Plug Flow Internally Recirculating Reactor (PFIR) for Pressurized Chemical Looping

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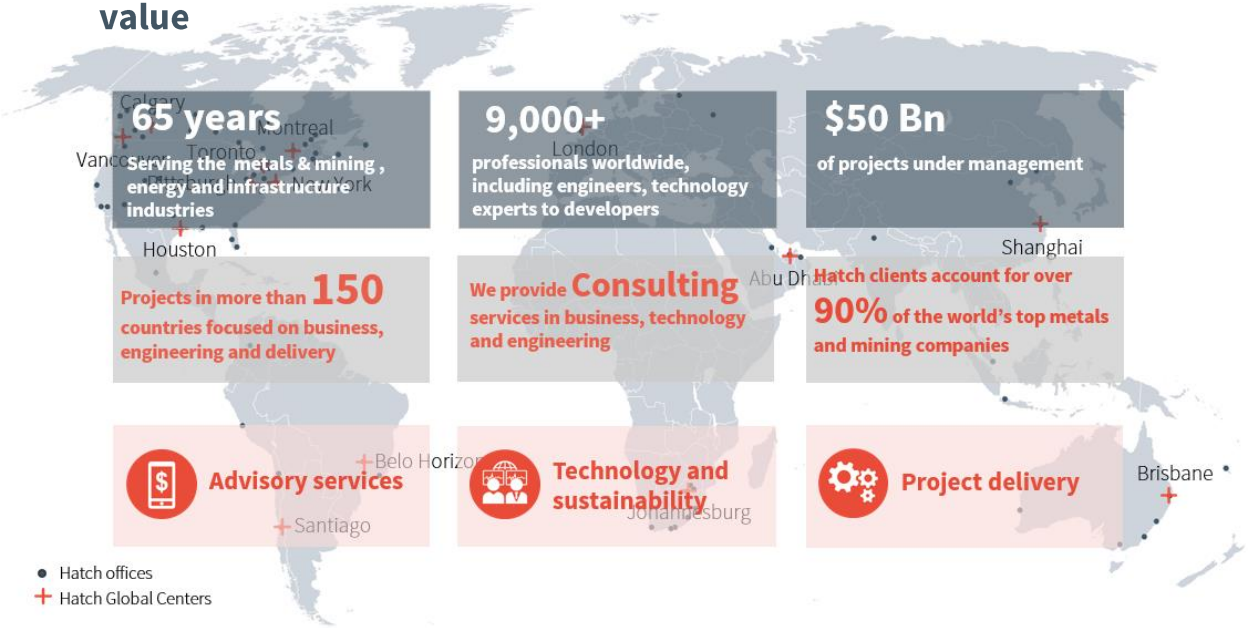
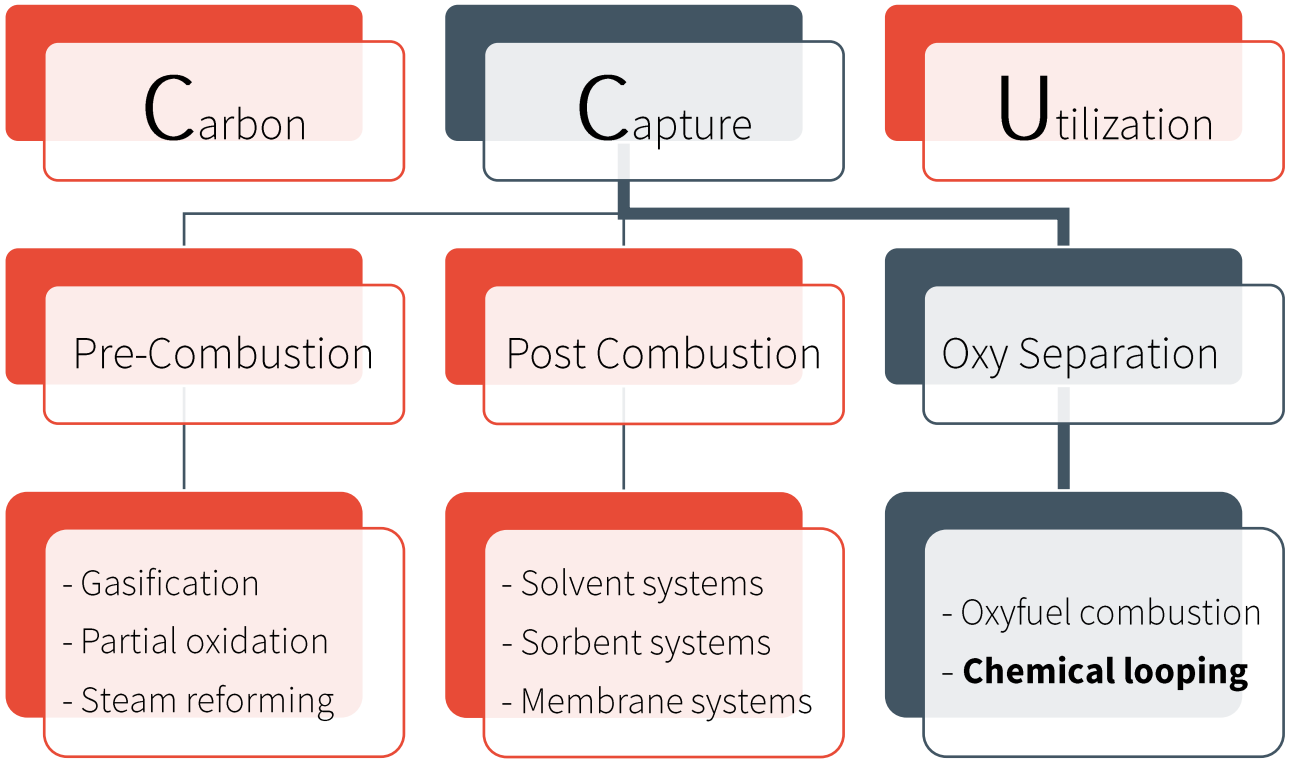


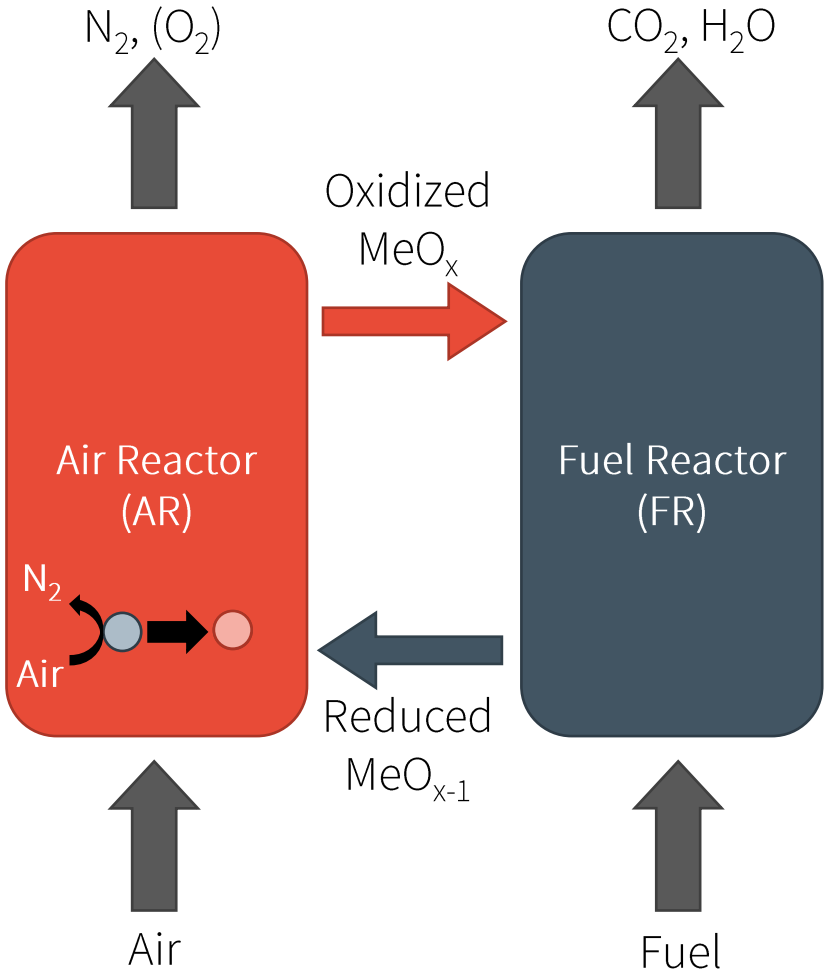
CCUS Landscape

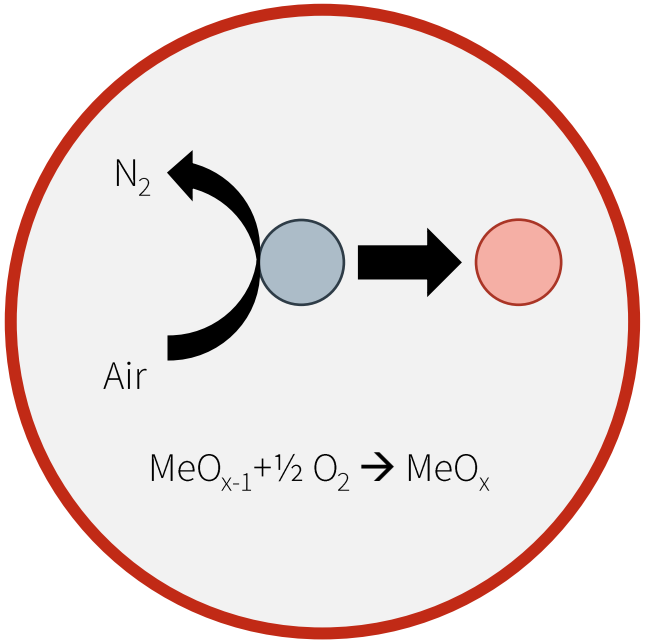


US DOE Milestone Plan: ***CL*** *has highest cost-reduction benefits, but also the lowest TRL*[1]

[1]US DOE, Report of the Carbon Capture, Utilization and Storage Experts Workshop, 2017

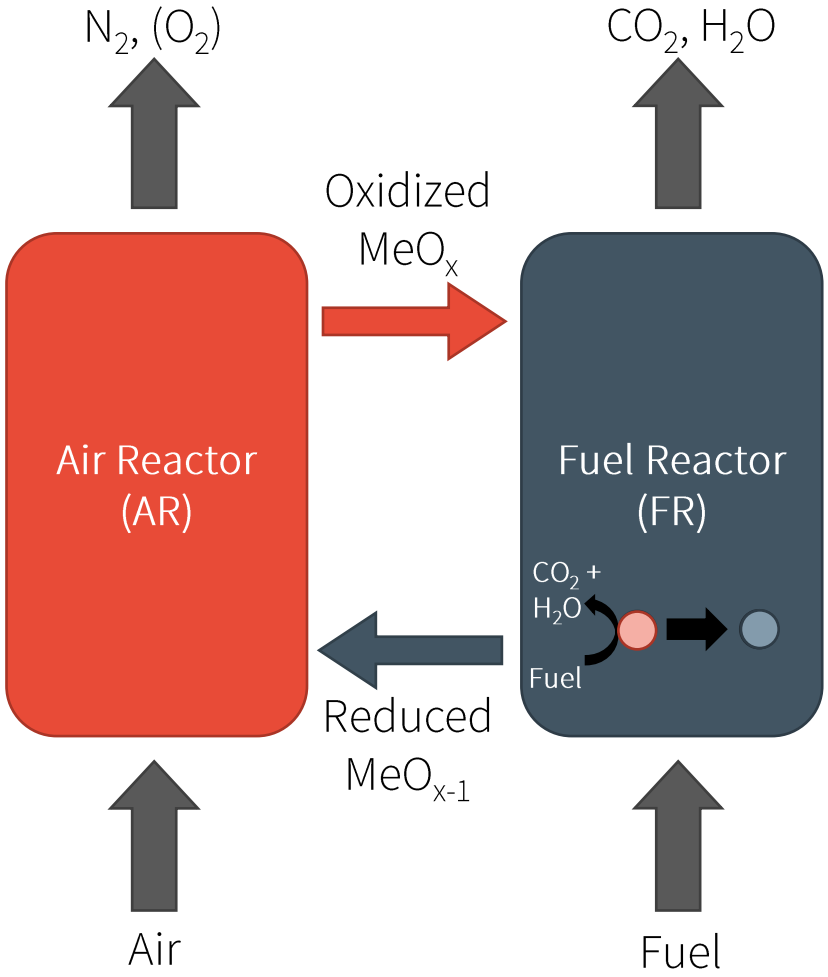
Chemical Looping
Concept

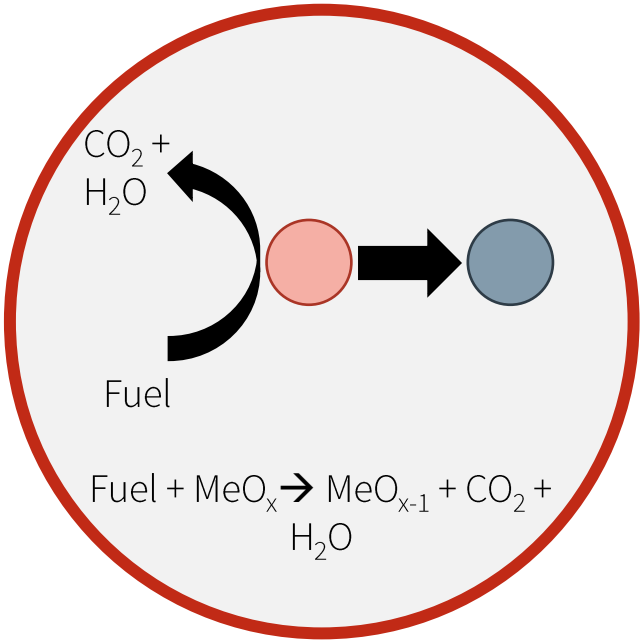




Eqs: [2]Lyngfelt *et al.*, Chem. Eng. Sci., 2001, 56, pp 3101-3113

Chemical Looping
Concept





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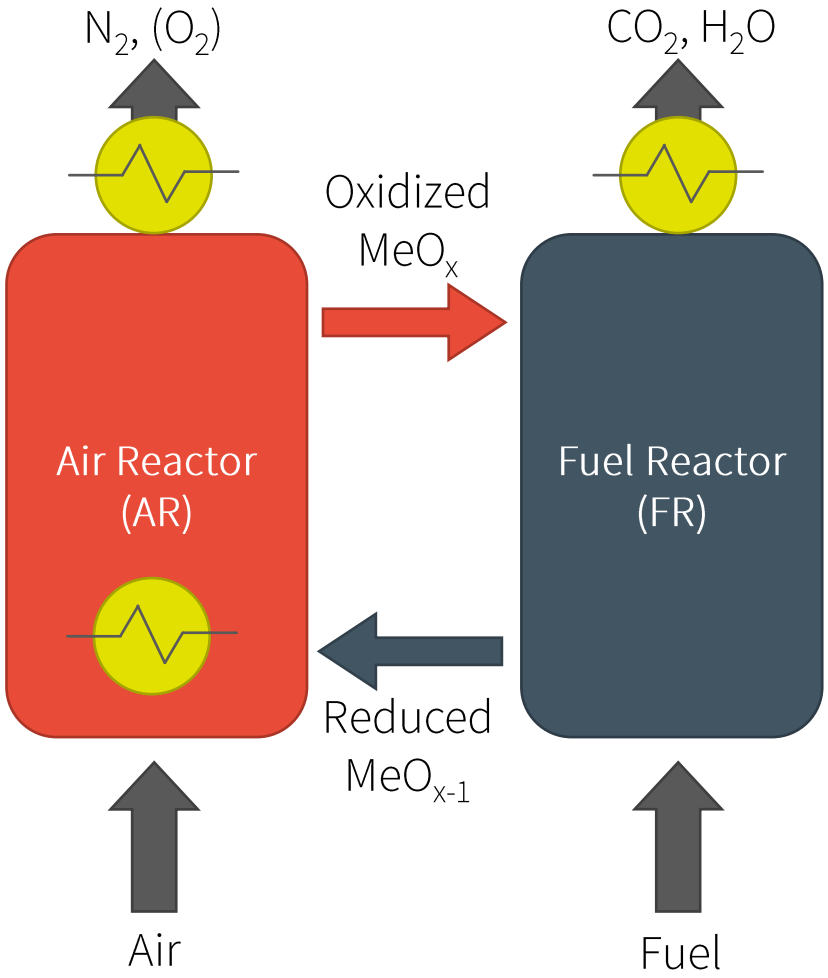


Chemical Looping
Concept

- Combustion technology with inherent separation of CO_2
- Direct contact between fuel and air avoided, O_2 is transferred via an oxygen carrier (OC)
  - Eliminates need for costly ASU or post-combustion capture
  - Can be utilized with gaseous, liquid and solid fuels

Applications:

- *Heat, steam, power*
- *Syngas and hydrogen (via reforming or gasification)*

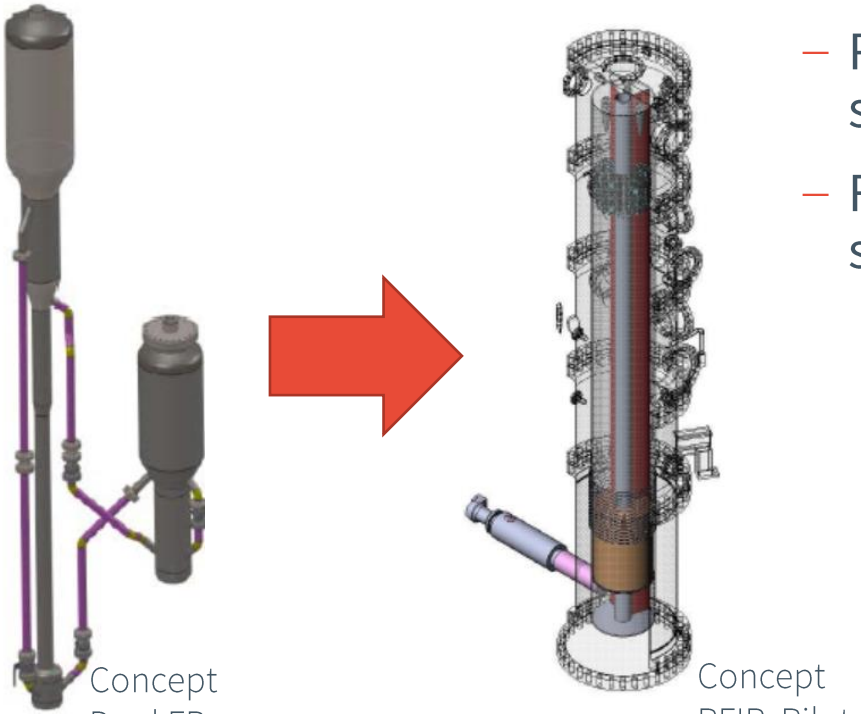
Conventional CL Reactors

– Key Gaps Identified at US DOE CCUS Experts' Workshop 2017[1]

Goal	Approach
Improve fuel conversion	Fuel reactor concepts with internal or multiple stages
Minimize CAPEX & OPEX	Novel reactor designs, non-mechanical devices for gas-solid flow control
Model reactive two-phase flow in fluid bed reactor systems	Advanced CFD

[1]US DOE, Report of the Carbon Capture, Utilization and Storage Experts Workshop, 2017

Hatch Contribution to Solution: PFIR Variant of PCL



Concept
Dual FB

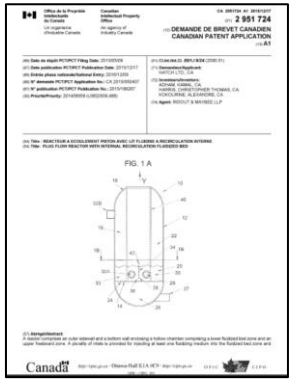
Concept
PFIR Pilot

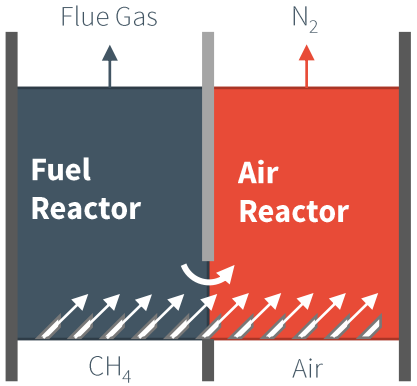
- Replace conventional 2-reactor CL system with single PFIR
- Fewer reactors, eliminates external solids transfer, leads to:
  - Lower CAPEX
  - Smaller footprint
  - Less downtime/operational issues
  - Lower rate of OC particle attrition, lower OC makeup
  - Higher circulation rates possible

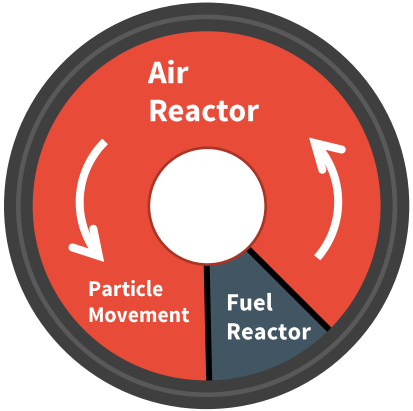
Hatch PFIR Technology

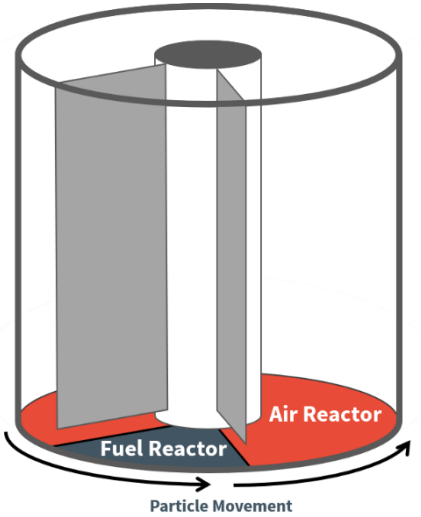
CA 2951724, US20170120211A1, granted 2017

- Patented Hatch **P**lug **F**low **I**nternal **R**ecirculation (PFIR) fluid bed reactor[3]
- Can replace 2 or more separate fl. beds and eliminate solids transfer between them, simply and cost effectively









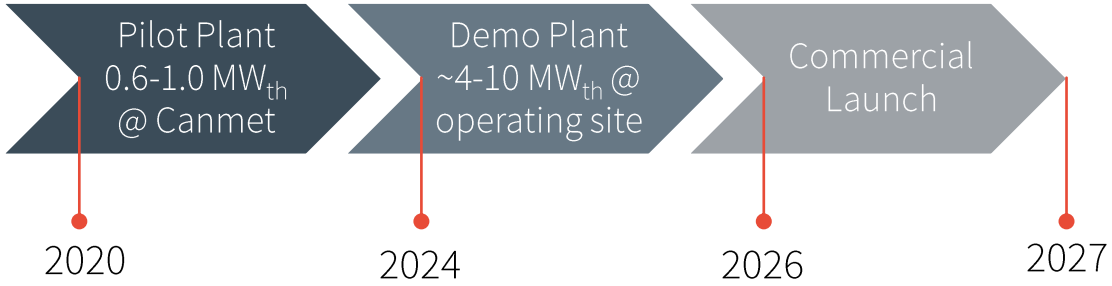
✓ Reactor with multiple internal stages

✓ Reactor with non-mechanical devices for gas-solid flow control

[3]K. Adham et al Chem. Eng. Process Technol. 08 (2017) 353

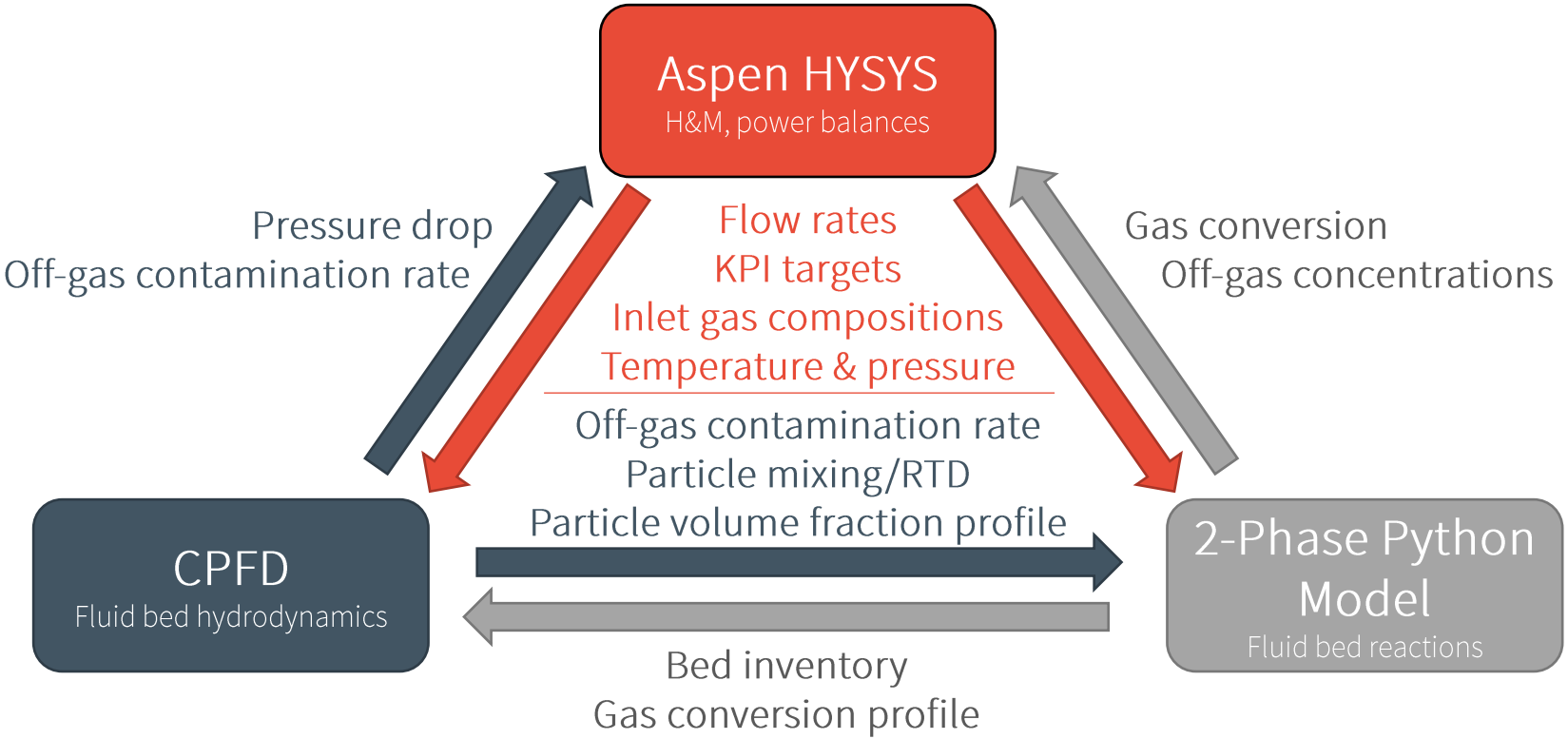
Collaborative Development with CanmetENERGY-Ottawa

CanmetENERGY	Hatch
• PCL Process technology • Process modeling, fluidization expertise • Lab and piloting at Ottawa facility • Chemical looping expertise	• PFIR Reactor technology • CPFD Modeling, fluidization expertise • Commercialization, EPCM, Equipment supply • Industry expertise



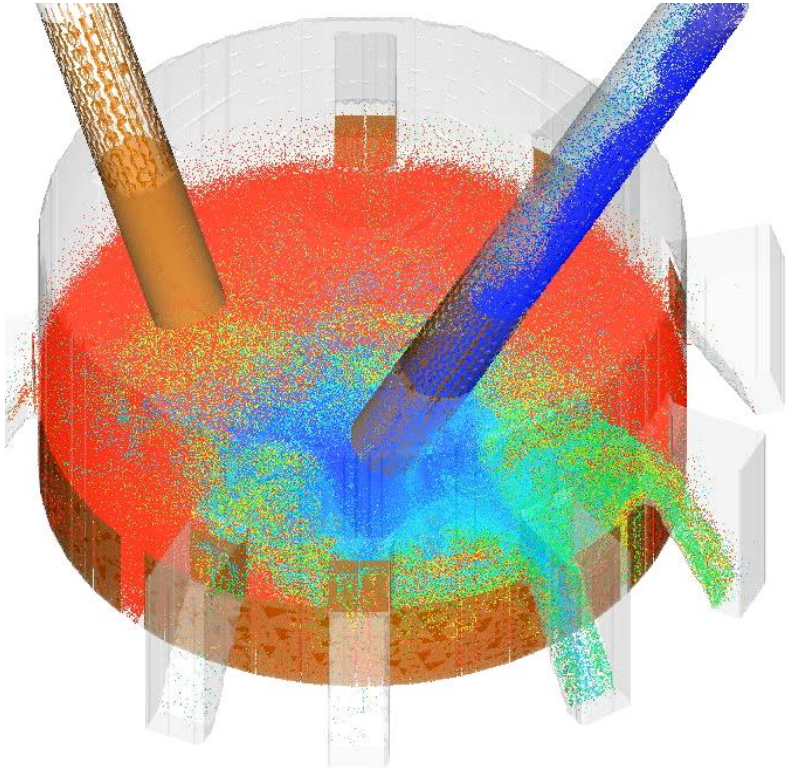
CanmetENERGY-Ottawa Pilot Facility

PFIR Development Methodology



CPFD Barracuda Virtual Reactor®

- **Hatch** has used **CPFD Barracuda®** software since 2012
- Multiple fluid bed systems were designed and/or optimized:
  - Bubbling, spouting and circulating FBs
  - Roasters, calciners, dryers, chlorinators and unconventional Reactors
  - Cyclones, classifiers, air slides, feed systems, rotary kilns and spray dryers



Commercial Scale PFIR CPFD

Objective: Determine a technically viable conceptual design of a 100 MW_{th} Commercial scale PFIR unit

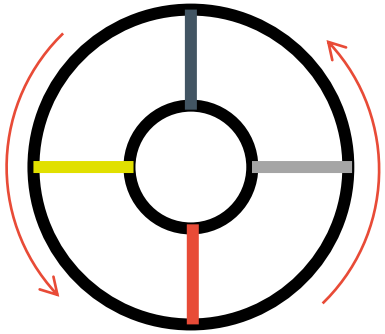
Key Performance Indicators

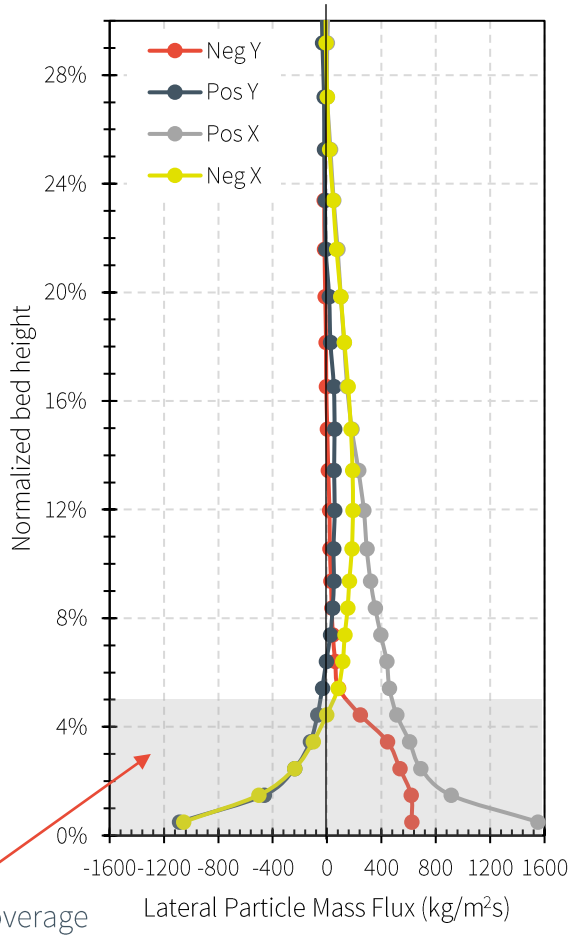
- Particle circulation rate
- Particle mixing
- Particle elutriation
- Off-gas composition

Parameter	Value
Bed aspect ratio (H_{bed} : annulus Width)	2
Fuel reactor size (°)	30
Under flow slot height (% of expanded bed)	5%

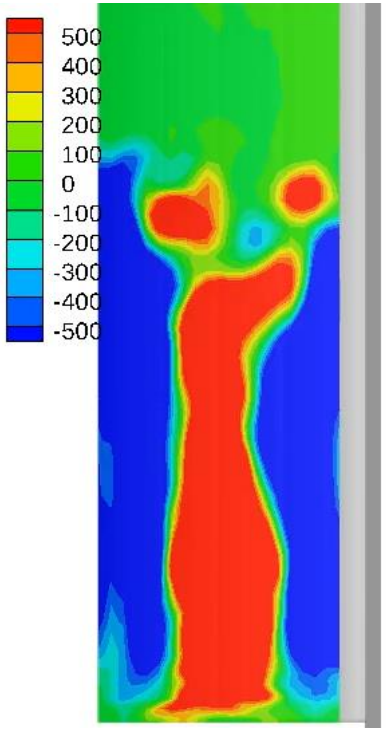
Particle Circulation

- Achieved circulation is **2.6 times** the minimum target
- Circulation localized to bottom regions of bed
- Angled jet influence reduces in height
- High particle interchange necessary for proper mixing

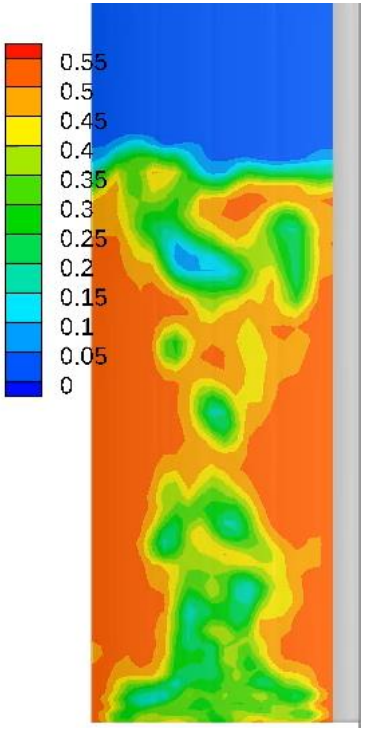




Particle Mixing



Particle Mass Flux in Z



Particle Volume Fraction

- Bed mixing characterized by particle up flow through center, and downflow at the walls
- Central plume is of moderate particle density
- Flow structure is consistent in height indicating a well mixed bed

Next Steps

Results indicate a well functioning commercial scale PFIR unit for PCL. Future work includes:

- Translating particle mixing into oxygen utilization
- Evaluation of gas conversion
- Addition of heat exchange surfaces
- Design & construction of the pilot scale unit

Acknowledgments

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CanmetENERGY

cpfd COMPUTATIONAL PARTICLE FLUID DYNAMICS

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Thank you

For more information,
please visit www.hatch.com

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Citations

[1] T. Niass, J. Kislear, M. Buchanan, J. Svalestuen, A. Park, D. DePaolo, J. Powell, Report of the Carbon Capture, Utilization and Storage Experts' Workshop, US. Department of Energy, CCUS Workshop, September 26-27, 2017

[2] A. Lyngfelt, B. Leckner, T. Mattisson, A fluidized-bed combustion process with inherent CO2 separation; Application of chemical-looping combustion, Chem. Eng. Sci. 56 (2001) 3101–3113. https://doi.org/10.1016/S0009-2509(01)00007-0.

[3] K. Adham, C. Harris, A. Kokourine, Modeling and Process Features of Plug Flow Reactor with Internal Recirculation for Biomass Pyrolysis, J. Chem. Eng. Process Technol. 08 (2017) 353. https://doi.org/10.4172/2157-7048.1000353.