13th INTERNATIONAL FREIBERG CONFERENCE ON CIRCULAR CARBON TECHNOLOGIES

TECHNISCHE UNIVERSITÄT DARMSTADT

Pyrolysis and Gasification Kinetics of Various Organic Waste Feedstocks for Emerging Conversion Pathways in CFB Reactors

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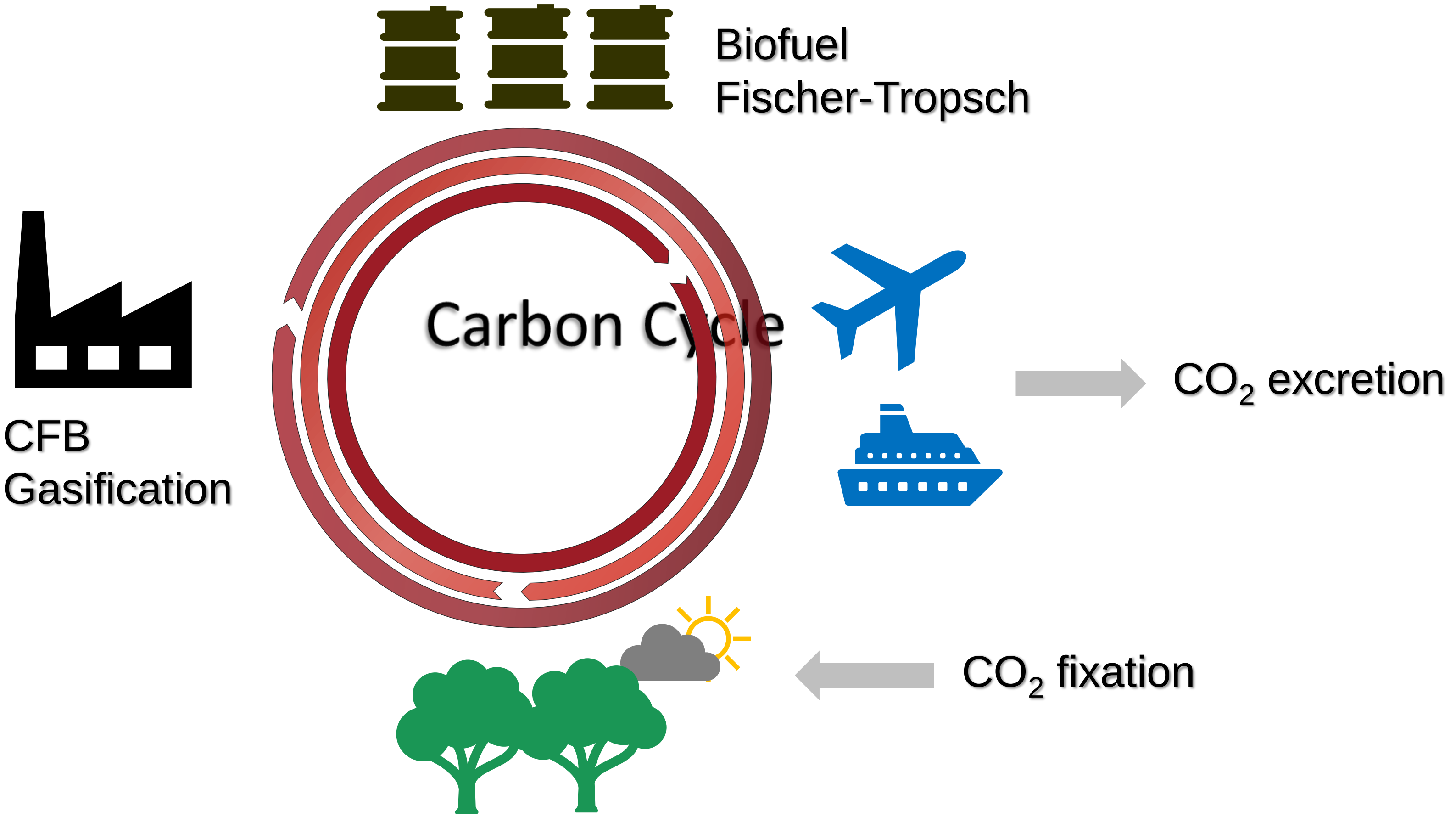
CARBIOW

INTRODUCTION

Green Transition and Circular Economy

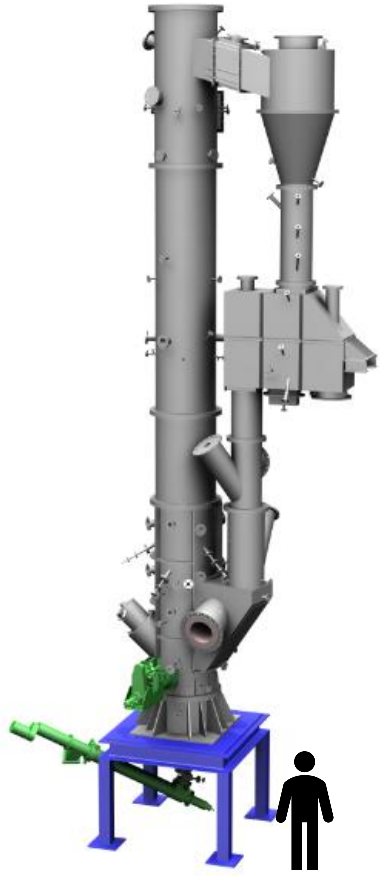
Organic waste to biofuels



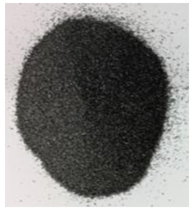
INTRODUCTION

An emerging organic waste conversion pathways in CFB gasifiers

- **Novel Bed Material Concept**
  - Replacing inert sand with oxygen carriers
- **1 MW CFB Gasifier-Pilot Demonstration**
- **Enhanced Syngas Quality**
  - in-situ oxygen availability
- **Feedstock Flexibility**
  - Torrefied organic waste feedstocks



1 MW CFB Gasifier



Ilmenite

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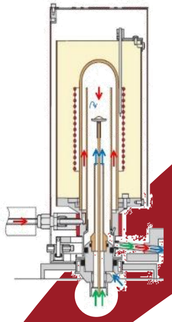
INTRODUCTION

Why?

- Study kinetics of unrefined organic waste conversion
- Use data in simulation to support pathway development

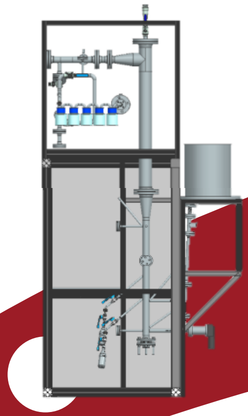
Aim & Goal

- Validate experimental data on lab scale and 1 MW_{th} pilot scale
- Support industrial-scale design



bench scale

- thermogravimetric analysis



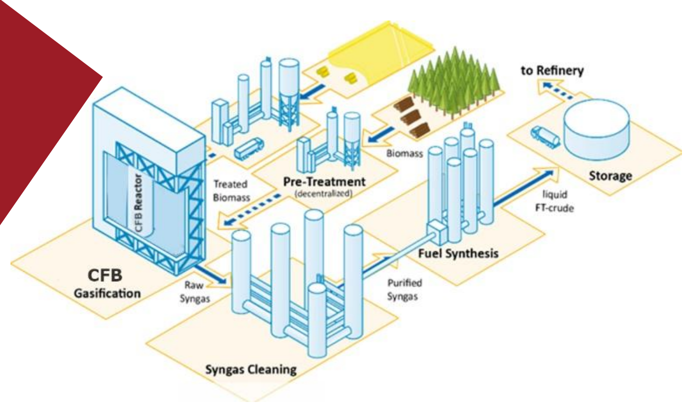
laboratory scale

- externally heated fluidized bed reactor

pilot scale

- 1 MW_{th} CFB fluidized bed reactors in pilot scale

industrial scale



FEEDSTOCKS

Municipal Solid Waste – organic fraction
Torrefied kitchen waste (TKW)


Source: https://de.wikipedia.org/wiki/Lebensmittelverschwendung

Agriculture (commercial feedstocks)
Torrefied corn residue (TCR)


Source : https://www.farmprogress.com/corn/corn-residue-collection-impacts-erosion-greenhouse-gas-emissions

Pulp & Paper Industry
Torrefied waste cellulose pulp residue (WCPR)

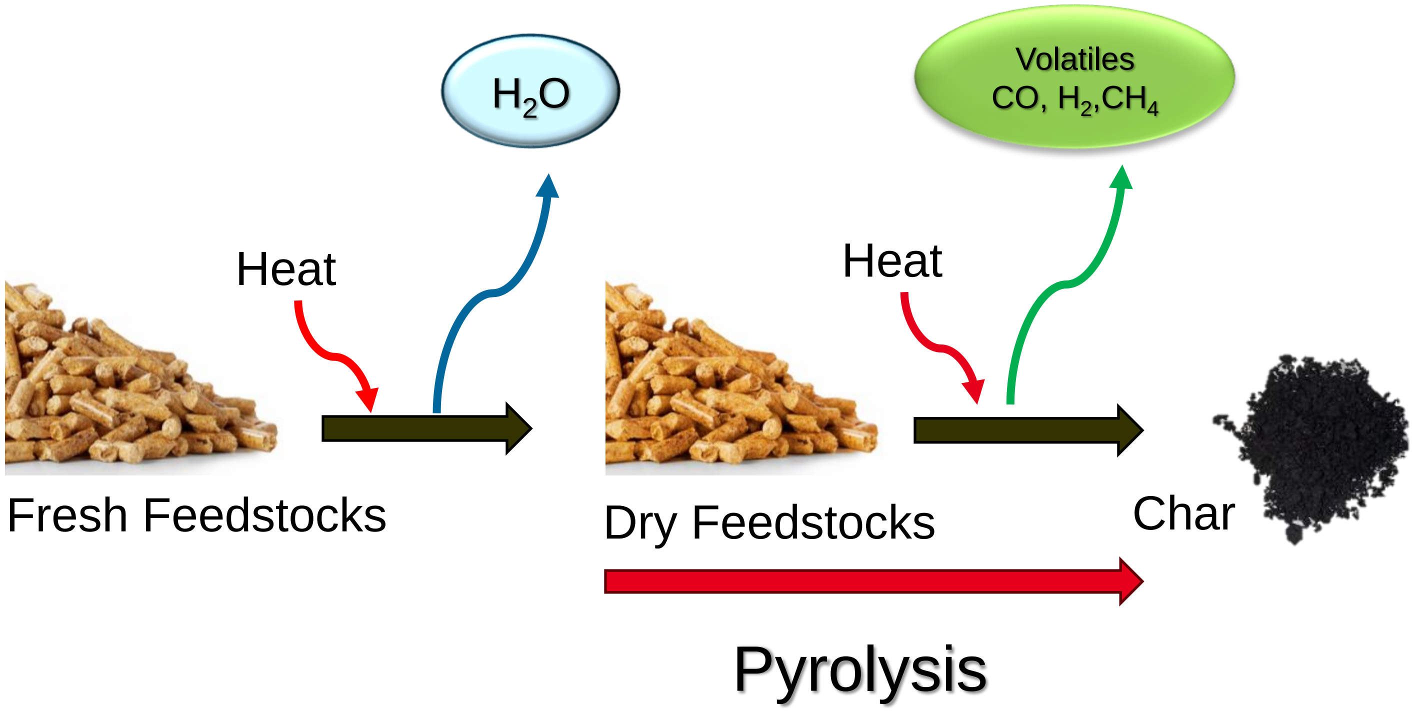

Source : https://www.berthold.com/en-us/process-control/industries/pulp-and-paper-industry/

Food Processing Industry
Torrefied cherry pits (TCP)


Source :https://www.tastingtable.com/692221/pit-a-cherry-straw-pitter-food-hack/

FEEDSTOCKS

Pyrolysis of organic waste



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PYROLYSIS

Method :

Three Pseudo Components Model

Conversion: X; Initial mass: m_0; Mass at unit of time: m_t; Final Mass: m_f

$$X = \frac{m_0 - m_t}{m_0 - m_f}$$

Reaction rate (min^{-1}): $\frac{dX}{dt}$; Rate constant (K): $A \exp\left(\frac{-E_a}{RT}\right)$; Reaction model: $f(X)$

$$\frac{\mathrm{dX}}{\mathrm{dt}} = \mathrm{A}\exp\left(\frac{-\mathrm{E_a}}{\mathrm{RT}}\right) f(X)$$

$$f(X) = (1 - X)^n$$

n=1 for pyrolysis

Reference: Qiang Hu et al , 2018

PYROLYSIS

Torrefied kitchen waste
(TKW)

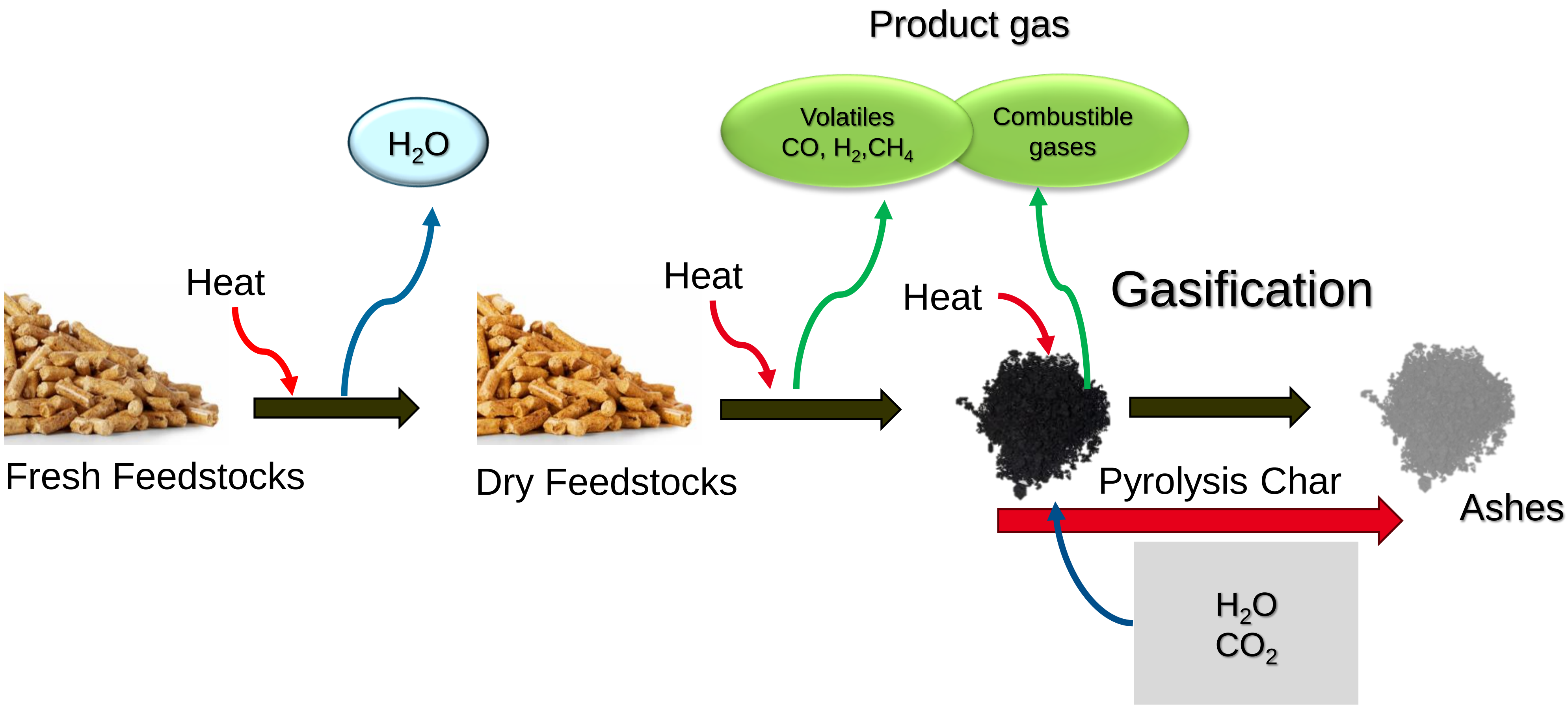
waste cellulose pulp residue
(WCPR)

Torrefied corn residue
(TCR)

Torrefied cherry pits
(TCP)

FEEDSTOCKS

Gasification of organic waste



GASIFICATION

Non-Isothermal –Model Free Method

Conversion, Initial mass, Mass at unit of time, Final Mass

$$X = \frac{m_0 - m_t}{m_0 - m_f}$$

Reaction rate (min^{-1}), Rate constant (K), Reaction model

$$\frac{dX}{dt} = A \exp^{\left(\frac{-E_a}{RT}\right)} f(X)$$

$$ln\left(\frac{\beta}{T^2}\right) = \ln\left[\frac{A.R}{E_X.g(X)}\right] - \frac{E_X}{R.T}$$

The Kissinger–Akahira–Sunose (KAS)

Torrefied kitchen waste (TKW)

GASIFICATION

Non-Isothermal –Model Free

GASIFICATION

Non-Isothermal –Model Free

waste cellulose pulp residue (WCPR)

GASIFICATION

Non-Isothermal –Model Free

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GASIFICATION

Isothermal method, Curve fitting

$$\frac{dX}{dt} = k(T, CO_2/H_2O)f(X)_{Reaction\,model}$$

Reaction model	Differential form f(x)	Symbol
Avrami-Erofeev	$m(1-X)(-\ln(1-X))^{\frac{m-1}{m}}$	AE

m = 4

Feedstocks:
Torrefied Kitchen Waste (TKW)
Agent: CO_2 (40%)
T = 900 °C

Agent: H_2O

	E_a ($kJmole^{-1}$)	A (min^{-1})
Isothermal		
Non-Isothermal		

Agent: CO_2

	E_a ($kJmole^{-1}$)	A (min^{-1})
Isothermal		
Non-Isothermal		

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CONCLUSION

- Kinetics data of hard-to-utilize **torrefied organic wastes** were determined.
- Pyrolysis :
  - The three-pseudo-component model revealed the material composition (hemicellulose, cellulose, lignin) and its overall thermal behavior.
- Gasification:
  - **Non-isothermal** & **isothermal** methods applied for pyrolysis char.
  - Kinetic data showed pyrolysis char reactivity as **TKW > TCR > WCPR** for both H_2O and CO_2 gasification.
  - Both methods complemented each other for **less reactive pyrolysis char** gasification.

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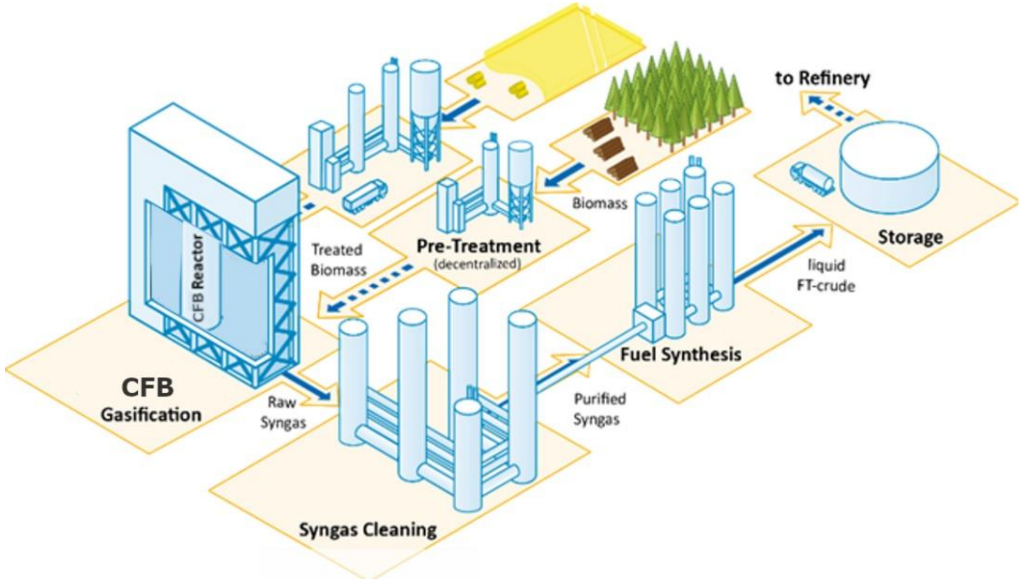
OUTLOOK

- Integration of kinetics data and validation of the simulation model using pilot- and lab-scale experimental data.
- SEM analysis of pyrolysis char to link kinetics data with material characteristics.
- Based on the successful 1 MW_{th} pilot-scale demonstration of organic waste conversion in CFB reactors, the next step is industrial-scale design and implementation.



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