Small-Scale Engineered High Flexibility Gasifier

DOE Award No. DE-FE0031531 2020 Annual Project review Meeting

Crosscutting Research, Rare Earth Elements, Gasification Systems and Transformative Power Generation

Virtual
September, 2020

Project Team

Mikhail Granovskiy, PhD-PI
Wesley Wilson,
Chanse Appling
Amit Goyal, PhD

Project Goals

- Develop a fuel flexible and modular/shop fabricated oxygen-blown small-scale coal gasifier to produce medium BTU syngas with a low tar content
- Demonstrate gasifier performance to meet target at bench-scale (10-50 lb/h)
- Conduct a technoeconomic evaluation (TEA) for syngas conversion to liquids (fuels, chemicals)

Project Tasks

- Computational modeling to optimize gasifier design - done
- Laboratory testing to obtain model input parameters - done
- Design and construct gasification rig
- Commission & test gasification rig, demonstrate performance
- Design 1-5 MW energy conversion system
- Develop Aspen-based model for integrated 1-5 MW energy conversion system, conduct TEA

PRB Coal Selected for Modeling and Testing

Ultimate analysis

Element	Wt,%
C	69.11
H	5.22
N	1.06
S	0.34
Ash	17.69
O by difference	6.59
Total	100

Proximate analysis

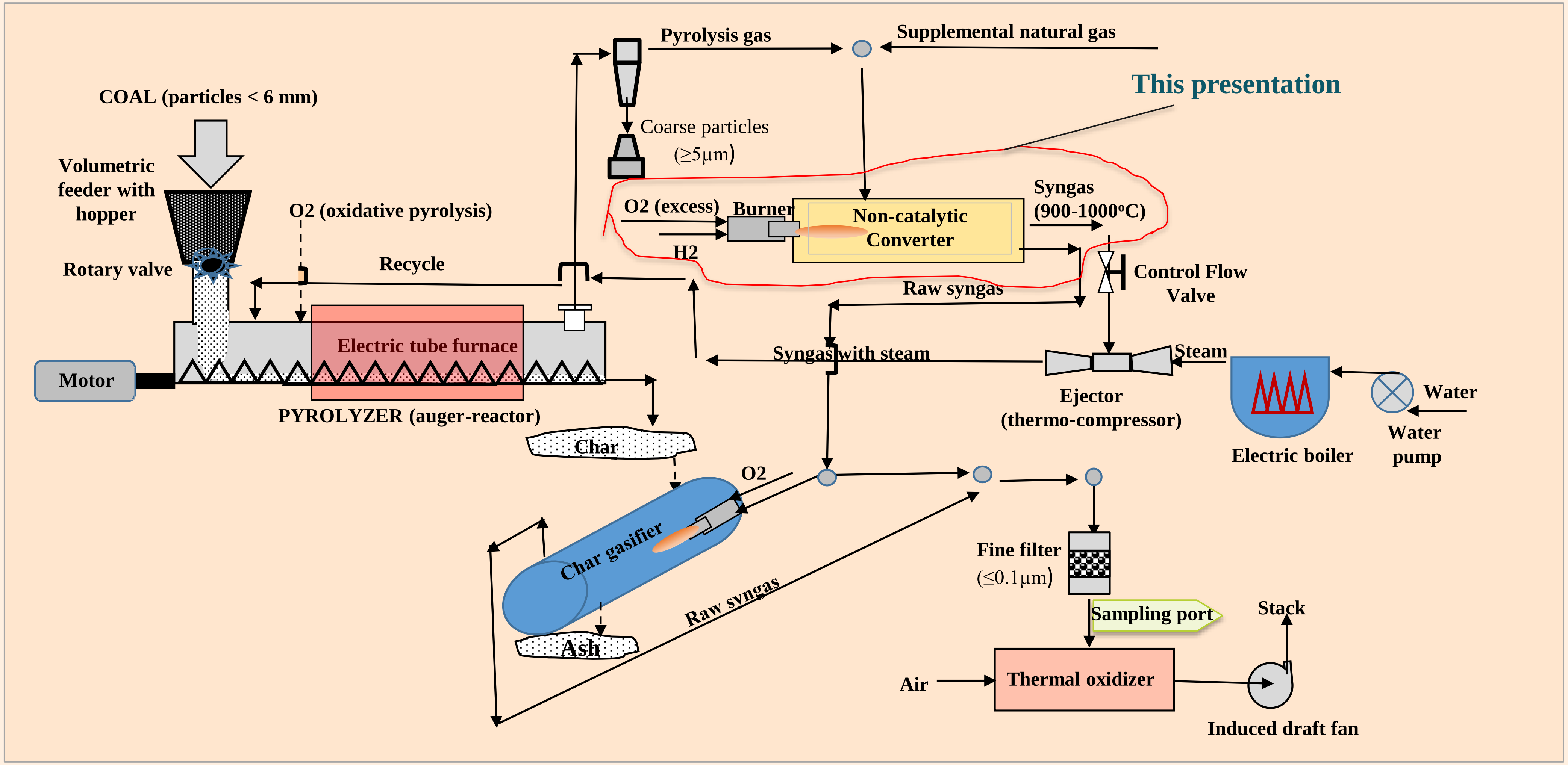
Component	Weight, %
Moisture	18.1
Volatile matter	22.9
Fixed Carbon	53.3
Ash	5.7

Initial Ash Fusion temperature: 1210°C

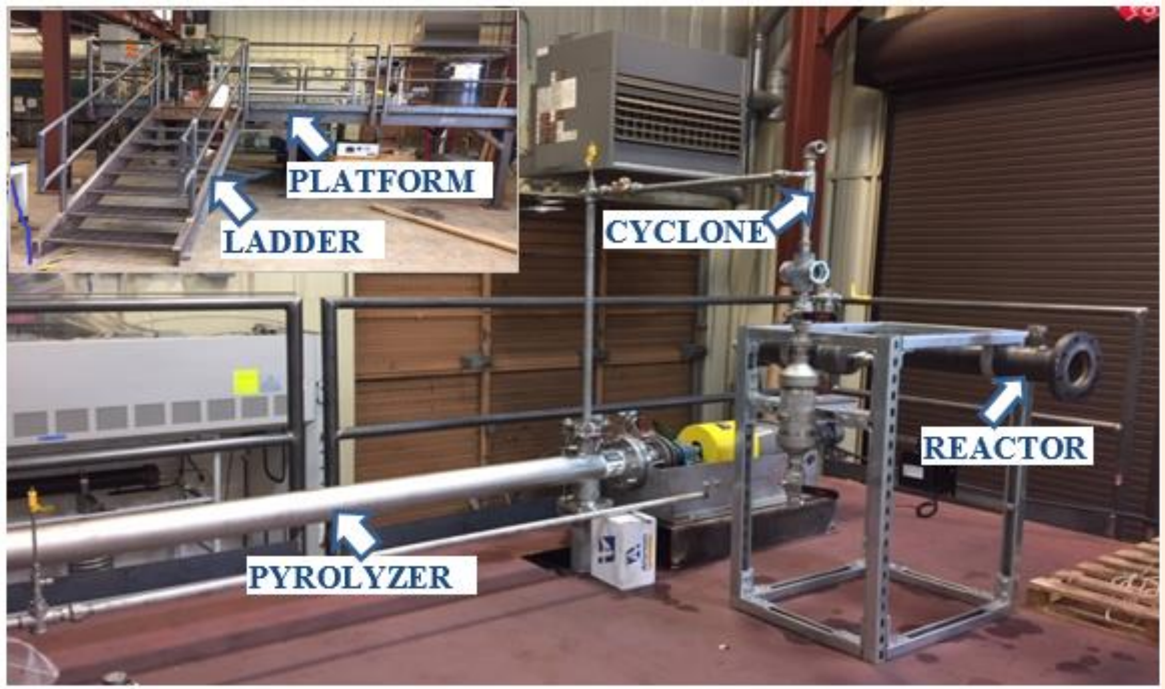
Major Ash Components (Wt%)

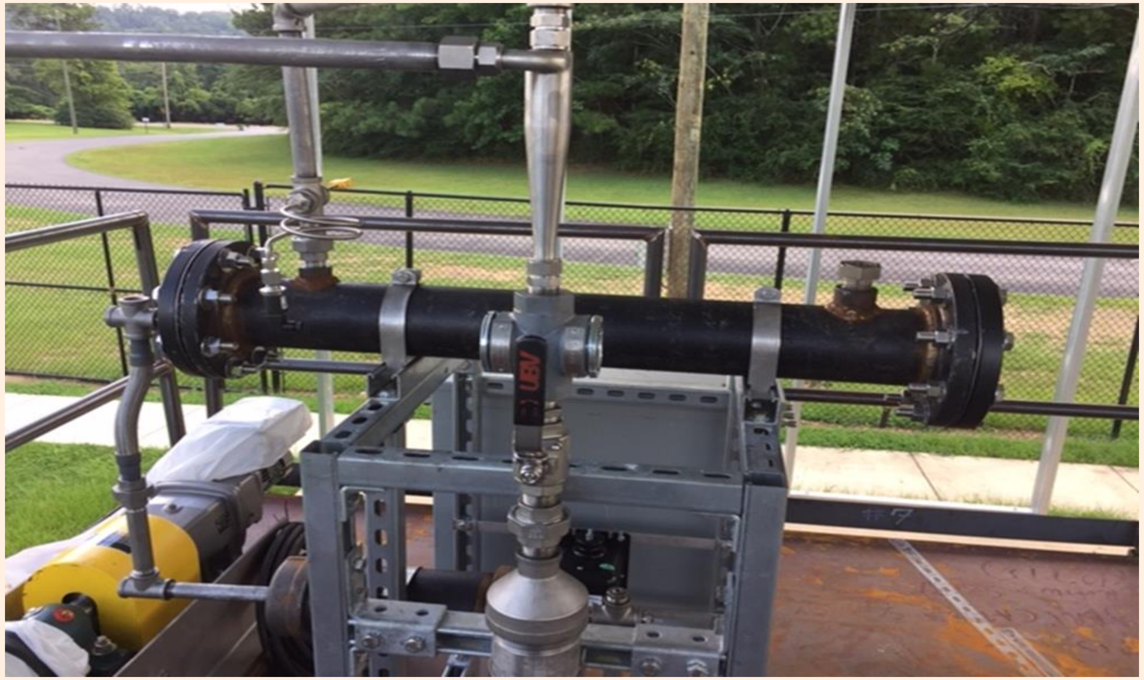
SiO_2	30.2
Al_2O_3	15.4
Fe_2O_3	5.9
CaO	24.3
MgO	4.8
SO_3	13

Feedstock flexibility (coal, biomass, natural gas) through modular structure of gasification skid



Construction of a pilot gasification rig is underway

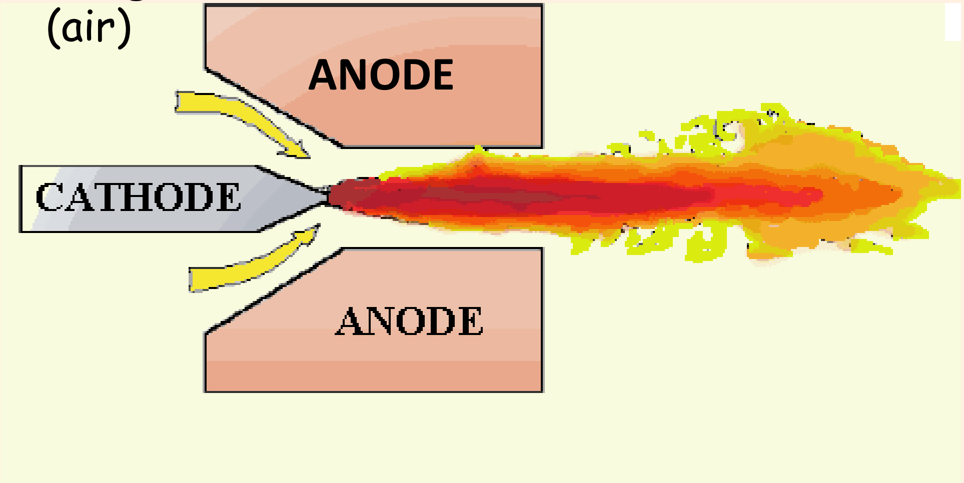




Non-catalytic plasma partial oxidation

An introduction of externally/internally created "active" plasma gas to be mixed with hydrocarbon vapours in order to promote their partial oxidation into syngas

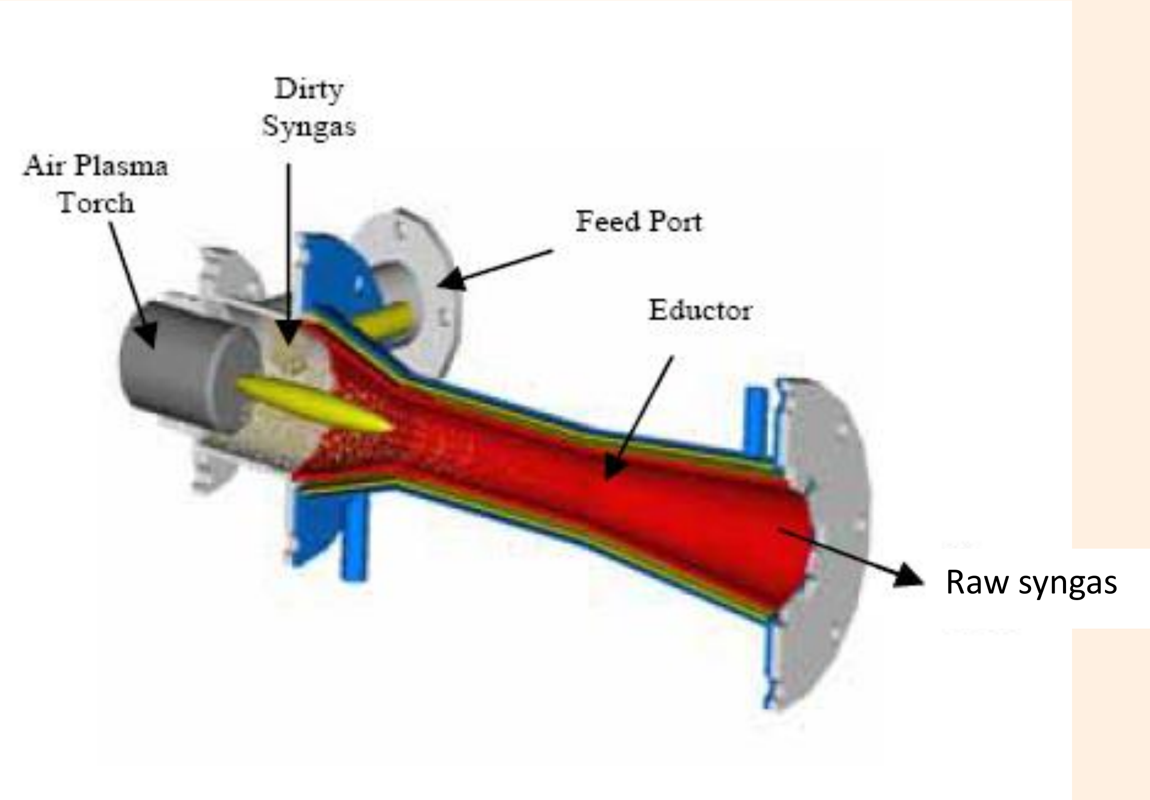
Plasma gas (air)



Hot plasma gas (~5000^{0}C) contains a certain amount of electrons, ions, and radicals which activate (it is believed) reforming of hydrocarbons

Example

The secondary gasifier developed by Pyrogenesis Inc. in collaboration with US Navy for on-board waste treatment system to produce syngas and generate electric energy



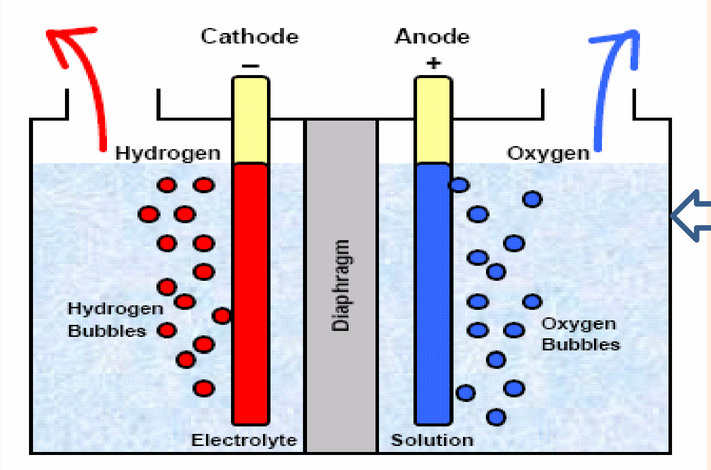
"Dirty Syngas" contains heavy hydrocarbons, "Raw Syngas" has them converted into syngas; all other contaminants stay the same

The oxy-hydrogen flame as a plasma gas

$$H_2 + \left(\frac{1}{2}\right)O_2 = H_2O + Heat$$

High temperature hydrogen/oxygen flame could be considered as a plasma gas. Combustion product (steam) at T~3000K contain significant amount of most active in hydrocarbons reforming OH· radicals

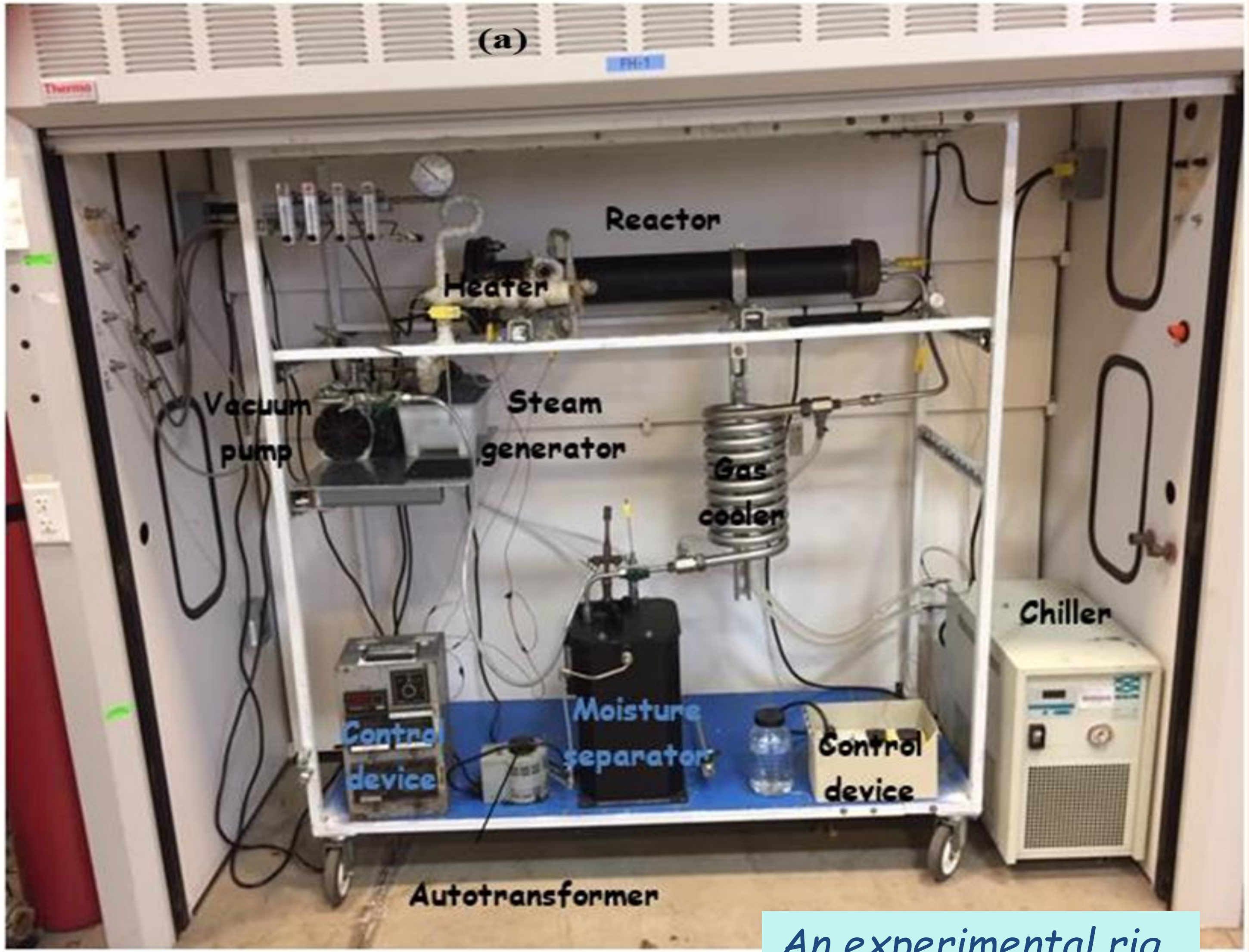
Water electrolysis



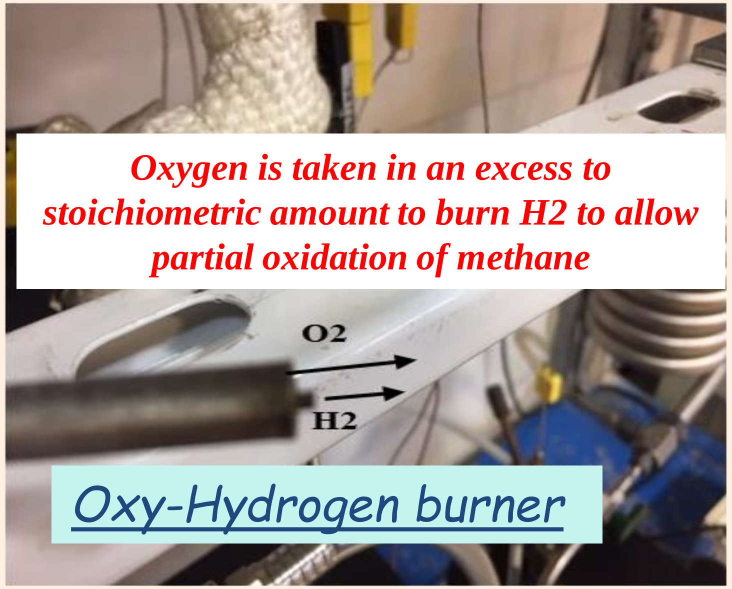
Standard Electrolysis

Efficiency of electricity consumption in water electrolysis to produce pure hydrogen and oxygen is in the same range as to generate plasma gas

An experimental rig to convert hard-to-reform methane into syngas



An experimental rig



Oxy-Hydrogen burner

Reaction zone

The purpose of hydrogen flame in partial oxidation of methane* (volatiles in the case of gasification)

Ideal partial oxidation

$$CH_4 + 0.5O_2 \dashrightarrow CO + 2H_2$$

The worst case scenario (no syngas)

$$(0.75+0.25)\ CH_4 + 0.5O_2 \dashrightarrow 0.25\ CO_2 + 0.5H_2O + 0.75CH_4$$

The purpose of hydrogen flame is to promote methane partial oxidation through steam-methane reforming (no catalyst)

$$CH_4 + H_2O \dashrightarrow CO + 3H_2$$

$$+ \quad H_2 + 0.5O_2 \dashrightarrow H_2O$$

$$CH_4 + 0.5O_2 \dashrightarrow CO + 2H_2$$

* Method and reactor are patent pending

Efficiency indicators

"C" in methane conversion to inorganic gases

$$\zeta_C = \frac{[CO + CO2]_{out}}{[CH4]_{in}}$$

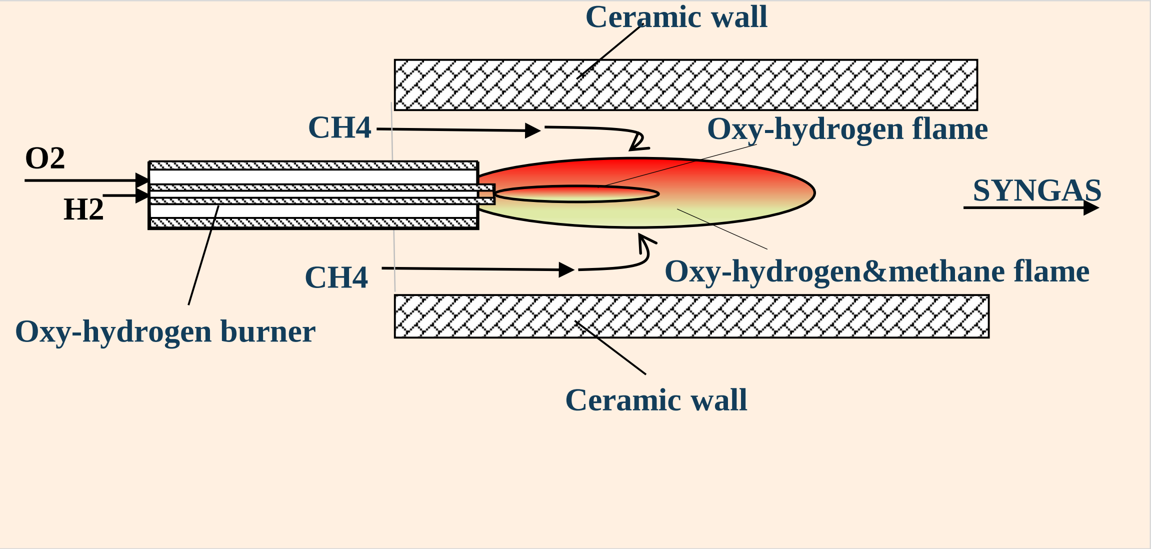
Syngas production (overall)

$$\zeta_{sg} = \frac{[SYNGAS(H2 + CO)]_{out}}{3 * [CH4]_{in}}$$

Syngas production (net)

$$\zeta_{sg}^{n} = \frac{[SYNGAS(H2 + CO)]_{out} - H2(burner)}{3 * [CH4]_{in}}$$

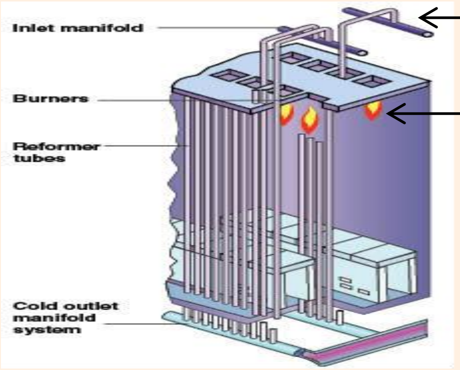
Reaction zone schematic



Results (no steam added)

Input parameters (volumetric ratios)		Output parameters (efficiency indicators)		
O_2_in /CH_4_in	H_2_in/CH_4_in	[$CO+CO_2$]/CH_4_in	[H_2+CO]/CH_4_in	[H_2+CO-H_2_in] / CH_4_in
1.1	0.27	0.91	1.7	1.4
Output parameters (syngas composition), % vol.				
H_2	CH_4	CO	CO_2	C_2H_2
47.05	2.97	31.42	11.22	0.58

SMR furnace



67% CH4 (conversion-95%)

33% CH4 (burning)

CH4+H2O = CO + 3H2 – 206 kJ (endo)

Syngas Production Efficiency

0.67*4*0.9=2.4 mol/molCH4

Syngas production efficiency

1.4 vs. 2.4

"C" in methane conversion to inorganic gases -→ "CO" production efficiency

0.91 vs. 0.6 (0.67*0.9)

Our method favors production of carbon monoxide meaning that at a substantial excess of H_2 over CO_2 (see syngas composition in the Table) the latter can be converted to CO by an industrially employed water-gas shift reaction (in opposite direction):

$$CO_2 + H_2 = CO + H_2O\ (vapor)$$

Decreasing oxygen/methane ratio

Input parameters (volumetric ratios)		Output parameters (efficiency indicators)		
O_2_in/CH_4_in	H_2_in/CH_4_in	[$CO+CO_2$]/CH_4_in	[H_2+CO]/CH_4_in	[H_2+CO-H_2_in] / CH_4_in
1.0	0.27	0.83	1.7	1.4
Output parameters (syngas composition)				
H_2	CH_4	CO	CO_2	C_2H_2
47.90	5.77	29.40	9.14	1.04

Methane conversion decreases but syngas efficiency stays the same. This means that with an increase in oxygen flow (from O2_in/CH4_in from 1.0 to 1.1) syngas generation is offset by its combustion.

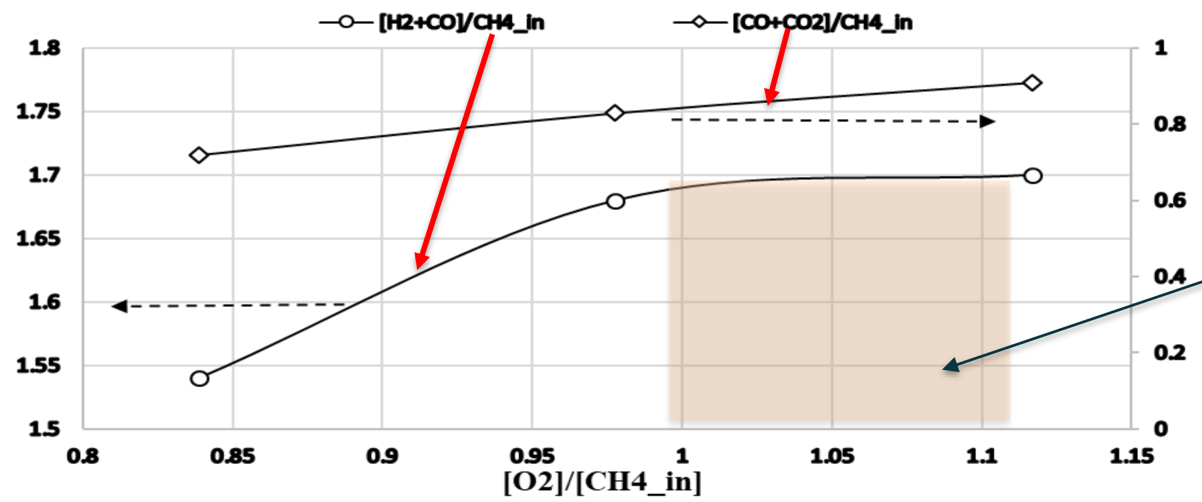


Fig. 3

A utilization of a catalytic block to proceed through steam or dry reforming of methane at higher degrees of methane conversion (higher than 0.8) is very complimentary to the non-catalytic partial oxidation

Fig.3 is a graph representing syngas production and methane conversion efficiencies as a function of O2 flow at a constant H2 gas supply into the burner (H2_in/CH4_in=0.27).

Decreasing oxygen/methane and increasing hydrogen/methane ratio

Input parameters (volumetric ratios)		Output parameters (efficiency indicators)		
O_2_in/CH_4_in	H_2_in/CH_4_in	$[CO+CO_2]/CH_4$_in	$[H_2+CO]/CH_4$_in	$[H_2+CO-H_2$_in$] / CH_4$_in
0.84	0.53	0.64	1.6	1.1

Output parameters (syngas composition)				
H_2	CH_4	CO	CO_2	C_2H_2
50.12	*13.20*	*22.98*	*5.52*	*1.59*

Methane conversion decreases to [CO+CO2]/CH4_in=0.64, net-syngas decreases to [H2+CO-H2_in]/CH4_in=1.1 but converted methane is mostly utilized toward syngas generation. Therefore, syngas production efficiency 1.6 closely corresponds to its stoichiometric value 0.64*3= 1.92 as per partial oxidation reaction (CH4 + 0.5O2 ----> CO + 2H2)

$$
\begin{array}{rl}
 & CH_4 + H_2O \dashrightarrow CO + 3H_2 \\
+ & H_2 + 0.5O_2 \dashrightarrow H_2O \\
\hline
 & CH_4 + 0.5O_2 \dashrightarrow CO + 2H_2
\end{array}
$$

This fact confirms that the phenomenological mechanism of the oxy-hydrogen flame interaction with a hydrocarbon gas to carry out its partial oxidation might be explained by a combination of steam reforming and hydrogen combustion.

A commercial success depends on a syngas utilization technology

Syngas: $2H_2 + 1\ CO$

Heating value: 767 kJ

Power (30% efficiency)

Electricity:230 kJ

Electricity:0.38 cents at
6 cents/KW-hour

Significant relative decrease if O_2 is used instead of air

Fischer-Tropsch: gasoline

$8CO + 17H_2 \rightarrow \underline{C_8H_{18}} + 8H_2O$

14 g C_8H_{18}
(per 3 mol. syngas)

Gasoline: 1.4 cents
at $1 per 1 kg

-O_2: 0.1-0.2 cents

Other industrial chemicals?

Methanol: 1.3 cents
at $ 0.40 per 1 kg

Conclusions and Future Work

- Lab scale experiments proved efficiency and allow to modify, optimize, and build a pilot scale volatiles reformer
- A proprietary reactor and method of hydrogen flame assisted reforming of hydrocarbons were patented (patent pending)
- Construction of a pilot-scale rig is underway

Disclaimer

This presentation was prepared as an account of work sponsored by an agency of the United States Government (DOE-NETL, Office of Fossil Energy). Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Thanks for Listening! Questions?

SOUTHERN RESEARCH

Solving the world's hardest problems.