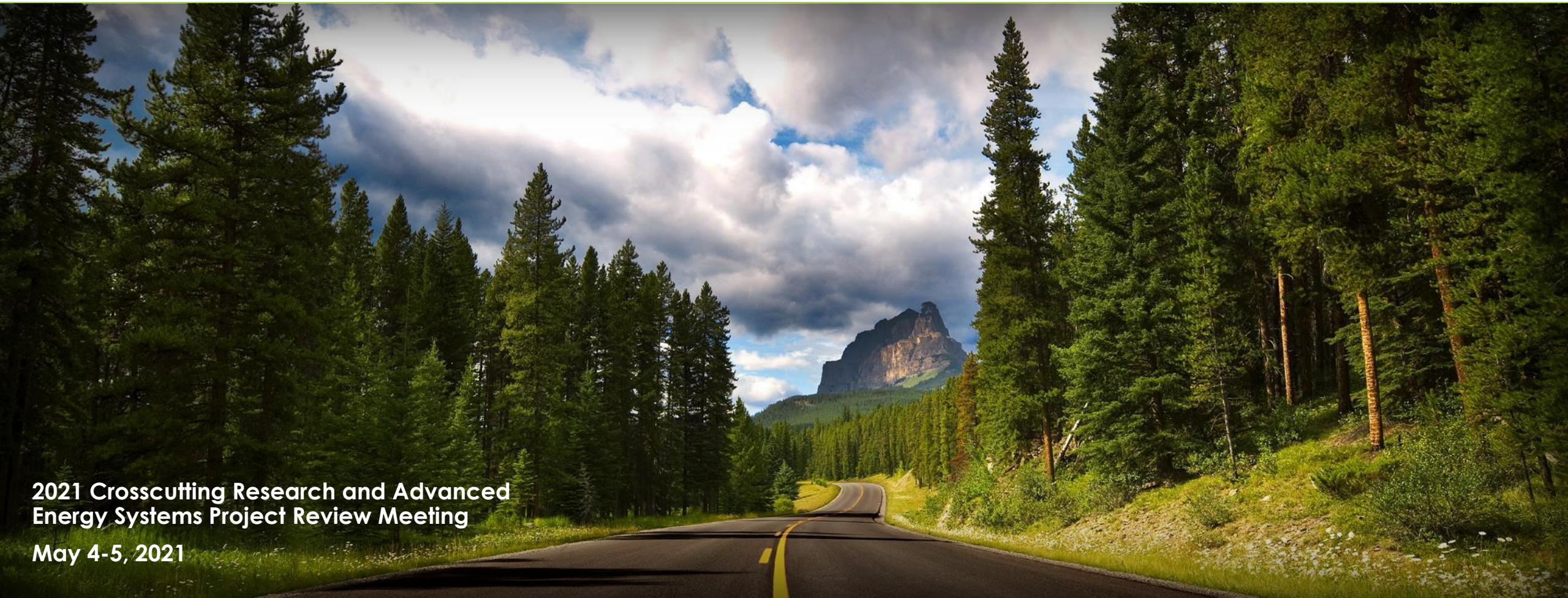
Advanced Reaction Systems (ARS) FWP1022405

Task 4: Advanced Manufacturing and Materials Technologies for Gasification

Jinichiro Nakano
Principal Scientist/Technical Fellow
Research & Innovation Center



2021 Crosscutting Research and Advanced Energy Systems Project Review Meeting

May 4-5, 2021

Disclaimer

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Authors and contact information

Jinichiro Nakano[1,2], Anna Nakano[1,2], Hugh Thomas[1], Kristin Tippey[1,2], Ömer Doğan[1]

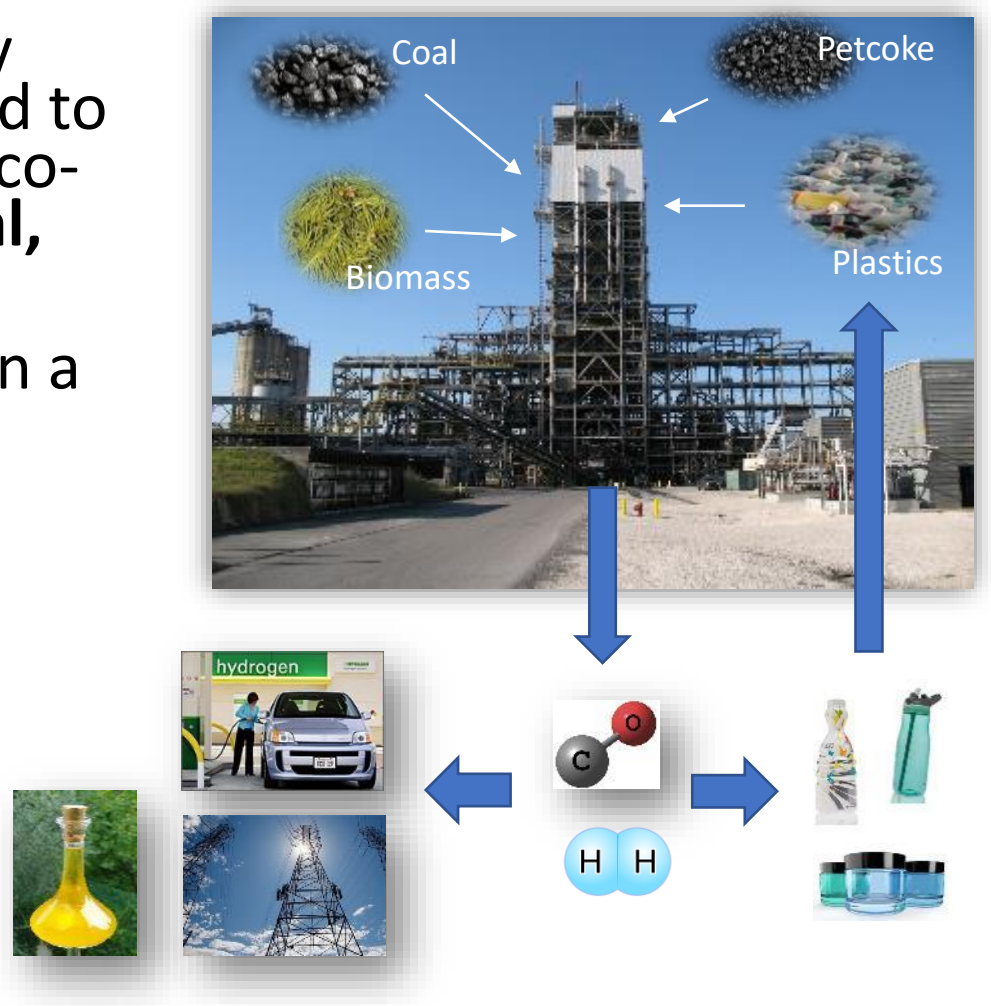
[1]National Energy Technology Laboratory, 1450 Queen Avenue SW, Albany, OR 97321, USA

[2]NETL Support Contractor, 1450 Queen Avenue SW, Albany, OR 97321, USA

Task Objectives

Task 4: Advanced Manufacturing and Materials Technologies for Gasification

- The objective of this effort is to identify **refractory** materials of construction and to demonstrate extended service life in a co-gasification environment; including **coal, biomass, and plastics**.
- The identified materials will be tested in a gasifier simulated environment at temperatures of up to 1200 °C for a duration of at least 50 hours.



EY21 Work Plan

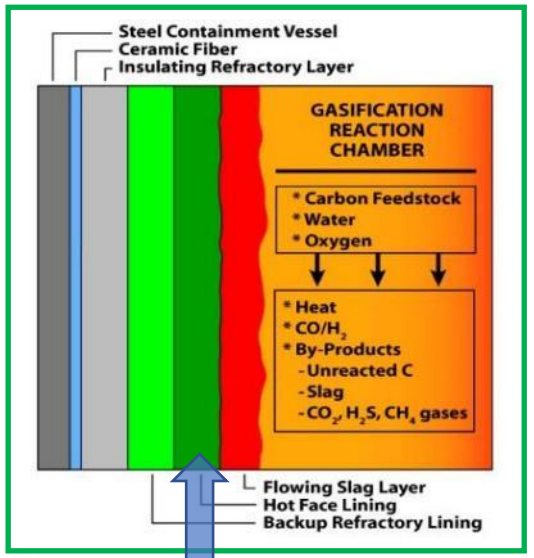
Task 4: Advanced Manufacturing and Materials Technologies for Gasification

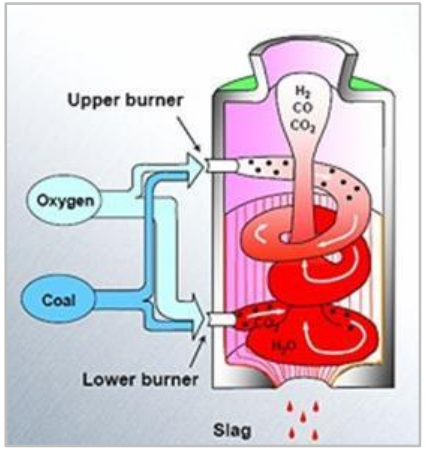
Goals:

- To enable diversified carbon feedstock options including **biomass and plastics** to help achieve **lower carbon emissions** and **the circular economy**.
- To contribute to building **small-scale** computer modeled ARS gasification modules that will meet the system performance requirement in laboratory studies.

Benefits:

- Development of cost-effective and high-performance refractory materials will aid **designing** of a modular gasifier operation **at lower cost**.
- A choice of chemically bonded refractory will accommodate **a small reactor design** (1t/hr), which would be otherwise challenging with traditional brick lining.
- **Lower carbon emissions** and **the circular economy** will be facilitated by enabling diversified feedstock options.





Milestones (EY20-EY21)

Identifier	Type	Expected Completion Date	Description
4.A	Major	6/30/2020	List appropriate material or combination of chemically bonded materials for the spectrum of the Radically Engineered Modular Systems (REMS)/ARS reaction chambers and the feasibility of using those materials to manufacture targeted reaction system designs. (note this now targets Usibelli coal). **Completed.**
4.B	Major	3/31/2021	Determine the performance of at least two chemically bonded materials against coal ash chemistry with up to 20 wt.% biomass in simulated gasifier environments at temperature up to 1,200 °C. **Completed.**
4.C	Major	09/30/2021	Determine the performance of at least two chemically bonded materials against ash chemistry from100 wt.% biomass in simulated gasifier environments at temperatures up to 1,200°C. **On track.**
4.D	Major	12/31/2021	Determine the performance of at least two chemically bonded materials against coal ash chemistry with up to 20 wt.% plastics in simulated gasifier environments at temperatures up to 1,200°C. **On track.**
4.E	Major	03/31/2022	Recommend at least one appropriate chemically bonded material and application technique to be used in the targeted ARS reaction chamber design. **On track.**

Deliverables (EY20-EY21)

Number	Deliverable Title	Expected Completion Date	Description
2	Chemically Bonded Refractory Liner, 1,200°C Applications	03/31/2021	Identify and produce at least two different test coupons of potential chemically bonded refractory liner materials on metal surfaces for evaluation in the first-generation ARS gasification module. These coupons will have been evaluated for at least 50 hours in a simulated gasification environment and shown little to no wear/corrosion. The coupons will be ready for longer term exposure in the NETL prototype gasifier, where it will encounter commercial gasification temperature and syngas exposures at temperatures up to 1,200°C. **Completed.**
3	AM Metal/Ceramic Liner Performance, 800°C Applications	03/31/2021	Identify and produce at least two different test coupons of potential AM ceramic and metal structures for evaluation in the first-generation ARS gasification module. These coupons will have been evaluated for at least 50 hours in a simulated gasification environment and shown little to no wear/corrosion. The coupons will be ready for longer term exposure in the NETL prototype gasifier, where it will encounter commercial gasification temperature and syngas exposures at temperatures up to 800°C. **Completed.**
4	Chemically Bonded Refractory Liners in Gasification Environment, up to 20 wt.% Biomass Additions to Coal	03/31/2021	Evaluation of at least two different test coupons of chemically bonded refractory liner materials and identify challenges and potential improvements to be used for the first-generation ARS gasification module. These coupons will have been tested for at least 50 hours in a simulated gasification environment with up to 20 wt.% biomass additions to coal and shown little to no wear/corrosion. If successful, the coupons will be ready for longer term exposure in the NETL prototype gasifier, where it will encounter commercial gasification temperature and syngas exposures at temperatures up to 1,200°C. **Completed.**
5	Chemically Bonded Refractory Liners in Gasification Environment, 100 wt.% Biomass, up to 20 wt.% Plastics Additions to Coal	03/31/2022	Evaluation of at least two different test coupons of chemically bonded refractory liner materials and identify challenges and potential improvements to be used for the first-generation ARS gasification module. These coupons will have been tested for at least 50 hours in a simulated gasification environment with 100 wt.% biomass and up to 20 wt.% plastics additions to coal and shown little to no wear/corrosion. If successful, the coupons will be ready for longer term exposure in the NETL prototype gasifier, where it will encounter commercial gasification temperature and syngas exposures at temperatures up to 1,200°C. **On track.**

Publications and Presentations (EY20)

Journal publications

1. H. Rao, I. Jayasekara, B. Dutta, D. Maurice, Segregation phenomena during deposition of functionally graded zirconia-based ceramics with Stellite 21 on a steel substrate, Surface & Coatings Technology, 383 (2020) 125270.
2. H. Rao, R.P. Oleksak, K. Favara, A. Harooni, B. Dutta, D. Maurice, Behavior of YSZ during laser direct energy deposition of an Inconel 625-YSZ cermet, Additive Manufacturing, 31 (2020) 100932.

Conference proceedings

1. A. Nakano, J. Nakano, J. Bennett, 'Real time evolutions of individual industrial coal particles in varied oxygen partial pressure environments,' MOLTEN 2021, Korea-Virtual, February 2021, EA20191205-0445.
2. C. Ortiz, J. Nakano, A. Nakano, J. P. Bennett, 'An investigation of the impact experimental equipment parameters have on synthetic slag behaviors in an oxidative environment using a confocal laser microscope,' proceedings of the TMS 2020, San Diego, CA, February 2020, 83-93.

Conference presentations

1. J.P. Bennett, J. Nakano, A. Nakano, and H. Thomas, 'The Role of Phosphates in Chrome Oxide Gasifier Refractories,' CIMTEC 2022, Montecatini Terme, Italy, June 2022, Invited – abstract accepted.
2. J. Nakano, A. Nakano, W. H. H. Nealley, H. Thomas, K. Tippey, Ö. Doğan, M. Lambert, D. G. Goski, 'In-operando investigations of refractory materials interacting with ash/slag from mixed feedstock gasification,' TMS 2021, Virtual, March 2021.
3. A. Nakano, J. Nakano, J. P. Bennett, 'Real time evolutions of individual industrial coal particles in varied oxygen partial pressure environments,' MOLTEN 2021, Korea-Vurtual, February 2021.

Result (EY20 - Present): Materials

Refractory compositions identified

(1) V-CAST

	wt.%
Al_2O_3	70.9
SiC + C	18.1
SiO_2	7.5
TiO_2	1.4

Alumina based

(2) TUFF-FLO

	wt.%
Al_2O_3	60.3
SiO_2	28.4
SiC	4.4
TiO_2	2.0
CaO	1.9
ZrO_2	1.3
Fe_2O_3	0.9
others	0.8

Mullite based

ALLIED MINERAL PRODUCTS

Refractory materials and coupons were manufactured by ***Allied Mineral Products*** in collaboration with NETL.

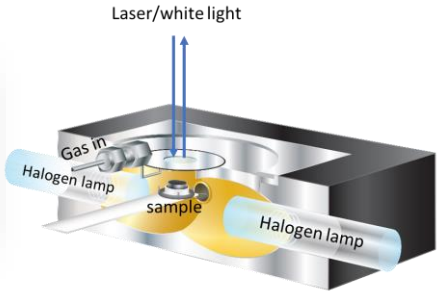
Feedstock ash chemistries

(wt.%)	100% Coal (Usibelli)	100% Biomass (Spruce)	20% biomass – 80% coal
Ash contents	7	0.31	
SiO_2	46.53	7.79	45.47
Al_2O_3	18.44	0.74	18.23
Fe_2O_3	8.93	0.65	8.9
CaO	22.27	71.19	23.28
MgO	1.88	8.12	1.98
K_2O	1.74	9.87	1.89
Na_2O	0.12	0.34	0.15
MnO	0.1	1.3	0.09
Total	100.00	100.00	100.00

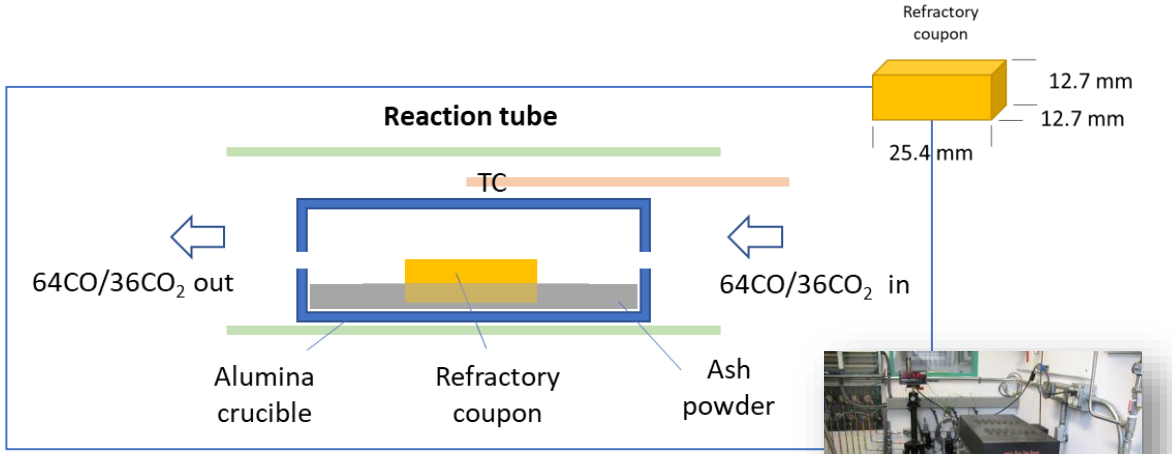
Coal: Usibelli coal data sheet, Usibelli Coal Mine, 2015
Spruce: J. Werkelin et al., Biomass and Bioenergy 35 (2011) 725-733

Result (EY20 - Present): Experimental Techniques

1. HT environmental confocal scanning laser microscope (CSLM)



2. Extended exposure tests (50 hrs)



50 hrs

800 °C /1200 °C

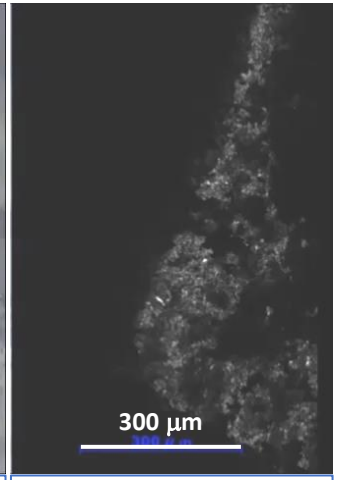
Result (EY20 - Present): CSLM Operando Analysis

NATIONAL ENERGY TECHNOLOGY LABORATORY

V-CAST (100% Coal Ash) 800°C

Movie speed: 8x

White light

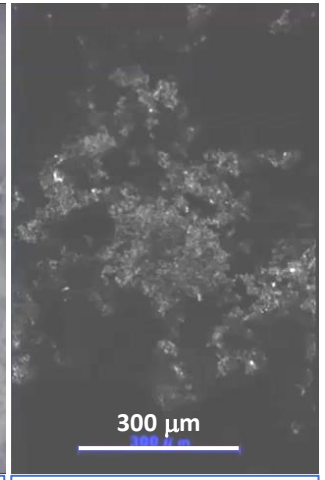


Laser

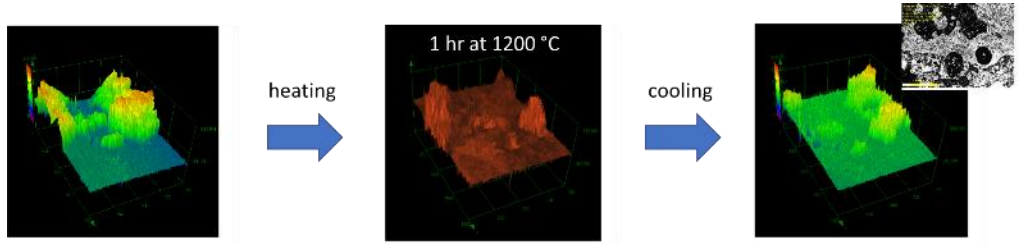
V-CAST (100% Coal Ash) 1200°C

Movie speed: 8x

White light



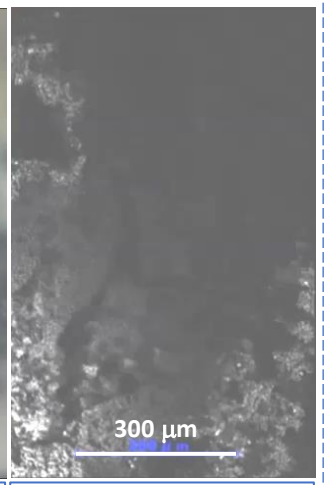
Laser



TUFF-FLO (100% Coal Ash) 800°C

Movie speed: 6x

White light

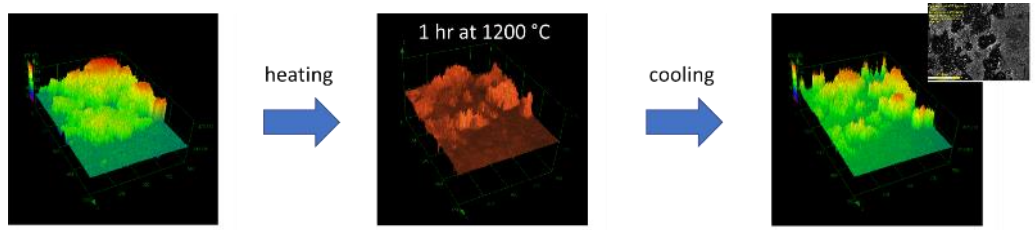


Laser

TUFF-FLO (100% Coal Ash) 1200°C

Movie speed: 6x

White light

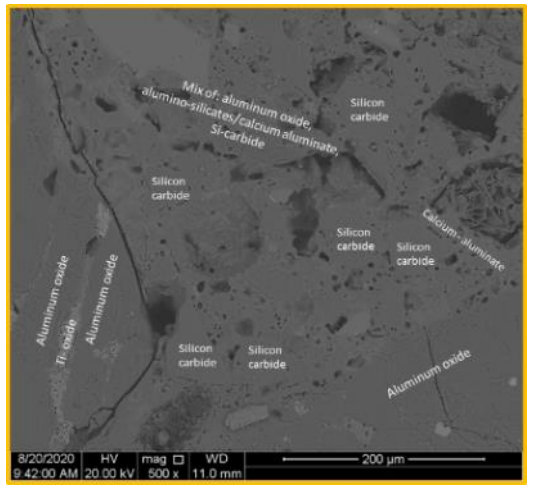


Result (EY20 - Present): Extended Exposure (50 hours)

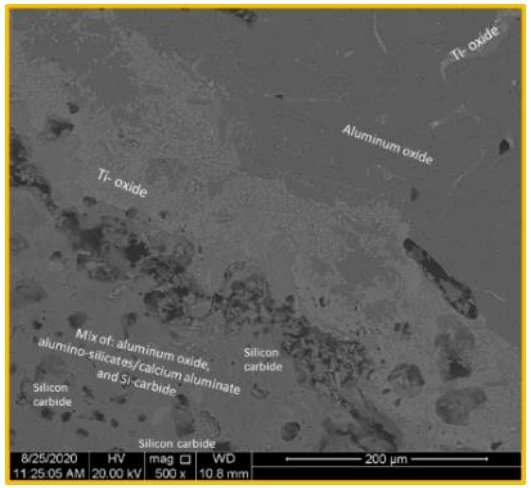
64%CO-36%CO_2 (1.1 x 10^{-19} atm Po_2 at 800 °C)

V-CAST (800 °C)

100% coal

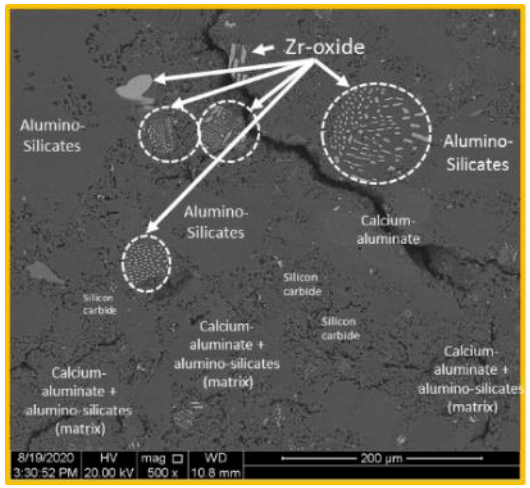


80/20 (coal/biomass)

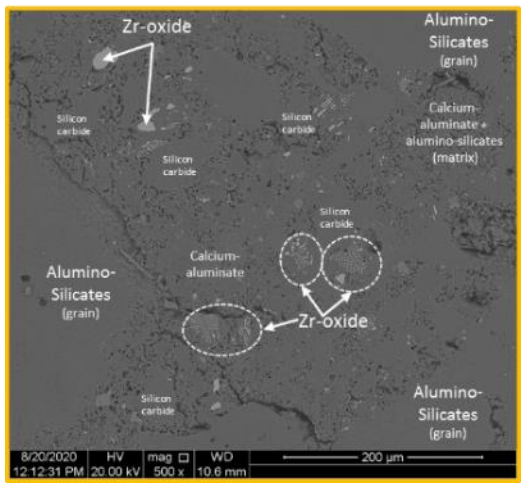


TUFF-FLO (800 °C)

100% coal



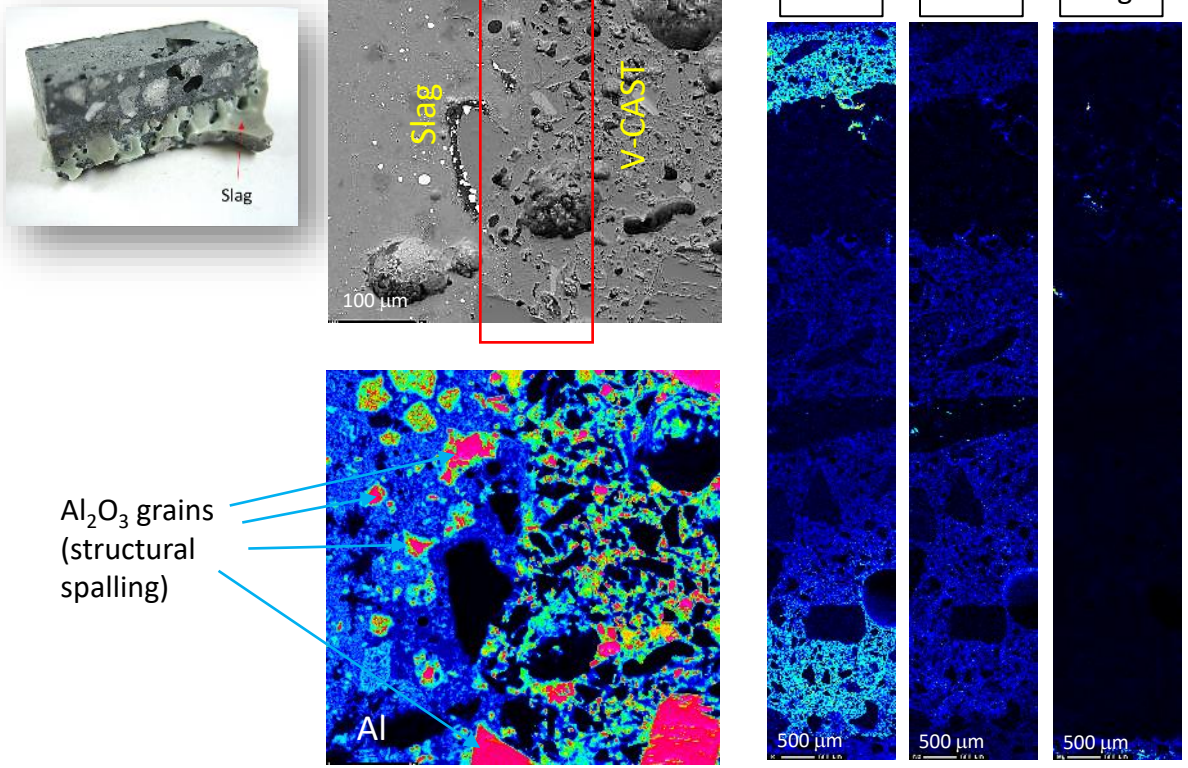
80/20 (coal/biomass)



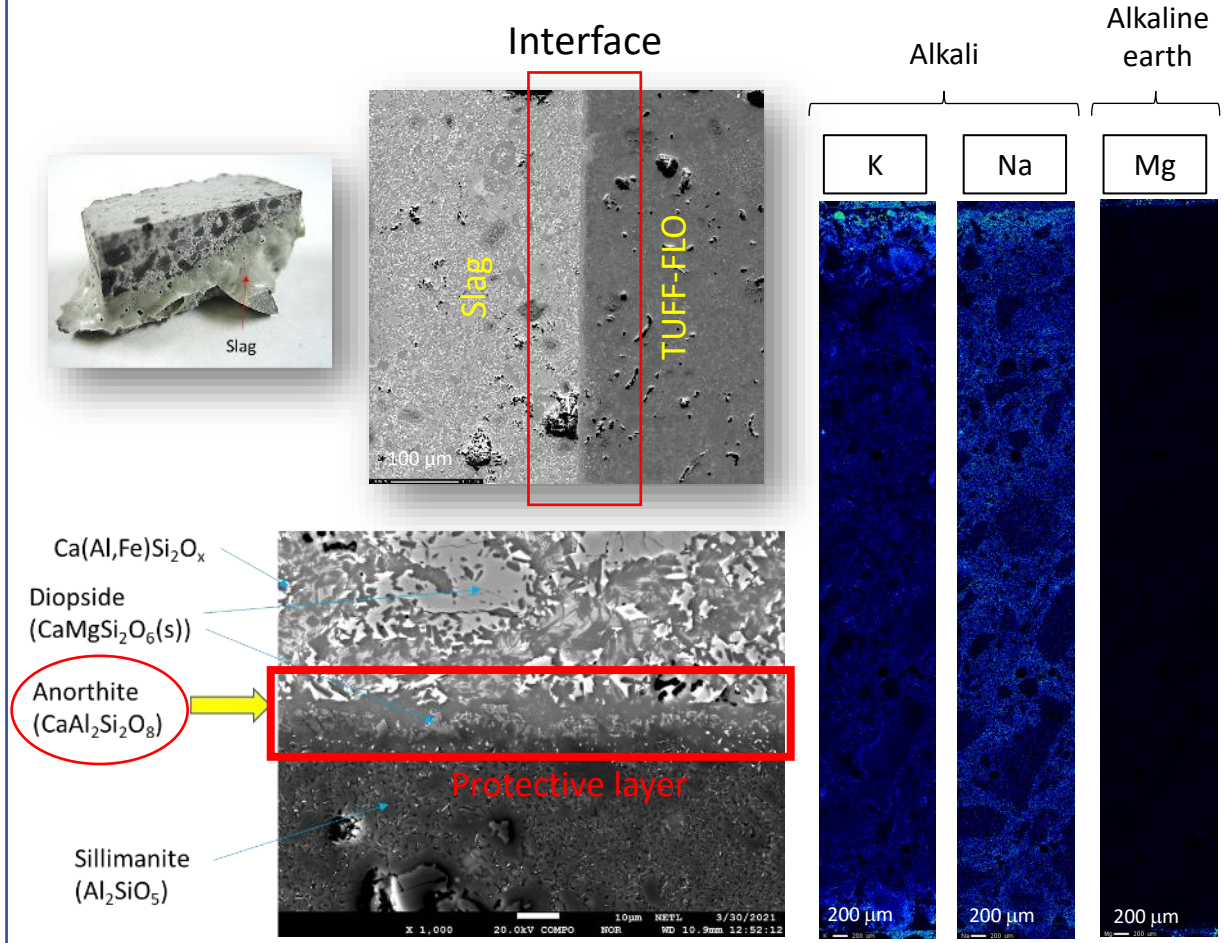
Result (EY20 - Present): Extended Exposure (50 hours)

64%CO-36%CO_2 (3.2 x 10^{-12} atm Po_2 at 1200 °C)

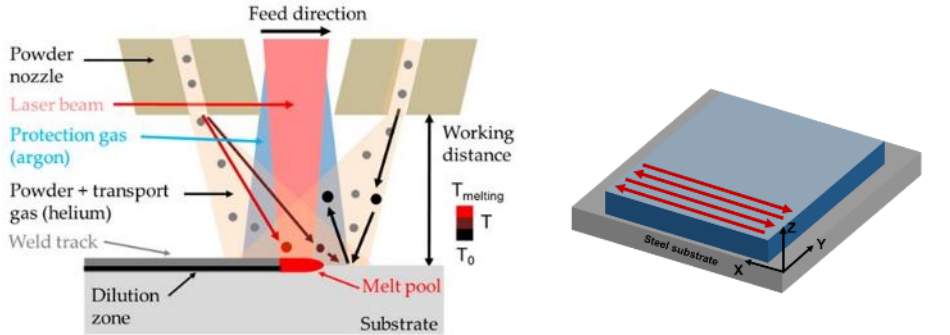
V-CAST (100% coal ash – 1200 °C)

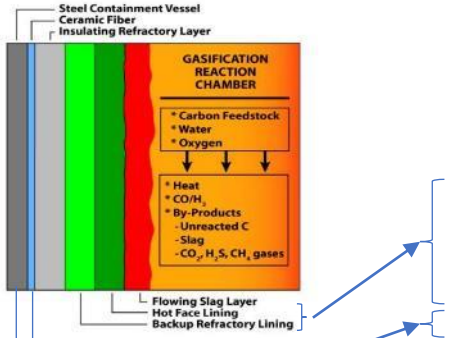


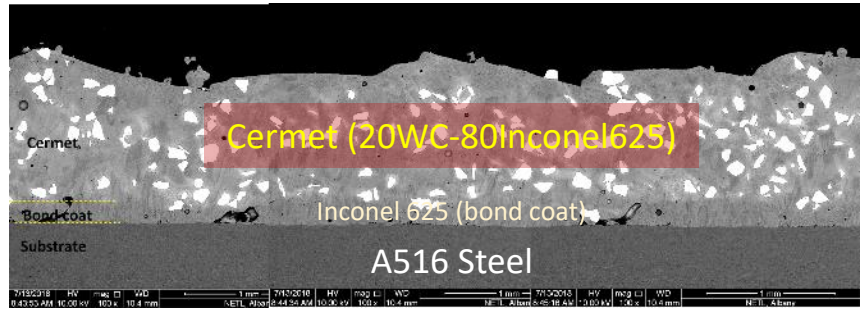
TUFF-FLO (100% coal ash – 1200 °C)

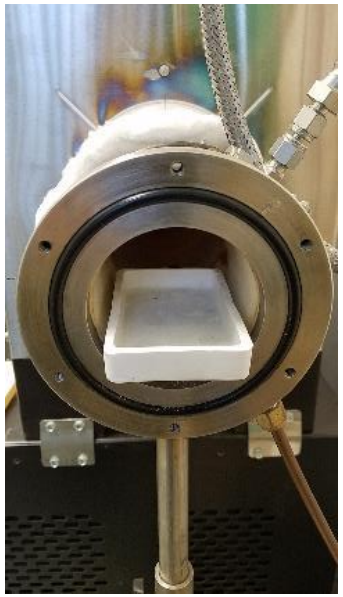


Result (EY20 - Present): AM Produced Coupons

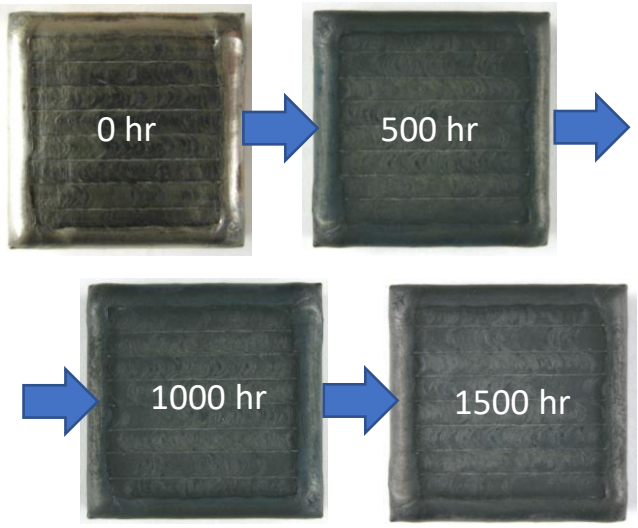


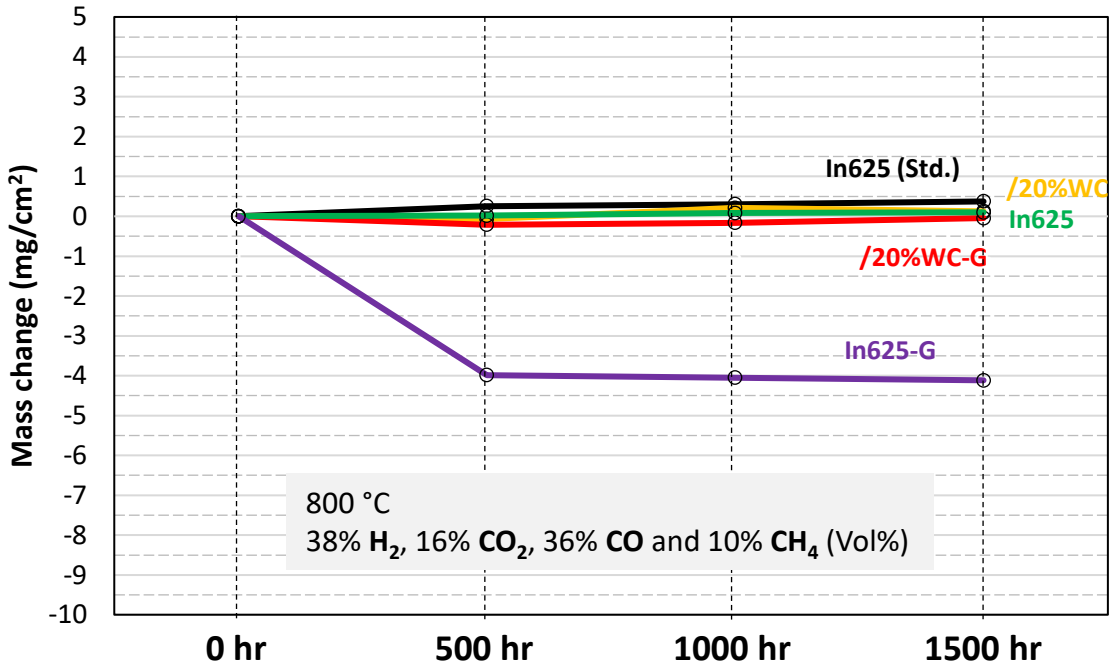






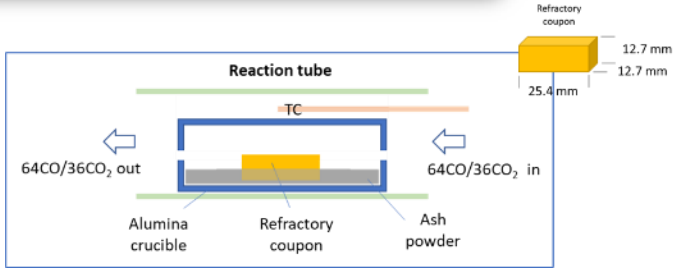
In625/20%WC Glazed

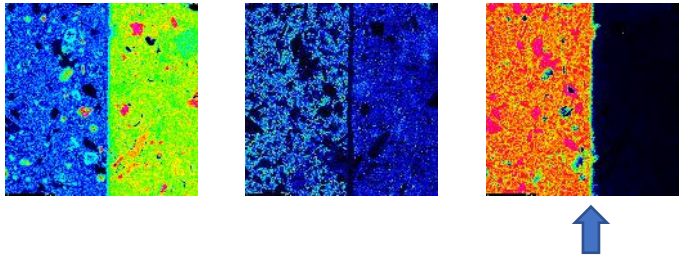




Conclusion

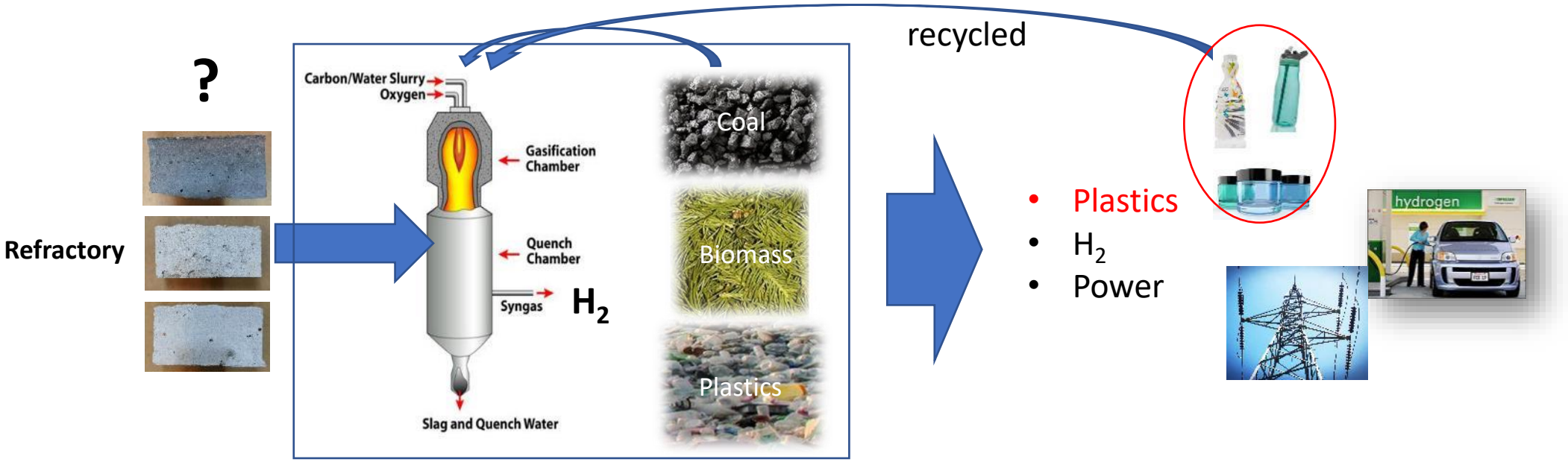
- Alumina- (V-CAST) and mullite-based (TUFF-FLO) refractory coupons were examined against coal ash with up to 20 % biomass addition in a simulated gasifier environment.
- 800 °C: No structural and chemical damage was noticed in both refractory coupons.
- 1200 °C: Structural spalling was noted in the alumina-based refractory, while the interfacial layer formation (anorthite) protected the mullite based refractory against molten slag.
- AM produced coupons (cermet-Inconel) exhibited minimal mass change after 1500 hours in a simulated gasification atmosphere at 800 °C.





Future Work

- Continue working with ***Allied Mineral*** for ***refractory*** investigations.
- Continue working with ***Eastman Chemical*** for ***plastics gasification.***
- **100% biomass** exposure test at 800 °C and 1200 °C.
- Up to **20% plastics** additions will be incorporated.



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Presenter contact: jinichiro.nakano@netl.doe.gov