Recovery Act: Oxy-Combustion

Oxygen Transport Membrane Development

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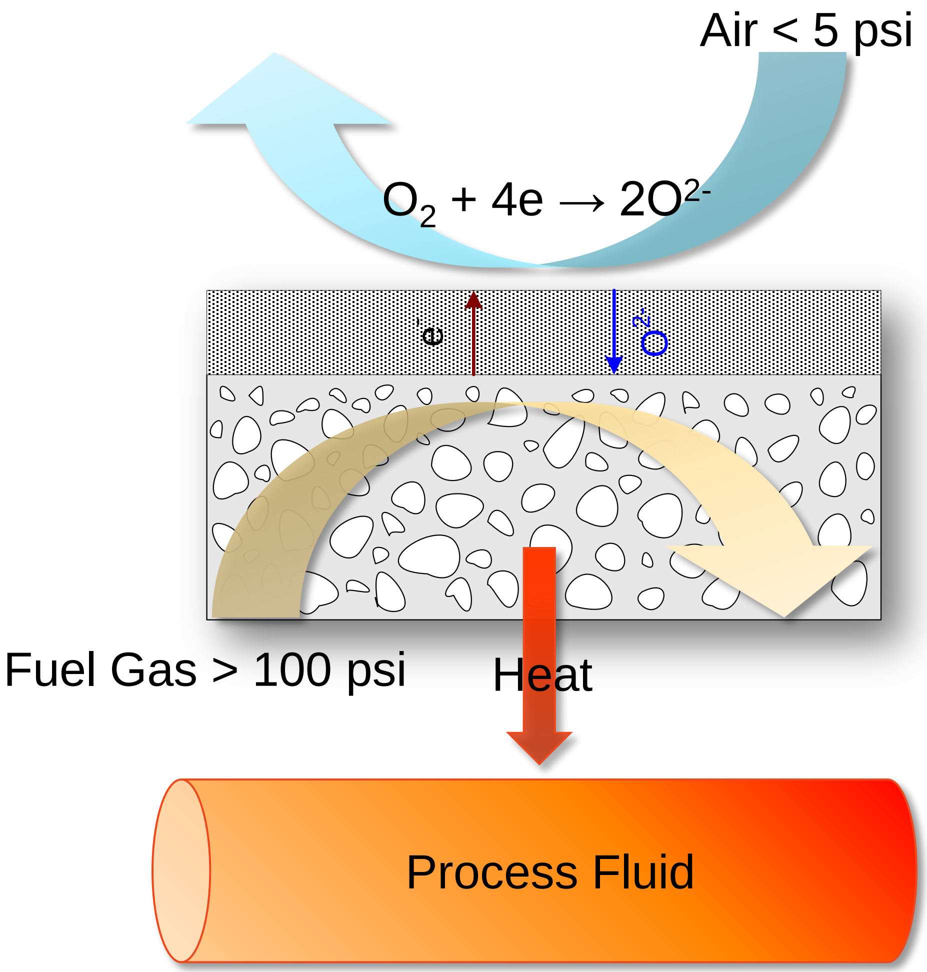
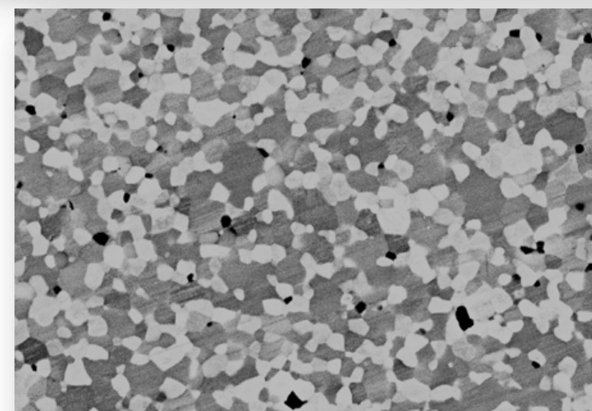
Program Overview: DOE NT43088

Phase 1	05/07 – 12/09	OTM integrated coal power plant Advanced oxy-combustion cycle Process economic evaluation Membrane performance improvement
Phase 2	01/10 – 6/12	OTM integrated coal power plant Advanced oxy-combustion cycle Scale-up membrane technology Equipment design for pilot demonstration
Phase 3	10/10 – 09/15	Industrial Applications ARRA funding OTM integrated process for conversion of natural gas to syngas 160,000 scfh syngas demonstration OTM modules qualified for scale-up and larger demonstration projects

Principle of Operation

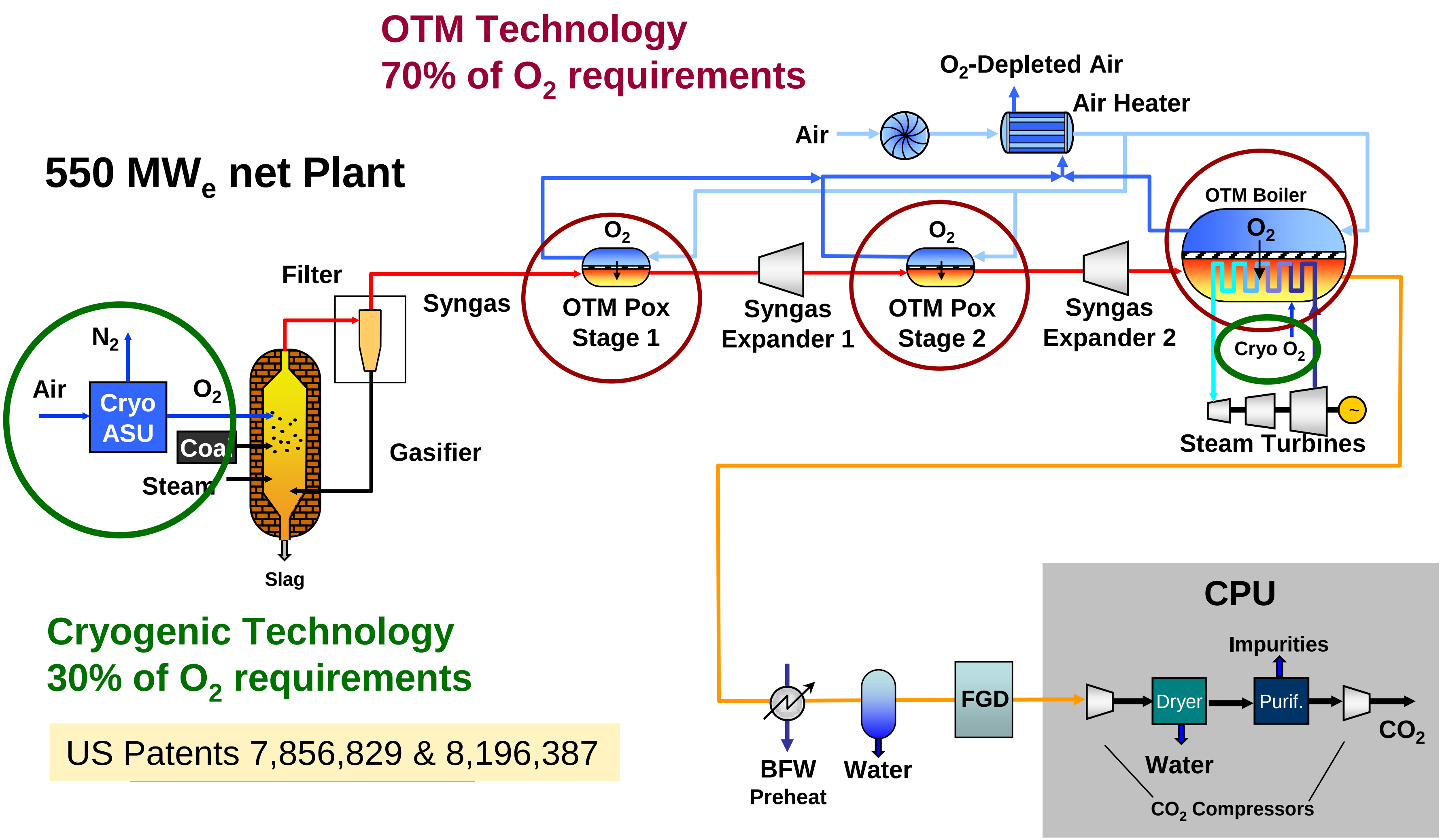




Gas separation layer

Oxy-Combustion Without Producing Oxygen

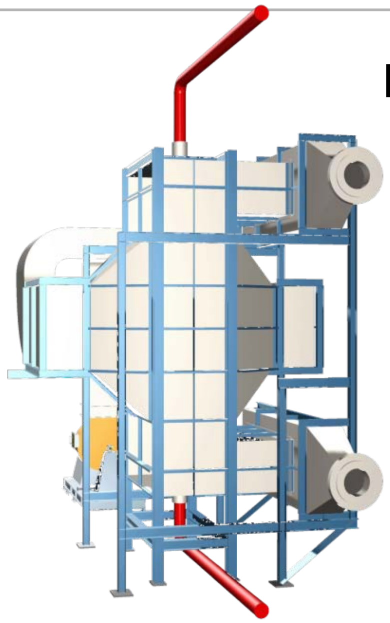
OTM Power Cycle



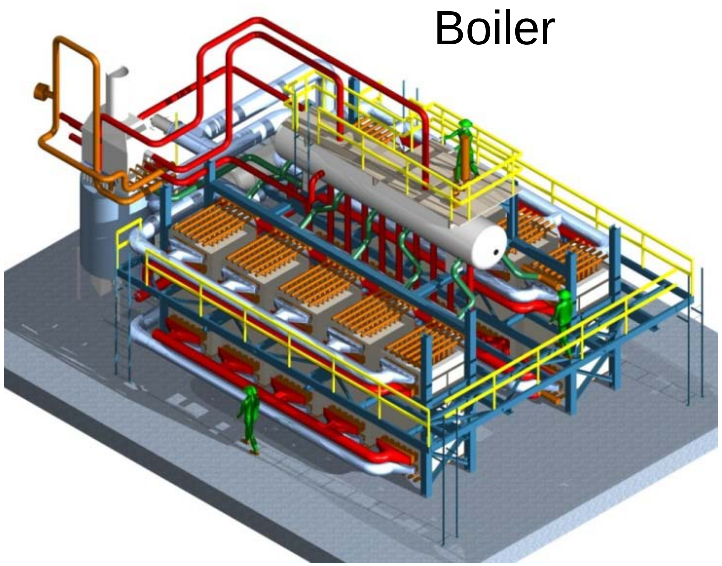
US Patents 7,856,829 & 8,196,387

Equipment Design

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

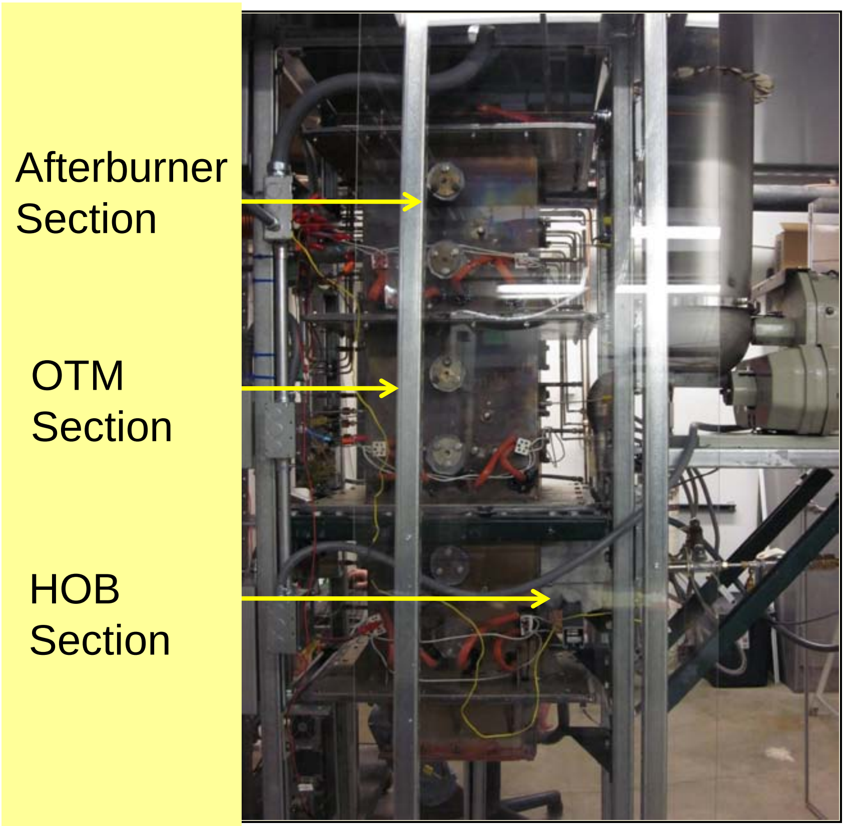


POx

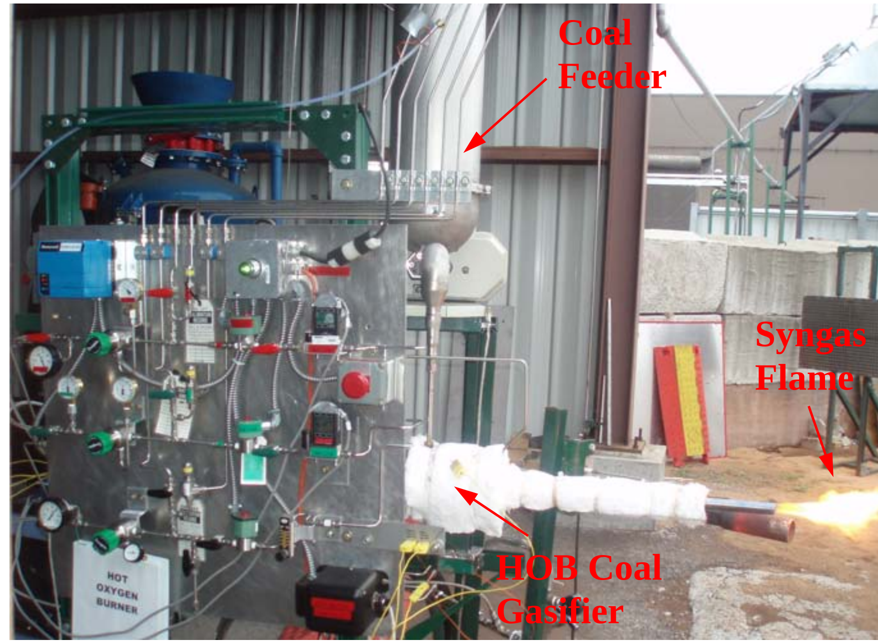


Boiler

OTM Testing with Coal Gas Fuel



OTM Coal Gas Reactor
University of Utah

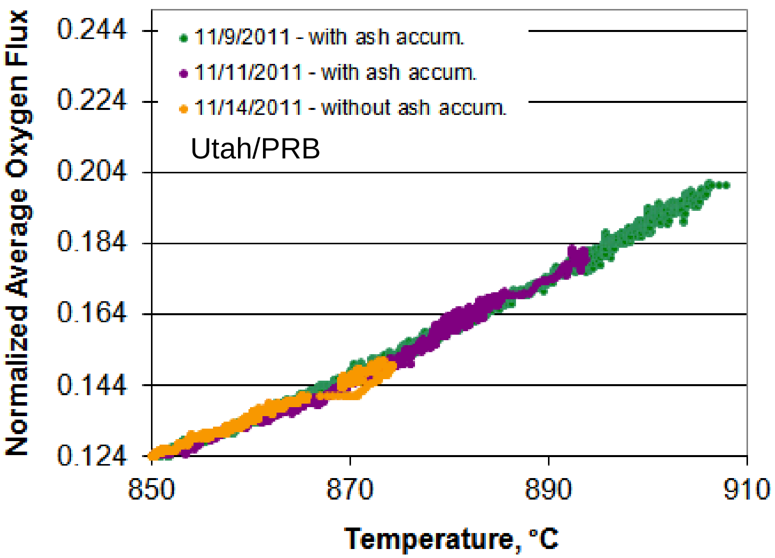


Praxair Hot Oxygen Burner for Coal Syngas

OTM Testing with Coal Gas Fuel

PRAXAIR
Making our planet more productive™

- Tests with 25/75 mixtures of Utah/PRB and 50/50 mixtures of Illinois/PRB
- No filter between HOB and OTM reactor
- Large build-up of ash on surface OTM tube
- Coatings inside tube are protected by substrate
- Significant corrosion of metal parts in furnace
- No reaction found in post-test analysis



Ash on surface of OTM tube

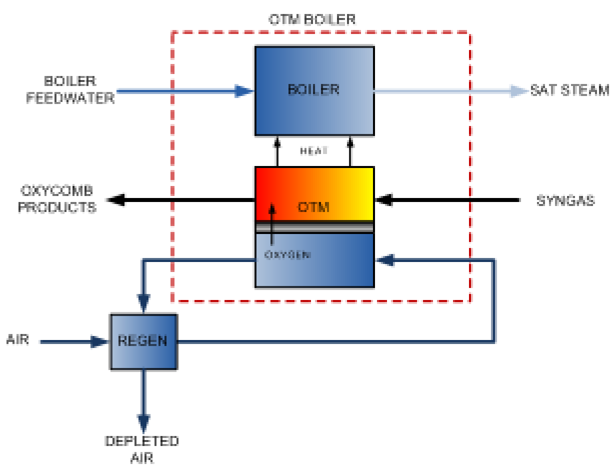
Coal Type	LOD (105ºC)	Ash (705ºC)	C	H	N	S	O (by diff)	Volatile Matter	Fixed Carbon	HHV (BTU/lb)
Utah	3.18	8.83	70.6	5.41	1.42	0.53	13.21	38.6	49.39	12606
Illinois	9.65	7.99	64.67	5.59	1.12	3.98	16.65	36.78	45.58	11598
PRB*	23.69	4.94	53.72	6.22	0.78	0.23	34.11	33.36	38.01	9078

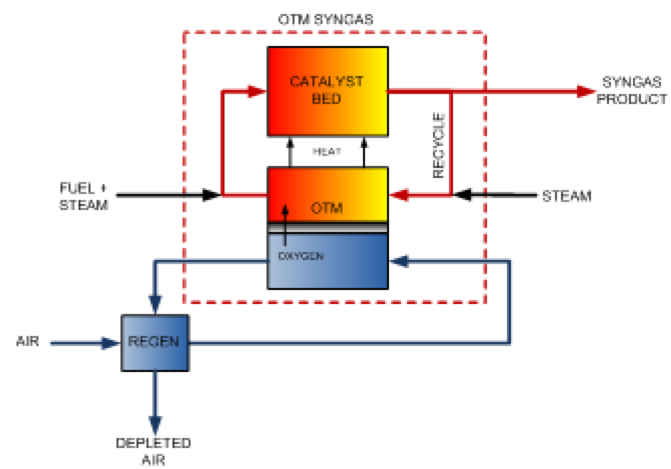
*North Antelope Powder River Basin

Applications

- OTM Boiler
  - Steam and Power with CCS
  - Process heaters
  - Long term applications

- OTM Autothermal Reformer
  - Syngas for liquid fuels and chemicals
  - Low H2O/C ratio
  - Near term applications

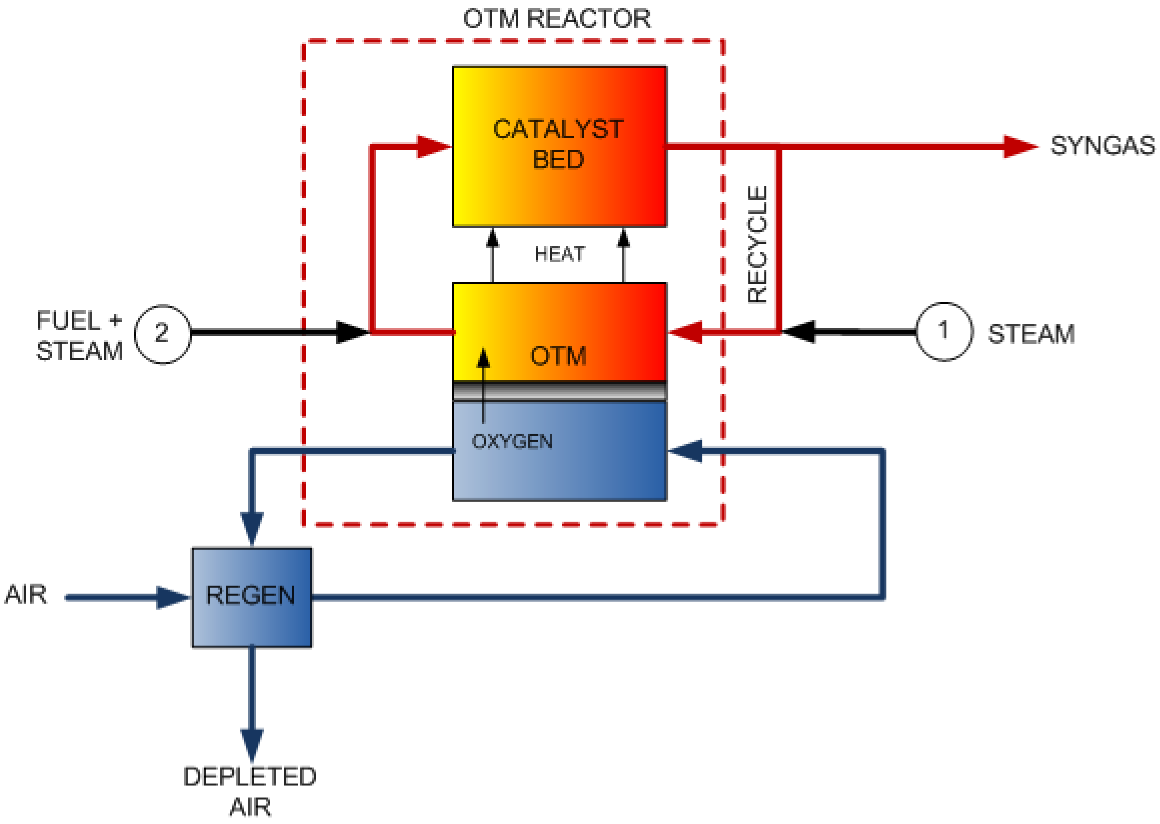




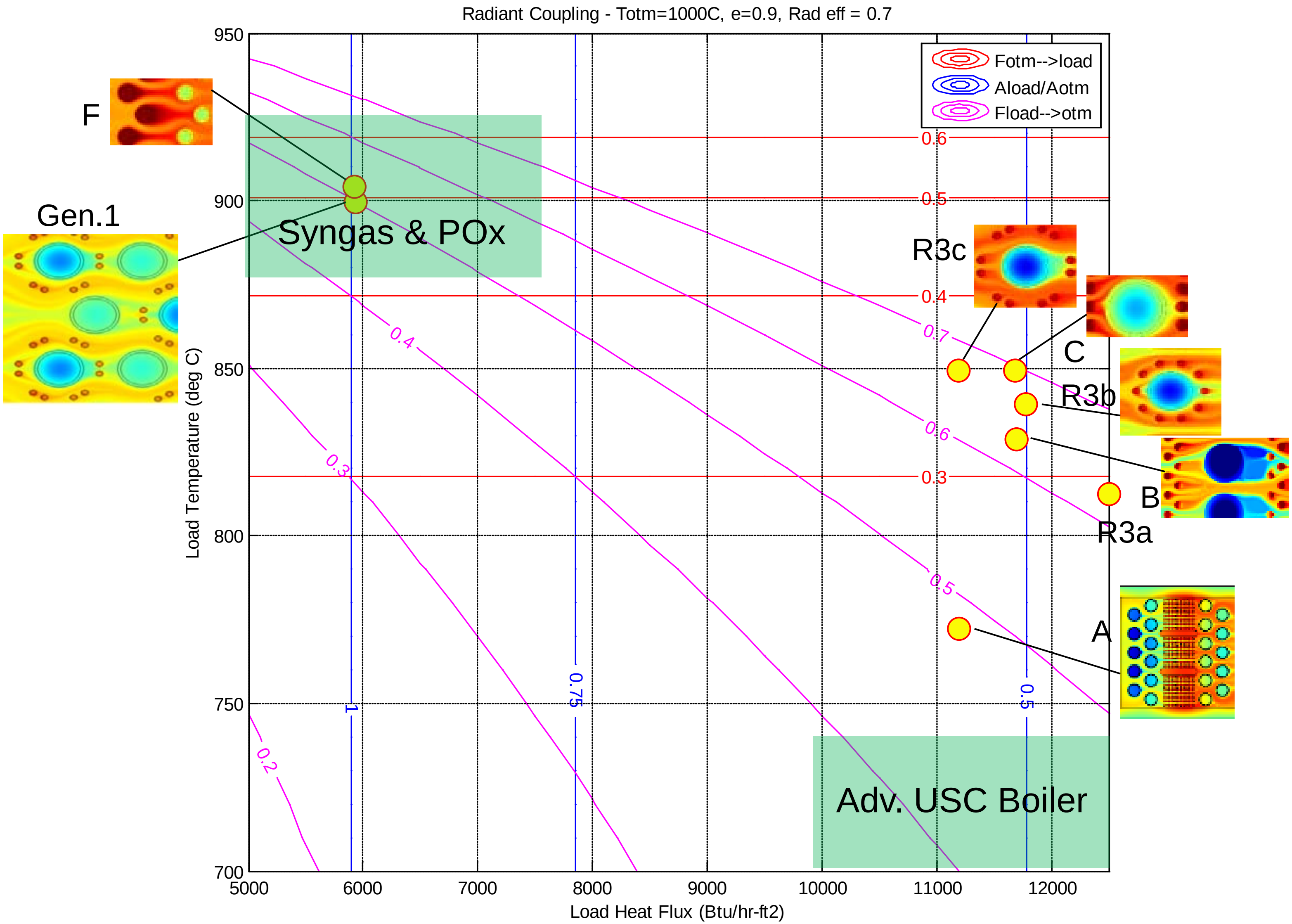
Heat transfer from OTM to process fluid is key to all applications

OTM Autothermal Reformer Process

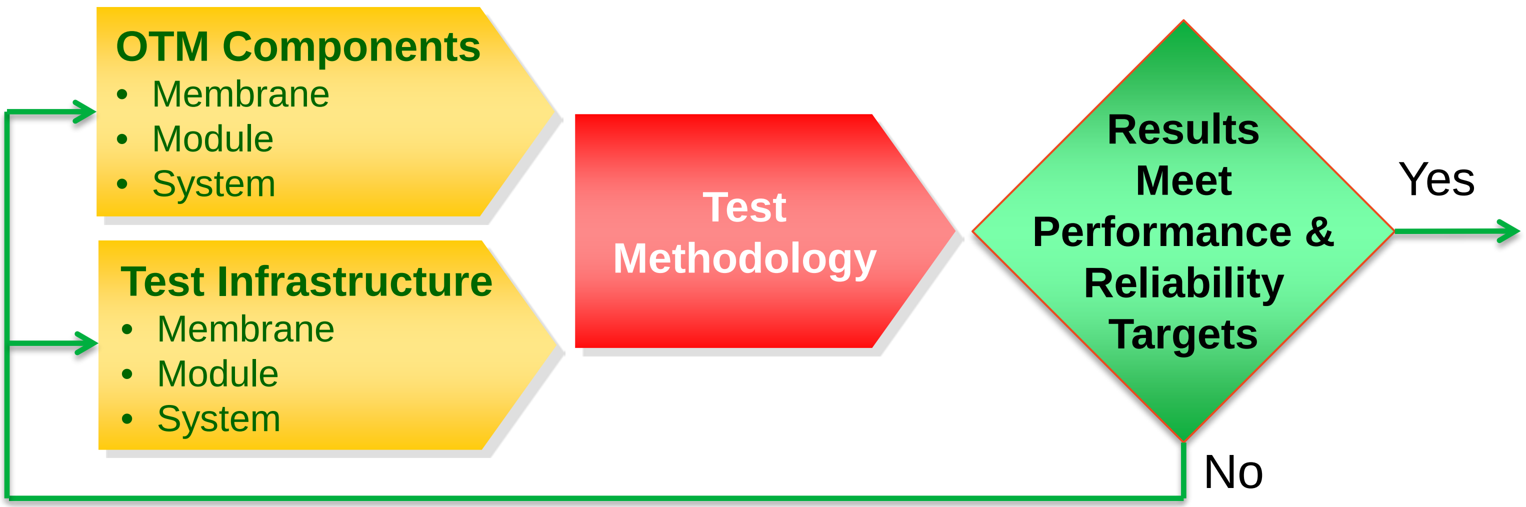
- Oxidize recycled syngas with OTM
- Steam and CO_2 reforming in separate catalyst section
- Improved coking resistance of feed stream
- Reactive fuel drives high oxygen flux without a catalyst
- Requires good thermal integration between catalyst and OTM



OTM Radiant Coupling to Load



Risk Reduction



- Development of robust test methodologies is critical
  - Large sample size and long times for success based testing with confidence
  - Engaged consultant with proprietary techniques
  - Initial focus on membrane, seal and identification of other high risk areas

Test Infrastructure

Preliminary Results from Commercial Scale Cost Study

- Comparison of conventional process to OTM process
  - 5,000 bpd syncrude from natural gas feedstock
- Conventional process technology
  - Syngas island: SMR + H2 membrane
  - FT island: Microchannel FT reactors
- Developed detailed process models to evaluate operating performance
- Working to establish cost targets for critical components based on capital estimates of flow sheets

Parameter	Benefits of OTM Based Process Over Conventional Process
CO2 emissions (lb CO2/bbl product)	70% lower
Gas conversion (scf/bbl)	23% lower

Development Roadmap

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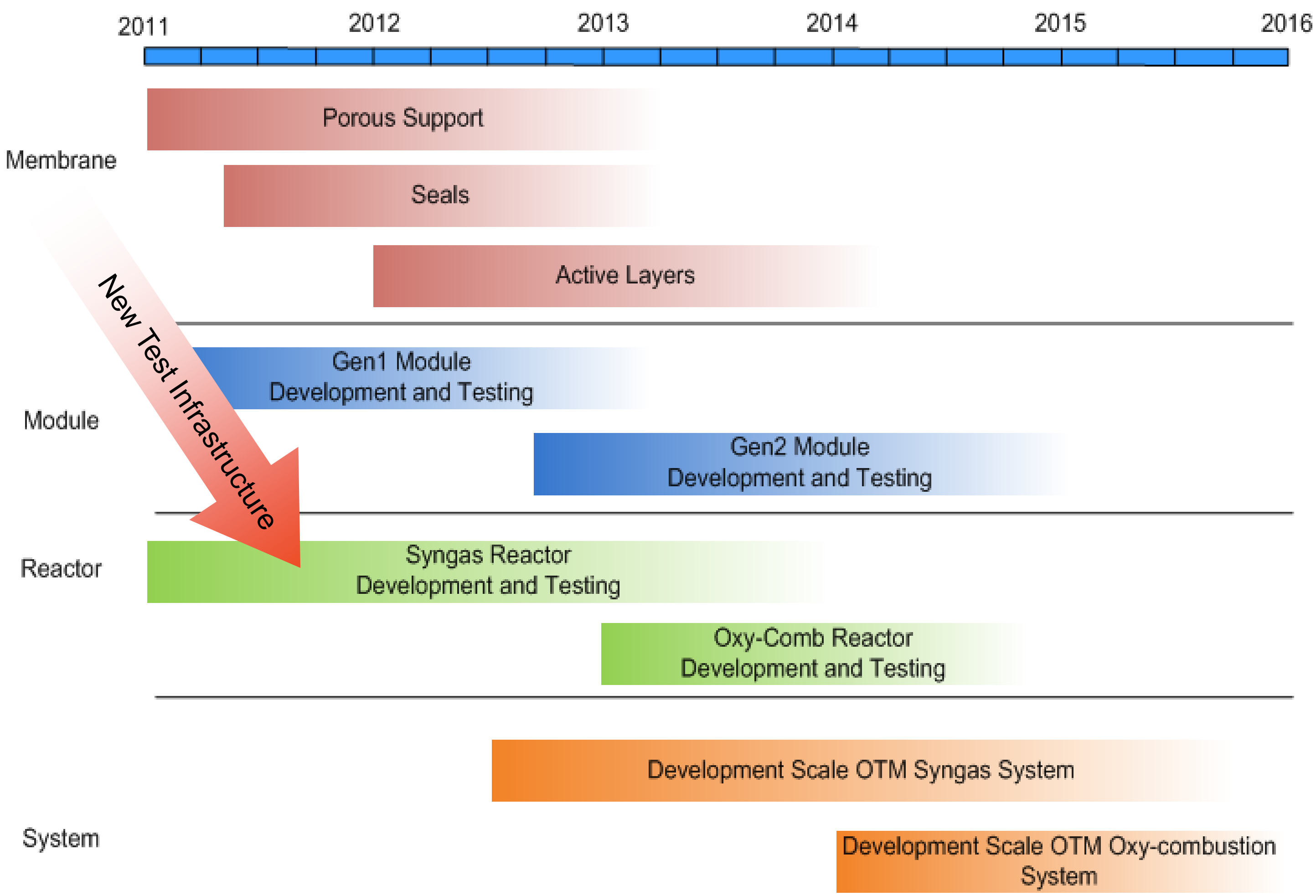

Cost, Performance, Reliability & Life

Acknowledgements

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