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Gasification of Mixed Blends of Coal, Biomass, and Plastic Waste

George Booras, EPRI

Hydrogen Shot Summit

DOE Project Award Summary

- **Award Number:** DE-FE0032044
- **Project Title:** Performance Testing of a Moving-Bed Gasifier Using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen
- **Funding:** $625k ($500k gov't, $125k cost share)
- **Period of Performance:** 7/1/2021–6/30/2023
- **DOE Program Manager:** Debalina Dasgupta
- **Applicant Name:** EPRI
- **Subs:** Hamilton Maurer International (HMI) and Sotacarbo S.p.A.
- **Principal Investigator:** George Booras

The project is just getting kicked-off

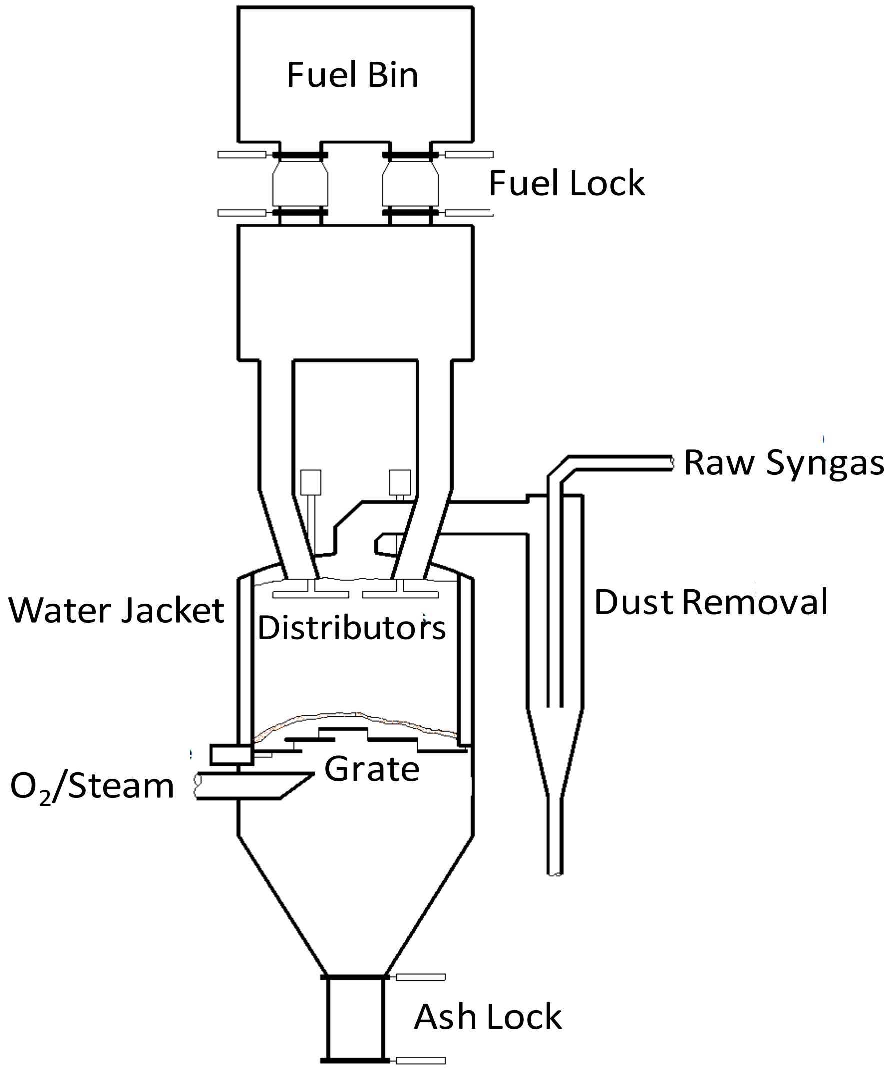
Project Objectives

- Qualify coal, biomass, and plastic waste blends based on performance testing of selected pellet recipes in a laboratory-scale updraft moving-bed gasifier
- Testing will provide relevant data to advance the commercial-scale design of the moving-bed gasifier to be able to successfully use these feedstocks to produce hydrogen
- Effects of the waste plastics on feedstock preparation (i.e., blending and pelletizing) and the resulting products (i.e., syngas compositions, organic condensate production, and ash characteristics) will be a focus

Developing data for unique blends for an established gasifier

HMI Moving-Bed Gasifier

- Moving-bed gasification has demonstrated gasifying many coal ranks as well as biomass. Testing suggests that it should be well suited for blends of coal, biomass, and plastic waste.
- As the fuel descends, it is dried, devolatilized, and the resulting char is gasified. Ash is removed through a grate and collected in a lock hopper.
- CO_2 produced by combustion and the steam from the blast react with the char in the gasification zone to produce CO and H_2
- Streams leaving are ash out the bottom and dry gas/tar/water vapor/dust out the top



California Pellet Mill (CPM)

- CPM will do the blended feedstock preparation in the form of pellets
- In 1931, the company created its first pellet mill, the 30-hp flat bed with stationary flat die, and became CPM
- CPM has had considerable experience creating fuel pellets including ones using biomass and waste and has worked with HMI and Sotacarbo on prior projects
  - Presented results of pilot gasifier test runs with coal/car fluff pellets at the 2007 Clean Coal Technology Conference in Sardinia

Sotacarbo R&D Facility

- Sotacarbo and HMI have collaborated for 17 years on the installation, commissioning, operation, and automation for enhanced operation and control of updraft moving-bed gasifiers for industrial multi-fuel gasification processes
- HMI designed the pilot-scale 12” inner diameter (ID) updraft moving-bed gasifier for coal/biomass gasification installed at the Sotacarbo Gasification R&D facility that will be used for this project
- Significant testing has taken place on this test facility including the current project team members from both HMI and Sotacarbo

Sotacarbo Pilot Moving Bed Gasifier

Major Project Tasks

1. **Project Management and Planning:** Monitoring and project reporting.
2. **Feedstock Procurement and Preparation:** Finalize feedstock selection and pellet formulations. Prepare and ship pellets.
3. **Test Plan Development:** Specify test data to be reported, review facility instrumentation, and specify sampling procedures.
4. **Gasifier Testing:** Perform baseline coal gasification test, and tests for 9 different pellet formulations
5. **Data Analysis and Reporting:** Correlate gasifier performance with pellet composition, assess overall prospects for gasification of mixed blends, and prepare the final report.

Overall project schedule is two years

Acknowledgment and Disclaimer

- **Acknowledgment**: This material is based upon work supported by the Department of Energy under Award Number DE-FE0032044.
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Multiphysics and Multiscale Simulation Methods for Electromagnetic Energy Assisted Fossil Fuel to Hydrogen Conversion

Dr. Su Yan, Howard University

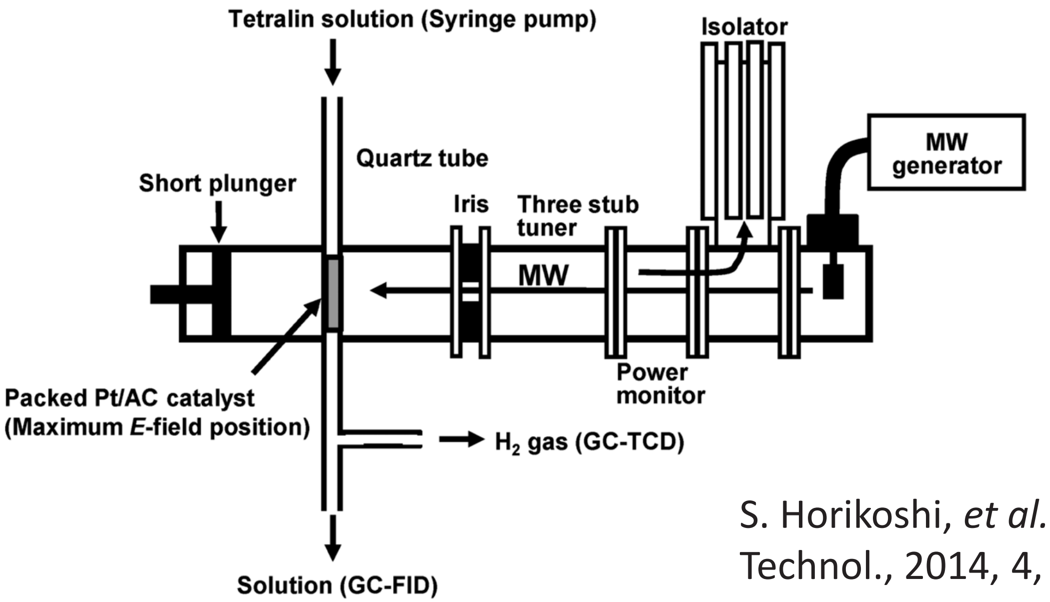
Hydrogen Shot Summit

Introduction

- Fossil fuels comprise 80% of current global primary energy demand and the energy system is the source of approximately two thirds of global CO_2 emissions.
- Develop new methods that use electromagnetic (EM) energy to assist fossil fuel to hydrogen conversion.
- Two major thrust areas:
  1. Modeling and simulation methods for coupled multiphysical phenomena across multiple spatial and temporal scales for accurate conversion process simulation; and
  2. Simulation-guided designs for EM energy assisted high-throughput, high-yield, and low-cost hydrogen generation from fossil fuels such as methane and methanol.

Overview

- **Focus:**
  - Understanding of 3D structures of catalysts and their supports;
  - Characterization of EM hotspots within the heterogeneous catalysis;
  - Multiphysics investigation of EM energy assisted catalytic active sites enhancement; and
  - System design and optimization for high-yield and low-cost hydrogen generation.



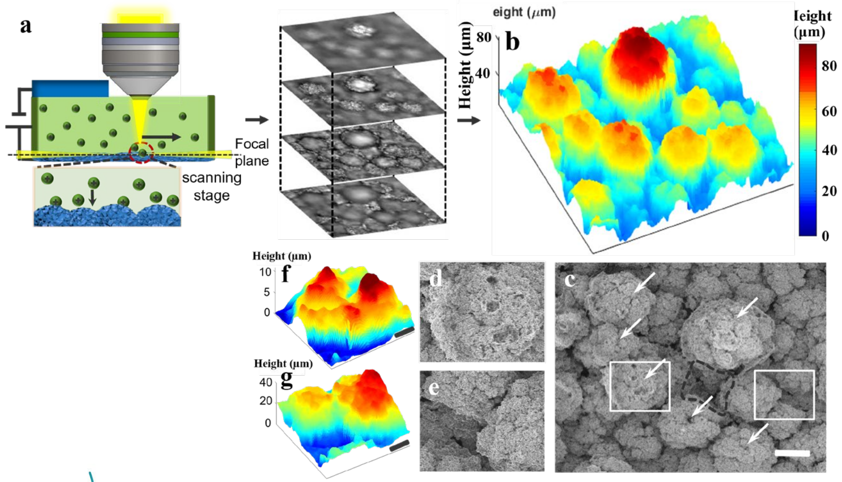
S. Horikoshi, *et al.*, Catal. Sci. Technol., 2014, 4, 1197.

3D Catalyst Structures

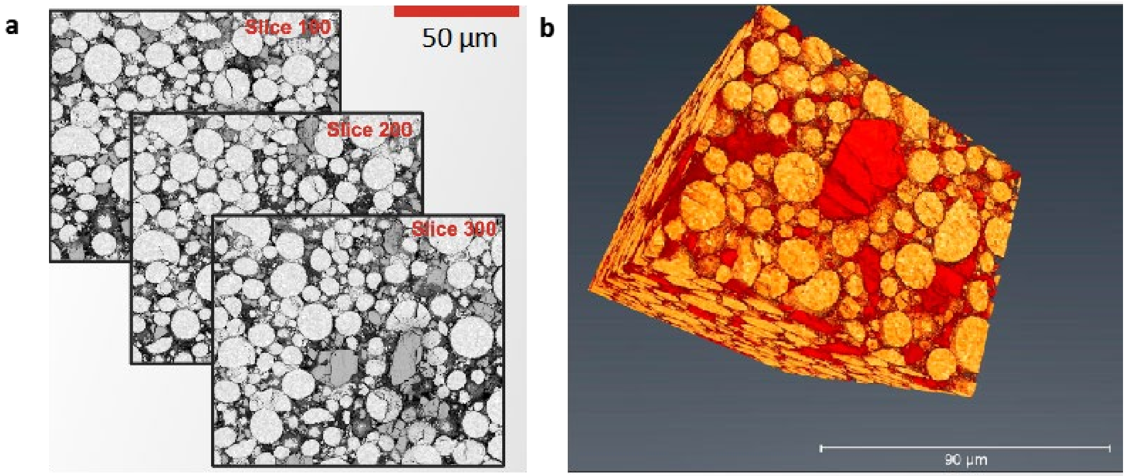
- The catalyst support and distribution determine the EM field/hotspot distribution and controls the reaction conversion efficiency and energy consumption for hydrogen generation.
- Image and study the 3D structure of the catalyst support and catalyst distribution.

3D Imaging of Electrode Surface

Optical 3D microscope:



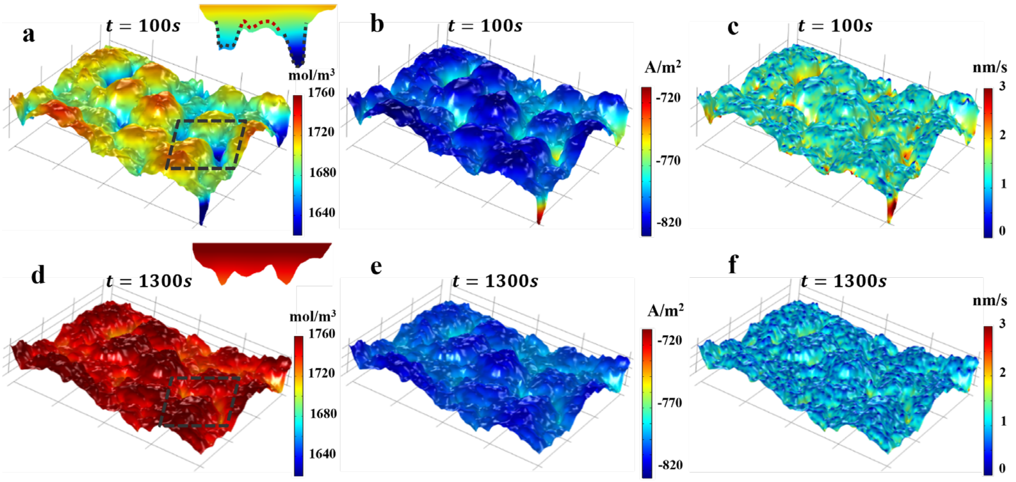
FIB-SEM sectioning:

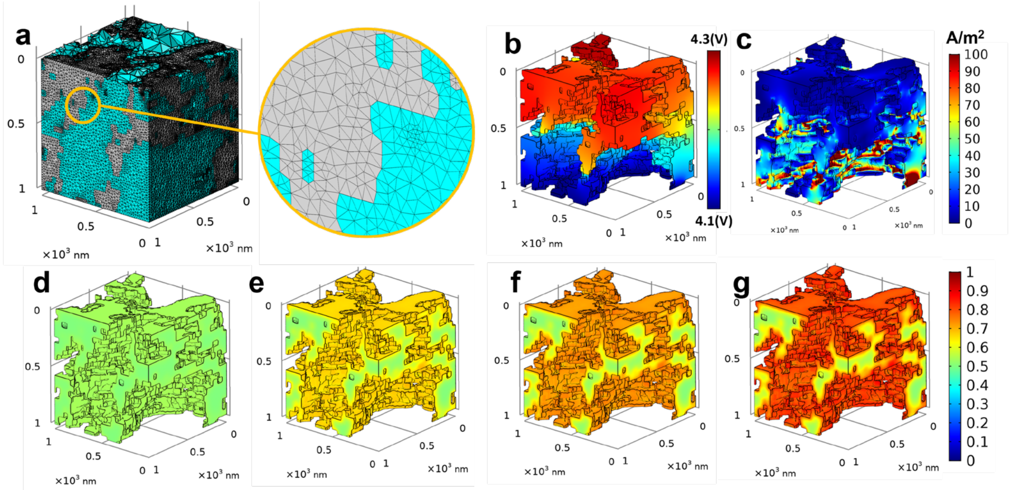


EM Hotspots Within Catalysis

- EM energy dissipation initiates and sustains the thermochemical procedure of fossil fuel to hydrogen conversion.
- Investigated EM hotspots and heat generation in heterogeneous catalysis.

1. **3D porous catalyst structure from image reconstruction**
2. **Homogenization of porous material using averaging formulas**

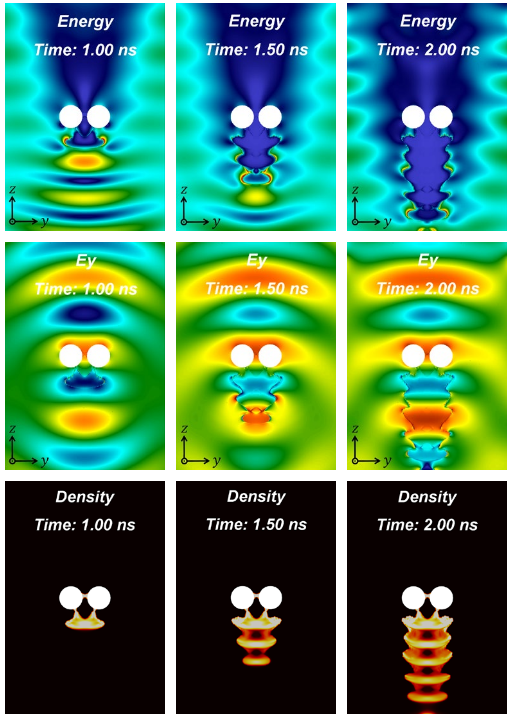


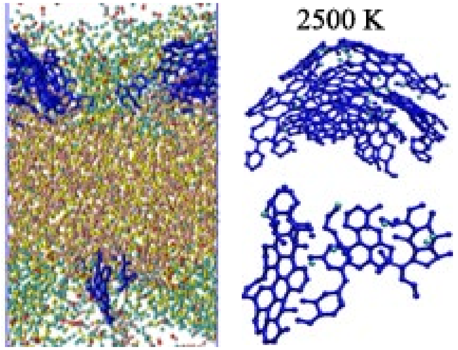


Multiphysics & Multiscale Investigation

- **Fossil Fuel to Hydrogen Conversion: a Multiphysics Process**
  - Fossil fuel fed through a reaction chamber filled with catalysts: Fluid dynamics
  - The reactants and catalysts heated up by EM energy dissipation: EM and thermal
  - Generation of plasma hotspots: micro plasma
  - Catalyzed thermochemical reaction: chemical and quantum

1. **Coupled EM-thermal-fluid-plasma simulations – Physical aspect**
2. **Quantum and atomistic simulations – Chemical aspect**
3. **Coupled physical-chemical simulations**





System Design and Optimization

- Conversion efficiency analysis
  - 3D morphology of catalyst
  - Multiphysics modeling and simulation capabilities
  - Quantum and atomistic modeling and simulation capabilities
- Design and optimize the reaction system for an improved hydrogen conversion efficiency with a lowered cost
  - chamber geometry
  - catalyst distribution and support geometry
  - temperature and flow control
- Optimize the shape of the reaction chamber for a uniform and efficient deposition of EM energy

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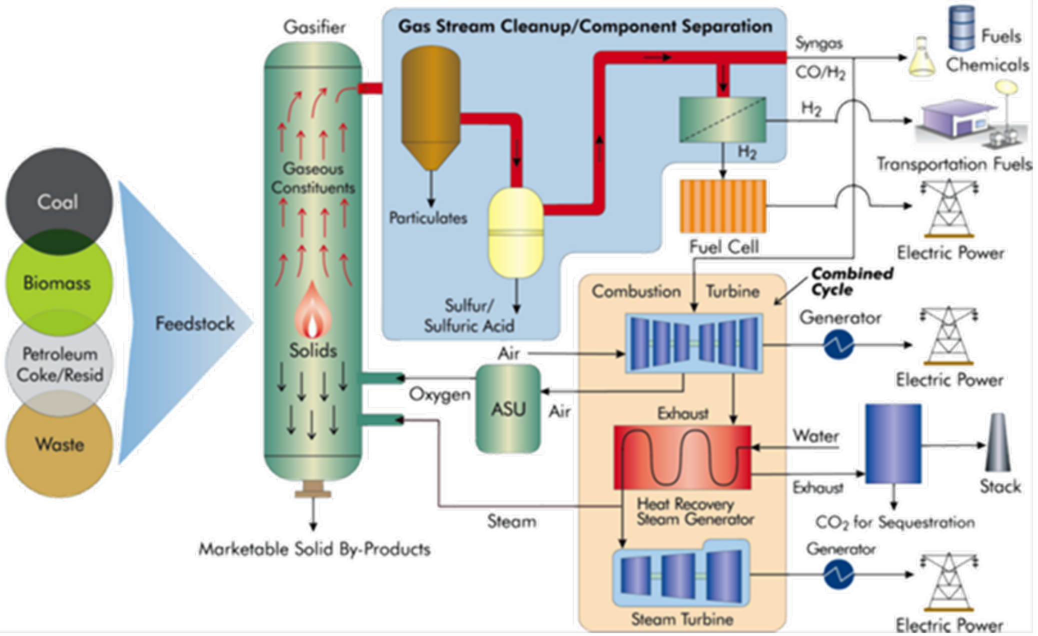
Air Separations – High Purity Oxygen Production

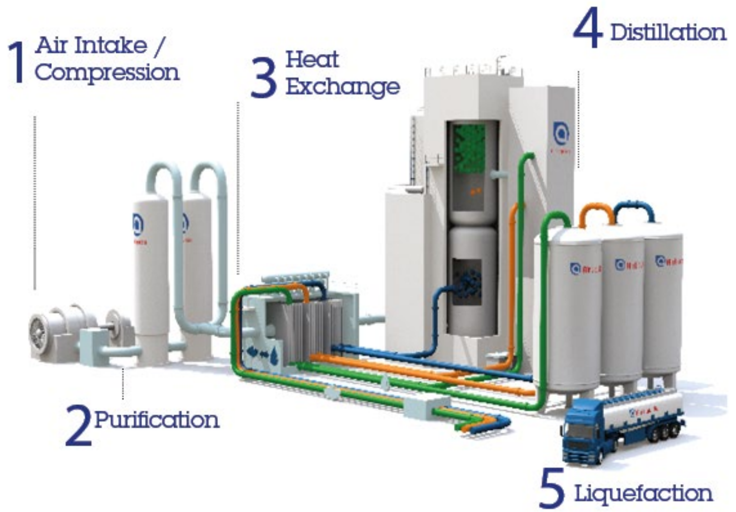
Rajinder P. Singh, Los Alamos National Laboratory

Hydrogen Shot Summit

Gasification – Air Separations Needs

- **Hydrocarbon fuel gasification with integrated carbon capture and sequestration**
- **Advanced technology needs for improving efficiency and cost reduction**
  - Air separation
  - Synthesis gas separations
- **Cryogenic distillation is *the* industrially preferred technique for large-scale, high purity O_2 production**
  - Scale dependent estimated specific energy consumption 23 to 63 kJ/mol (~ 40-50 $/ton, large scale)
  - High capital cost & long start-up/shut-down cycle

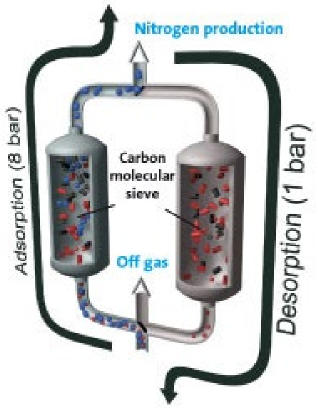


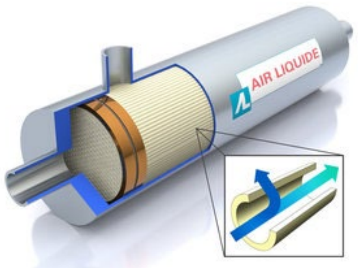


Ref: *Images from* NETL *& Air Liquide website*

Air Separations – Technology Landscape

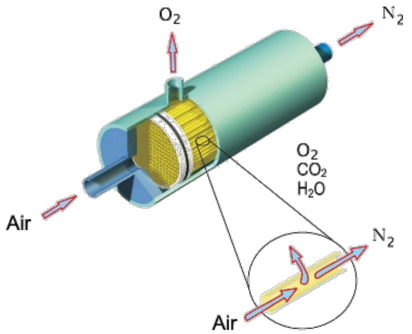
Modular Air Separation Technologies



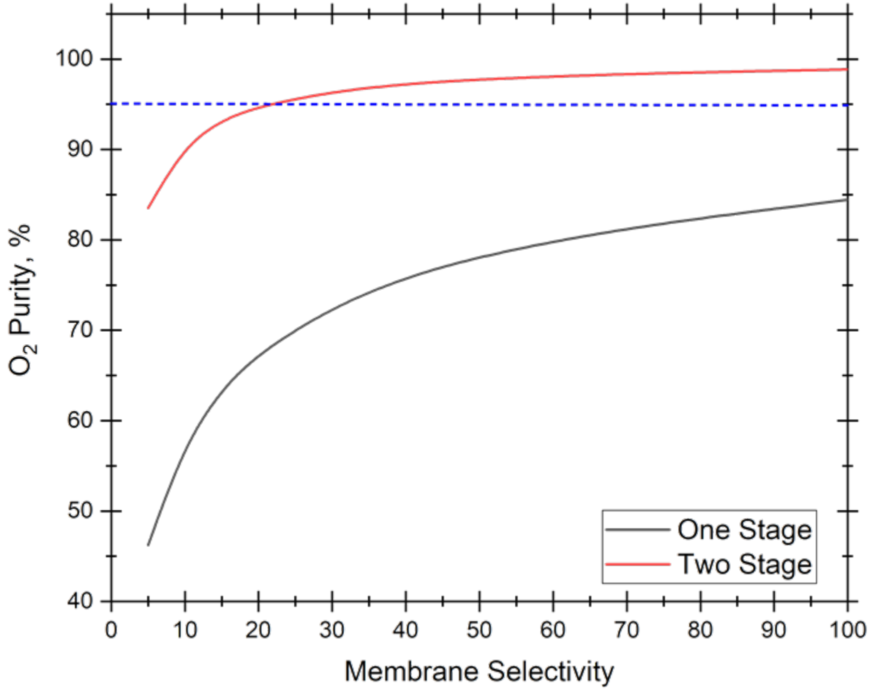


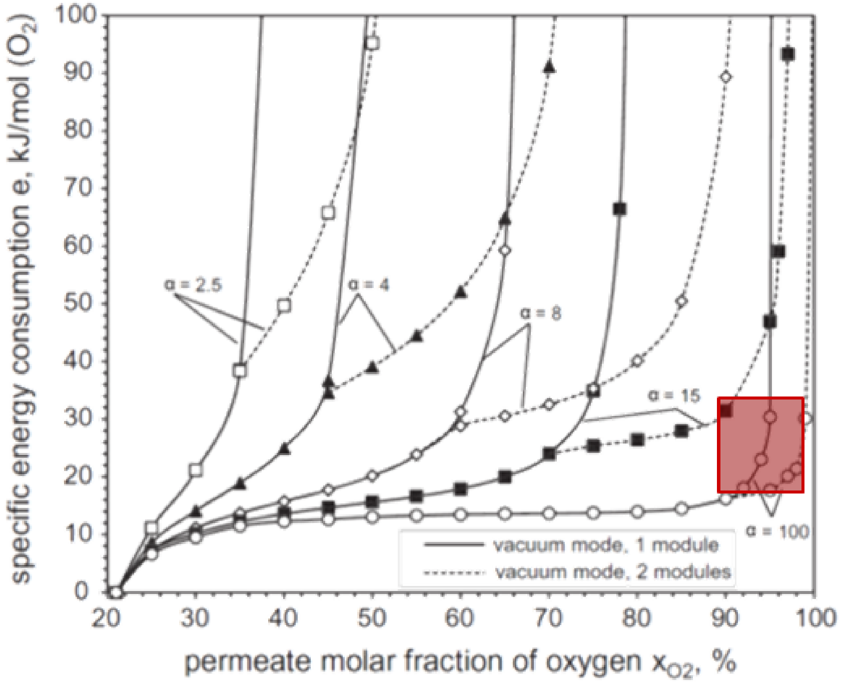
Technology	Cryogenic	Adsorption	Ion transport membranes (ITM)	Membranes
Development stage	Mature	Mature	Developing	Semi-mature
O_2 purity (%)	99+	95+	99+	~40
Capacity (ton/day)	1,000~4,000	100~300 (Larger) 20~100 (Small)	Unknown	Up to 20
Driving force	Electricity	Electricity & Heat (70-90 °C)	Electricity & Heat (800 °C)	Electricity
Startup time	Hours to days	Minutes to hours	Hours	Minutes

Membrane Technology for Air Separations



- **Membrane-based air separation processes have advantages over competing technologies**
  - Modular & small foot print
  - Multi-stage process required to achieve high purity O_2
  - Improved energy economics

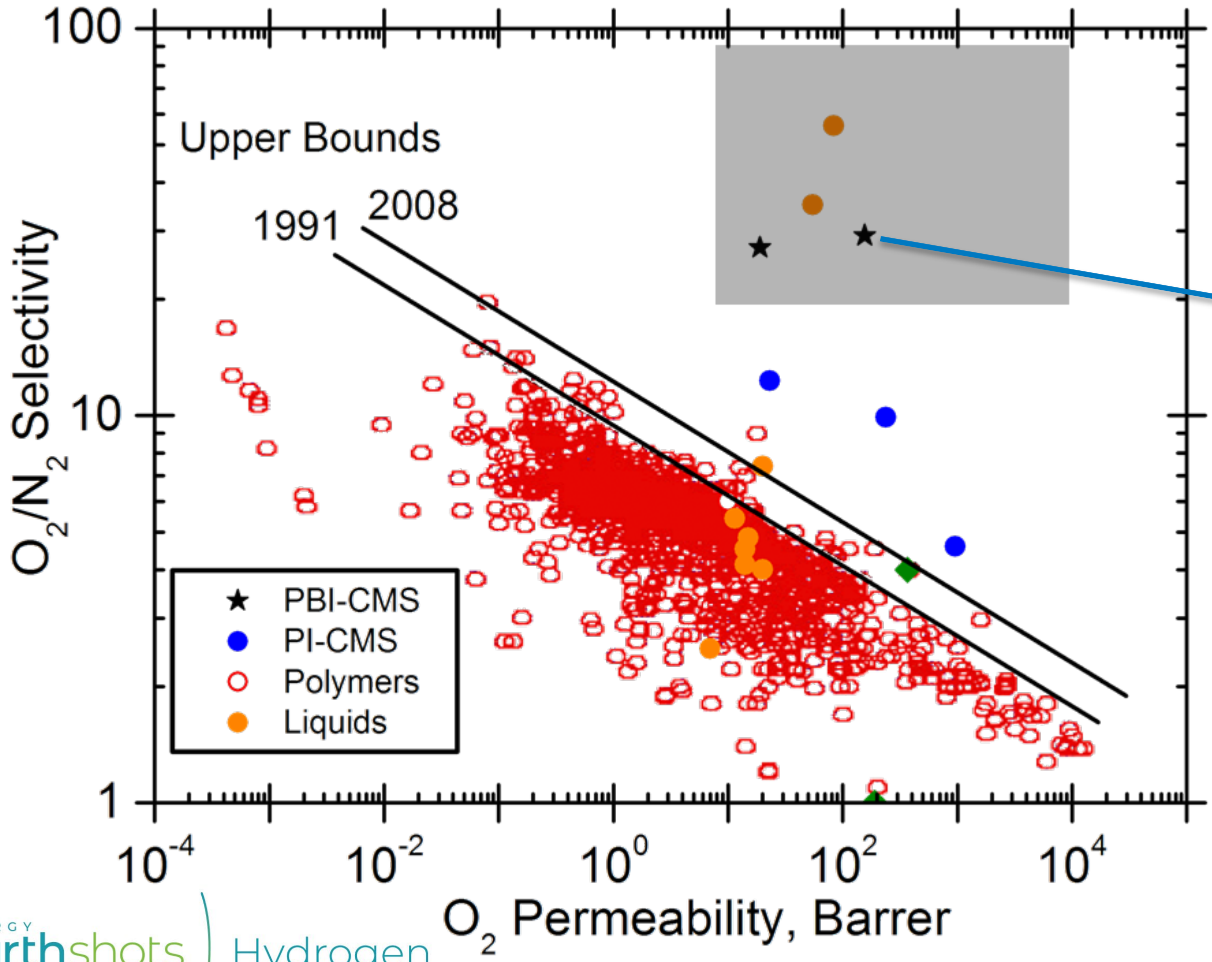




Ref: Meriläinen et al. / Applied Energy, 94 (2012) 285-294

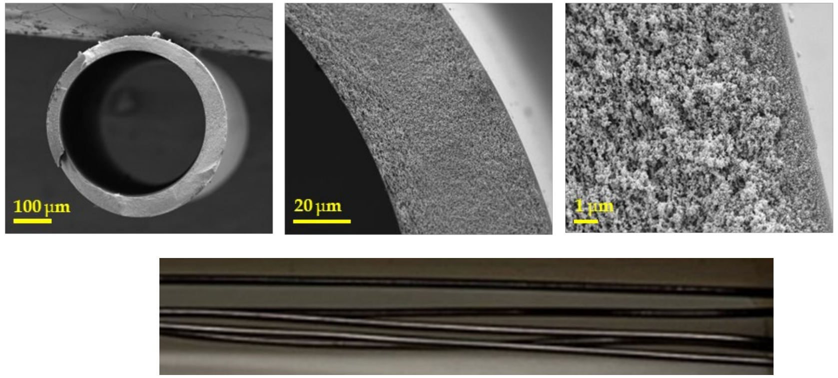
Membrane Separation Challenges

- **Materials Need – High O_2/N_2 selectivity, O_2 permeability, and low cost**
- **Deployment – Industry relevant large scale platform**

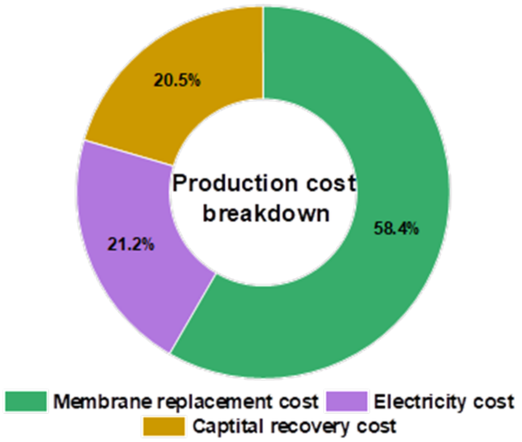


Ref: Robeson, J. Membr. Sci., 320 (2008) 390-400

Carbon molecular sieve hollow fiber membranes

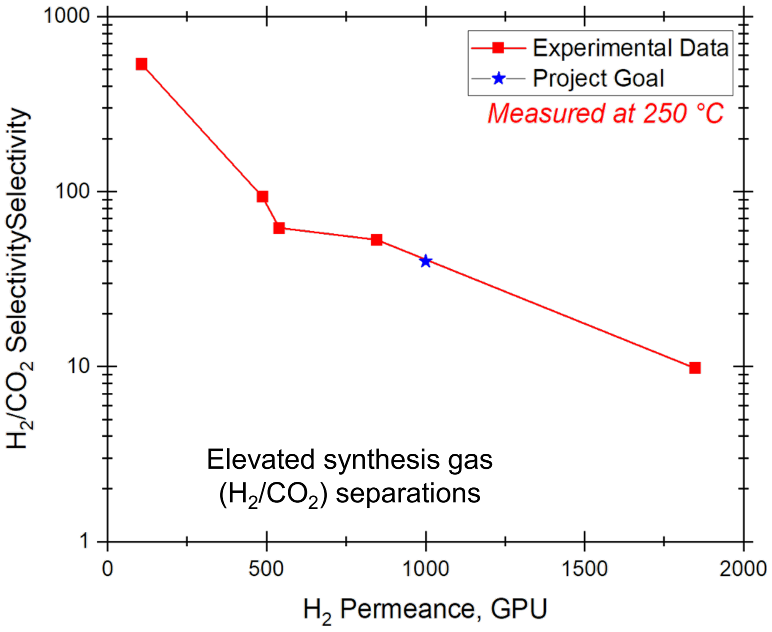


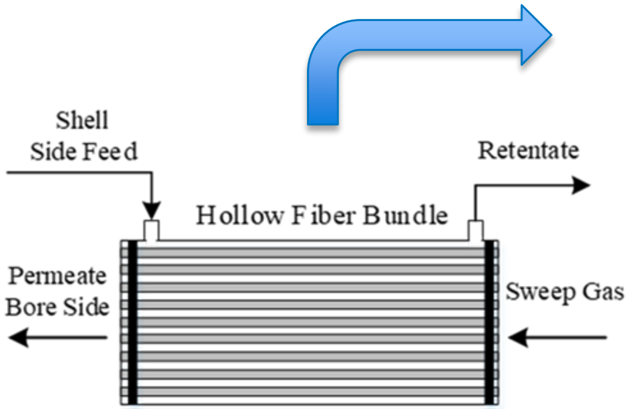
Membrane cost dictates the O_2 production cost

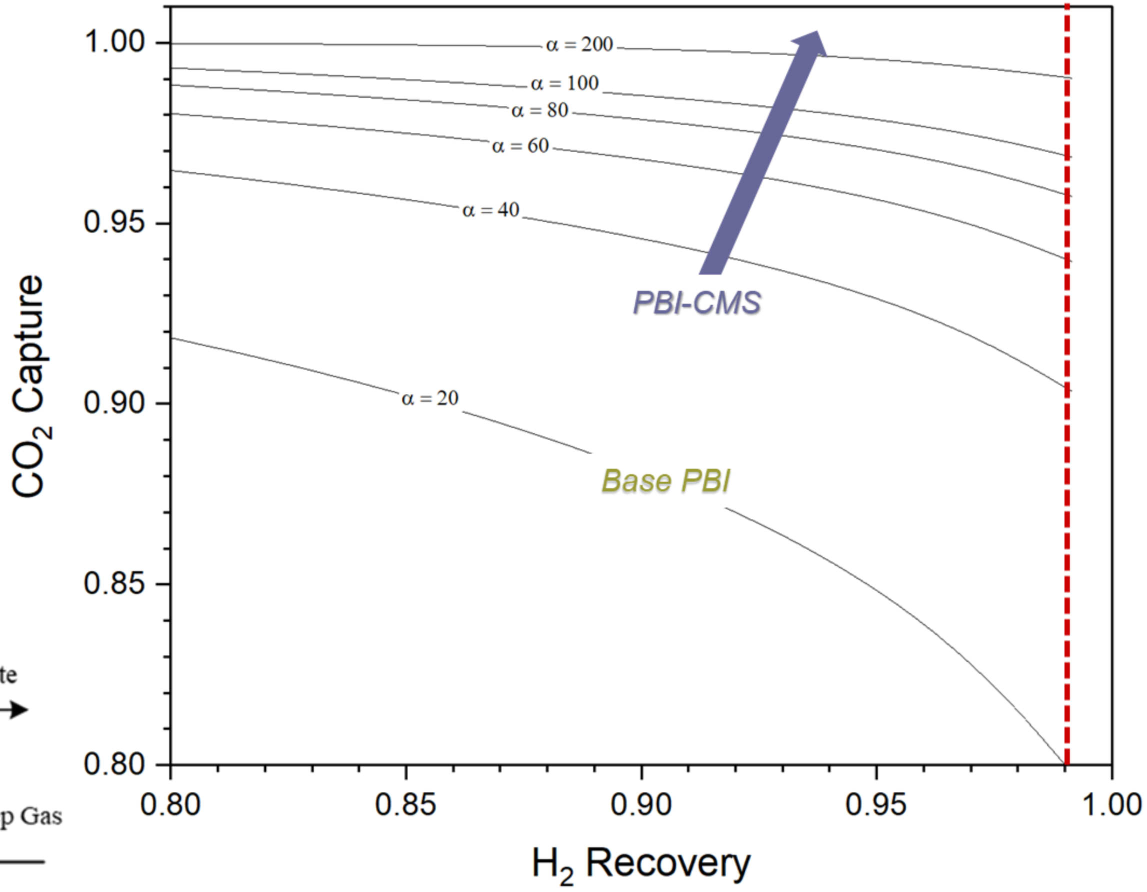


Pre-combustion Carbon Capture

- **PBI-CMS HFMs have exceptional H_2/CO_2 separation at syngas relevant operating conditions**
  - Elevated temperature H_2 selective membrane with warm syngas clean-up







Simulated H_2 Recovery and CO_2 Capture as a function of membrane selectivity at coal derived syngas operating conditions

Thank You!!

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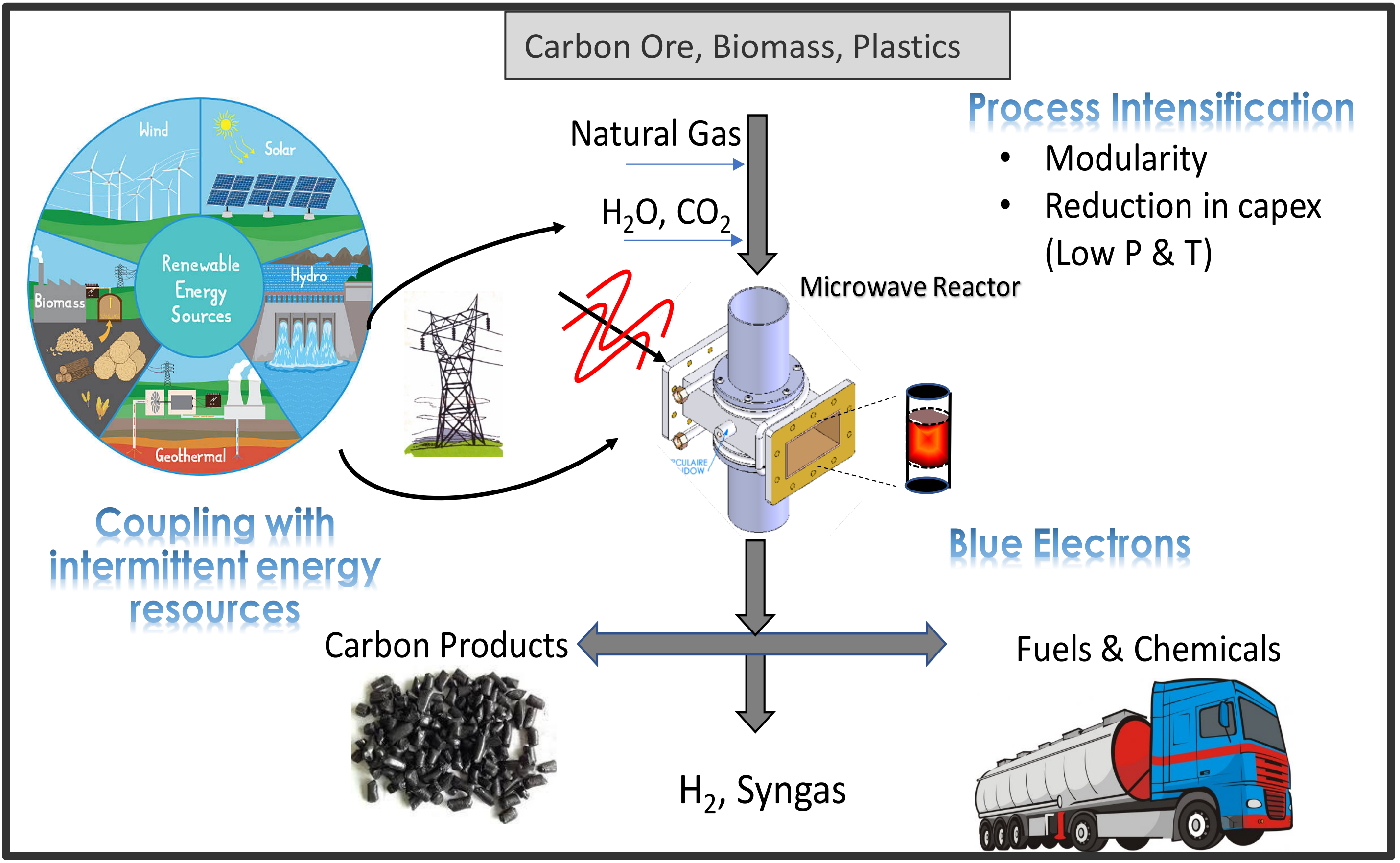
Microwave Reactions for Gasification

Christina Wildfire

National Energy Technology Laboratory, DOE

Hydrogen Shot Summit

Using Microwaves for Gasification



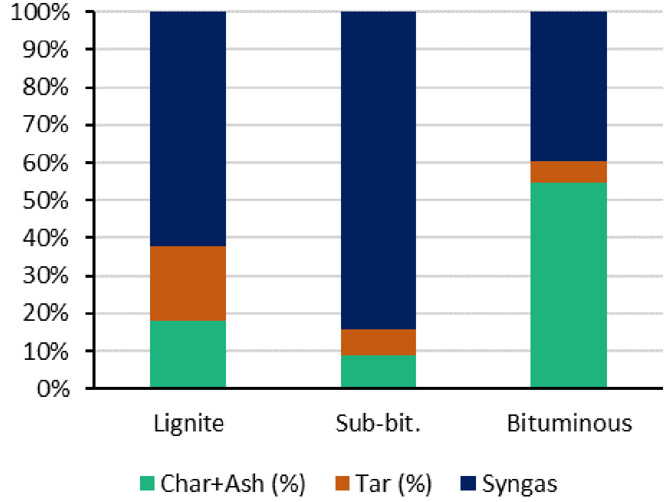
- Process intensification benefits
  - Rapid, selective heating
  - Modularity
  - Cost reduction
- Flexibility and tunability
  - Responsive to feed variations
  - Pairs with intermittent renewables
- Assist traditional gasification methods
  - Treatment for upstream/downstream to integrate carbon capture

MW Gasification Increases H_2 Production

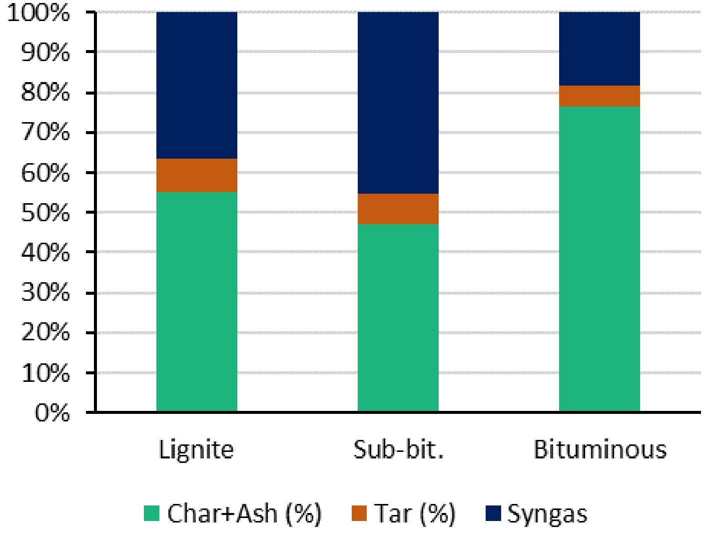
Effect of Carbon Ore:

- Microwave gasification led to greater hydrogen yields
- Much greater conversion (lower char yield) under microwave

Microwave

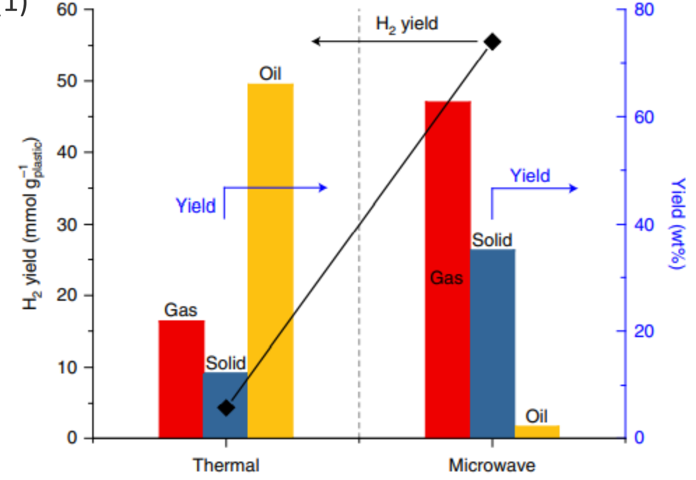


Conventional



Polymer Waste

(1)

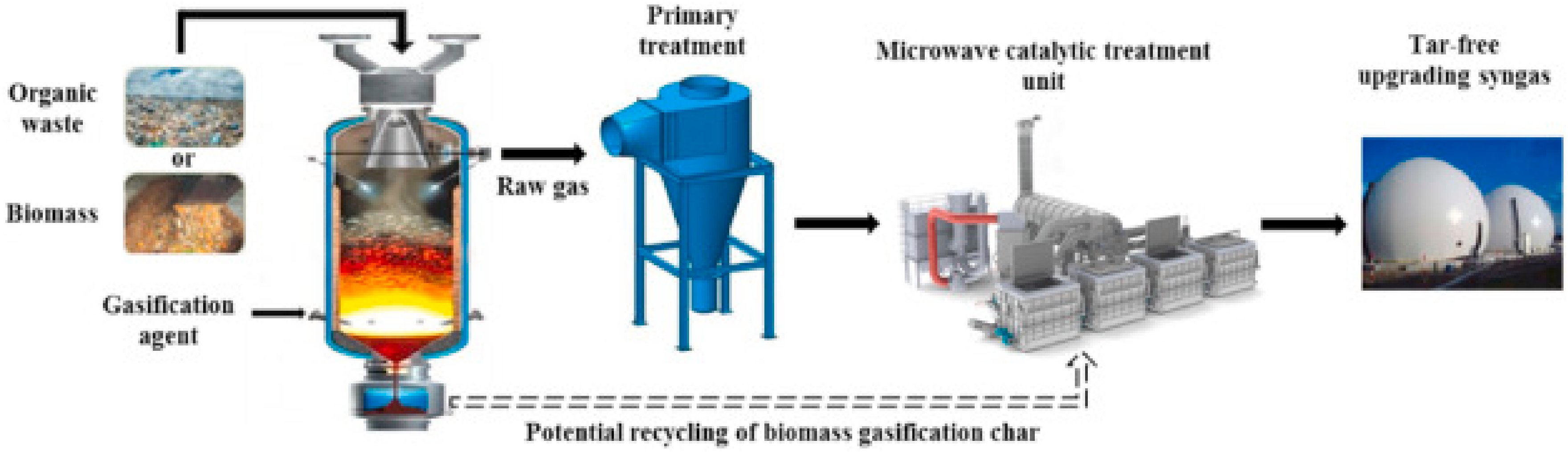


Trends with Biomass/Plastic:

- Microwave biomass leads to increased gas production and tar conversion
- Mixed waste streams ideal for microwave

(1) Jie, X., Li, W., Slocombe, D. *et al.* Microwave-initiated catalytic deconstruction of plastic waste into hydrogen and high-value carbons. *Nat Catal* 3, 902–912 (2020)

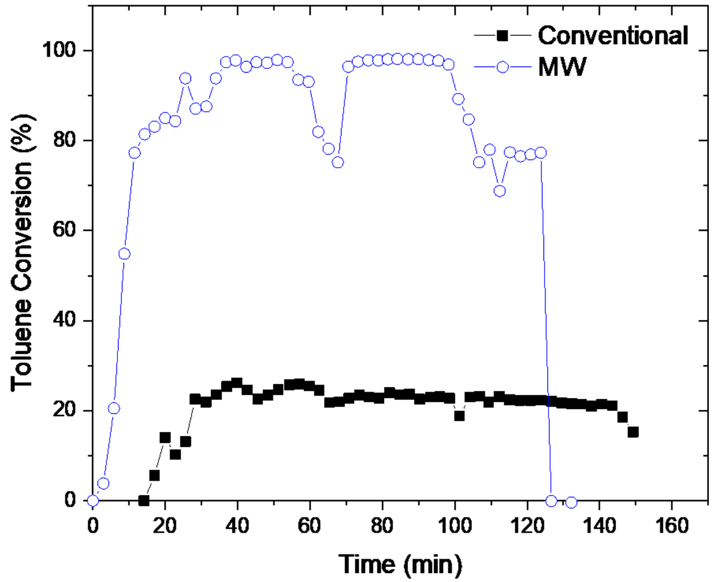
Microwaves for our H_2 Future



(2)

Opportunities:

- Modular waste stream gasification
- Microwave tar treatments
- Companion processes to traditional processes

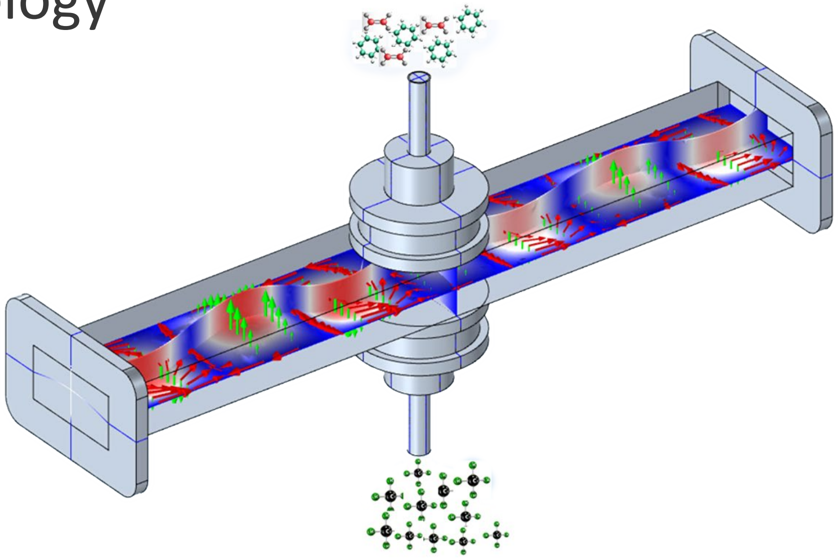


(2) J. Li, J. Tao, B. Yan, L. Jiao, G. Chen, J. Hu, Renewable and Sustainable Energy Reviews,150,2021

Reaching the 1:1:1 Goal

Major challenges and current efforts:

- Fundamental understanding of microwave interactions
- Scaling for specific application
- Field testing technology
- System integration



World's first large-scale microwave chemical plant Chemicals, 10t/day production M3K start-up (3)

M3K, the world's first large-scale microwave chemical plant,
completed in Suminoe, Osaka.

(3) https://mwcc.jp/en/service_technology/platform03.html

Acknowledgements

DOE/NETL:

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Dushyant Shekhawat
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Pranjali Muley

Hari Paudel

Mike Bergen

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Abul Hasan
RF Engineer

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EERC

Advanced Gasification Pathways to Hydrogen – Small, Modular, Distributed Production Versus Central Plants

Josh Stanislowski, Director of Energy Systems Development

Hydrogen Shot Summit

ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

- Nonprofit branch of the University of North Dakota focused on energy and environmental solutions.
- More than 254,000 square feet of state-of-the-art laboratory, demonstration, and office space.

EERC

Heart of North Dakota Energy Industry

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OUR FACILITIES

254,000 SQ FT OF FACILITIES

DOE-DESIGNATED NATIONAL CENTER FOR HYDROGEN TECHNOLOGY®

- In 2004, the EERC was awarded the designation of National Center for Hydrogen Technology (NCHT) by the U.S. Department of Energy (DOE).

Is Hydrogen the Fuel of the Future?

At the EERC, the answer is yes. Whether by advanced combustion or electrochemical oxidation in a fuel cell, when hydrogen is processed to yield thermal, electric, or kinetic energy, process emissions essentially comprise…water. To realize the global environmental and life-sustaining benefits of a commercially viable carbon-free hydrogen economy, key challenges to overcome are centered on:

How best to monetize hydrogen's attributes of high-mass-based energy content and carbon-free composition while most efficiently accommodating its deficiencies of low-volume-based energy content and high carbon intensity of currently deployed production methods.

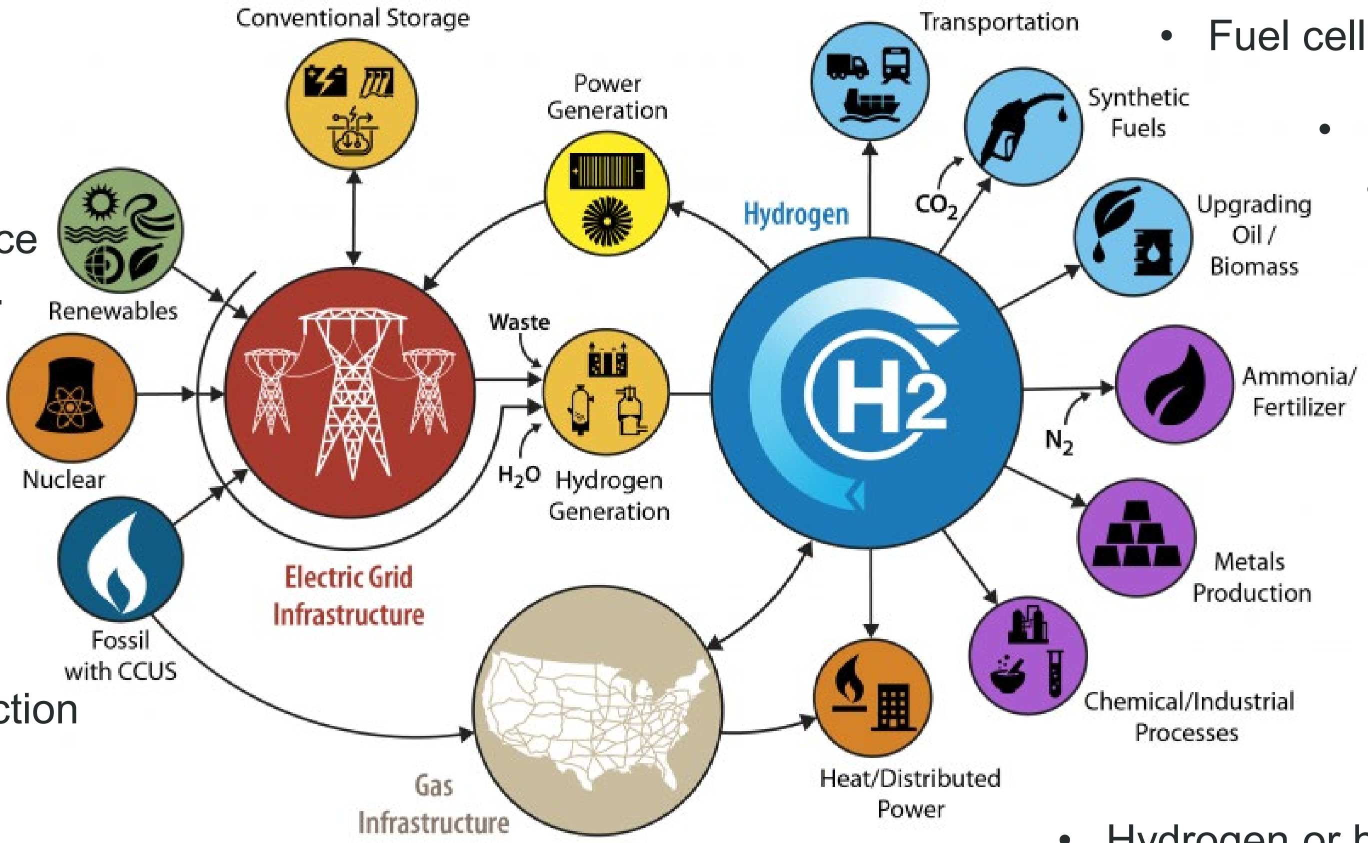
At the EERC, we believe these challenges are opportunities and are equipped, dedicated, and ready to work with like-minded industry, investor, academic, and government partners to shape, build, and usher in the hydrogen economy.

HYDROGEN OPPORTUNITIES IN NORTH DAKOTA

Hydrogen and Power Production

Electrolysis-Based Hydrogen Production

- Electricity from fossil and renewable resources can produce hydrogen from water.



Direct Hydrogen Production

- Coal and biomass gasification
- Natural gas reforming

Hydrogen Uses

- Fuel cell vehicles
- Coal and biomass gasification and synfuel production
- Refining: petroleum and renewable oil
- Fertilizer manufacture
- Petrochemical manufacture
- Hydrogen or hydrogen–natural gas mix for industry or building applications
- Pipelines inter- and intrastate

HYDROGEN OPPORTUNITIES IN NORTH DAKOTA

Source: H2@Scale | Department of Energy

Hydrogen and Power Production

Electrolysis-based Hydrogen Production

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THE FUTURE OF HYDROGEN PRODUCTION

- **Scale Considerations**
  - Multiple smaller units
  - Traditional large-scale systems
- **Polygen considerations**
  - Gas separation for CO_2 and H_2 production
  - Additional coproducts with hydrogen to maximize revenue streams
  - Syngas to liquid fuels, chemicals, fertilizer, and other products
- **Feedstock availability**
  - Economics of transport
  - Coal and biomass blending

The EERC has worked on numerous microgasification projects:

- Woody biomass
- Corn stover
- Switchgrass
- Waste streams
  - Municipal solid waste
  - Coffee waste
  - Turkey litter

Bring the system to the feedstock versus bring the feedstock to the system.

EERC Truck Mounted Gasifier

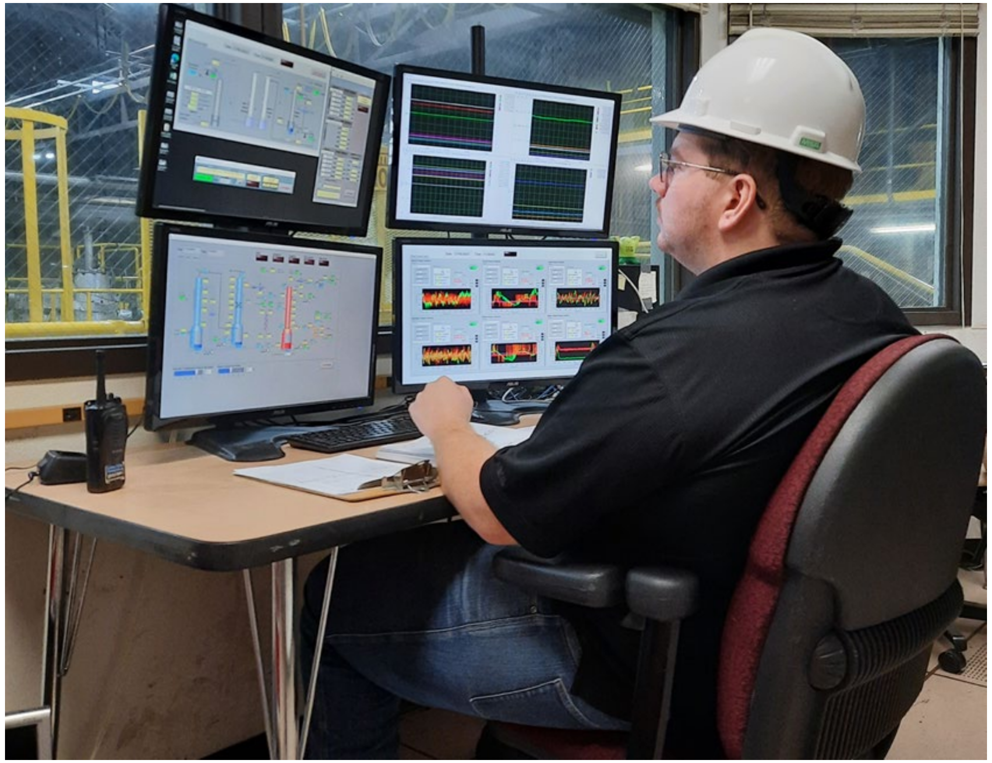
Biomass Waste-to-energy and Liquid Fuels Production

- **Great Plains Synfuels Plant in North Dakota**
  - Diverse product mix has been key to longevity of the plant.
    - Synthetic natural gas
    - Ammonia/urea
    - Other chemicals
  - Planning to create a blue hydrogen hub in North Dakota in partnership with Bakken Energy and Mitsubishi Power America.

Establishment of a hydrogen market is key!

BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS)

- Goal: Develop technology that results in hydrogen production with a net-carbon-negative footprint by using coal and biomass blends.



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