Institute for Chemicals and Fuels from Alternative Resources

Western University

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Western

Advanced Thermal Treatment Technologies

Franco Berruti, PhD, PEng

May 14, 2019

Institute for Chemicals and Fuels From Alternative Resources (ICFAR)
Western University, London, Ontario
CANADA

WHO ARE WE?

Institute for Chemicals and Fuels
from Alternative Resources
Western University

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Department of Chemical and Biochemical Engineering
Faculty of Engineering

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The Team

Cedric Briens Franco Berruti

Charles Xu

Dominic Pjontek

- **5 full-time Professors:**
- **Franco Berruti**, Director (General), Senior NSERC Industrial Research Chair in "Thermochemical Conversion of Biomass and Waste into BioIndustrial Resources"
- **Cedric Briens**, Senior NSERC – ExxonMobil – Syncrude Industrial Research Chair in Fluid Coking Technologies
- **Dominic Pjontek**
- **Charles Xu**, NSERC-FP Innovations Industrial Research Chair in Forestry Biorefinery
- **Naomi Klinghoffer** (from August 2019)

- **12 Associate Members (Professors)**
- **1 full time Seconded Scientist from NRCAN**
- **2 ~ 3 Visiting Professors per year**
- **~ 35 graduate students (Master and PhD)**
- **~ 6 summer students (Undergrad) per year**
- **4 ~ 5 international visiting students per year**
- **1 senior research scientist**
- **8 ~ 10 postdoctoral fellows**
- **1 administrative staff**
- **2 technologists (mechanical and chemical)**

and many local, national and international collaborations (UK, France, Spain, Germany, China, Ecuador, Italy, USA, The Netherlands, Brazil, ….)

The ICFAR Research Team

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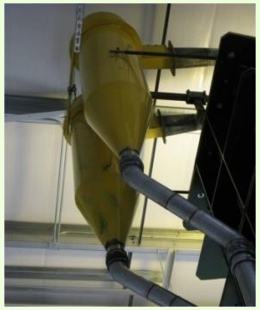
The Laboratory

Pilot Plants



Analytical Equipment

Research Focus

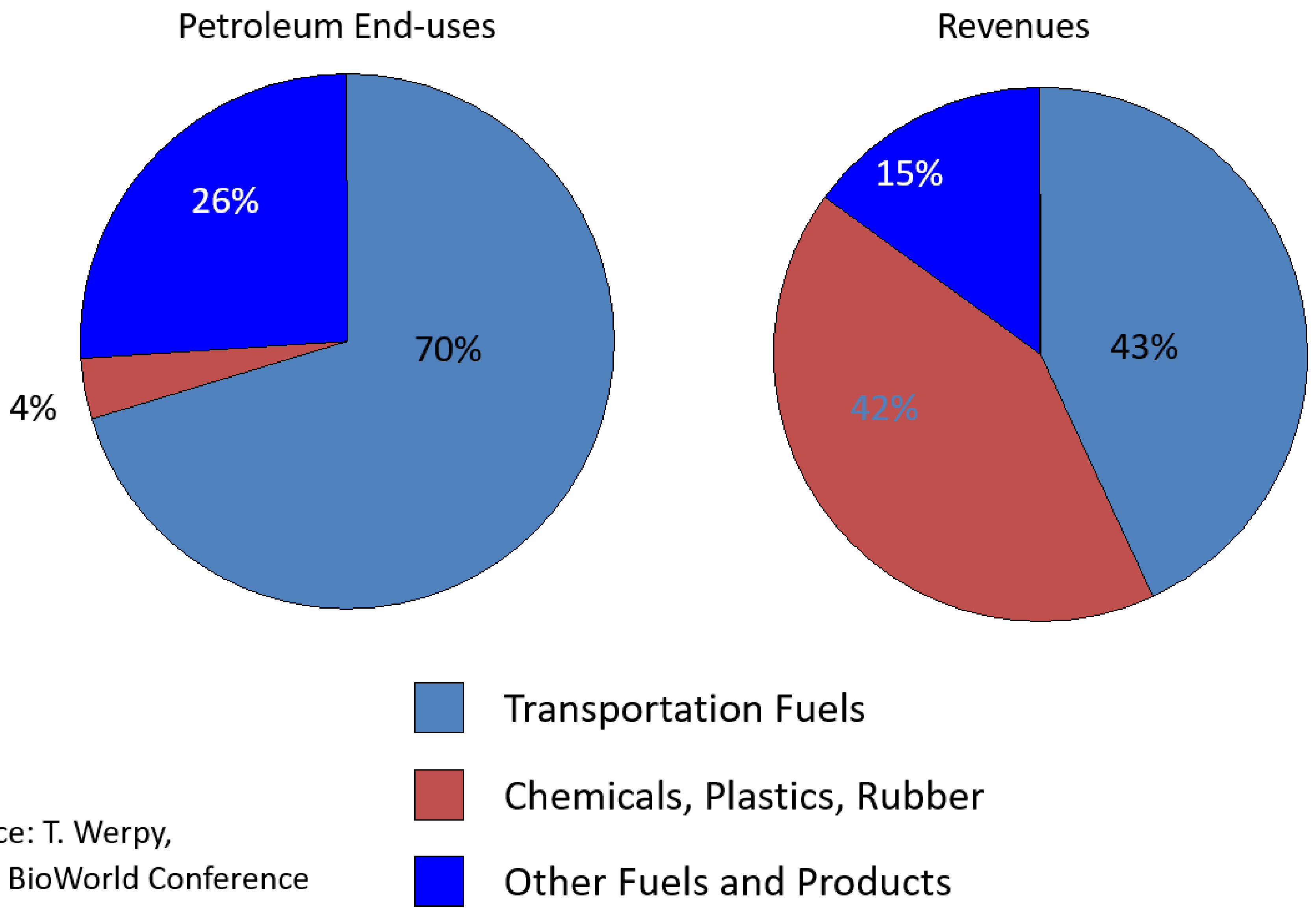
- **Reactor technologies for thermal cracking of biomass residues and organic wastes** into condensable vapors (bio-oil), solids (bio-char) and gas: **PYROLYSIS** and **HYDROTHERMAL** conversion

- Identification, characterization, separation and potential **applications of all products**

- Maximization of products' value by **upgrading**

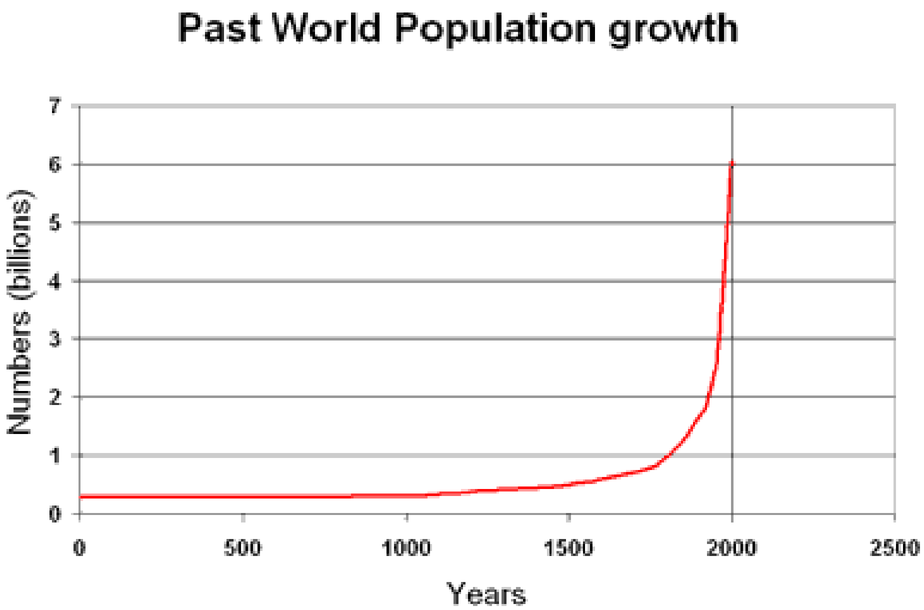
A FEW KEY ISSUES TO KEEP IN MIND….

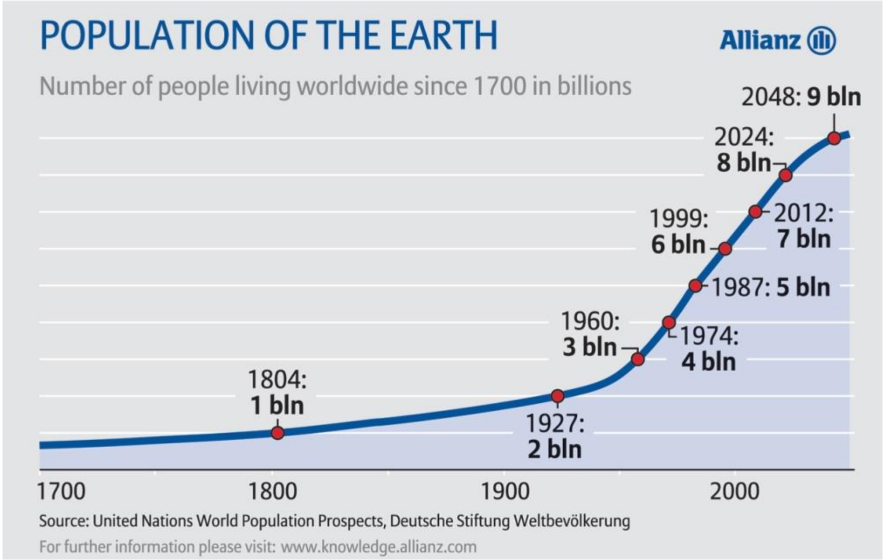
A Lesson from Petroleum Refineries



Source: T. Werpy,
2009 BioWorld Conference

World Population Growth





Current World Population

7,702,843,017

May 9, 2019

Earth Capacity

$$EC = P * C * B$$

$where:$

$EC = Earth\ Capacity$

$P = Total\ Population$

$C = Individual\ Consumption\ (Economic\ Activity)$

$B = Conversion\ Factor\ between\ Consumption\ and\ Environmental\ Burden$

Since EC is constant, if P and C are increasing,
then <u>B needs to DRASTICALLY decrease</u>!

Biomass Issues

- Low density, seasonal, moisture, bulky, perishable

Waste Issues

Canada's Greenhouse Gas Inventory shows that Canadian landfills account for 20% of national methane emissions, corresponding, in 2015 to approximately 30 Megatonnes (Mt) of carbon dioxide equivalent (eCO2)

Government of Canada

8 million tonnes of plastic end up in the oceans each year

At the current rate, there will be more plastic in the ocean than fish by 2050

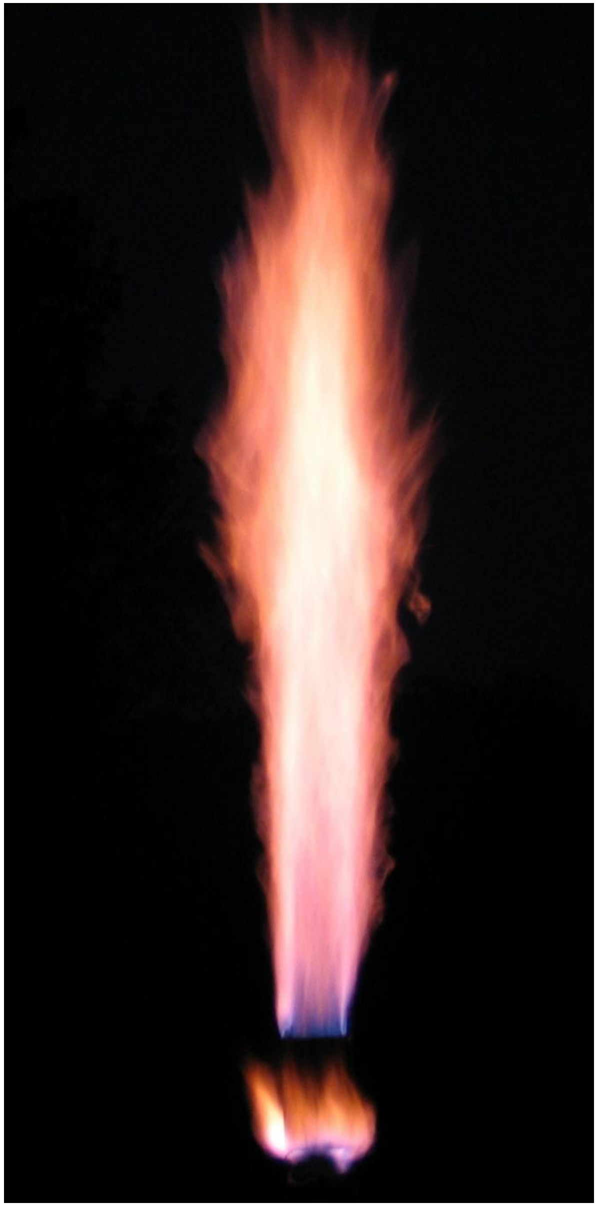
Globe Forum 2018

ADVANCED THERMAL TECHNOLOGIES:

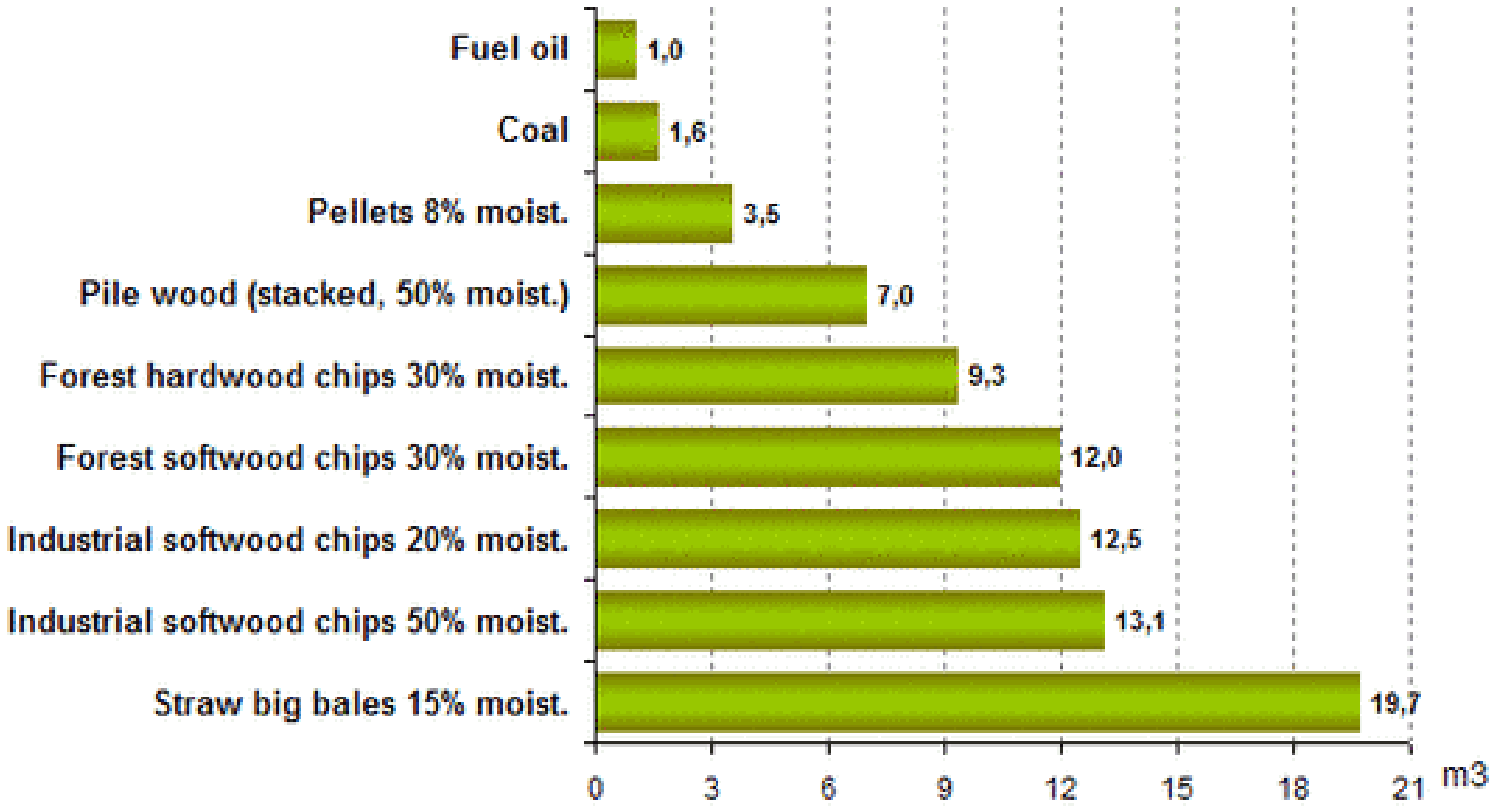
1: COMBUSTION

Feed Characteristics

- **Gross heating values:**
  - Hydrogen: 142 MJ/kg
  - Carbon: 33 MJ/kg
  - Methane: 55 MJ/kg
  - Diesel: 45 MJ/kg
  - Gasoline: 46 MJ/kg
  - Bioethanol: 29 MJ/kg
  - Biodiesel: 40 MJ/kg
  - Dry Wood: 16 MJ/kg



Feed Characteristics



Volume required to substitute for 1 m^3 of fuel oil, to get the same energy

Pellets/Briquettes

- Easier to handle and transport
- Easier to store
- Easier to use
- Standardize various feedstocks
- Much cleaner combustion
- More expensive than natural gas

Combustion in small scale facilities

- Low net CO_2 emissions
- High particulates $PM_{2.5}$
- High Volatile Organic Carbon
- High Carbon Monoxide
- High Polycyclic Aromatics

Fireplaces are really bad!

Combustion in large power plants

- Effective particle collectors are needed!

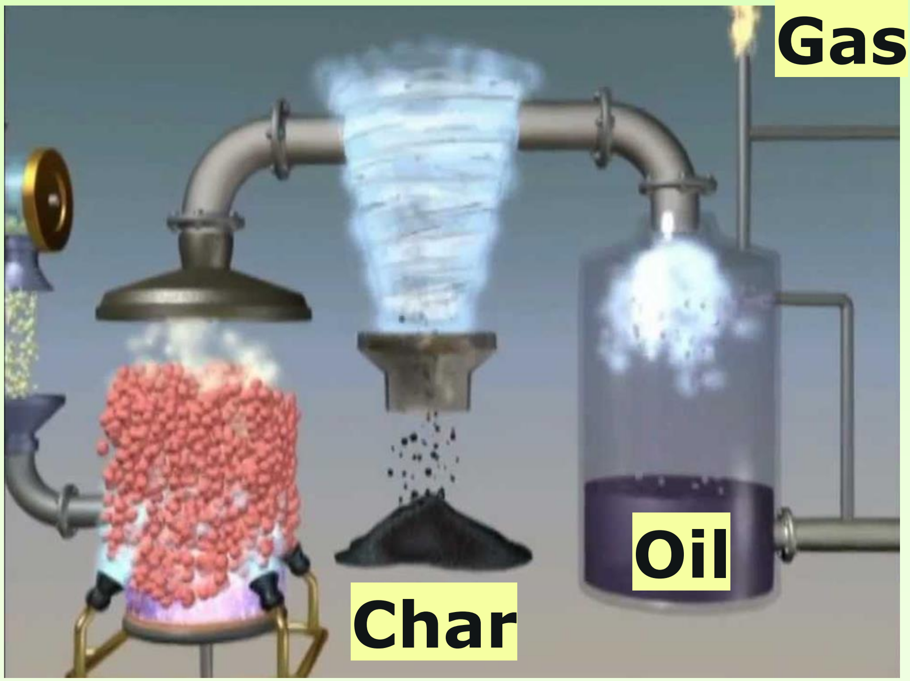
- **Dioxins emissions** in both particles and gas:
  - Worst for wood scrap (demolition and construction sites)
  - Can be reduced with expensive additives

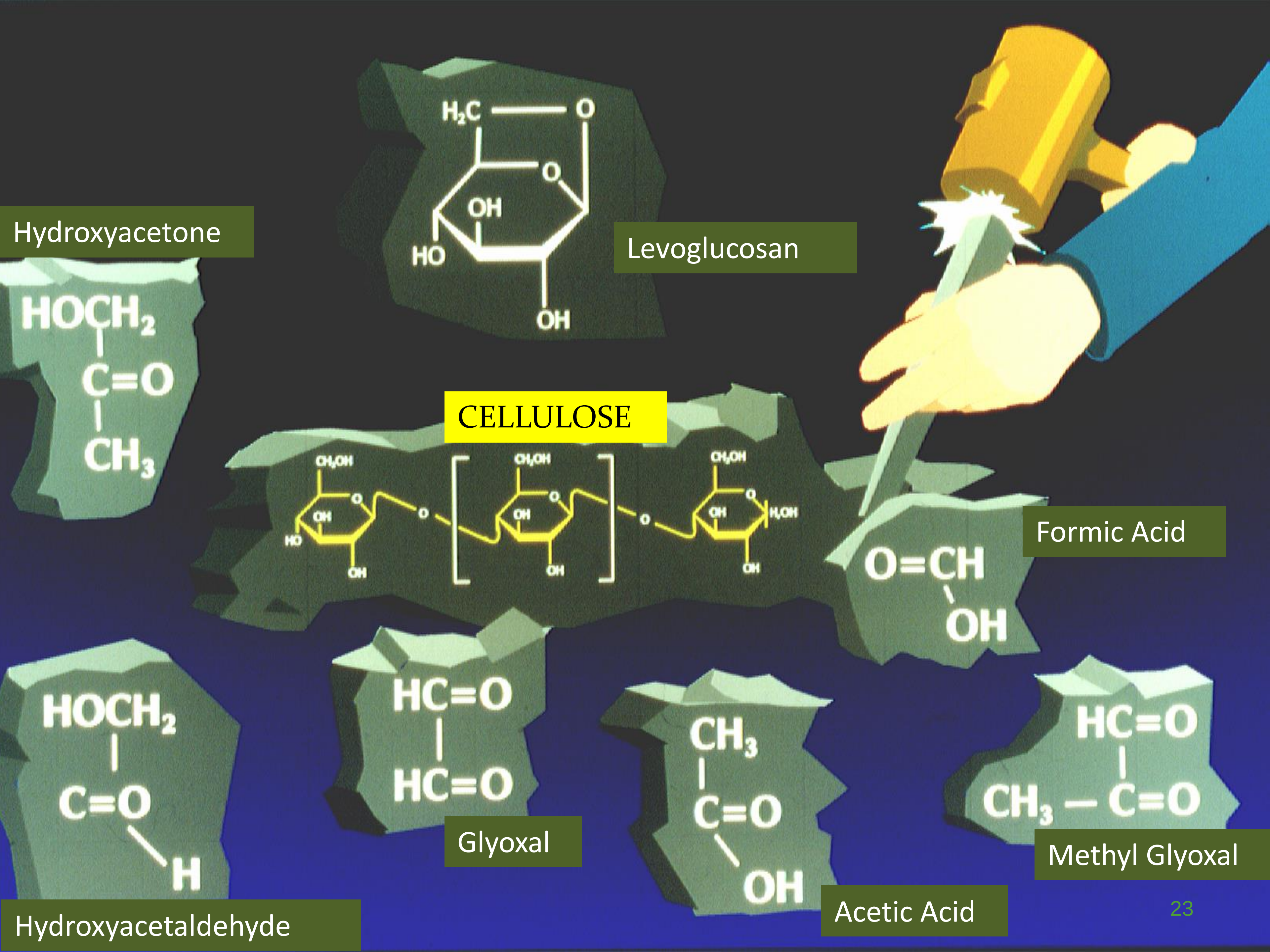
- **Fouling:** because of low ash sintering temperature
  - Wood: 1000 °C
  - Bark: 850 °C
  - Most agricultural residues: around 800 °C
  - Lower combustor temperature: lower thermodynamic efficiency

- **Straws, cereals, grains and fruit residues** have more ash, N, Cl and S than wood
  - **More emissions of NO_x, SO_x, HCl, dioxins**

ADVANCED THERMAL TECHNOLOGIES:

2: PYROLYSIS



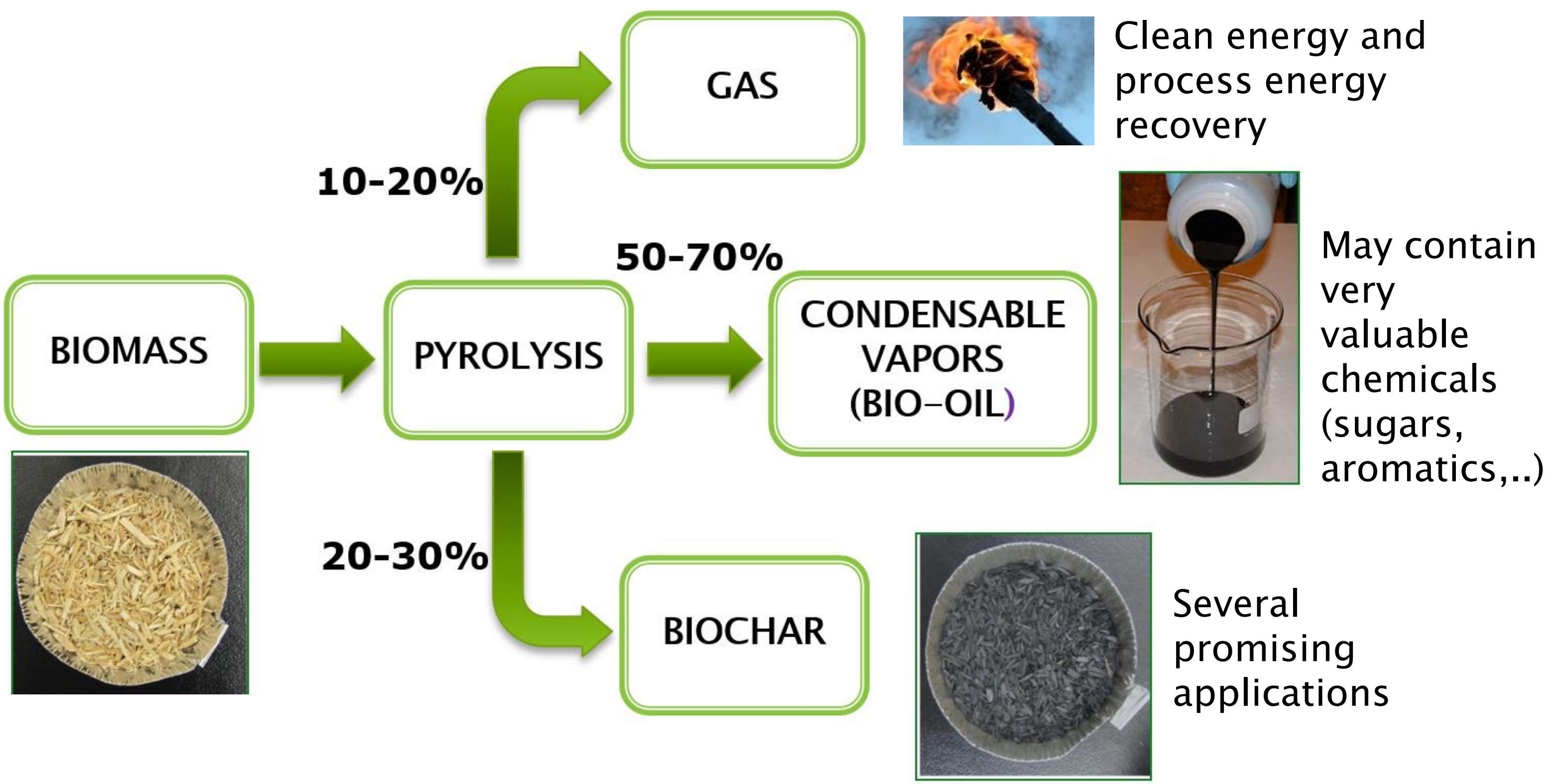


Hydroxyacetone
Levoglucosan
CELLULOSE
Formic Acid
Glyoxal
Acetic Acid
Methyl Glyoxal
Hydroxyacetaldehyde

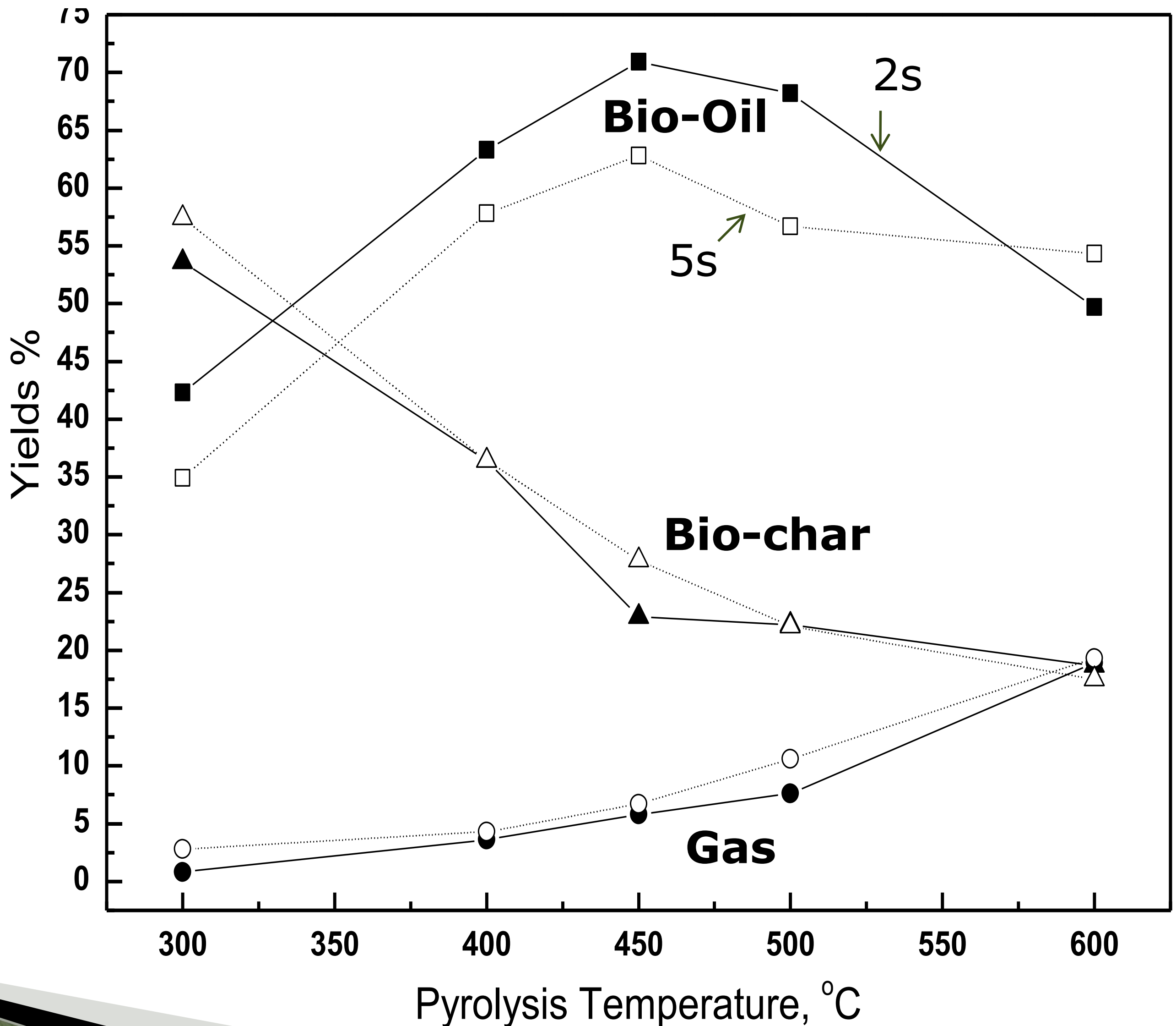
Pyrolysis

- Thermochemical decomposition of organic materials **<u>in the absence of oxygen</u>**

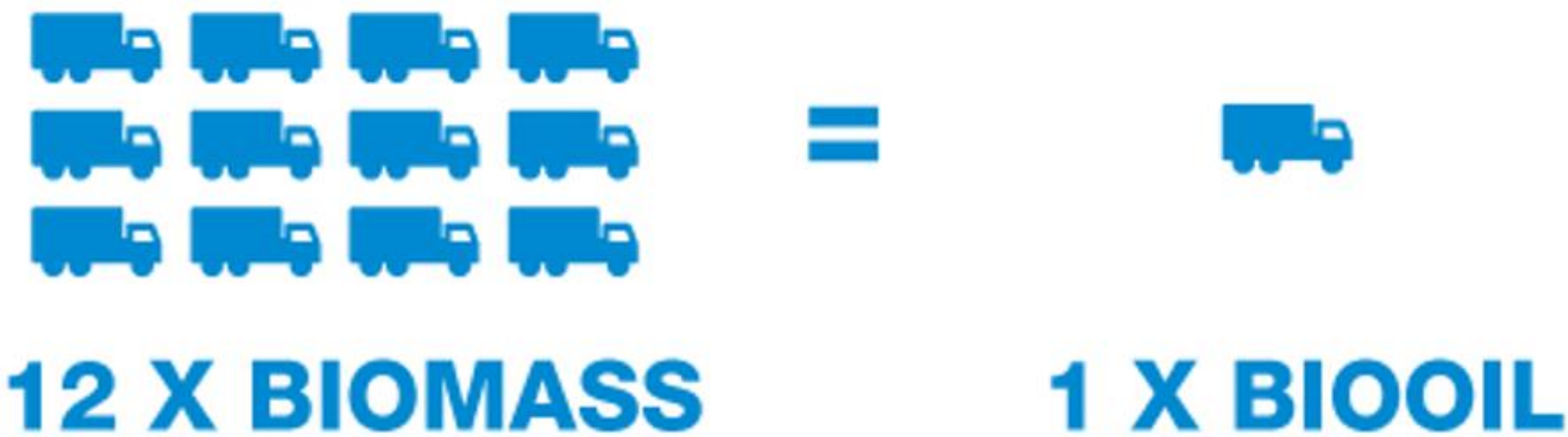
The word is coined from the Greek-derived elements ***pyro*** **"fire"** and ***lysis*** **"separating"**



Typical Experimental Yields



Bio-oil Energy Density



Bio-Oils

- Pharmaceutical products
- Flavors and food additives
- Anti-oxidants
- Pesticides
- Fine chemicals
- Resins and adhesives
- Fuels

BIO-CHAR

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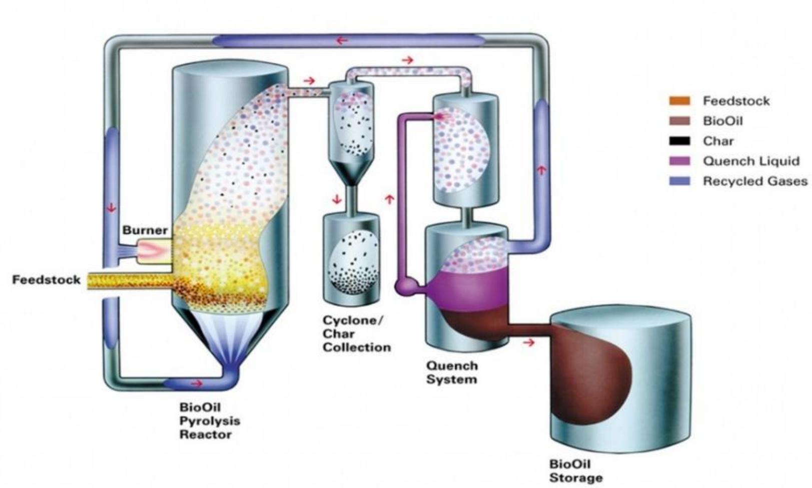
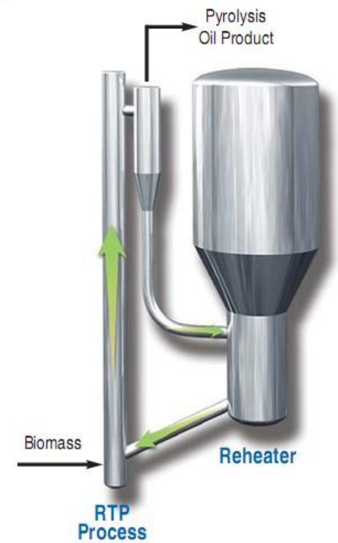
Possible uses of bio-char

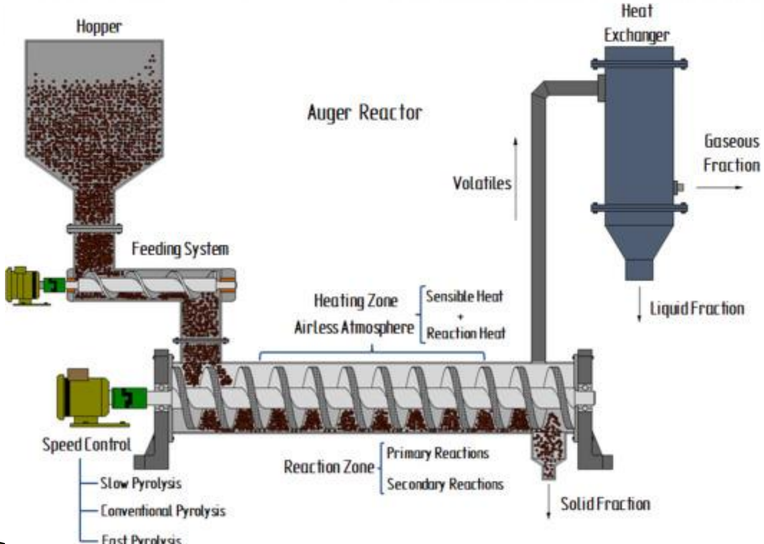
VALUE

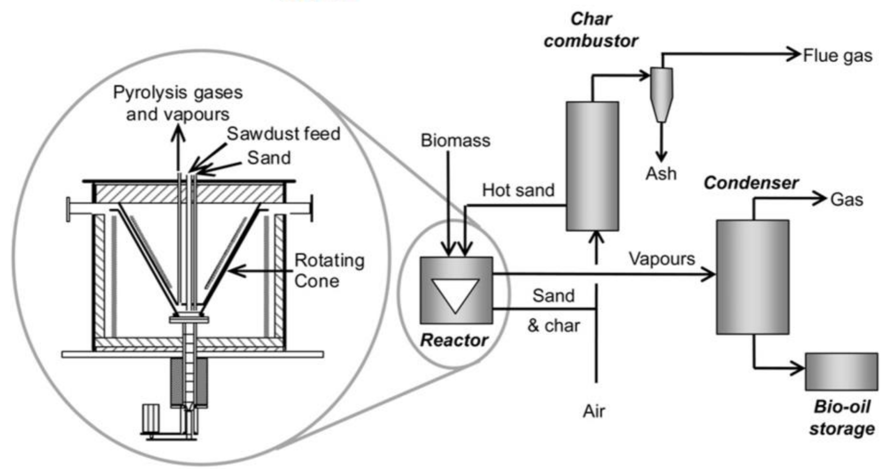
- Pharmaceuticals and cosmetics
- Food and feed additives
- Activated carbons
  - Wastewater treatment
  - Air purification
  - Removal of contaminants (mercury, arsenic,..)
- Composite and advanced materials (filler, fibers, carbon nanotubes), catalysts, electrodes,…
- Coal substitute or coke substitute: bio-coal or bio-coke
- Soil amendment and carbon sequestration: bio-char

Many Pyrolysis Technologies……









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REMEMBER: Biomass logistics!

- Low density, seasonal, moisture, bulky, perishable

10 t/day Mobile Pyrolysis Process (Pre-Commercial)

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2.5 t per day ICFAR Mobile Pyrolyzer

Bio-Techfar
Converting Biomass - Creating Value

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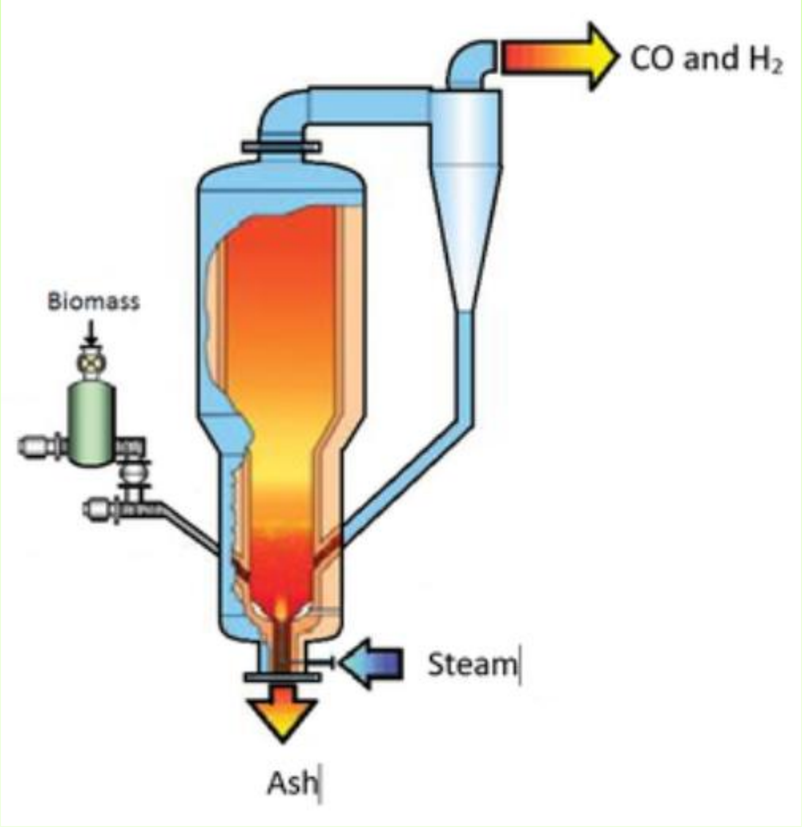
ADVANCED THERMAL TECHNOLOGIES:

3: GASIFICATION



Types of application for the gas

- **Fuel**
  - Replace natural gas for heat generation
  - Power generation:
    - Modified diesel generators
    - Gas turbines
  - Substitute transportation fuel

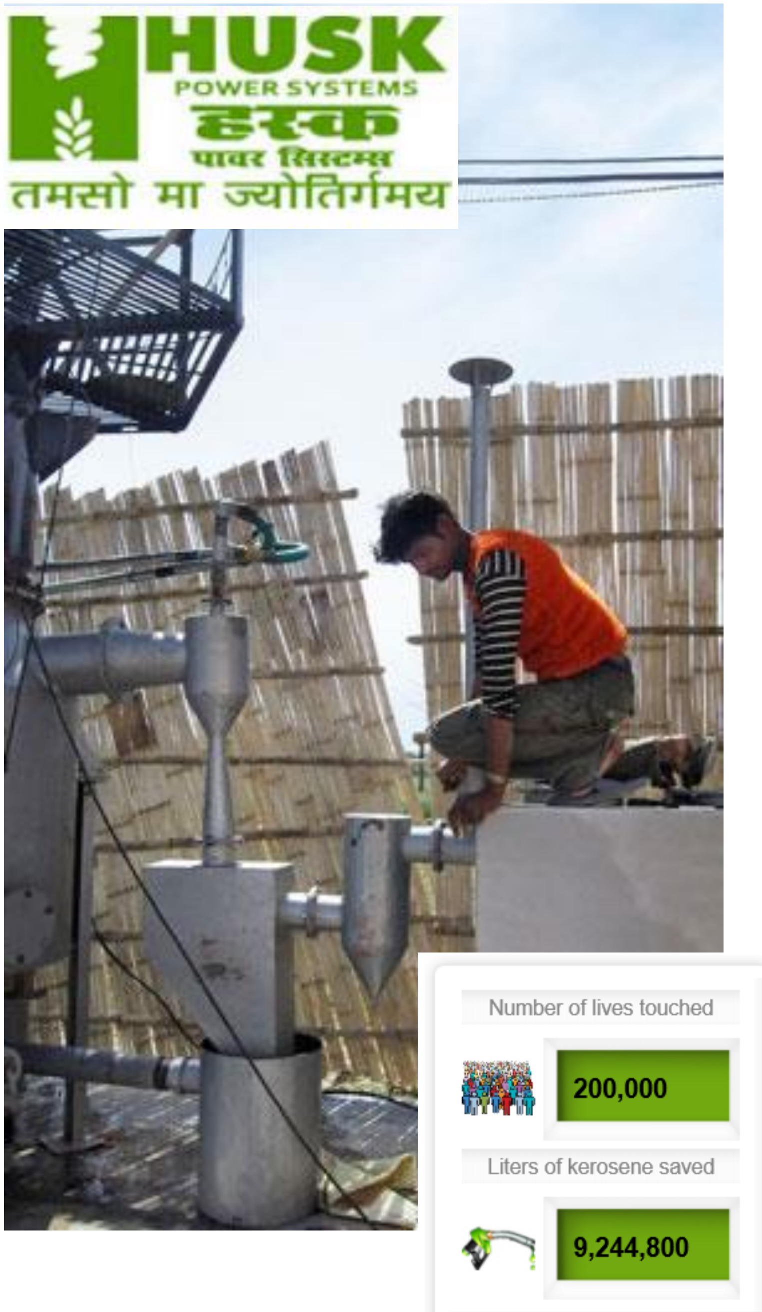
- **Syngas**
  - To produce chemicals and advanced fuels

Gasification vs. Combustion

- Combustion of a gas is much better controlled than the combustion of a solid fuel:
  - Much less pollution
  - Better temperature control
- Easier to retrofit plants with gas burners
- Easier to distribute fuel to many locations within a plant
- Can fuel small electrical power generators

Energy content

- The energy content of biomass varies depending on the type of biomass
- Water content is a major problem
- Ash content also must be considered based on the type of gasifier used
- Anything can be gasified, but is it of value?

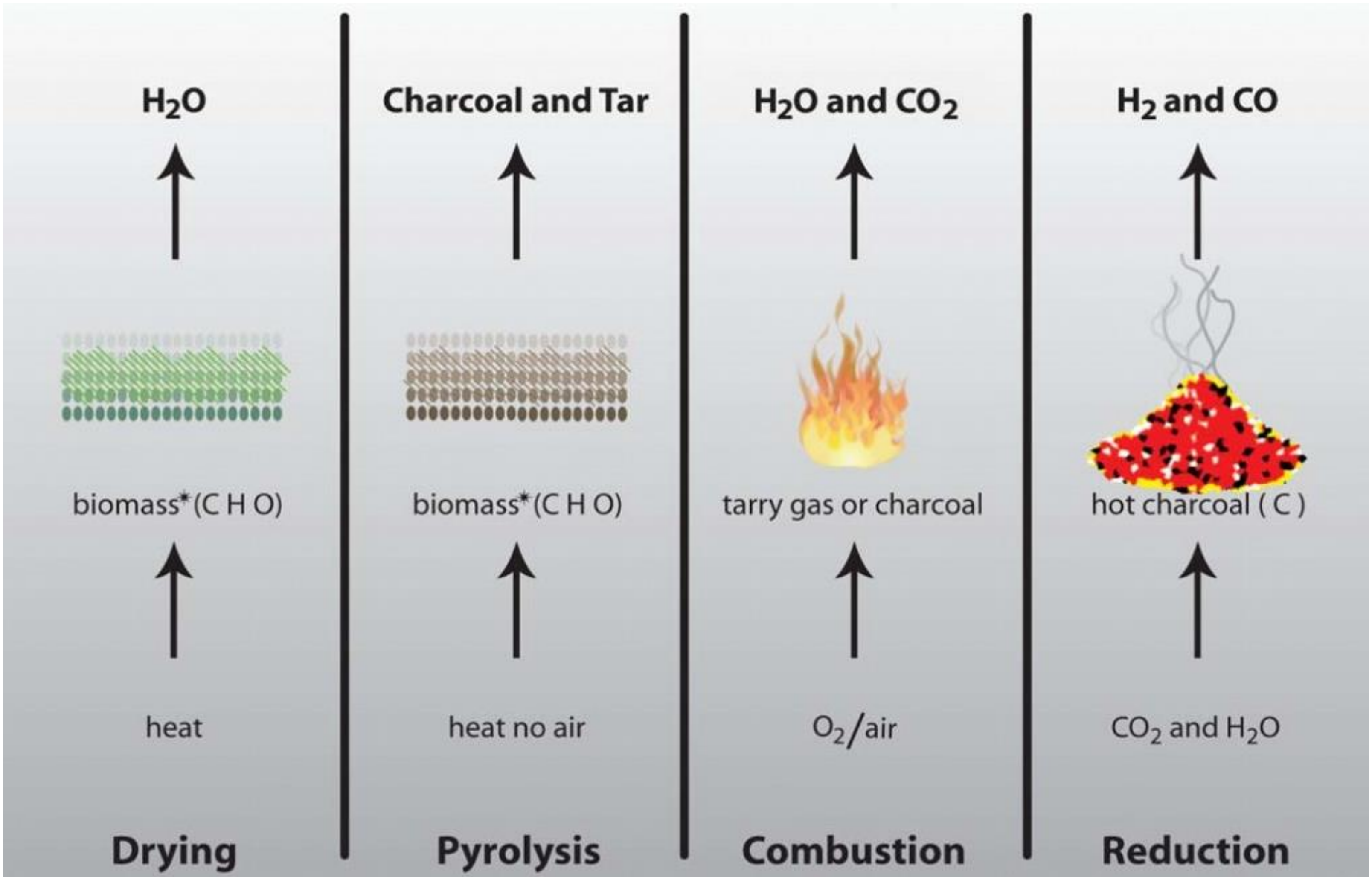


Husk Power Systems

- Gasifiers connected to old diesel generators
- Generate electricity from rice husks
- Microgrids for very poor areas of India that currently have no power
- > 80 plants
- Cost = $ 0.13 – 0.15 / kWh

Normal for India $ 0.06 - 0.12 / kWh

Reaction steps in gasification

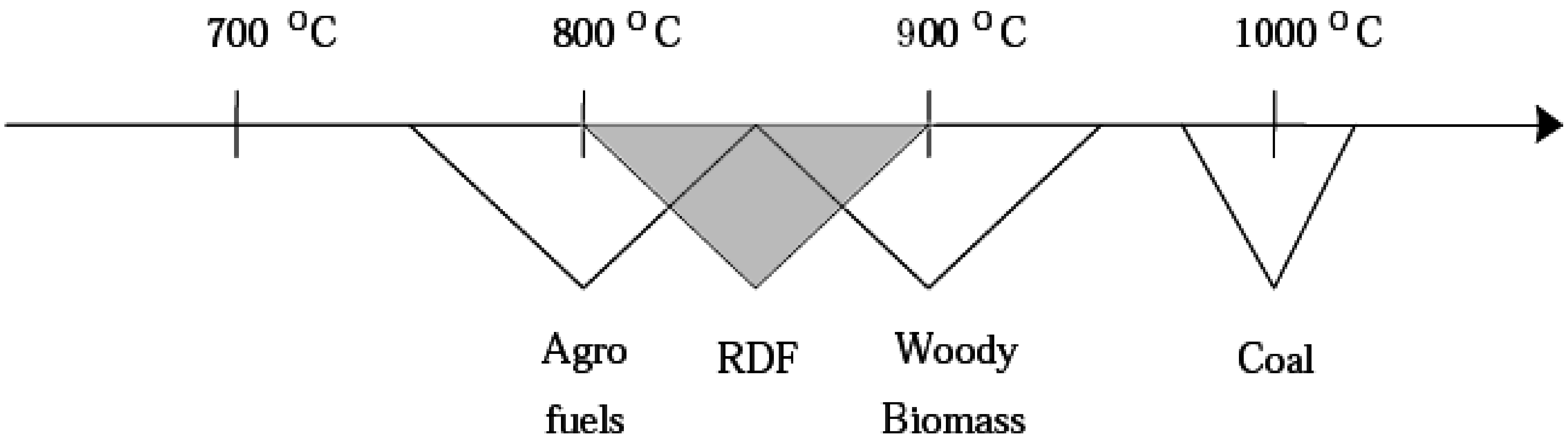


Gasification agent and gas quality

- Biomass + **air + (steam)** → low energy gas
  - Dilution by N_2
  - LHV = 3-7 MJ/Nm^3
- Biomass + **pure oxygen + (steam)** → medium energy gas
  - No dilution by N_2
  - LHV = 12-28 MJ/Nm^3
- Biomass + **steam + additional heat** → medium energy gas
  - Energy balance requires additional heat transferred to reactor
  - LHV = 10-18 MJ/Nm^3

Selection of best gasifier temperature

Higher	←	Gas heating value	→	Lower
Higher	←	Tar content	→	Lower
Lower	←	Char conversion	→	Higher
Decreasing risk	←	Sintering	→	Increasing risk



Gasifier types

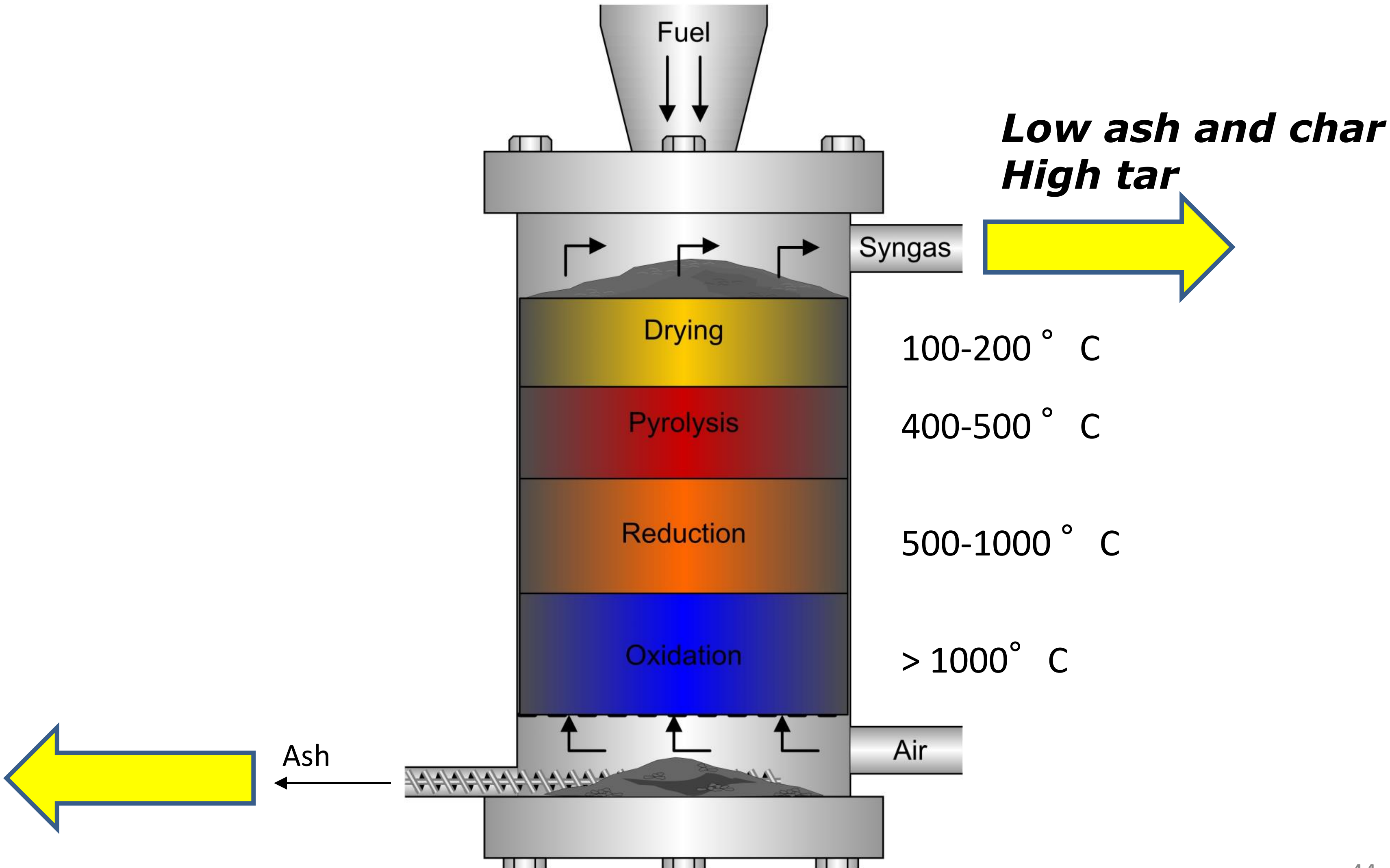
- **Fixed beds** of biomass:
  - The **bed of solids** actually moves **down** slowly
  - Direction of **gases and vapors**:
    - **Up**: “updraft”
    - **Down**: “downdraft”

- **Fluidized beds**:
  - Usually a fluidized bed of sand particles
  - Bubbling bed:
    - Sand remains in place
  - Circulating bed:
    - Sand is circulated between different vessels
    - Sand may be used as a heat carrier

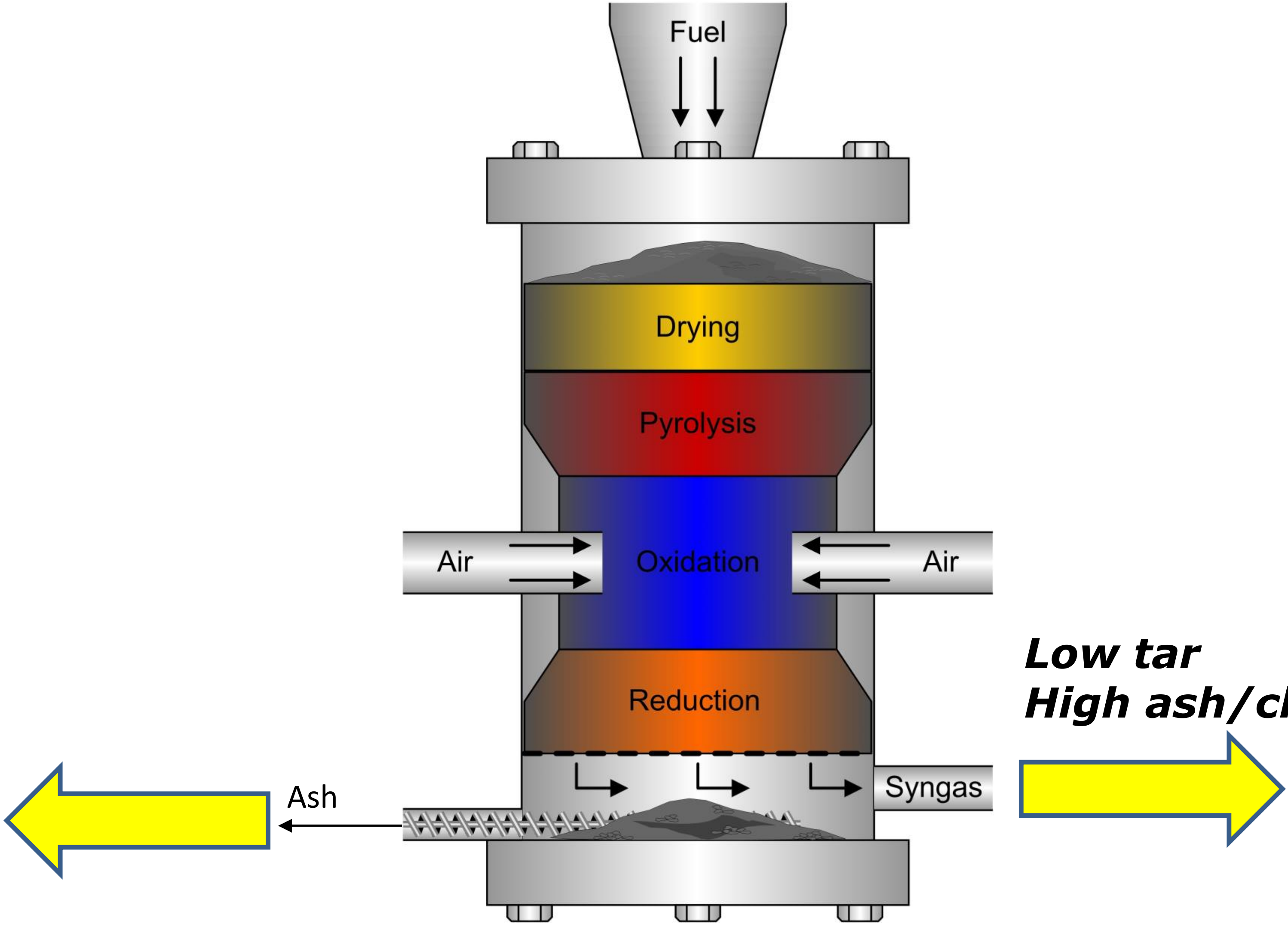
Gasifier types

Gasifier type	Partial combustion of	Additional heat
Updraft fixed bed	Char	N/A
Downdraft fixed bed	Vapor/gases	N/A
Bubbling fluidized bed	Char/vapors/gases	Through in-bed heat exchangers
Circulating fluidized bed	Char/vapors/gases	Sand reheated in a burner vessel

Updraft gasifiers

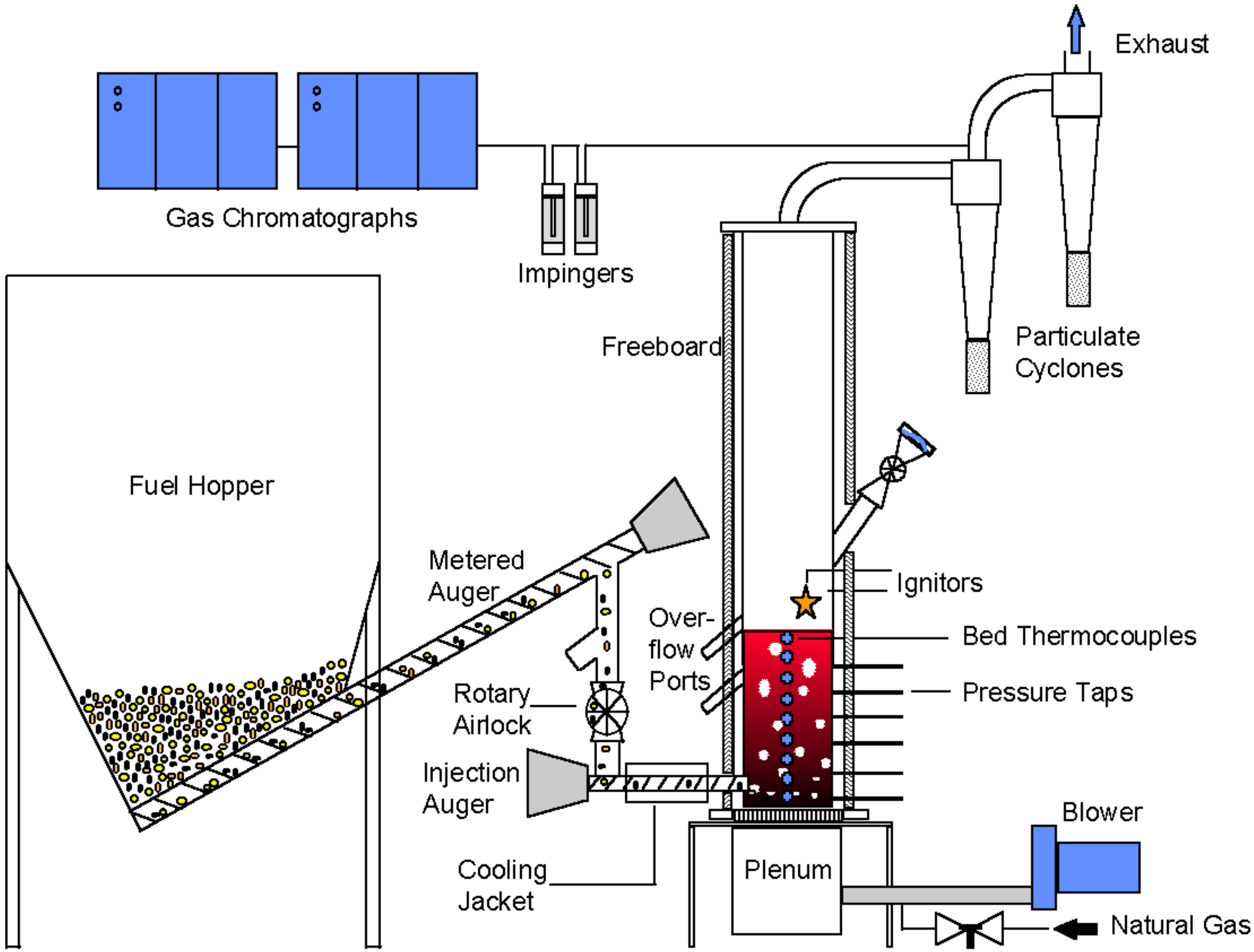


Downdraft gasifiers

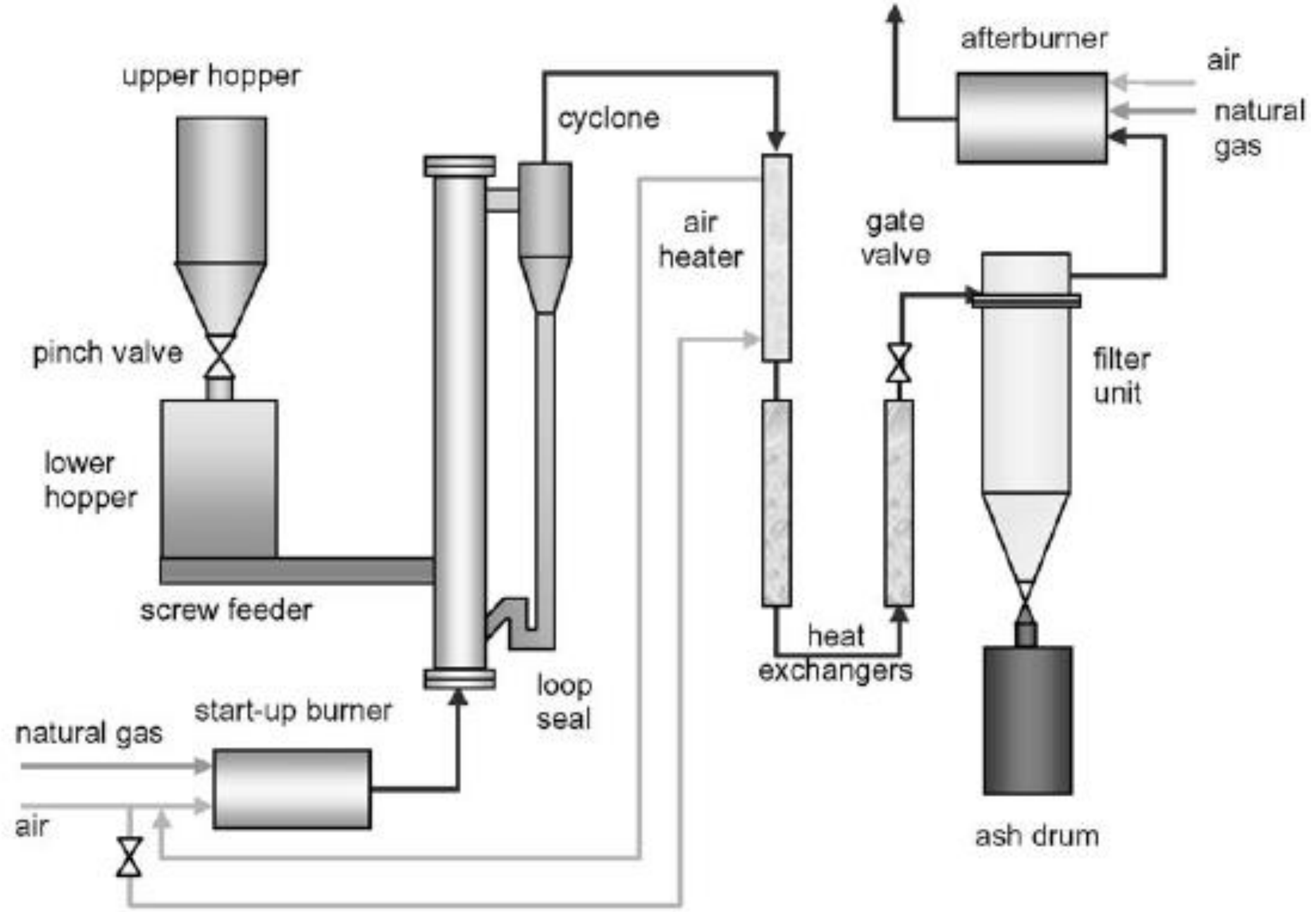


Low tar
High ash/char

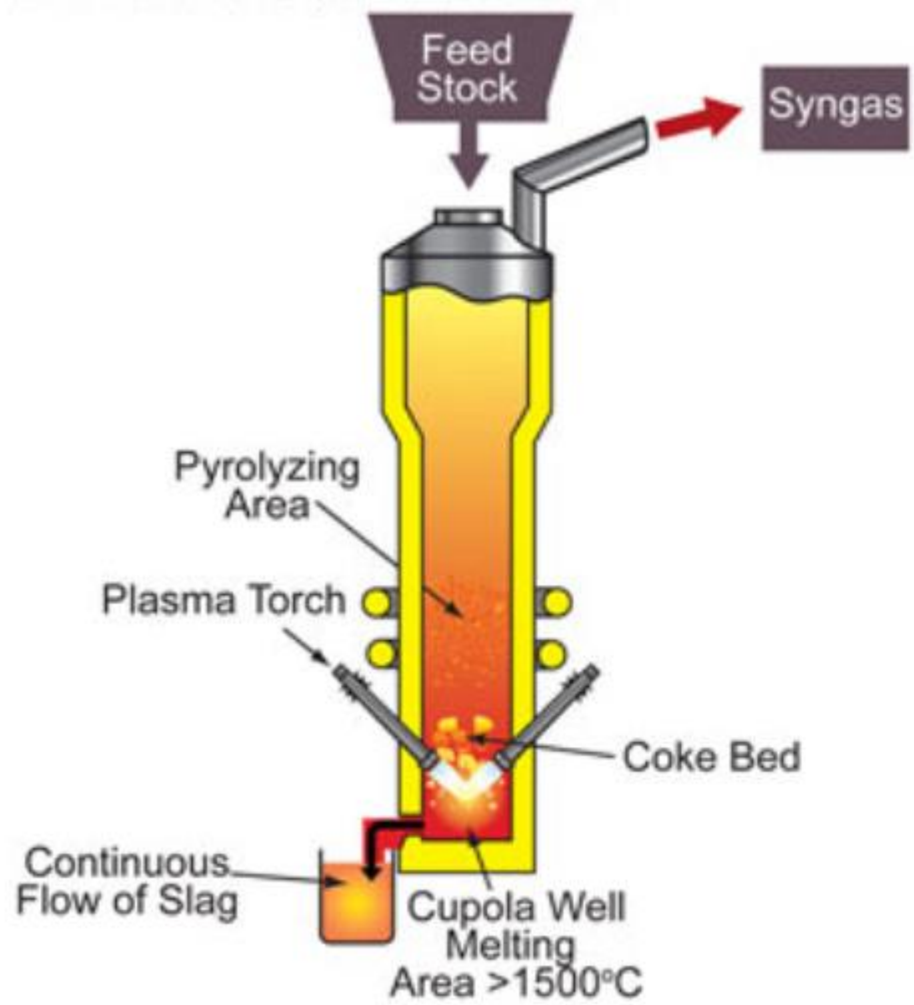
Fluidized bed gasifiers



Circulating bed gasifiers



Plasma gasifiers



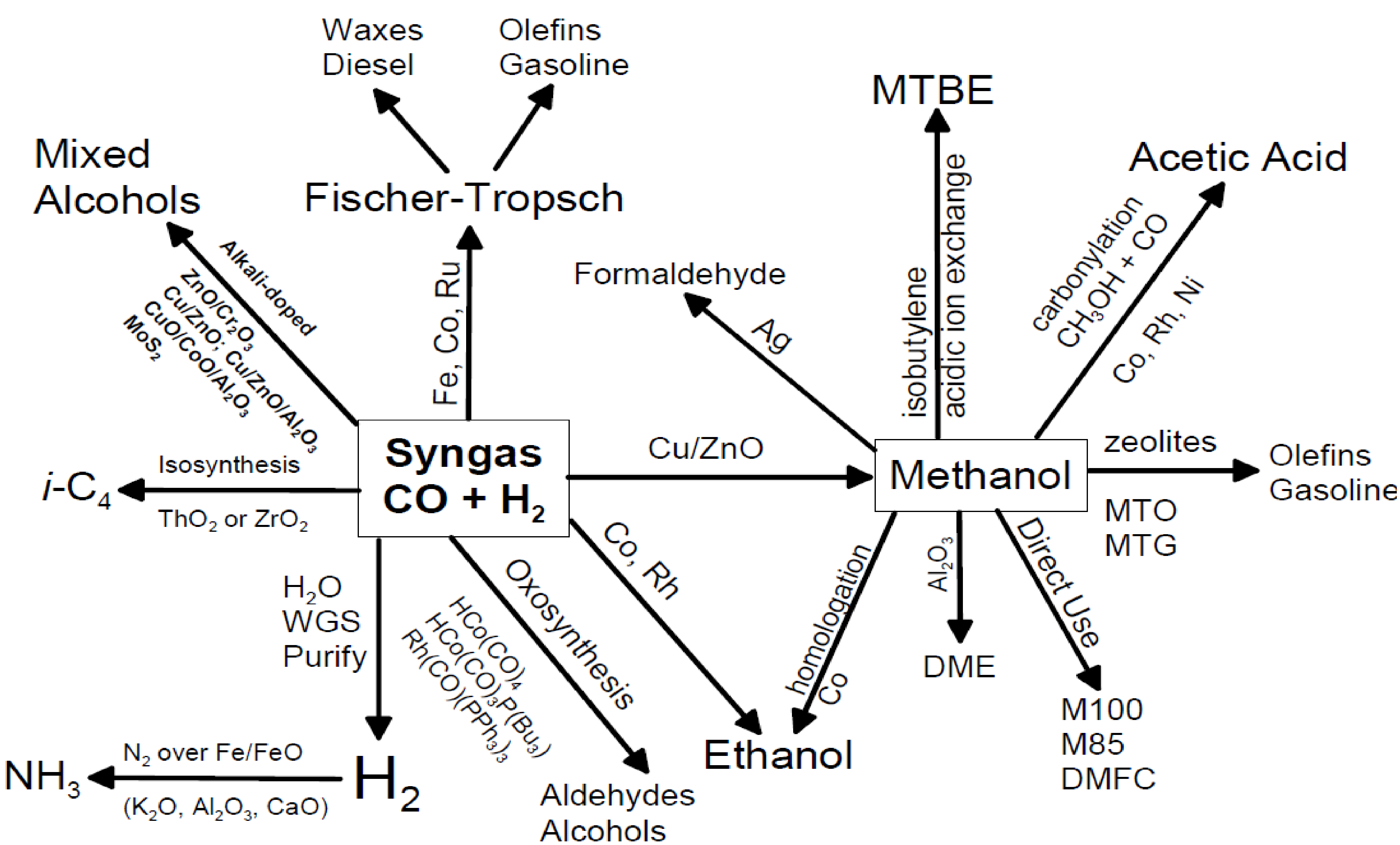
Applications of Syngas

- **Hydrogen** production
- **Diesel/gasoline** using **Fischer-Tropsch** synthesis
- **Methanol**

in addition to:

- Methane
- Higher alcohols
- Chemicals (glycerol, fumaric acid..)
- Fertilizers, through ammonia
- Electricity, through combustion

From Syngas to……..

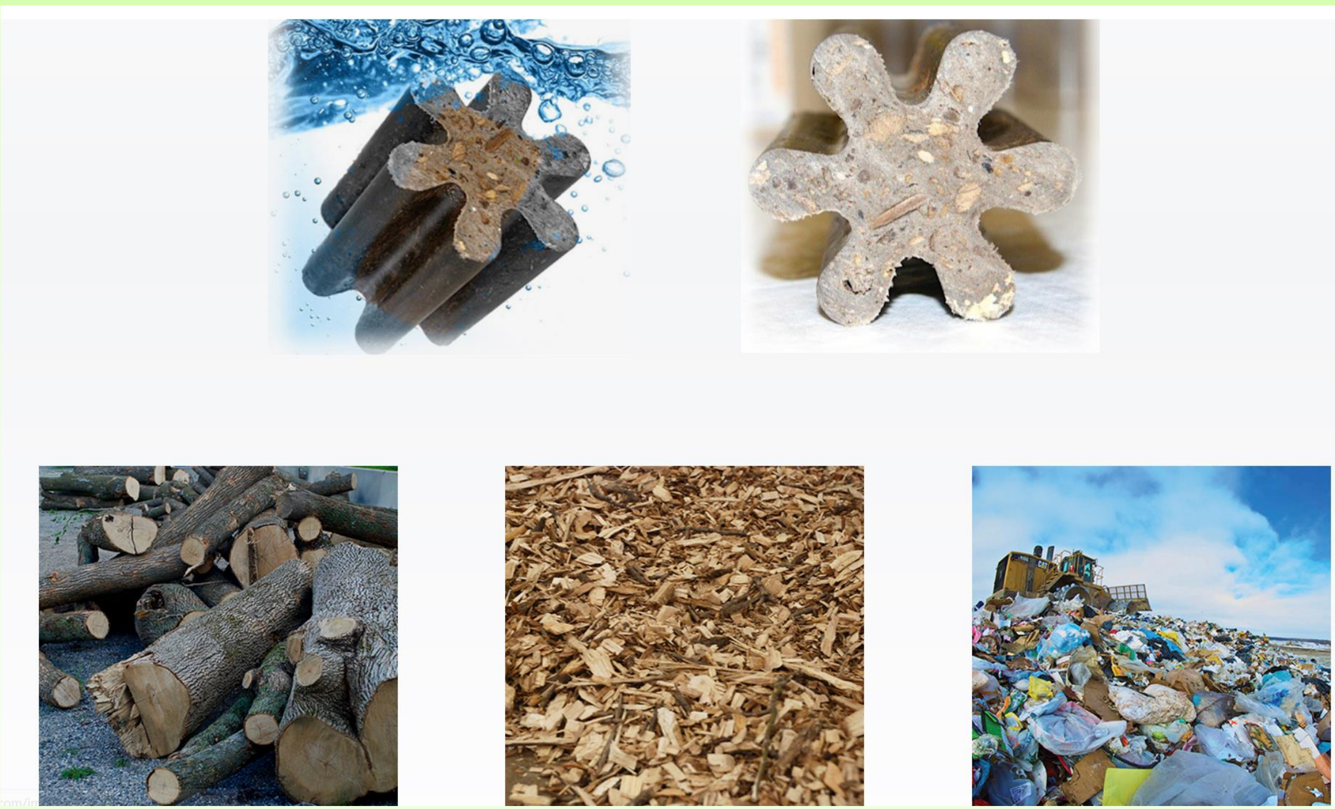


ADVANCED THERMAL TECHNOLOGIES:

ADOPTION, SUCCESSES, LESSONS LEARNED…..

Combustion

- **ERS Fuels, St. Marys, Ontario, Canada**



Pyrolysis

Host Organisation	Country	Technology	Capacity kg feed/h	Capacity kg bio-oil/h	Applications	Status	Year
Green Fuel Nordic	Finland	BTG-BTL - Rotating cone	5,000	3,250	Fuel	Construction	2019
Twence / EMPYRO	Netherlands	BTG-BTL - Rotating cone	5,000	3,250	Fuel	Operational	2014
Fortum - VALMET	Finland	VTT Fluid bed / riser	10,000		Fuel	Operational	2013
AE Cote-Nord Bioenergy	Canada	Ensyn Fluid bed / riser	9,000	6,400	Fuel	Construction	2017
Red Arrows	Canada	Ensyn Fluid bed / riser	1,667		Fuel	Operational	1996

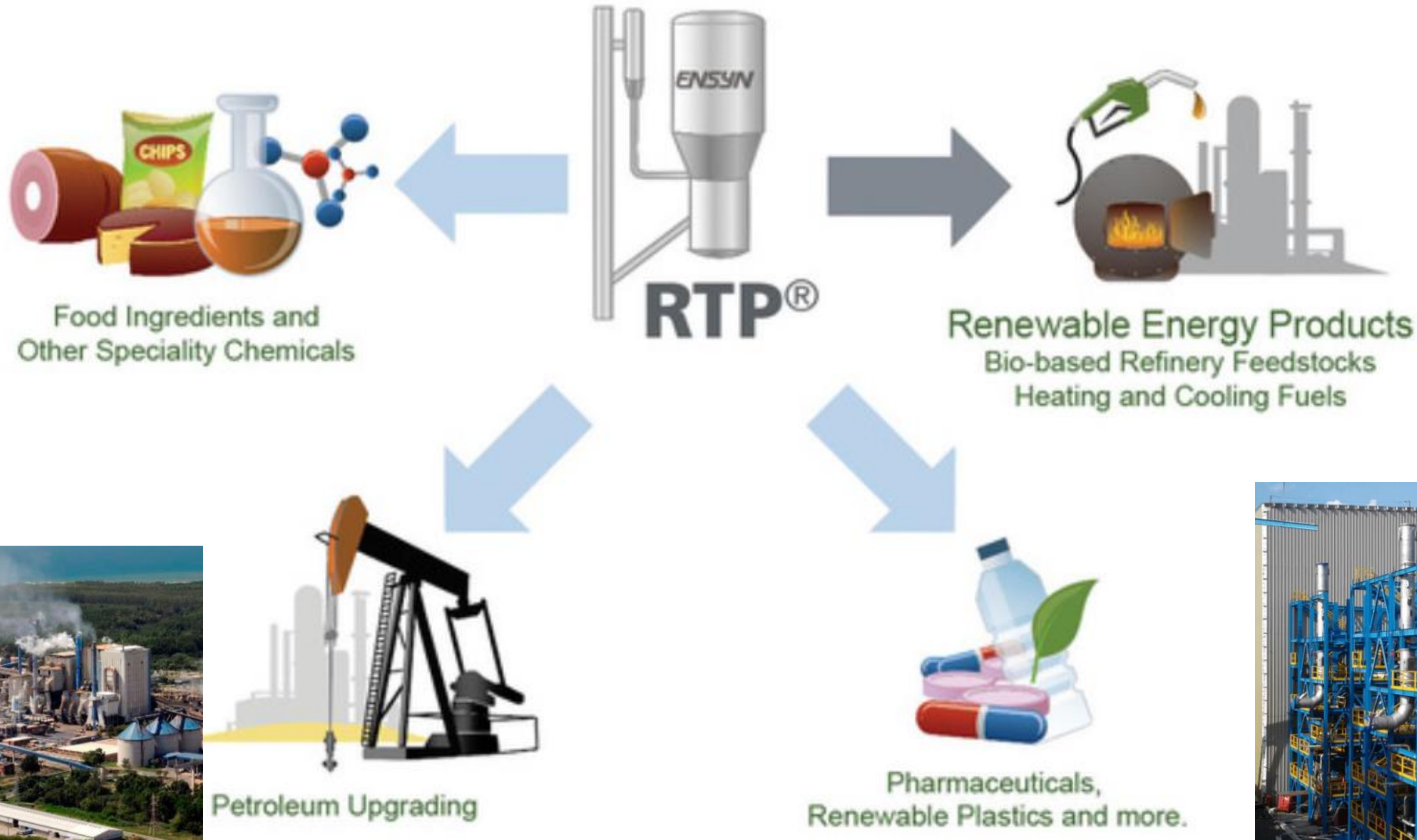
Empyro-BTG-BTL,
The Netherlands

Fortum VALMET, Finland

Pyrolysis

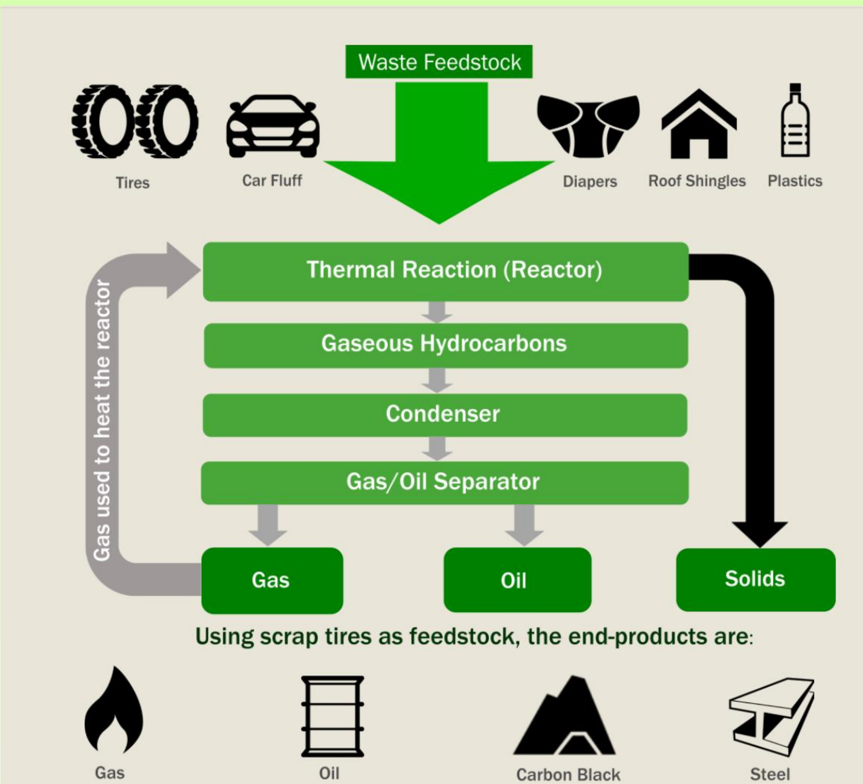
ENSYN

Ottawa, Canada



Pyrolysis

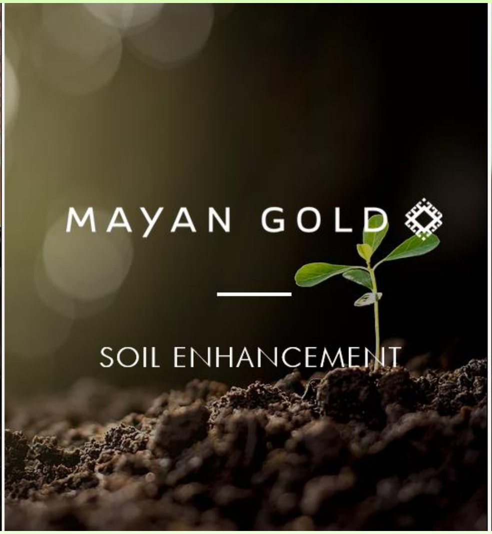
Montreal, Quebec



Pyrolysis

TITAN Carbon Smart Technologies

Craik, Saskatchewan



Pyrolysis

PYROWAVE™
CLOSING THE LOOP

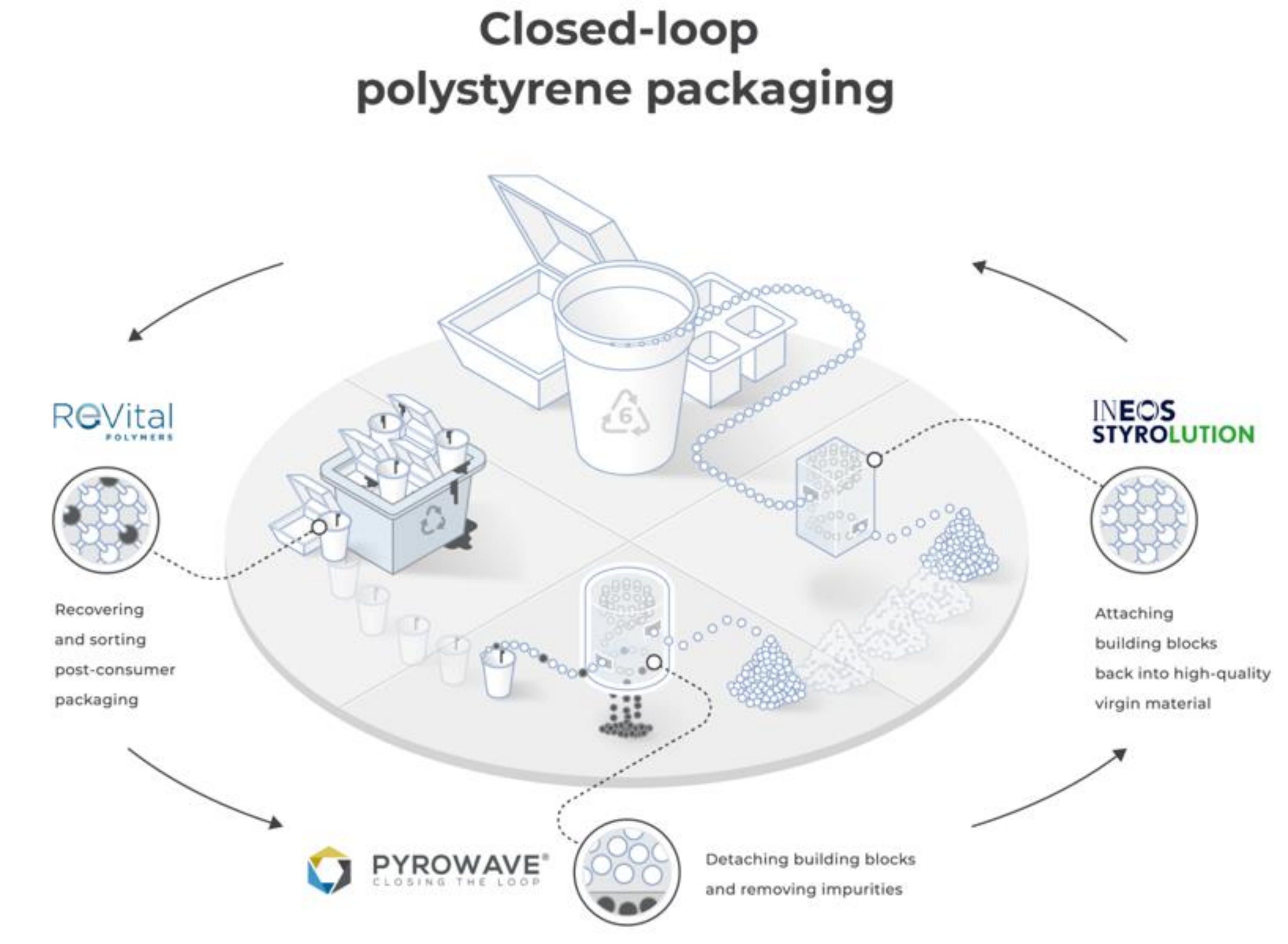
Montreal, Quebec

Catalytic Microwave Depolymerization (CMD)

50 and 100 kg per cycle and each cycle lasts 30 minutes

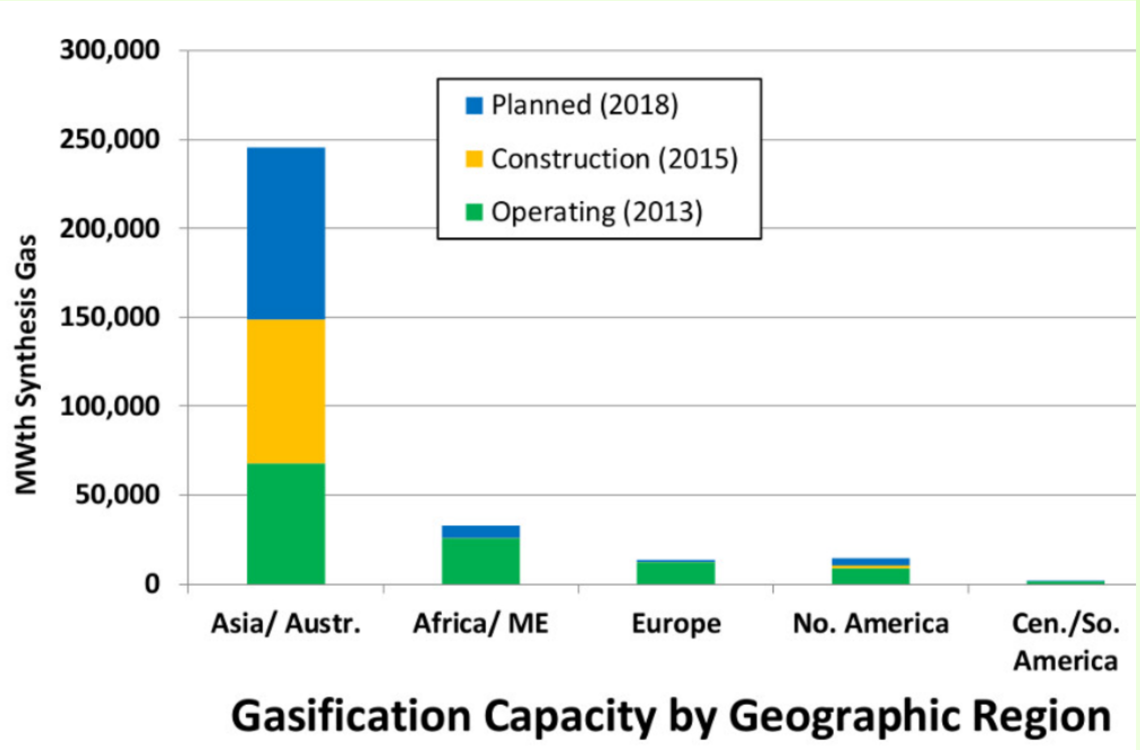
Pyrolysis

PYROWAVE™
CLOSING THE LOOP



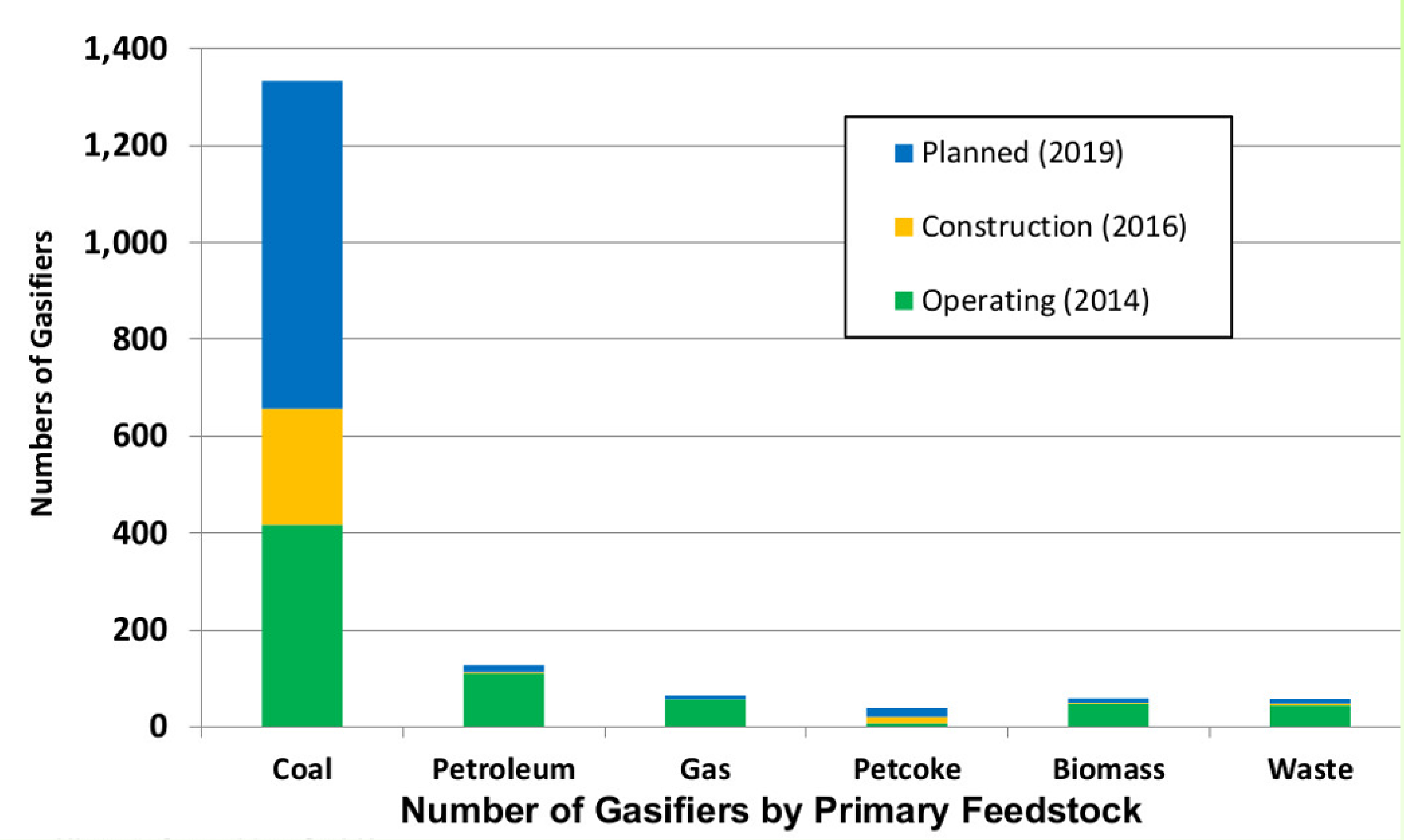
Gasification

- More than 272 plants with over 686 gasifiers worldwide
- Gasification for chemicals is the most important application



Gasification

- However, **most of the gasifiers use coal**



Gasification

- Waste gasification:

Enerkem

Sherbrooke, Quebec

"Waste to Methanol to Ethanol"

Enerkem, Edmonton, Alberta

Enerkem, Westbury, Quebec

Enerkem Varennes: the first facility in Quebec that will produce cellulosic biofuels from non-recyclable residual materials

Enerkem in Rotterdam: 'Waste to Chemicals' (W2C) plant

Acknowledgments

RÉSEAU BIOFUELNET CANADA

NSERC CRSNG

LIGNOWORKS
The NSERC Biomaterials and Chemicals Network

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