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Fast pyrolysis bio-oil production in an entrained flow reactor pilot

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Pyroliq 2019: Pyrolysis and Liquefaction of Biomass and Wastes

An ECI Conference

June 16-20, 2019
Maryborough Hotel
Cork, Ireland

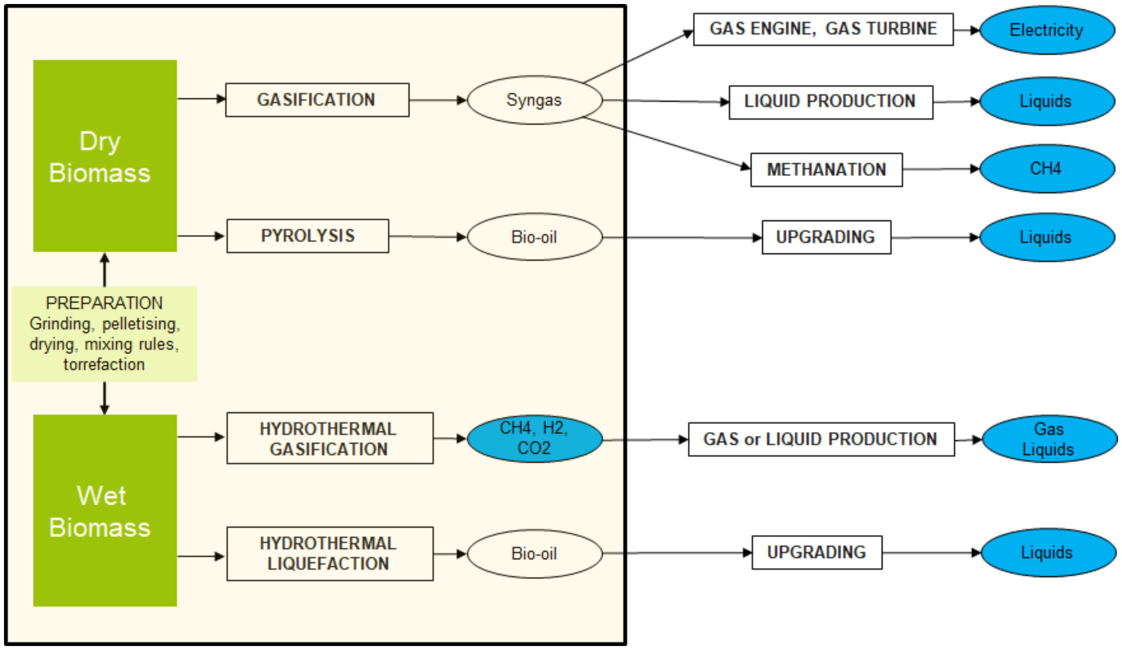
FAST PYROLYSIS BIO-OIL PRODUCTION IN AN ENTRAINED FLOW PILOT REACTION

PYROLIQ Conference Cork Irland 2019, June - M.PEYROT

THE CEA LITEN BIORESOURCES LABS

The CEA LITEN Bioresources Labs

Develop innovative thermochemical conversion technologies and processes of biomass and wastes into energy, chemicals and materials



15 years of experience – 40 people – 20 analytical devices and pilots

CEA PLATFORM

Powder
MEB, morphology
Flowability, injection P_{atm}-30bar

Drying and grinding
Powder preparation <500 µm
Continuous pilots up to 50 kg/h

Torrefaction
TGA, batch 1g-2kg, continuous pilot up to 200 kg/h

Pyrolysis and gasification
Continuous pilots: pyrolysis 10 kg/h, fluidized bed 5 kg/h, entrained flow: 50 kg/h-35bar

Hydrothermal liquefaction
Batch 500 mL, continuous pilot
250-350°C, 200 bar, 0,5-2,5 L/h

Supercritical water gasification
Batch 500 mL, continuous pilot
400-700°C, 300 bar, 1-10 L/h

OUTLINES

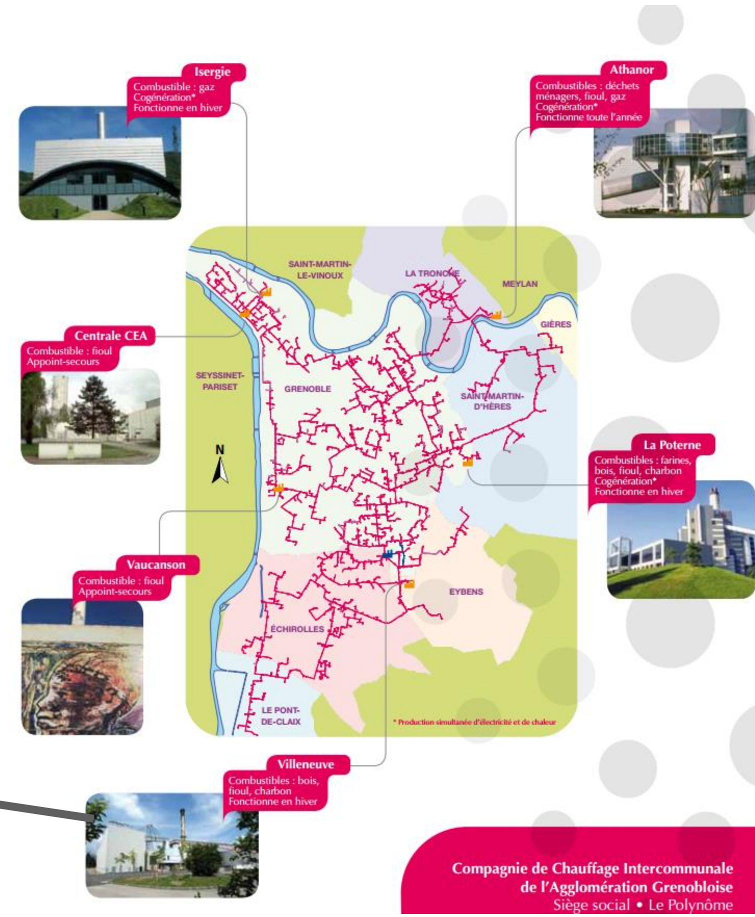
1. Introduction
2. Lab-scale study
3. Pilot-scale study
4. Combustion tests
5. Economical study
6. Conclusions & Outlooks

CONTEXT

- This work was performed with the CCIAG company (that deals the Grenoble district heating) in the BOIL project.

- Grenoble district heating : 2[nd] larger in France after Paris

- Villeuneuve Boiler inputs: biomass, coal and during high energy demands fossil fuel.

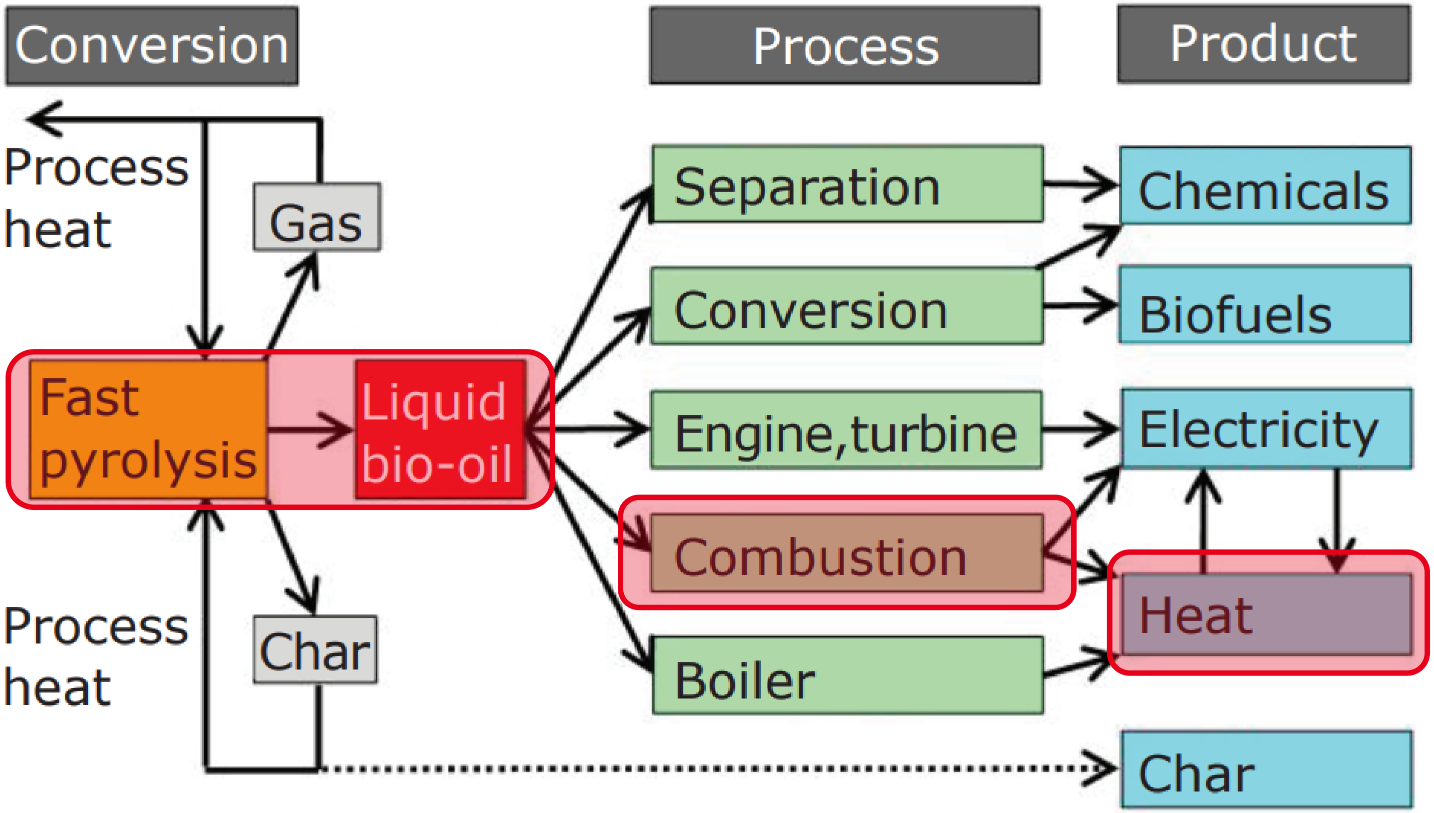


- **Alternative to fossil liquid fuel :**

Bio-oil produced from biomass fast pyrolysis

Compagnie de chauffage

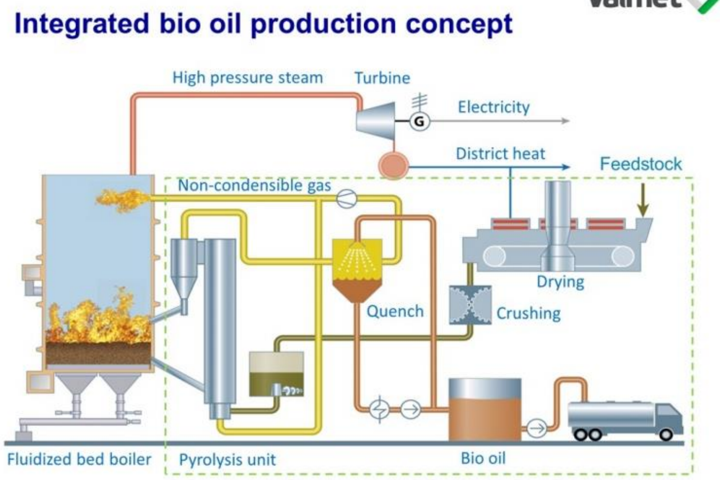
APPLICATIONS FOR FAST PYROLYSIS PRODUCTS



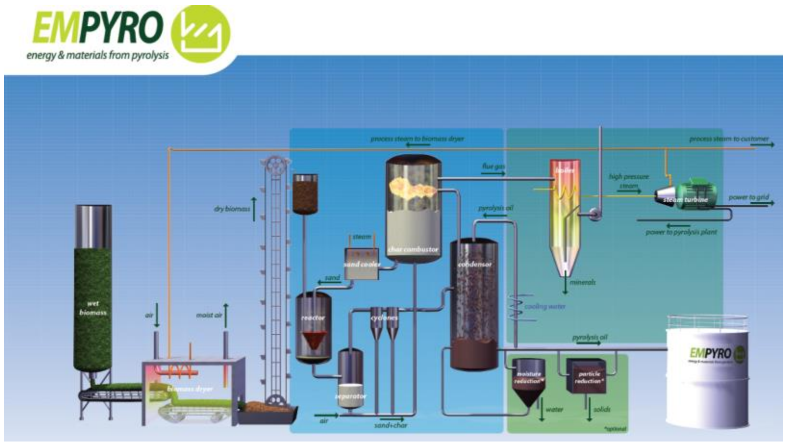
Bridgwater 2018 - Johnson Matthey Technol. Rev, 62, (2), 150

TECHNOLOGIES FOR BIO-OIL PRODUCTION

- Biomass fast pyrolysis for bio-oil production is most commonly performed in Fluidized Bed Reactors (FBR) or Rotating Cone.
- Commercial units for combustion application:



Fortum – VALMET VTT (Finland)
Biomass flow 10 t/hr



BTG-BTL / EMPYRO (Netherlands)
Biomass flow 5 t/hr

- Production of bio-oil in an entrained flow reactor has not been studied a lot up to now: an alternative technology?

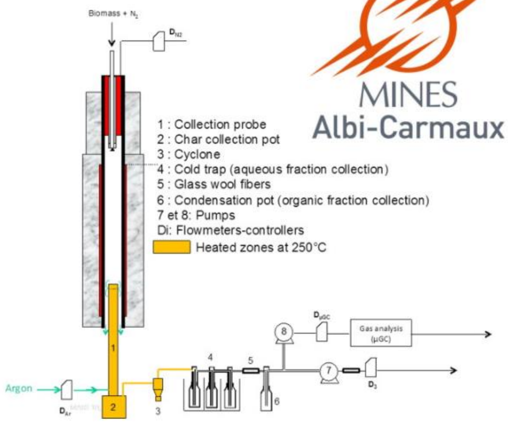
EFR & BOIL PROJECT OBJECTIVES

- **Entrained Flow Reactor advantages:**
  - Simplicity: particles are injected in powder form (< 1mm) at the top of the reactor and are directly in contact with the hot gas with no heat media
  - No need to separate char from heat media

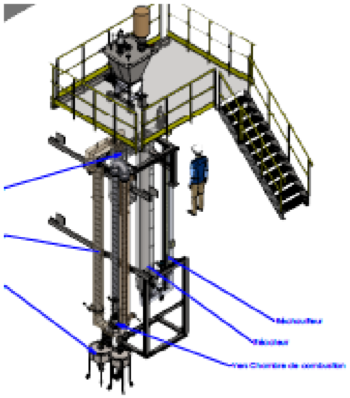
- **BOIL objectives (4 years 2014-2018 1.5M€):**
  - Develop a new EFR design
  - Produce bio-oil pyrolysis
  - Bio-oil combustion tests
  - Economical and environmental evaluations

BOIL PROJECT WORK PACKAGES

WP 1: Laboratory-scale study
$Q_{biomass} = 0.06$ kg/h
Investigation of woody biomass fast pyrolysis in a drop tube reactor (experiments and 1D modeling)



WP 2: Pilot-scale study
$Q_{biomass} = 10$ kg/h
Pilot design (from WP1 results and CFD modeling)
Pilot experiments (85 kg of bio-oil produced)



WP 3: Bio-oil combustion tests

WP 4: Economical and environmental studies

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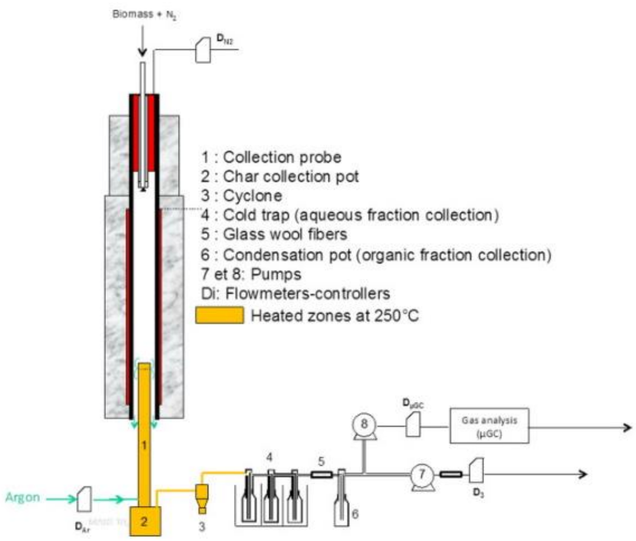
LAB-SCALE-STUDY

Parameters investigated

Feedstock	Beech particles
Particle size (μm)	370, 490, 640
Temperature (°C)	450, 500, 550, 600



- Optimum conditions:

  T = 500°C and particle size = 370 μm

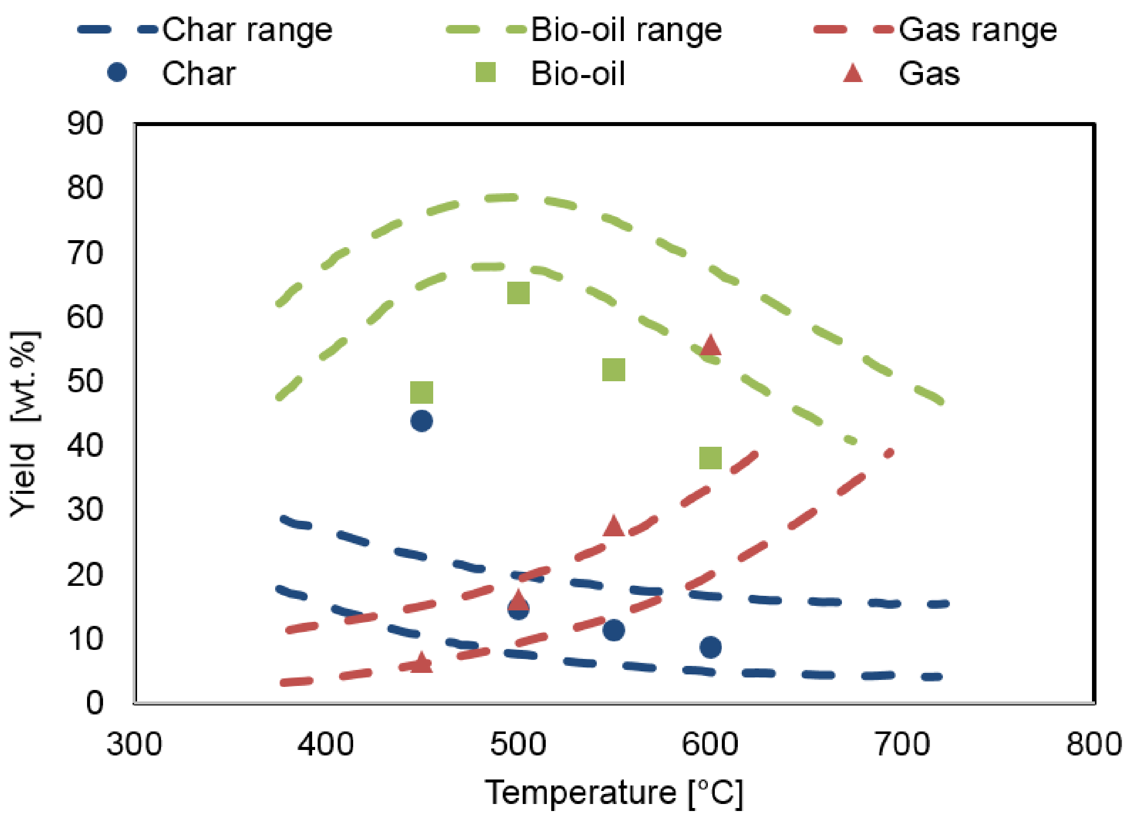
  HHV ~ 15.5 MJ/kg

  Bio-oil mass yield ~ 63% wt

- Validation of the model GASPAR1D

Guizani et al. - Biomass fast pyrolysis in a drop tube reactor for bio oil production: Experiments and modeling. Fuel, Elsevier, 2017, 207, pp.71-84.

COMPARISON WITH THE FLUIDIZED BED YIELDS



Bio-oil yields close to those observed in fluidized bed reactors

Comparison of pyrolysis products yields in drop tube furnace with the data given in the literature related to fluidized bed reactors (dashed lines) (Di Blasi 2009)

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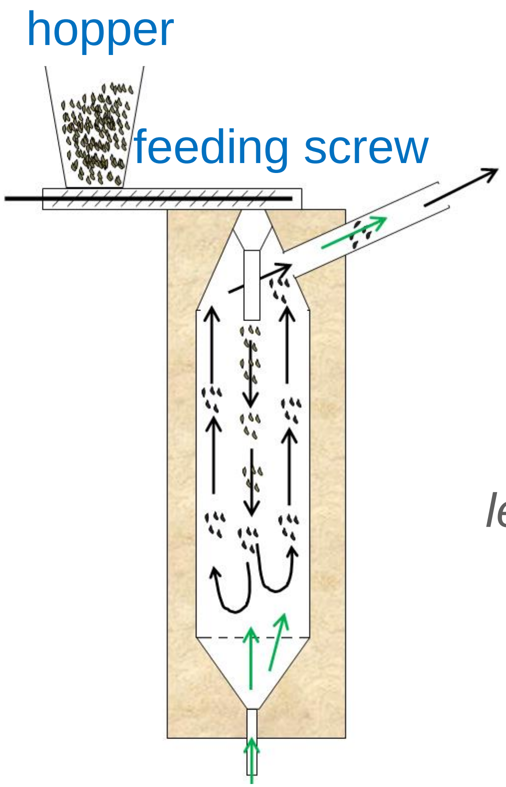
PILOT SCALE STUDY

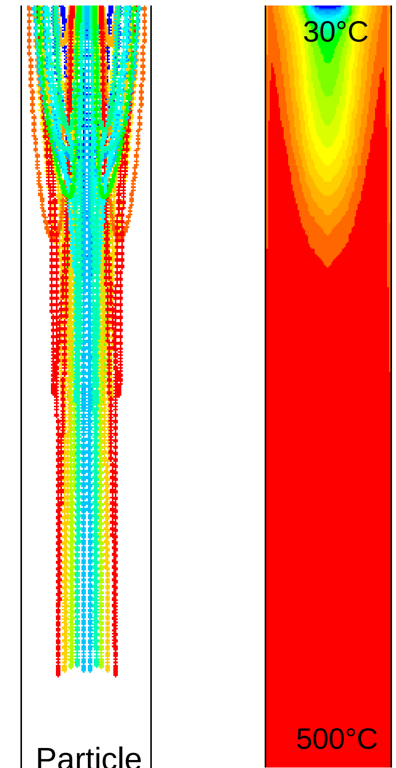
- Pilot design: from experiments and GASPAR 1D modeling performed in the drop tube reactor and also CFD modeling (ANSYS FLUENT)



Outlet:
- condensable gases
- incondensable gases
- and char

Counter current flow nitrogen 500°C

Biomass ~ 10 kg/h
length 4 m - diameter 20 cm

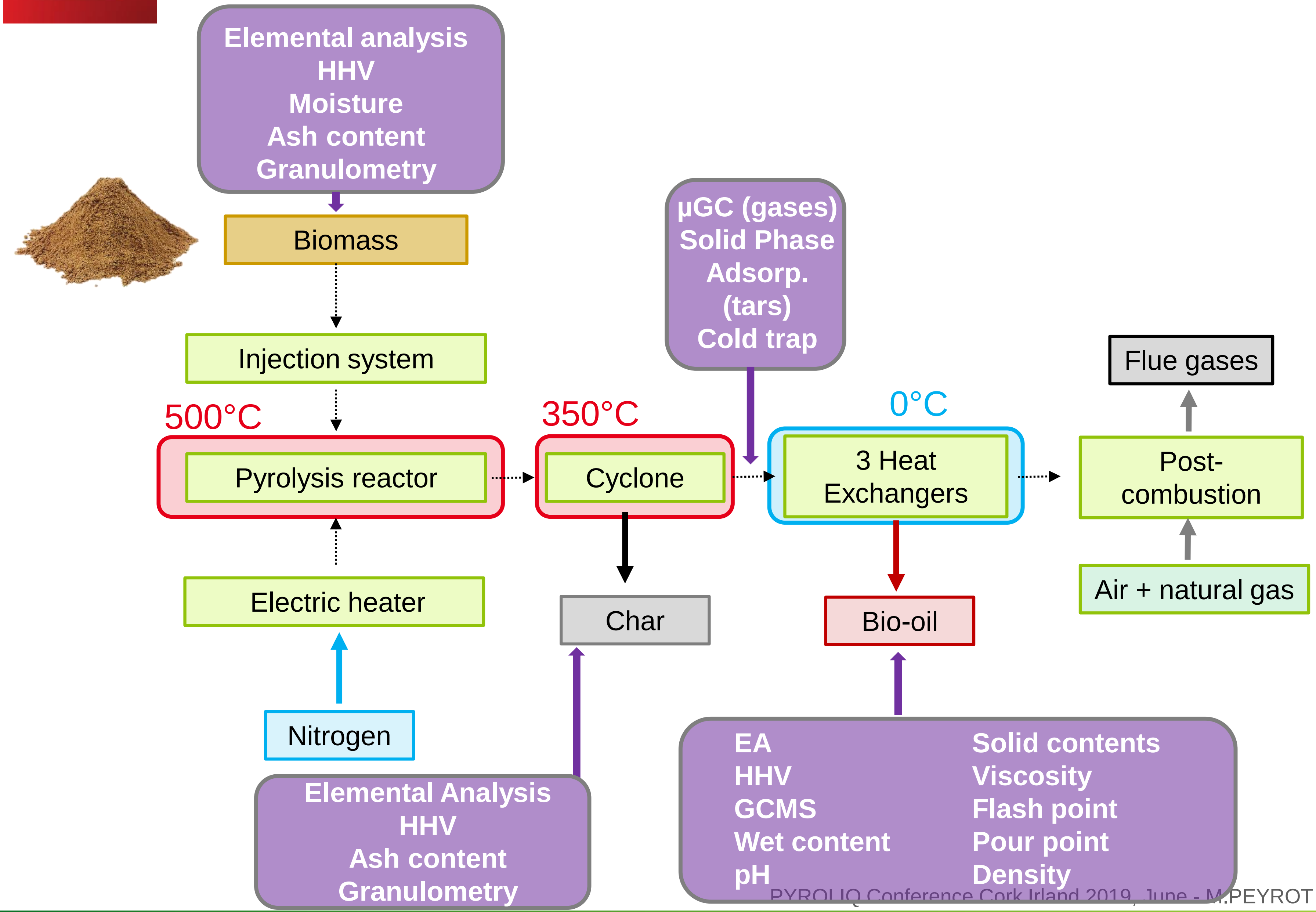


Particle trajectories

Temperature

Fast Pyrolysis reactor for organic biomass materials with against flow injection of hot gases US 20170166818 A1

BOIL PROCESS AND ANALYSES

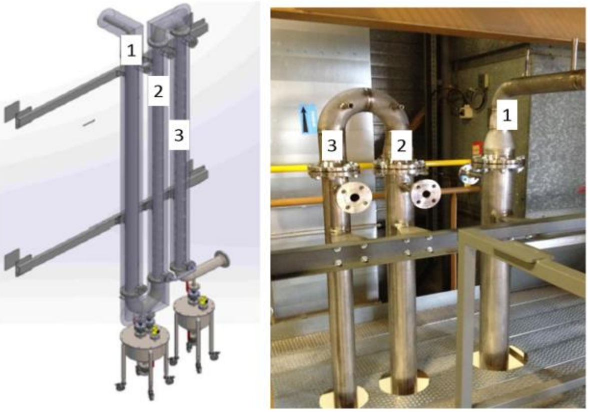


BOIL PILOT

Biomass injection
(powder < 1mm)

Bottom
reactor

Top of the pyrolysis reactor



3 heat exchangers

BOIL bio-oil

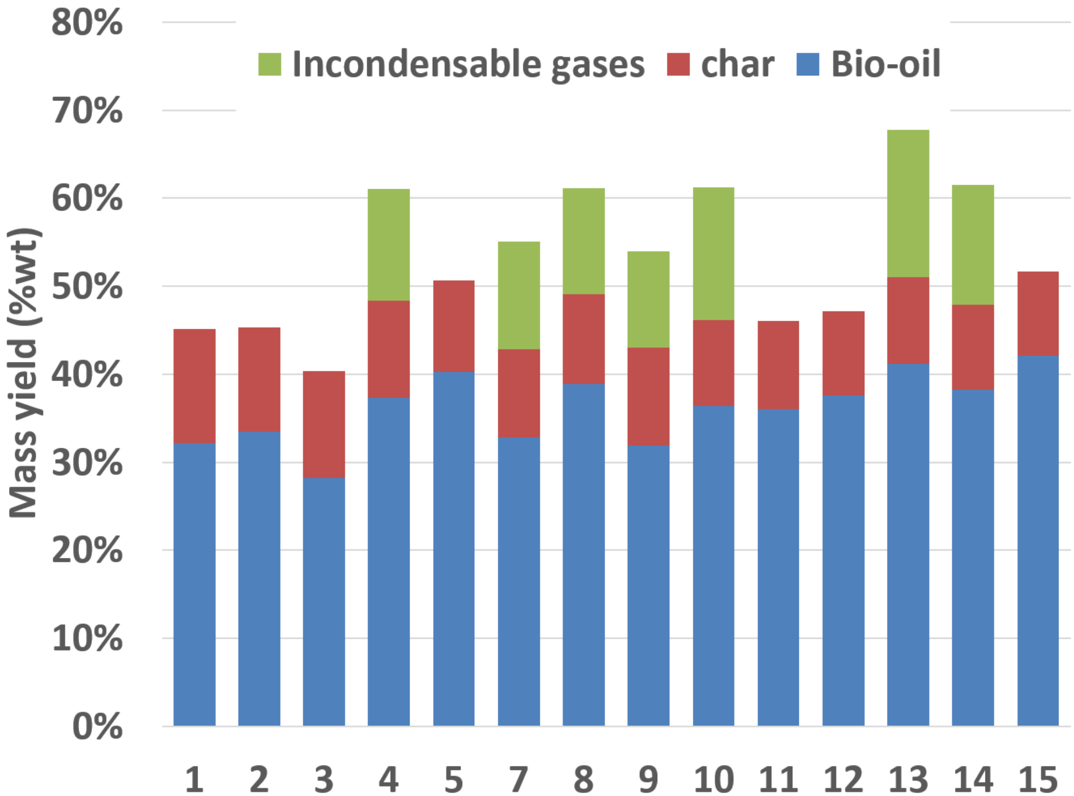
EXPERIMENTAL CONDITIONS

- 14 runs – 85 kg bio-oil produced → objective: bio-oil production for combustion tests
- Biomass flow: from 2 to 9 kg/h
- Nitrogen velocity = 1 m/s
- 3 biomass resources: (size < 1 mm)

	moisture [%wt]	ashes [%wt db]	HHV [MJ/kg db]	Ultimate analysis [wt.% db]			
				C	H	N	S
Pine	9.5	0.3	19.94	50.72	5.35	0.09	0.05
Beech 1	7.8	0.4	19.58	49.46	5.89	0.13	0.03
Beech 2	12.1	0.46	19.1	48.4	5.6	0.15	0.02

- Reactor temperatures: 500°C, one run at 450°C (run 9)
- Heat exchanger temperatures:
  - 30°C, 0°C, 0°C
  - 55°C, 0°C, 0°C (run 12)

RESULTS: MASS YIELD



- The total mass balance varies between 55 to 70%
  - Bio-oil mass yield ~ 40%
  - Char mass yield ~ 10%
  - Incondensable gases ~ 12%
  - No unburnt particles

Problems identified:

- About 15% of the bio-oil go through the heat exchanger
- Some char particles go through the cyclone
- Plugging of the first heat exchanger

COMPARISON TO THE EUROPEAN STANDARD RECOMMENDATIONS

PR NF EN 16900 Fast pyrolysis bio-oils for industrial boilers — Requirements and test methods

Generally applicable requirements and test methods for fast pyrolysis bio- oils for boiler use

	Unit	Limits EN 16900		Bio-oil BOIL
		min	max	
Lower Heating Value	MJ/kg	14		14.10
Water content	% (m/m)		30	26
pH		2		2.05
Density at 15°C	kg/dm^3		1.3	1.21
Pour point	°C		-9	<-36
Nitrogen content	% (m/m) b.s			0.06
Flash Point	°C	35		104.8

Emission and burner dependent requirements and test methods for fast pyrolysis bio oil for boiler use

	Unit	Limits EN 16900		Bio-oil BOIL
		grade A	grade B	
Kinematic viscosity at 40°C	mm^2/s max	125	50	18.9
Sulfur content	% (m/m), b.s, max	0.1	0.05	0.017
Solids content	% (m/m), max	2.5	0.5	0.2185
Ash content	% (m/m), max	0.25	0.05	0.155
Na, K, Ca, Mg	% (m/m), b.s, max		0.02	<0,01

Empyro plant in Hengelo, The Netherlands
https://www.btg-btl.com/en/applications/oilproperties

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BIO-OIL COMBUSTION
PRELIMINARY TESTS

- **2 burners tested:**
  - Air assisted burner

    Kroll KGUB 20
    20 to 40 kW

Well adapted to vegetable oil and heavy fioul combustion

  - Pressure jet burner

    Riello 40N10
    34 to 100 kW

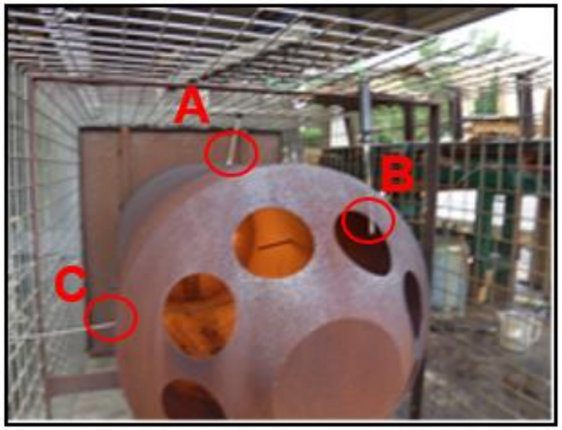
Well adapted to heavy fioul combustion

- **Combustion chamber 250 kW**

Flame visualisation

BIO-OIL COMBUSTION

- **Measurements**



Outlet Temperatures

Wall Temperature

Gas sampling probe (flue gas)

- **Kroll (20 kW)**
  - Stabilized flame
  - Acceptable CO concentration

- **Riello (100 kW)**
  - Unsuccessful to stabilized the flame

- **Co-combustion would be necessary (natural gas) to stabilize the flame**
- **Complementary tests required to go further**

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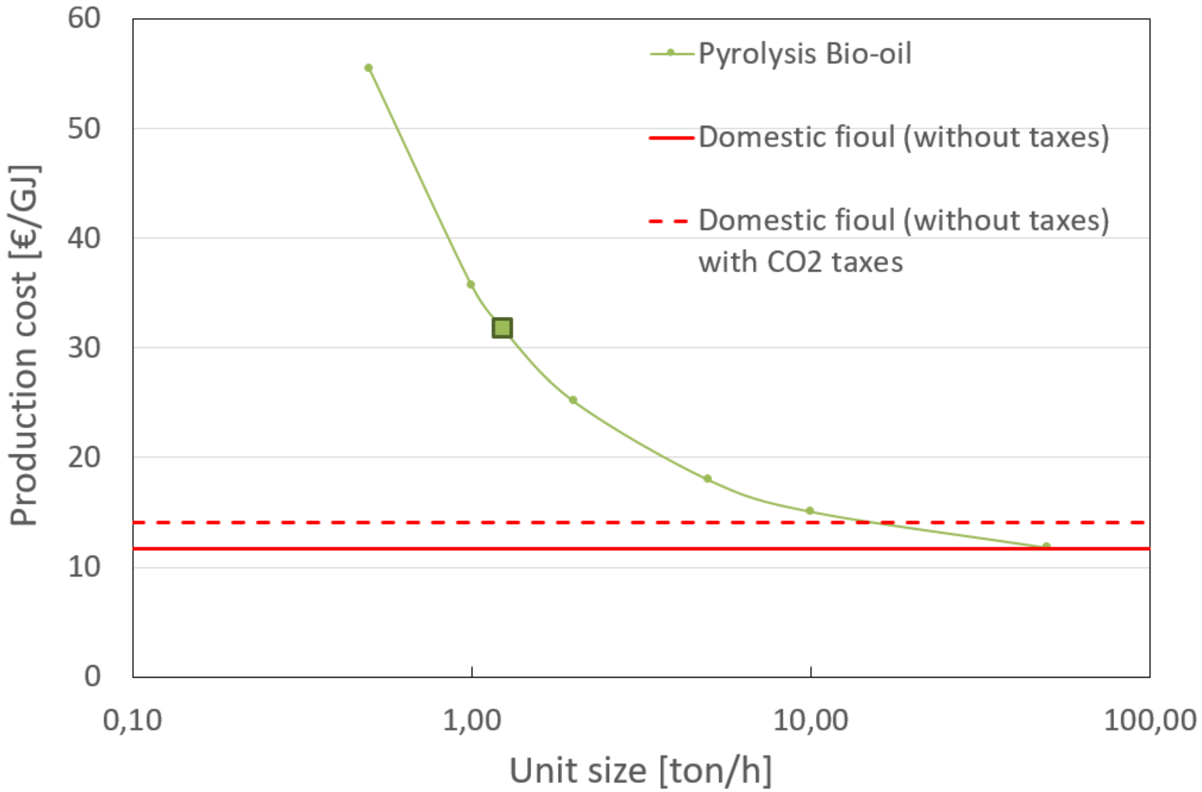
ECONOMICAL STUDY

- **Study case (CCIAG requirements for their boiler):**
  - 1.2 t/h unit working 4000 h/year
  - Bio-oil production: 2000 t/year

- **Hypothesis:**
  - Bio-oil yield: 60%
  - Bio-oil HHV: 16 MJ/kg

CAPEX	3.6 M€
Bio-oil production cost	0.51 €/l
Bio-oil production cost	32 €/GJ

ECONOMICAL STUDY



- **The unit size (ton of biomass per hour) seems to be determinant**
- **Shared unit of bio-oil production in region Rhône Alpes with other end users?**

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CONCLUSIONS

- Bio-oil yield 40%, HHV 15 MJ/kg - Total mass balance not satisfactory

- Identified problems:
  - Heat Exchanger efficiency
  - Cyclone efficiency
  - Heat exchanger plugging

- With a regularly cleaning of the first heat exchanger, we successfully produce bio-oil with physical and chemical properties in agreement with the European Standard recommendations.

- Preliminary combustion tests encouraging

OUTLOOKS

- For future projects:

  - Technical pilot modifications:
    - to increase bio-oil yield
    - to minimize heat exchanger cleaning

  - Integrated energetic process (no nitrogen but recirculation of incondensable gases)

  - Upscaling process (CFD modelling)

  - Test other resources: agricultural biomass or solid recovered fuels or plastics ….

THANK YOU FOR YOUR ATTENTION

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