PYROBIOFUEL

LEAP-RE

Long-Term Joint EU-AU Research
and Innovation Partnership on Renewable Energy

The LEAP-RE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

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Consortium

Project coordinator:

- *Cairo University, Egypt*

Project partners:

- *Cairo University, Egypt*
- *Ibn Tofail University – Research Institute for Solar Energy and New Energies (IRESEN), Morocco*
- *Uni. Witwatersrand, South Africa*
- *Brandenburg University of Technology, Germany*
- *CNRS PIMM, France*

Aim of the project

Create a unique knowledge infrastructure that supports decentralized, sustainable, and cost-efficient conversion of biomass to sustainable fuels, relevant to both Europe and Africa

Relevance vs MARs

MAR3: Smart stand-alone systems

PyroBioFuel will design and validate innovative processing technologies, including a compact catalytic Fischer-Tropsch synthesis (FTS) reactor and hydrocracking (HCR) reactor that will increase the efficiency of the fuel conversion process

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Key challenges addressed by the project

1. *Increase availability of advanced biofuels and energy in the EU and Africa through reliable, inexpensive, stand-alone system architectures that can be easily deployed in off-grid rural and remote areas*
2. *Introduction of tailored technologies, using local renewable sources and for local use of population and economy*
3. *Strengthen European and African technology base and accelerate development of sustainable fuels to replace fossil alternatives*
4. *Development of technical and managerial competences and capacities in the area of biomass conversion and renewable energy generation*
5. *Currency devaluation due to international crisis.*
6. *Late delivery of equipment*
7. *Export problems*

Expected results :

- ***Mid-term expected results (end 2023)***
  - *Synthesis, characterization and optimization of highly efficient catalysts for FTS, HCR and bifunctional FTS-HCR at small-scale*
  - *Development of a combined experimental-modelling approach for the microchannel reactors for integrated FTS-HCR*
- ***End of project expected results (2025)***
  - *Synthesis and characterization of highly efficient FTS-HCR catalysts at meso-scale, able to reach 70% conversion to fuel*
  - *Implementation of designed catalysts into MCR at lab scale (at BTU) and 2 pilots scale (pyrolysis rig at WITS & CU)*
  - *Successful hosting of the workshop on «Use of hybrid FTS/HCR technologies in the Bioenergy Industry»*
  - *Successful completion of 1 PhD thesis*
  - *Submission of at least 3 publications to high-impact peer-reviewed journals*

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End of project expected results (2025) (Cont'd)

- *Implementation of designed catalysts into MCR at lab scale*
- *Experimentation of pyrolysis at the micro-scale and at the laboratory scale accurate material/products balance and kinetics determined and with scaling laws for large scaling projects.*
- *Numerical modeling of the processes that will allow optimal cost, products output and efficiency calculation for life cycle analysis (LCA)*
- *Validation of the integrated biomass to fuel conversion technologies on pilot scale*
- *Techno economic analysis (TEA) and LCA for European and African case studies based on region specific feed-stocks, costings, and scale impact*
- *Socio-economic impact study of biomass pyrolysis*

- *Successful completion of 1 PhD thesis*
- *Successful completion of 1 postdoctoral training*
- *Submission of at least 8 publications to high-impact peer-reviewed journals*
- *Successful hosting of 5 workshops on:*
    - *"Showcasing modelling in the Bioenergy Industry"*
    - *"Use of hybrid FTS/HCR technologies in the Bioenergy Industry"*
    - *"Environmental and LCA assessment of biomass pyrolysis"*
    - *"Bioenergy Industry promoting Gender equity and SMEs development"*
    - *"Integrated PyroBioFuel technology"*

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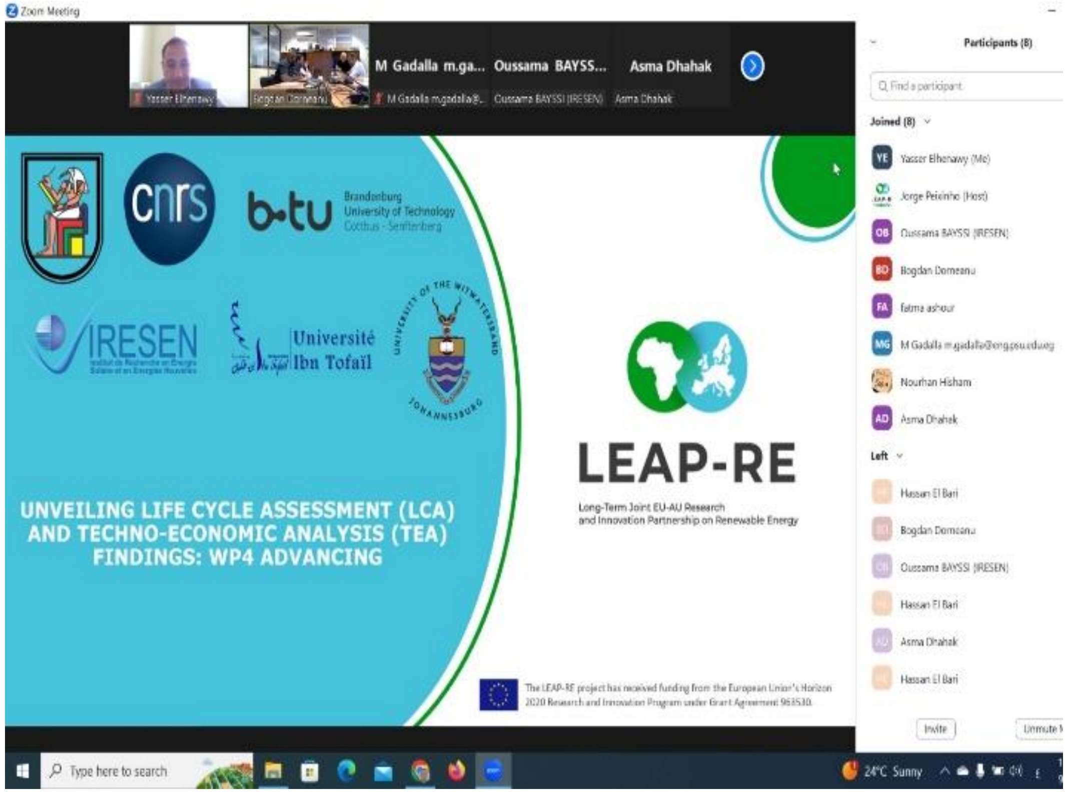
Meetings and Activities

- *Periodic online meetings have been carried out with the partners to discuss the different aspects of the engineering of pyrolysis systems and biomass.*
- *Attended the LEAP-RE to hold its first Stakeholder Forum in Pretoria in October 2022.*
- *Kick-off meeting in Cairo, November 2022*
- *Participation in the COP27 in Sharm El-Sheikh, Egypt (November 2022) with a poster entitled " Production of biofuel and potable water using agricultural waste“ [WITS & Cairo University]*
- *Participation in the IEA Bioenergy UNIDO online workshop on 22-23 May 2023.*
- *Meeting of the PyroBioFuel partners at the Laboratoire de Procédés et Ingénierie en Mécanique et Matériaux, in Paris in September 2023.*
- *Preparation of a Joint review article (All partners) entitled “Recent advances in catalytic fast pyrolysis of lignocellulosic biomass: Approaches for improving the quality and production”, 79 pages, 5 tables, 7 figures and about 320 references.*

Kick-off Meeting in Cairo
November 2022



Meeting in Paris
September 2023

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Publications

- *"A Comprehensive Review of Biomass Pyrolysis to Produce Alternative Biofuel". at the First International Conference on Engineering Solutions toward Sustainable Development (ESSD 2023). http://essd.psu.edu.eg/*
- *Recent Advances in Biomass Pyrolysis Processes for Bioenergy Production: Optimization of Operating Conditions. Sustainability, 15(14), 11238. https://doi.org/10.3390/su151411238*
- *"Thermodynamic Analysis and Experimental Study of Alternative Biofuels Using Sawdust Slow Pyrolysis". https://programme.eubce.com/abstract.php?idabs=20096&idses=1515&idtopic=20 in the 31st European Biomass Conference & Exhibition (5-9June 2023, Bologna, Italy). CU & WITS*

- *"Biofuels production from camel thorn biomass using pyrolysis process". " https://akcongress.com/jtacc/ the 3rd Journal of Thermal Analysis and Calorimetry Conference and 9th V4 (Joint Czech-Hungarian-Polish-Slovakian)*
- *"Experimental analysis and numerical simulation of biomass pyrolysis" https://akcongress.com/jtacc/ the 3rd Journal of Thermal Analysis and Calorimetry Conference and 9th V4 (Joint Czech-Hungarian-Polish-Slovakian)*

- *Workshop:*
- *Sustainable aviation fuel-design, production and impact on climate change, Bad Honnef, Germany, May 2023*
- *Towards an innovative process for the production of sustainable aviation fuels from biogenic raw materials*
- *ECCE/ECAB 2023, Berlin, Germany, September 2023*
- *Green and sustainable fuel from syngas via the Fischer-Tropsch synthesis process: Bifunctional cobalt-based catalysts*

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Technical Activities:

1- Purchase of the CU Pyrolysis pilot equipment. Locally fabricated in Egypt.

2- Communications and meetings with the pyrolysis equipment companies for the WITS partner to find the most suitable way to manufacture the pyrolysis unit.

3- Communications with the supplying companies to discuss the delayed delivery of the components of the pyrolysis system.

4- WITS partners attended a training week at the factory fabricating the pyrolysis unit and specialized in thermal analysis in China from July 29th to August 4th.

5- Supply order was issued to manufacture the apparatus for pyrolysis that is still being assembled in China and will be delivered in November 2023.

6- Laboratory experiments were carried out on another device in Egypt, until the completion of the apparatus.

WITS UNIVERSITY

Thermodynamic Analysis and Experimental Study of Alternative Biofuels Using Sawdust Slow Pyrolysis

EUBCE 2023
31st European Biomass Conference & Exhibition
5 - 8 JUNE CONFERENCE & EXHIBITION
9 JUNE TECHNICAL TOURS

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[1]Port Said University, [2]University of the Witwatersrand, South Africa, [3]Higher Future Institute of Engineering and Technology ,[4]Cairo University, Egypt

Overview

Energy is regarded as an essential ware, and consumption has been rising in tandem with rising populations and economic activity. Biofuels are being developed as sustainable substitutions for fossil fuels. Utilizing biomass fuels to produce electricity can help to lower emissions of CO_2 gases and additional impurities. Hydrocarbons could be generated from biomass through thermochemical, biochemical, and biological procedures as presented in Fig.1. A variety of valuable products for various purposes can be produced using Low-value resources. Wood maintains to be the primary source of biomass for a variety of purposes today. A by-product of the furniture sector, sawdust is created when the wood is shaved, trimmed, cut, and ground in order to prepare it for furniture production. This study reviews and discusses more recent studies about lignocellulosic biomass pyrolysis.

Pyrolysis principles

Once an organic substance is heated in a non-reactive atmosphere, an extremely complicated procedure is called pyrolysis. In this procedure, organic elements in biomass begin to thermally decompose at 350°C to 550°C and then reach 700°C to 800°C in the absence of oxygen or air. During pyrolysis, the biomass's lengthy chains of oxygen, hydrogen, and carbon components decompose into condensable vapors (oils and tars), gases, and solid charcoal as diminished molecules. Three main classifications can be used to categorize pyrolysis, comprising fast, slow, and rapid pyrolysis, based on the feedstock's amount.

lignocellulosic biomass

Lignocellulosic is among the extremely attractive replacements to fossil fuels since they are yielded via biological photosynthesis from ambient CO_2, water, and sunlight. Lignocellulosic biomass, obtained from plants, divides into one of the following four broad categories: Farm materials, grasses, hardwood, and softwood. A long-chain carbohydrate with both crystalline and amorphous sections, cellulose. Due to its packed cellulose structure, the crystalline area of cellulose exhibits greater heat stability than the amorphous region. Fig. 2 depicts the basic form of lignocellulosic biomass.

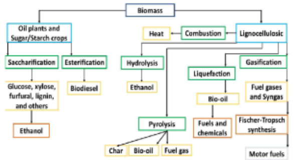

Fig. 1. Biomass conversion schematic diagram

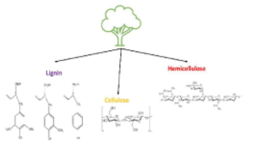

Fig. 2 Lignocellulosic biomass structure

Lignocellulosic Biomass conversion to biofuel

The four main types of pretreatments are physical, chemical, physiochemical, and biological pretreatments, as shown in Fig. 3. These bioenergy processes each have several processes. They involve the creation, gathering, or harvesting of biomass, it's processing to enhance the fuel's physical features, its pre-treatment to modify its chemical characteristics, and its transformation to usable energy. To unravel the complex structure of lignocellulosic biomass and separate its constituent parts, including cellulose, hemicelluloses., and lignin, pretreatment is required.

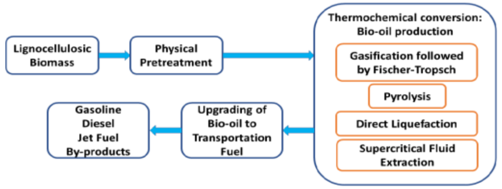

Fig. 3. Lignocellulosic transportation fuel

Challenges and possible results

Energy needs and the development of inhibitors throughout pretreatment and downstream synthesis are the main problems that occur in the application of pretreatment for the extraction of biofuel from biomass leftovers. Also, the superiority and stability of bio-oil yields, reactor dependability, scalability, and overall outcome superiority criteria for producers and customers are some obstacles to thermochemical conversion methods of lignocellulosic biomass.

Conclusion

Since the manufacture of liquid biofuel via lignocellulosic biomass exhibits great yields, there are still many obstacles to overcome before it can be commercialized. The production mechanisms for thermochemical biofuels are almost fully developed and are currently in the early commercial prototype development. Pyrolysis, the term for the heat degradation of sawdust biomass in the absence of oxygen, involves a sequence of intricate reactions comprising hundreds of different substances. However, more study and improvement are required to improve the thermochemical biofuels' resistance to difficult process conditions in terms of the material selection for various production.

Acknowledgements

The researchers would like to acknowledge the assistance provided by the south African national energy development institute (sanedi) for funding the project. This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement 963530.

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sanedi
South African National Energy Development Institute

WITS UNIVERSITY

Cairo University

<u>Pyrolysis equipment for agricultural residues including:</u>

1. Steel chassis to carry all components of the reactor.
2. Electric heated stainless-steel reactor of approximate volume of 40 liters.
3. Water-cooled condenser with copper coil.
4. Condensed liquid collector.
5. Two thermocouples with digital indicator(s) one for the reactor and another one for the condenser.
6. Reactor temperature controller
7. Electric and control panel
8. All pipes and connection required for the prototype reactor.

Purchased Pyrolysis Pilot Equipment
Egypt

PYROBIOFUEL EXAMPLE OF PARTNERS ACTIVITIES

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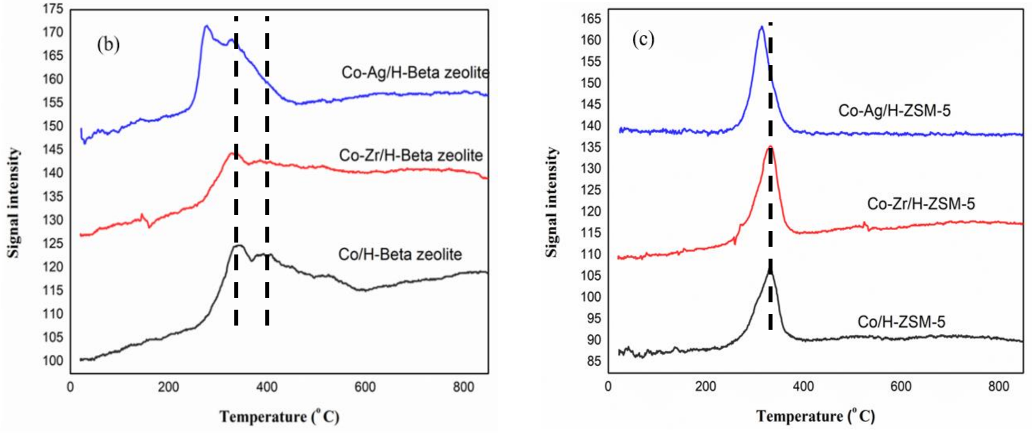
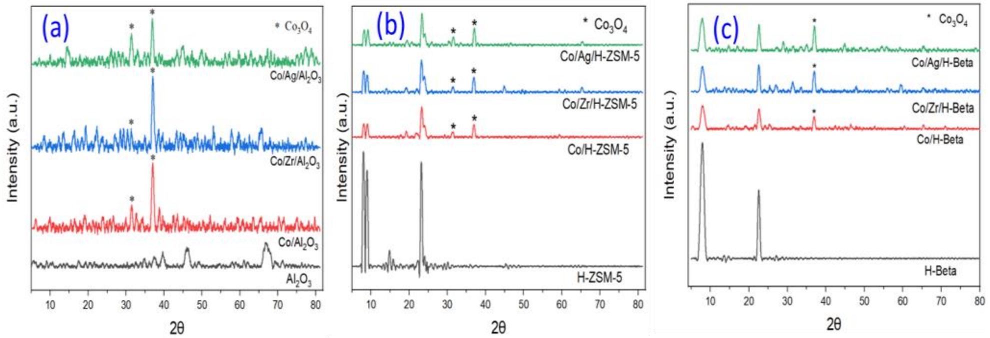
Development of novel bifunctional catalysts for FTS and HCR

- *Co – zeolite catalysts*
- *Temperature programmed reduction (TPR)*
  - *Ag and Zr – cheaper promoters than Ru*
  - *Ag – significant decrease in reduction temperature*
  - *Zr – slight decrease in reduction temperature*
- *X-Ray diffraction*
  - *Co successfully incorporated into zeolites*
  - *Co crystallite in the range 15.24 – 17.80 nm*





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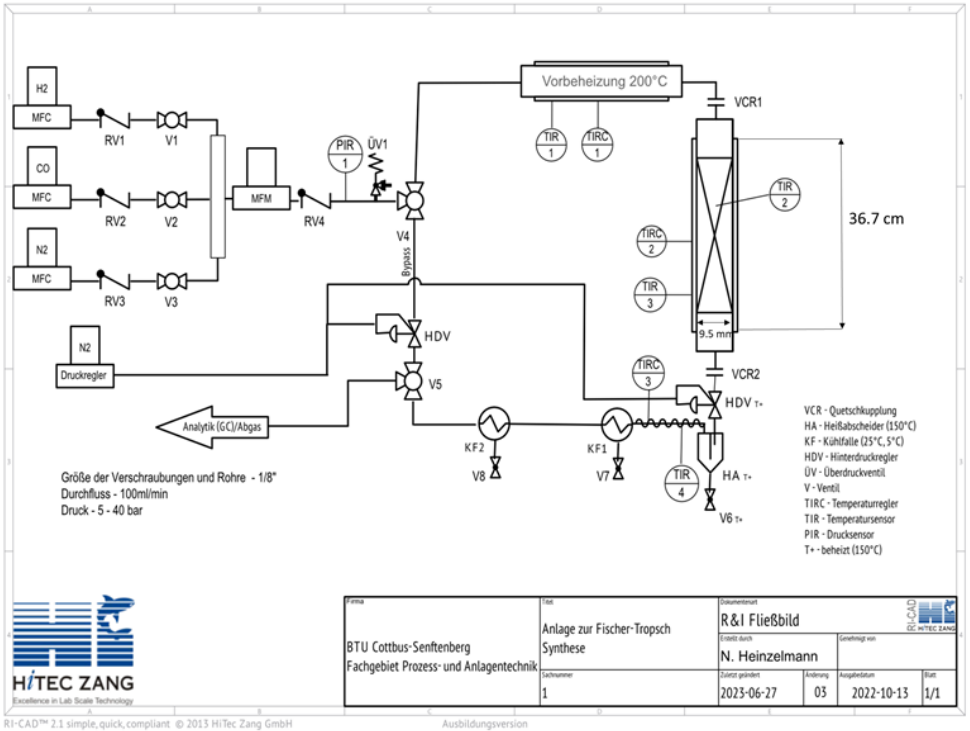
Future work

- ❑ *Catalytic activity tests*
  - ➢ *Syngas (H_2, CO) of different ratios (1:1, 1:2)*
  - ➢ *Temperature: 220 – 250 °C*
  - ➢ *Pressure: 10 – 20 bar*
  - ➢ *Space velocity: 1800 – 3120 mL/g_{cat}h*
- ❑ *Design and testing of microchannel reactors (MCR) for FTS and HCR*



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Brandenburg University of Technology Cottbus - Senftenberg

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Publications

- Workshop: Sustainable aviation fuel-design, production and impact on climate change, Bad Honnef, Germany, May 2023
  - *Towards an innovative process for the production of sustainable aviation fuels from biogenic raw materials*
- ECCE/ECAB 2023, Berlin, Germany, September 2023
  - *Green and sustainable fuel from syngas via the Fischer-Tropsch synthesis process: Bifunctional cobalt-based catalysts*

Project timeline & deliverables

IRESEN Institut de Recherche en Energie Solaire et en Energies Nouvelles

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Part 1

Theoretical Foundation

2023

Exploring the Knowledge Landscape

Part 2

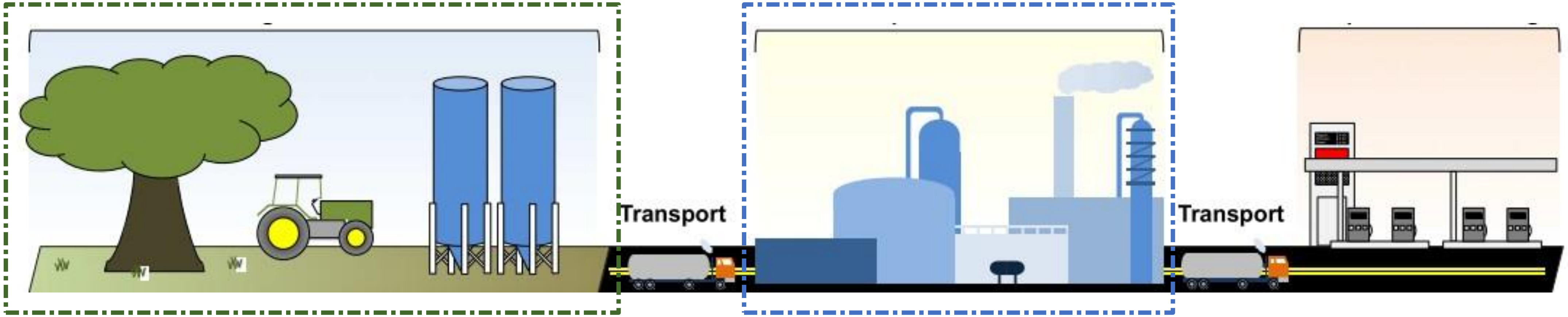
Applied Dimension: The Practical Facet

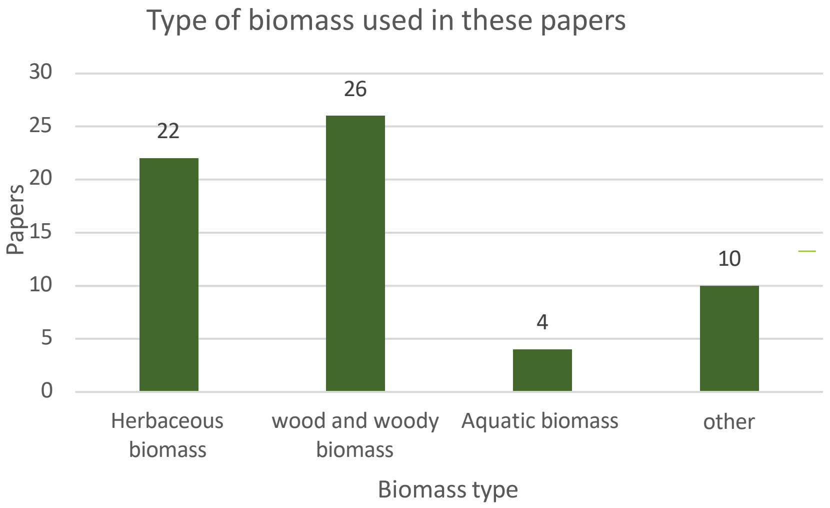
2024

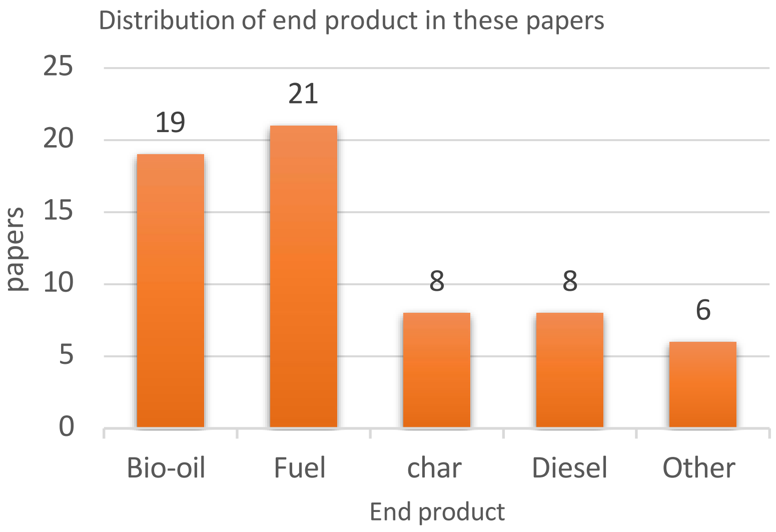
2025

Environnemental assessment and Techno-Economic Analysis (TEA)
Life Cycle Assessment (LCA) of the PyroBioFuel process
European and African cas studies

Feedstock Process End product

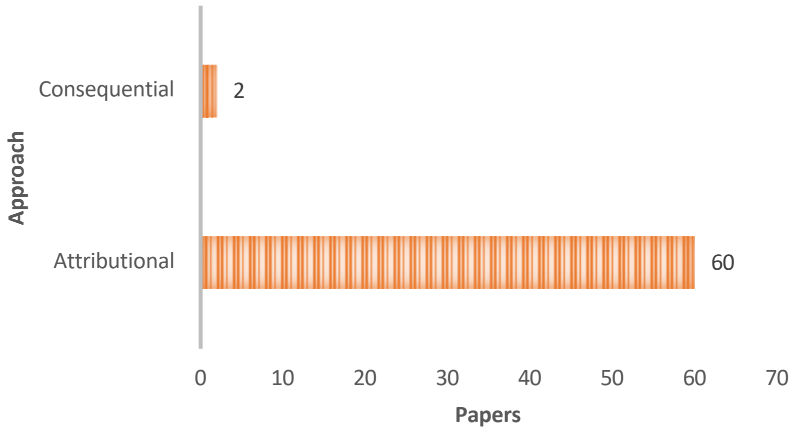




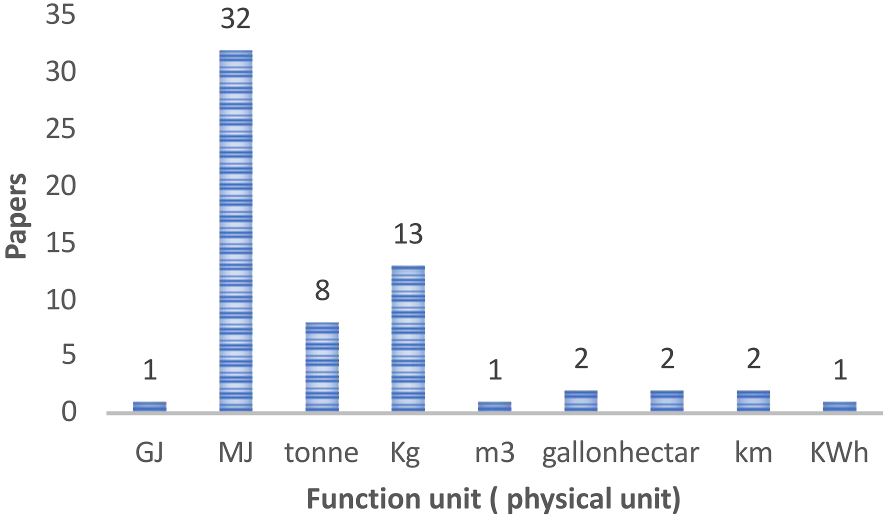


First results

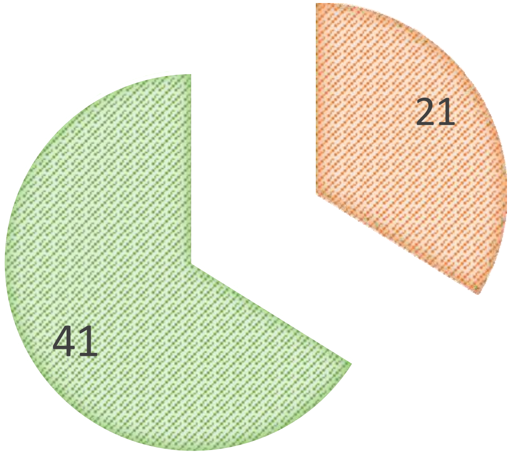
- **Life cycle assessment approach**



- **Functional unit**



Specified (papers with scenarios)



No specified (papers without scenarios)

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IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

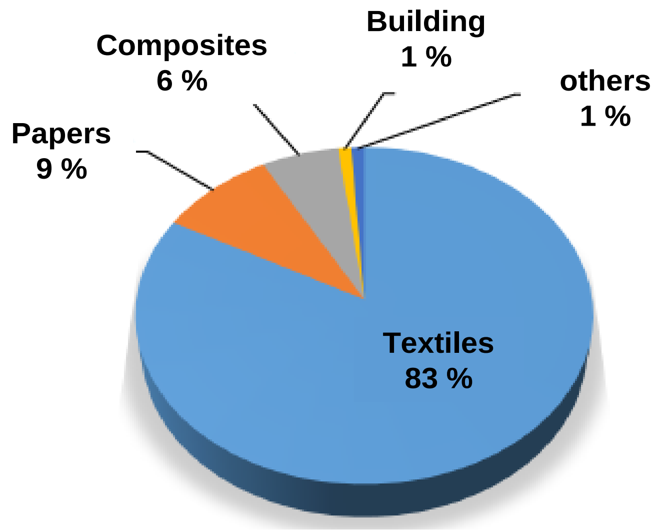
Human resources & purchase

- *Engineer (joining our team in October 2023)*
- *Technician (to join our team at the end of 2023)*
- *Softwares (LCA & TEA) : expected in 2023 Q4*
- *Pyrolysis laboratory material purchase: expected in October 2023*

WP4 next steps:

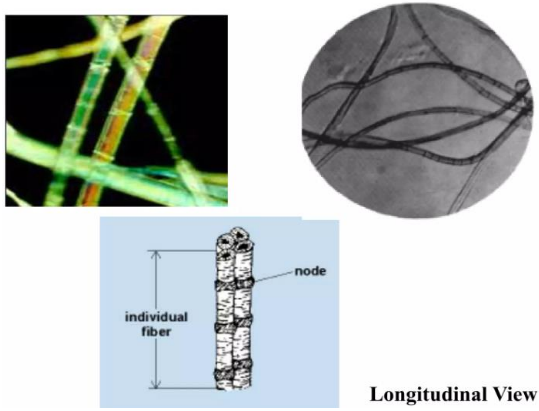
- *Submitting LCA review article (September-October 2023)*
- *Preparing the data collection/inventory: 2023 Q4*

Flax fiber: Composition and uses



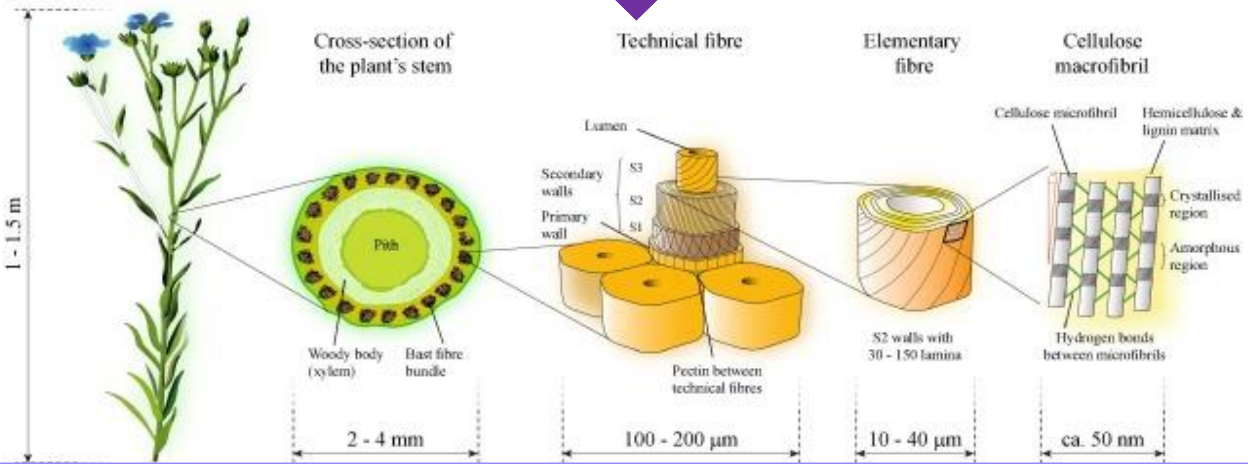
Chemical constituent	Range (%)
celluloses	65-85
Hemicelluloses	5-20
Lignin	1-5
Waxes	1
Water	8-10
soluble materials	4

Structure of Flax Fiber

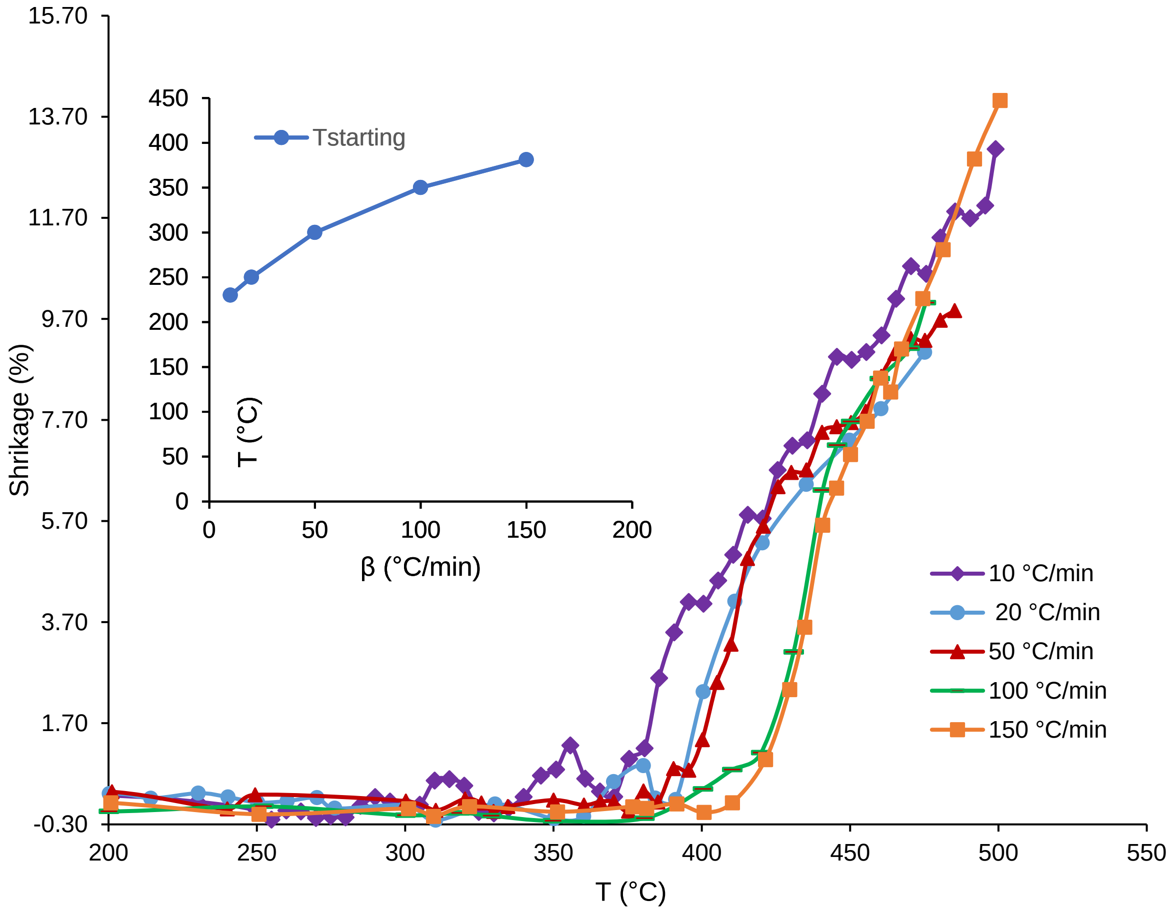


Longitudinal View

Fast pyrolyze in microreactor



The effect of heating rates on flax fiber pyrolysis



- Thermogravimetric tests on cellulose and flax fibers
- Kinetic analysis
- Organization of the PyroBioFuel Paris meeting