Working on experimental design

Value chain 2 – Technical novelties

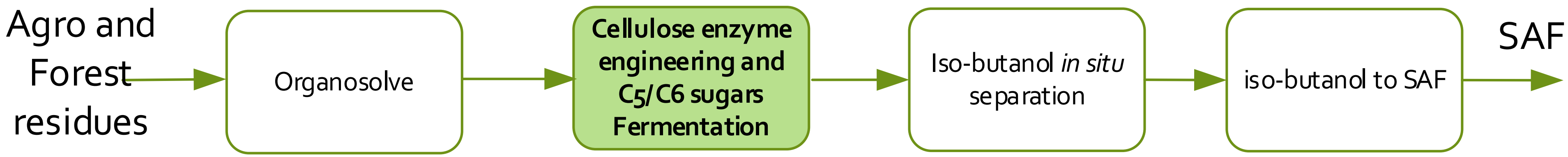
2

Alcohols to SAF

Exploring various methods for converting alcohols, such as ethanol and methanol, into sustainable aviation fuels, taking into account technological advancements and economic considerations.

Innovations

- to optimize yeast for the direct conversion of cellulose and C5 and C6 sugars into isobutanol
- to engineer secretion of cellulolytic enzymes in 2G isobutanol yeast
- to minimize the need for an expensive cocktail of enzymes and lower enzyme cost in biomass saccharification



Value chain 2 – Current status

Tasks	Current Status
T2.3.1: Fractionation of C5 and C6 sugars	➢ Lab-scale pre-extraction and fractionation
T2.3.2: Cellulolytic enzyme engineering	➢ Beta-glucosidase enzyme stably expressed as cell wall attached protein in the 2G isobutanol strain BMD191 resulting in strain IMD1 ➢ Strain IMD1, expressing the cell wall attached beta-glucosidase, was able to utilize about 25g/L cellobiose in less than 48h, and produced about 12g/L isobutanol (1.2%) ➢ The rate of cellobiose utilization was very good (± 0.5 g/L.h), but can be improved further by genomic integration of additional gene constructs for beta-glucosidase
T2.3.3: Kinetic studies in batch operational system	➢ Acquisition of Pilot PV system - under-contract, waiting for delivery

Value chain 3 – Technical novelties

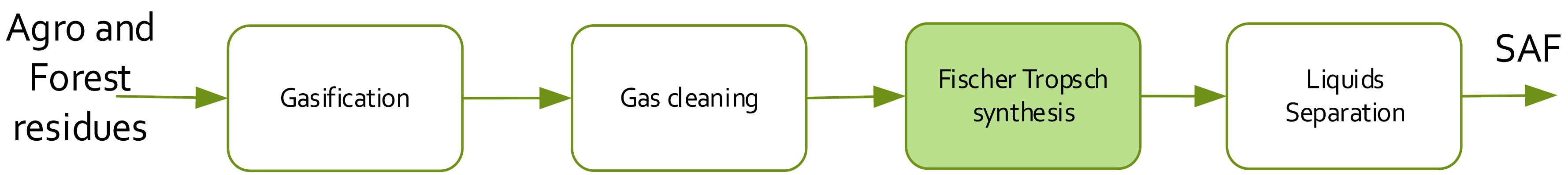
3

Syngas to SAF

Assessing the current and emerging technologies for syngas production from gasification, gas conditioning, and upgrading, as well as analyzing the relevant policy developments and regulatory frameworks.

Innovations

Design and testing of a new FT catalyst,
- to produce only liquid products
- to allow smaller sized plants fitting much better with the local availability of biogenic residues.
- to significantly reduce the CAPEX and hence improve the economic viability of this pathway.



Value chain 3 – Current status

Tasks	Current Status
T2.4: Develop a new FT catalyst maximizing liquid yield product	➢ Syngas-to-SAF through olefin synthesis identified as most promising ➢ Highest selectivity obtained with Na-Ru/SiO2 catalyst

Sustainability Analysis – Technical novelties

Sustainability

To secure a sustainable transition to a large-scale use of SAFs

Innovations

- To establish a novel framework for the sustainability analysis from a value chain perspective of SAFs that are at a precommercial stage, to facilitate their sustainable development and realize sustainability-driven innovation.
- The environmental analysis will take a future-oriented (prospective) approach to embed forthcoming technological and socio-economic changes
- New approaches will be used to estimate effects of scaling-up the technology to a commercial scale
- The process model-based approach will provide a basis to systematically connect processing stages also to reverse-engineer decision making suggesting means to debottleneck conversion and downstream inefficiencies

Best practices and concepts

Best practices

To develop future best practices and concepts along the entire value chain for the three technological pathways selected in Icarus

Innovations

- To propose a set of recommendations to accelerate the scaling up of the three value chains
- Create strong synergies between the private industry and the scientific community by providing further guidance for SAF certification and coordinating the engagement with oil industries, airports and end-users
- Foster international knowledge transfer to establish long-lasting interactions on the upscaling of SAF, with special focus on the MIC and Africa

Further reading

Deliverables (soon to be released in our website @ https://www.icarus-biojet.eu/)

- D1.1 Overview of biogenic feedstocks
- D1.2 Overview of the Value Chain: Biocrude oils to SAF
- D1.3 Overview of the Value Chain: Alcohols to SAF
- D1.4 Overview of the Value Chain: Syngas to SAF
- D1.5 Policies Overview for SAF

Thank you for your attention

Stay tuned….

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Partners

Associated Partners

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