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Recovery Act: Oxy-Combustion Oxygen Transport Membrane Development

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July 11th, 2013

…if we didn't need to go this big

…it would be easier to maximize NG value creation

OTM is a modular solution that may enable future low cost syngas production at small scales

Program Overview: DOE NT43088

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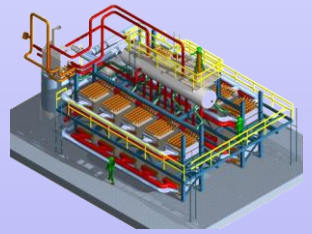
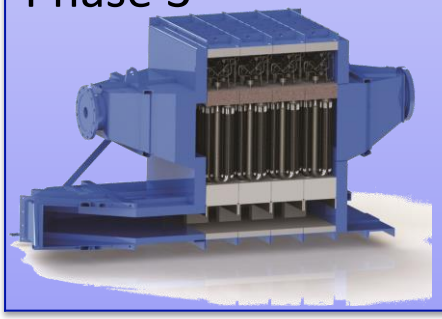
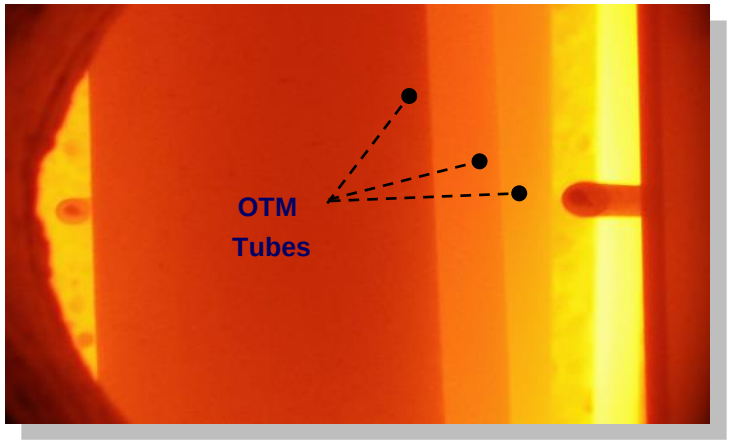
Phase 1 	May'07 to Dec'09	• OTM integrated coal power plant • Advanced oxy-combustion cycle • Process economic evaluation • Membrane performance improvement
Phase 2 	Jan'10 to Jun'12	• OTM integrated coal power plant • Advanced oxy-combustion cycle • Scale-up membrane technology • Equipment design for pilot demonstration
Phase 3 	Oct'10 to Sept'15	• Industrial Applications • OTM integrated process for conversion of natural gas to syngas • 160,000 scfh syngas demonstration

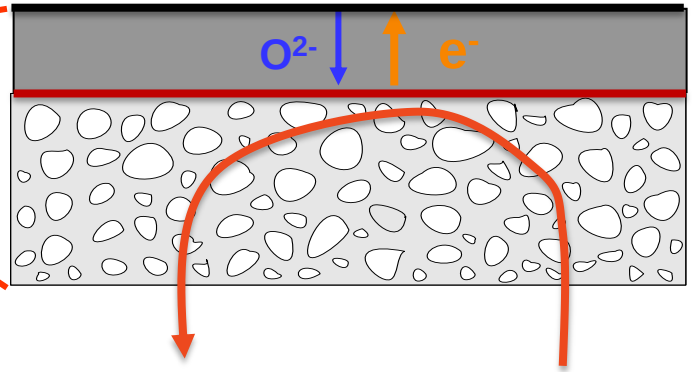
Praxair Oxygen Transport Membranes (OTM)



Oxy-Combustion on OTM Surface

$$O_2\ \text{flux} \propto \ln\left(\frac{P_{O_2[Air]}}{P_{O_2[Process]}}\right)$$

Low pressure Air (typ. 5 psig)



Reaction Products
CO_2, H_2O, CO, H_2, etc.

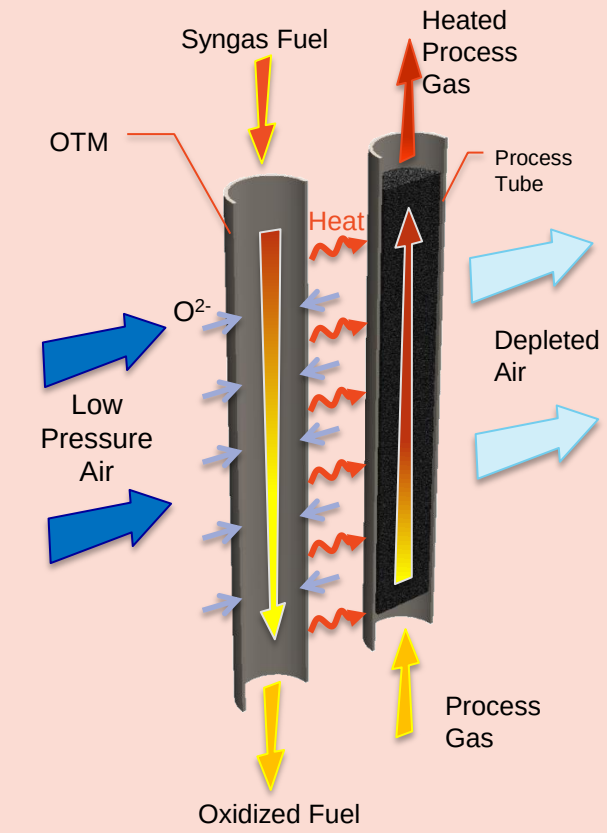
Reactive Gases
CO, H_2, CH_4, etc.

Process pressure typ. 100 – 250 psig
Temperature range 900 – 1,025 °C

Advanced architecture enables oxycombustion and syngas applications

OTM Applications for the Power Cycle

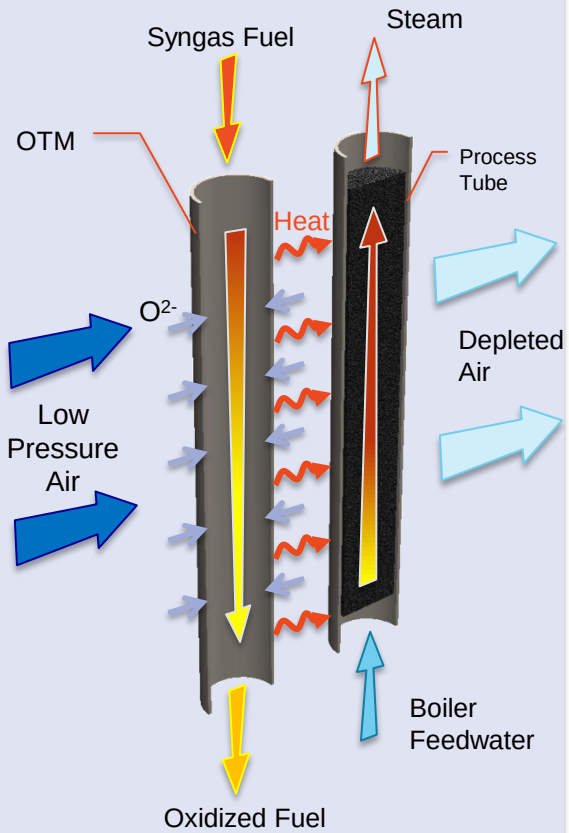
US Patent Nos. 7,856,829 & 8,196,387



OTM POx

- Process gas heating
- *Applications:* power cycle and industrial processes

US Patent Nos. 7,856,829 & 8,196,387



OTM Boiler

- Steam generation
- *Application:* power cycle

OTM Power Cycle

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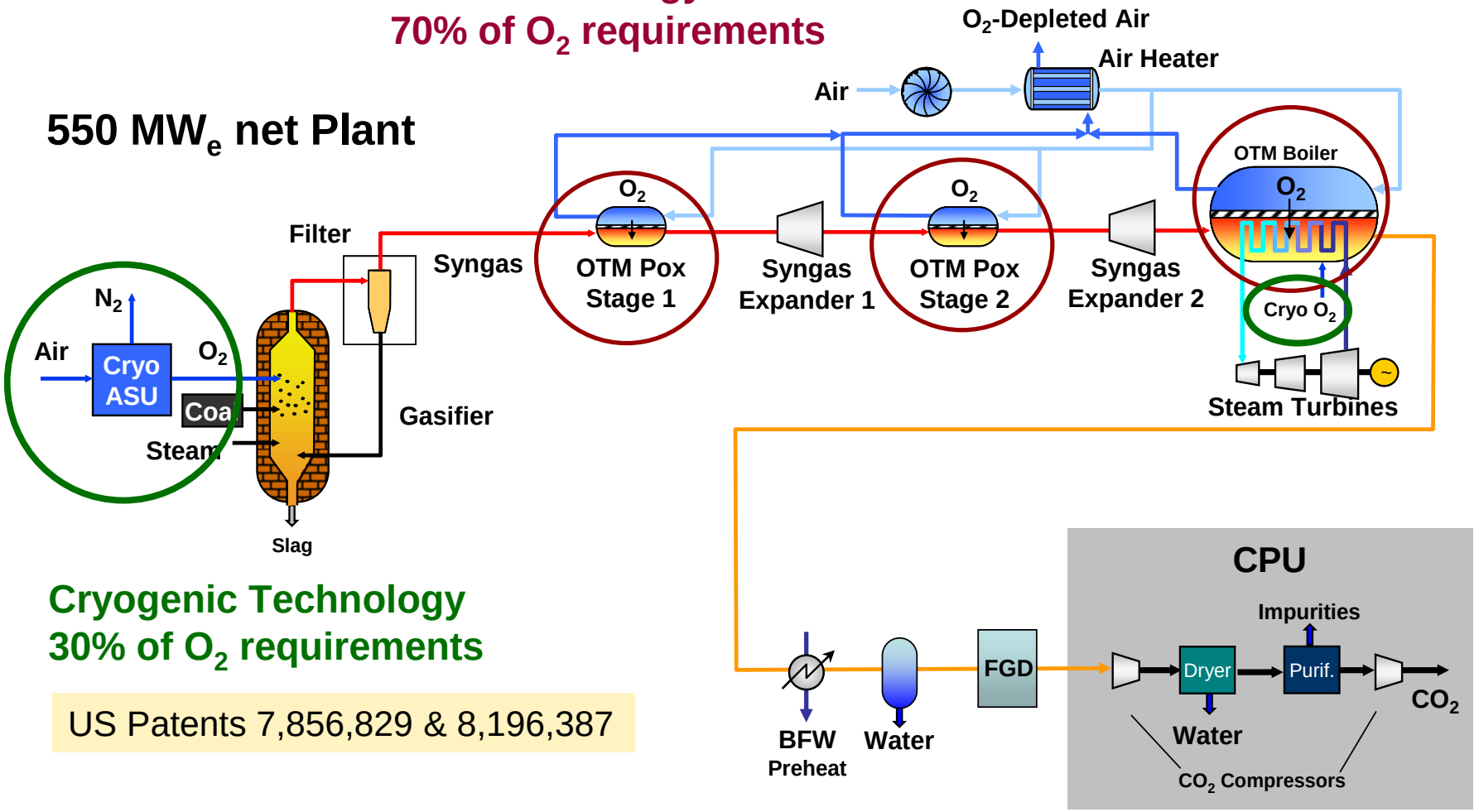
OTM Technology
70% of O_2 requirements

550 MW_e net Plant



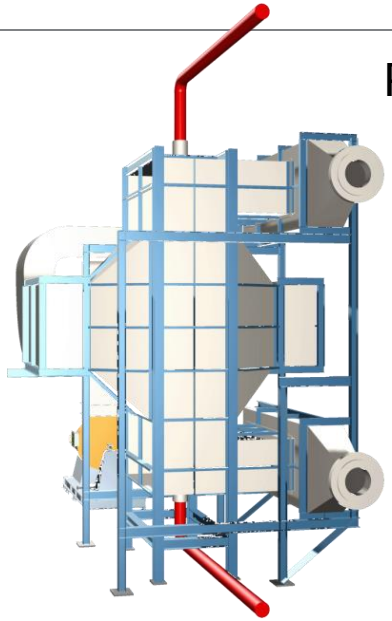
Cryogenic Technology
30% of O_2 requirements

US Patents 7,856,829 & 8,196,387

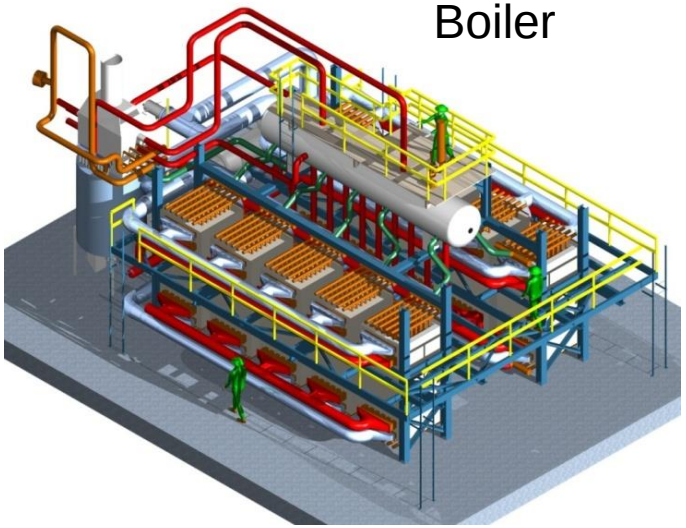
Equipment Design

- Basic design of pilot units and cost estimate with scaling factors completed
- 5 tpd O2 partial oxidation unit
- 7.5 MW_th boiler
- Scaling factors established
- Concepts used to cost large scale equipment
- Update to power cycle economics
- Meets DOE cost of electricity targets

POx



Boiler



OTM Technology Roadmap

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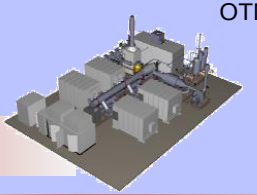
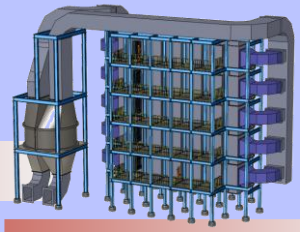
2014 2016 2018 2020 2022 2024 2026 2035

OTM NG-Syngas 160,000 scfd (ARRA)



OTM NG Syngas to Liquids Pilot



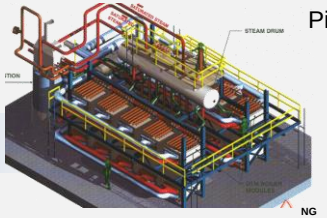
OTM NG Syngas to Liquids Demonstration

Commercial Syngas to Chemicals

MeOH→Gasoline, Olefins, DME, FT Diesel

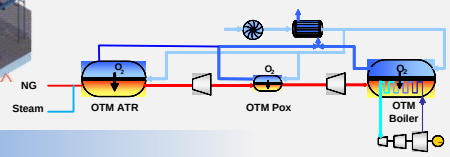
NG to Synfuels and Chemicals

OTM POx Pilot



OTM Power Boiler Pilot

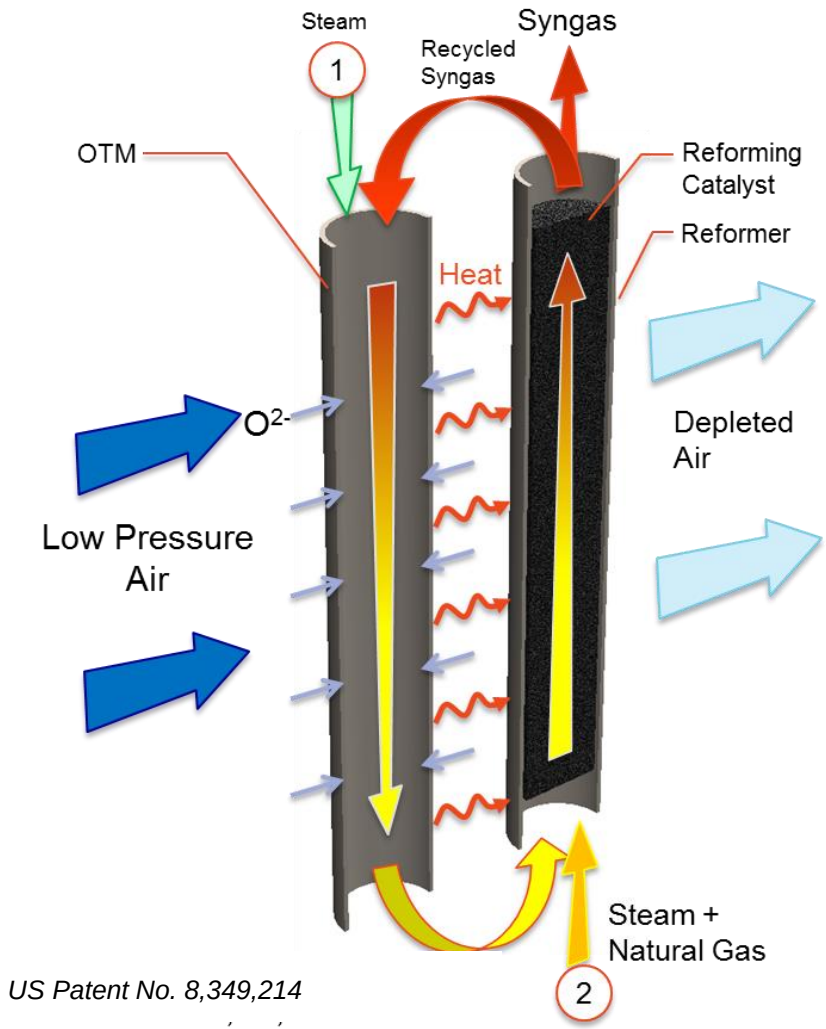
OTM NG Power Cycle Demonstration (CCS enabled)



NG Utility Power + Off-peak Fuels + CCS Enabled

NG to Power and SynFuels with CCS (Oxycombustion)

Improved OTM Syngas Process

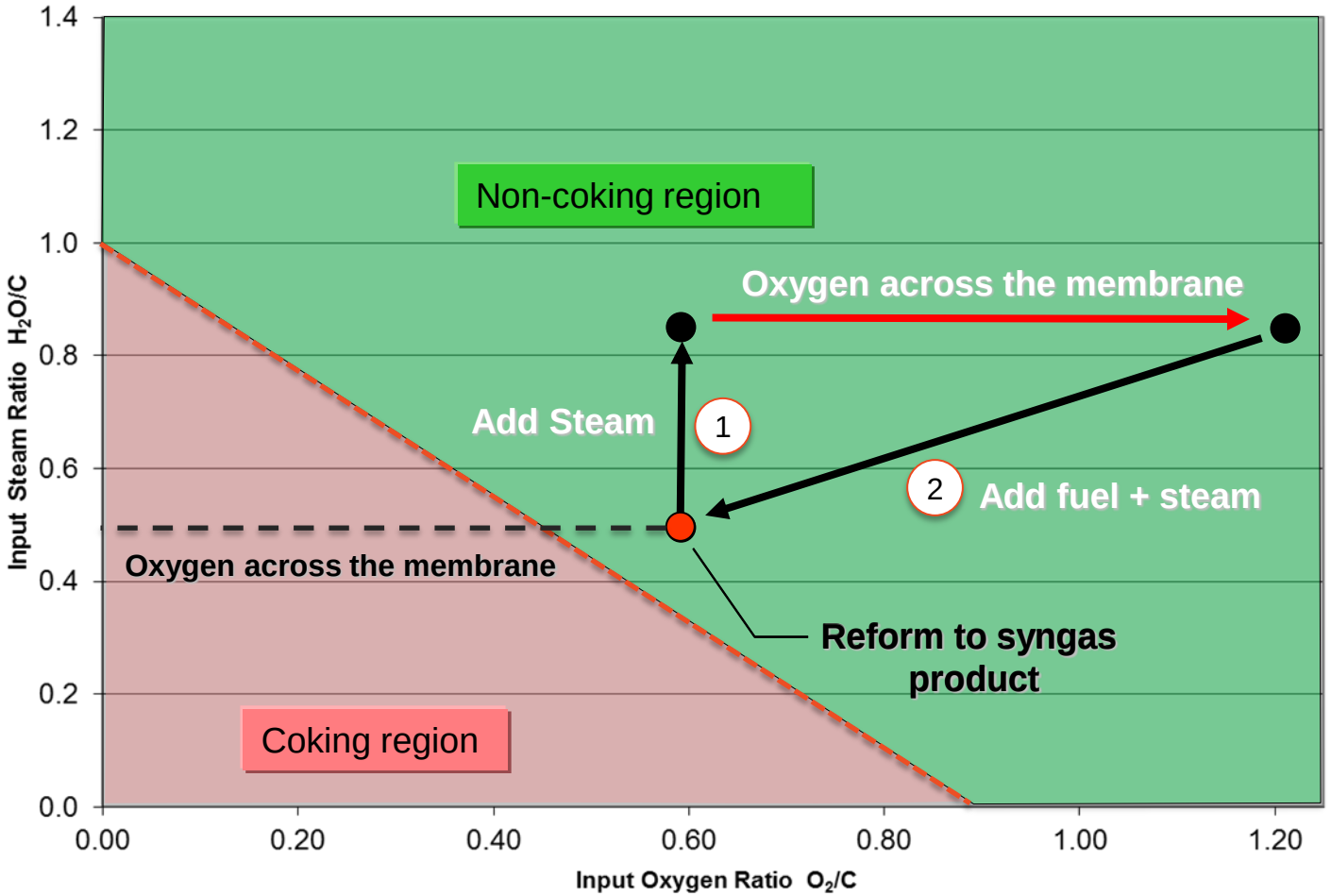


US Patent No. 8,349,214

- Use <u>recycled syngas as fuel</u>
- Steam and CO_2 reforming in separate reforming catalyst
- Reactive fuel drives high oxygen flux
- Inherent coking mitigation

Auto-thermal reformer with O_2 generation onboard

OTM Syngas Process Explained



Reference: NASA CEA Code

Gen.1 OTM Syngas Module

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Eliminate pressure vessel:

- Internal pressure within membranes
- Low pressure air on shell-side

High thermal integration:

- Radiative coupling - OTM surface and reformer

Catalyst:

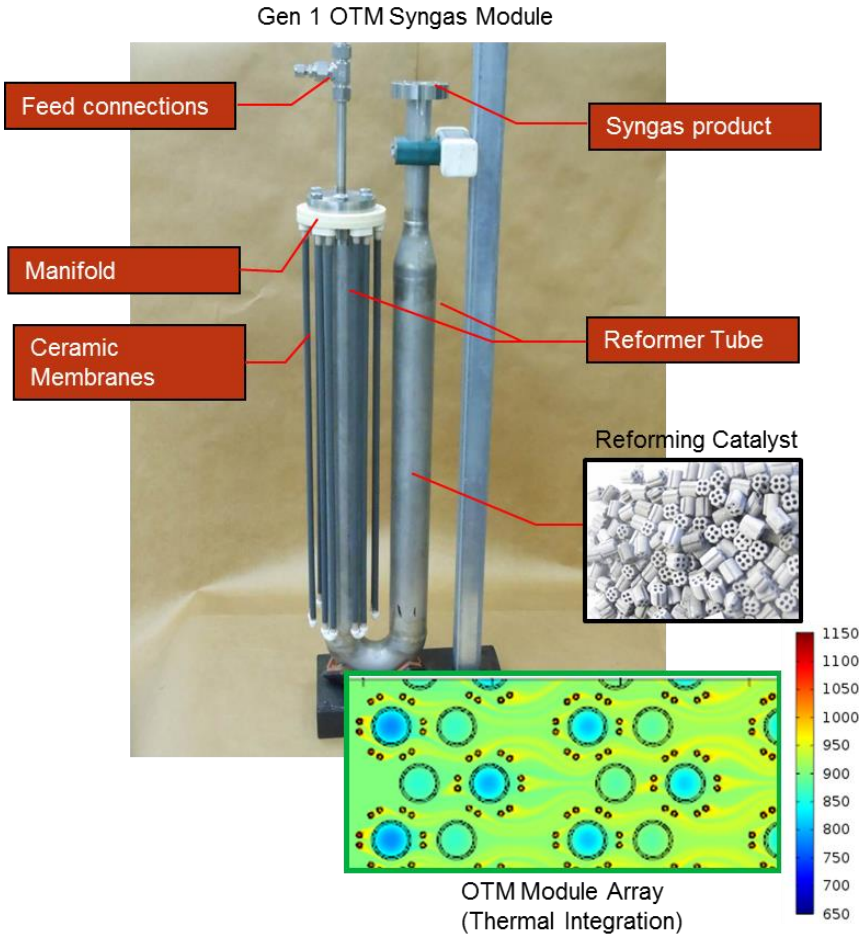
- Commercial catalyst used

Module fault isolation:

- Integrated within module

Scale:

- Smaller than power applications



Modular technology, from NG to Syngas on a single module

Module Laboratory Test Results

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- OTM module successfully operated
  - OTM reforming test at high pressure
  - Demonstration of new process with recycle
- Next Steps
  - Test limits of operation
  - Evaluate long-term performance

Syngas Product Composition		
	Actual	Theory
H_2	67%	66%
CO	25%	25%
CO_2	7%	7%
H_2O	0.6%	1.5%
CH_4	0.1%	0.1%

H_2/CO=2.7

99% Conversion

Demonstrated process for OTM syngas

Syngas Development System - 2013

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- Construction Completed
  - Subsystem commissioned
  - System operational (non-fluxing modules)
- **Next Steps**
  - Operate with fluxing modules
  - Obtain reference operating data for technology

On-track for syngas operation in 2013

Closing Remarks

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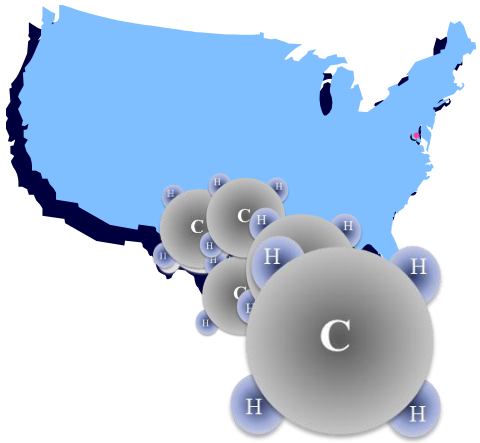
More work is needed, but future is looking promising



Natural Gas

OTM

- Diesel
- Methanol
- Synthetic Crude
- Gasoline

Broader applications spectrum for NG conversion to chemicals and fuels…at a lower cost

Acknowledgements

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