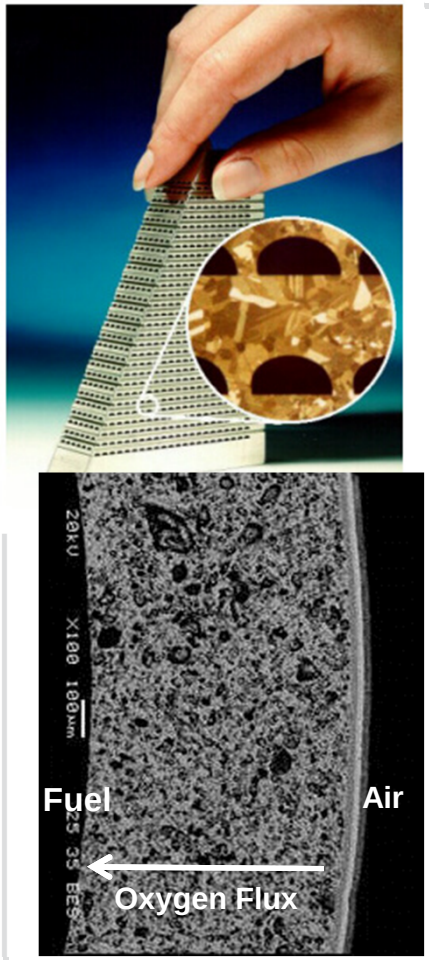
Process Intensification



Monica Zanfir

Praxair, Inc

September, 2014

NSF Process Intensification Workshop

Washington DC

Process Intensification

- Today's drivers:
  - Capital investment reduction
  - Energy use reduction
  - Raw material cost reduction
  - Inventory reduction
  - Increased process flexibility
  - Attention to quality
  - Process safety
  - Sustainable environmental performance

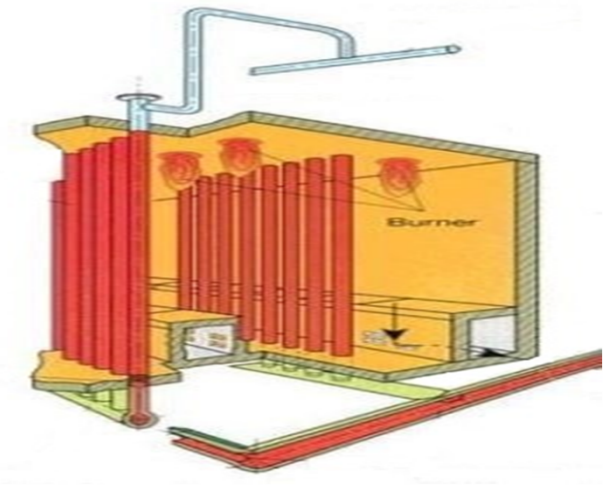
"Do more with less, better and faster !"

Process Intensification – Holistic Approach

- **Process Intensification must be driven by business requirements, although process drivers remain important;**
- **Steps to achieve Process Intensification**
  - Identify business and process drivers
  - Overview the whole process
  - Identify rate-limiting steps
  - Generate design concepts
  - Analyze design alternatives
  - Select equipment
  - Compare PI solutions vs conventional equipment in a holistic manner
  - Make decision on implementation
  - Drive customer adoption

Process Intensification Case Study: Syngas Generation

- **Syngas Generation – an enabler for cheap natural gas monetization towards more valuable products: FT liquids, methanol, hydrogen, chemicals**
- **Conventional technologies**
  - Steam Methane Reforming
  - Autothermal Catalytic Reforming
  - Partial Oxidation



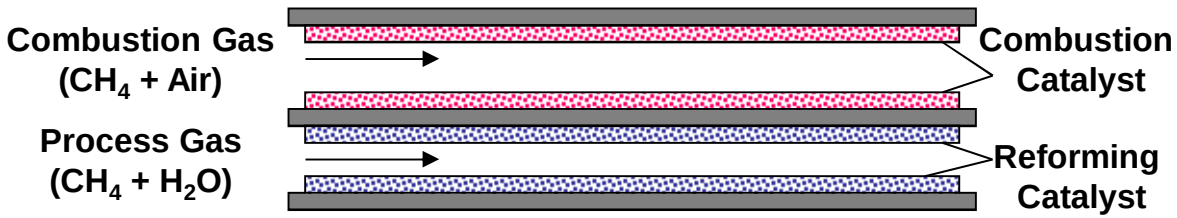
- **Opportunities for intensification:**

  Novel Reactor Design
  - SMR → Catalytic Plate Reactor - microchannel design
  - ATR → Oxygen Transport Membrane Syngas Generator

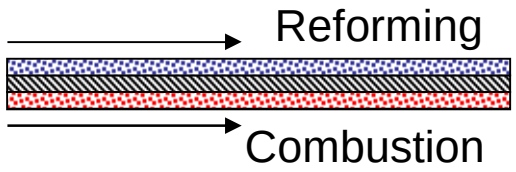
  Operational and Control Strategy
  - Furnace monitoring and balancing

Syngas Generation in Catalytic Plate Reactors

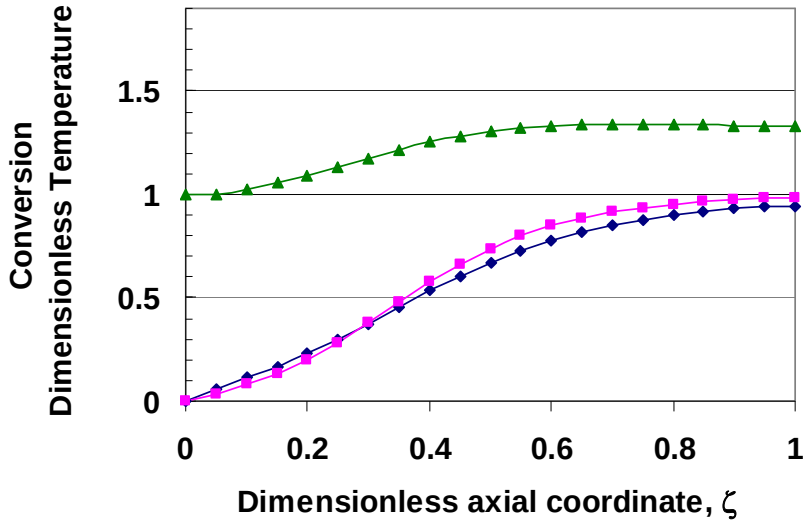
- **Catalytically coated channels 1-2 mm**
- **Exothermic and endothermic reactions take place in alternate channels**
- **Autothermal coupling by means of indirect heat transfer**
- **Reaction system**
  - Endo: Steam methane reforming,
  - Exo: Catalytic Combustion
- **Advantages**
  - Size reduction
  - Intensified heat transfer
  - Lower operating temperature
- **Disadvantages**
  - Unstable thermal behavior
    - **Hot spots – catalyst deterioration**
    - **Cold spots - reactor extinguishes**

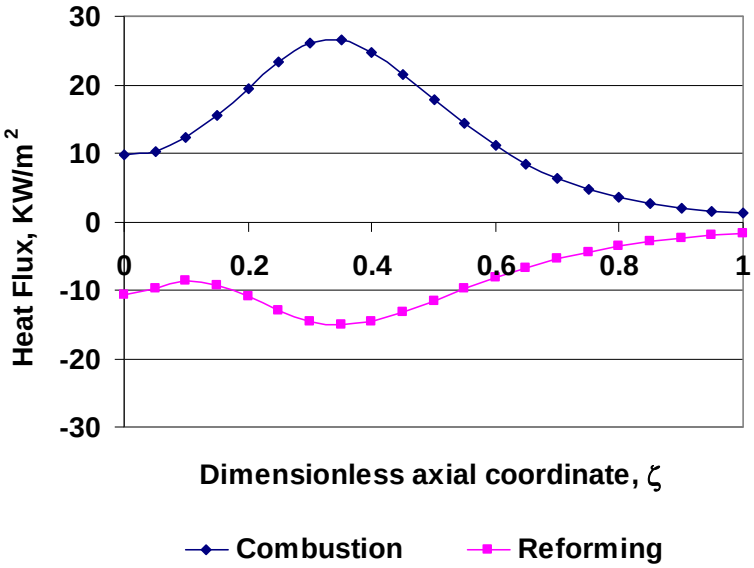


CPR
Catalytic Combustion Assisted Methane Steam Reforming



Gas Phase	Reforming	Combustion
Inlet conditions		
Composition % (vol)	21.28 % CH_4 71.45 % H_2O 1.19 % CO_2 2.60 % H_2 3.48 % N_2	9.1 % CH_4 90.9 % Air
Temperature	793 K	
Pressure	1.1 bar	
Velocity	4 m/s	3.2 m/s
Geometry		
Plate Length	0.3 m	
Channel Half Height	1 mm	
Catalyst Layer		
Thickness	20 μm	
Pore radius	10 nm	
Porosity	0.4	
Tortuosity	4	
Thermal conductivity	0.4 W/mK	
Solid Wall		
Thickness	0.5 mm	
Thermal conductivity	25 W/m K	

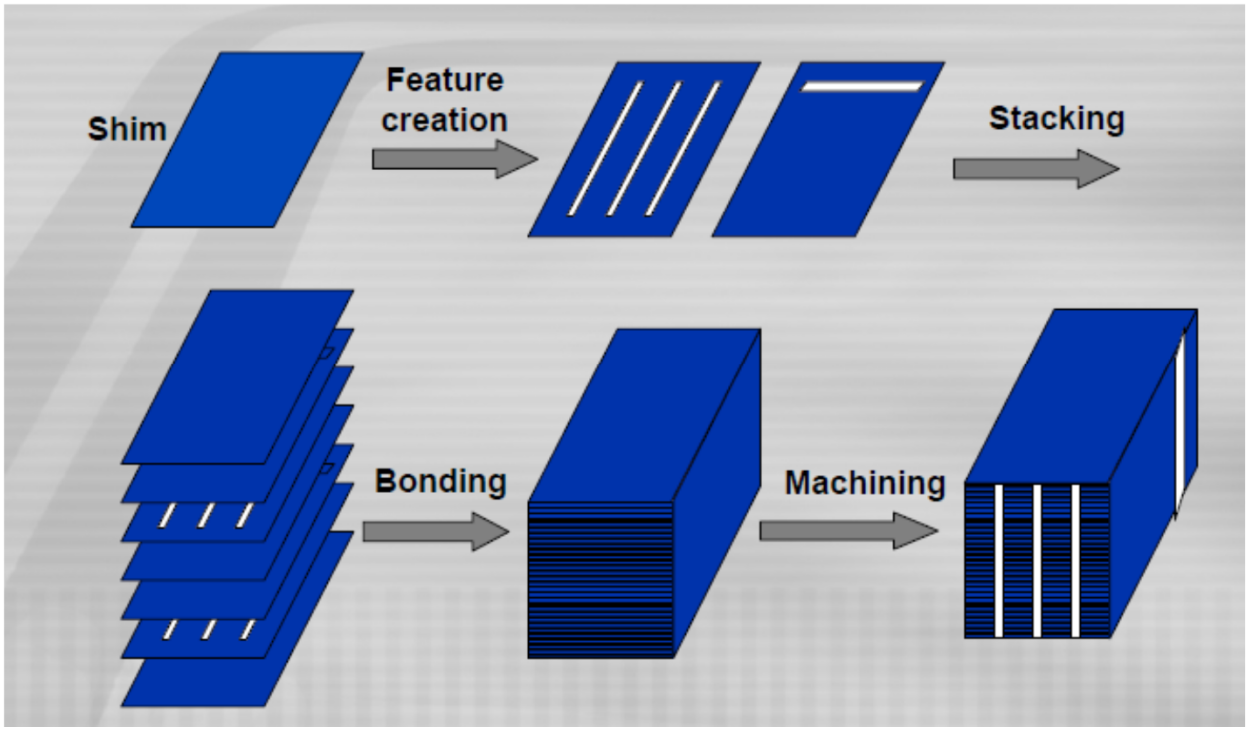


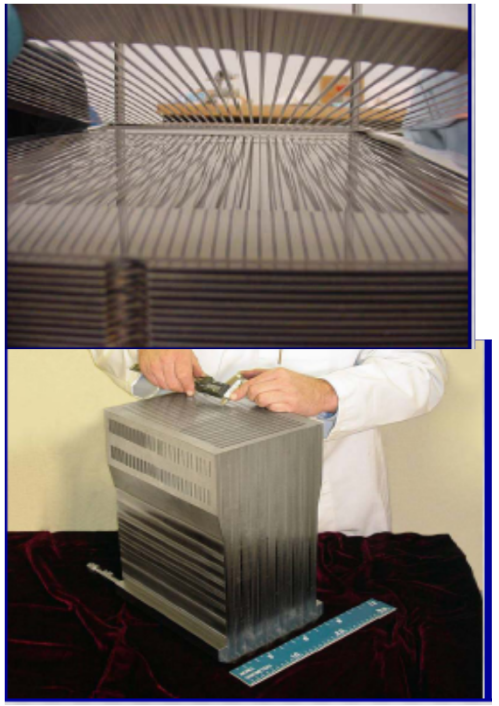


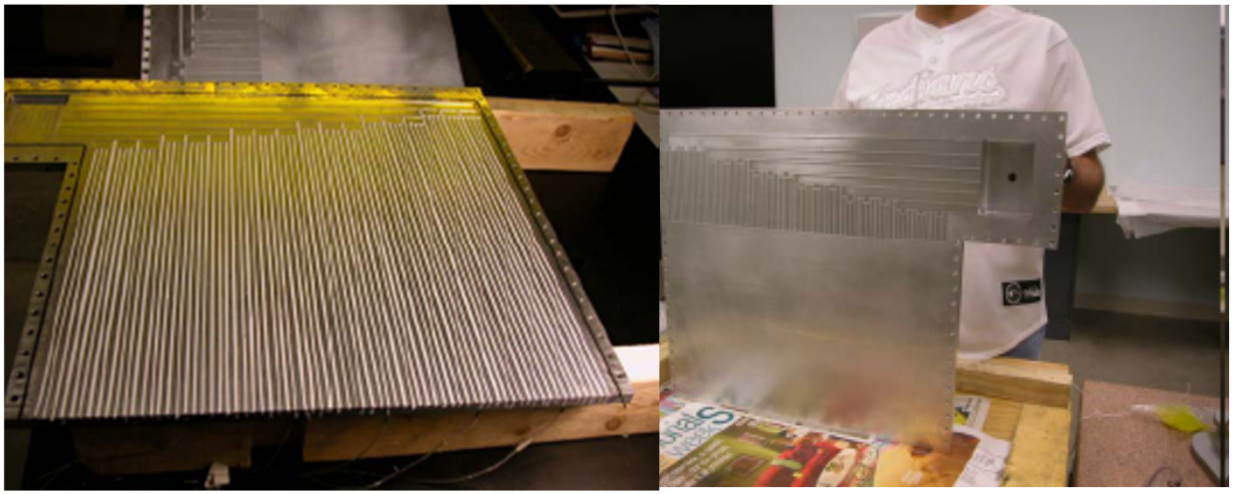
- **Reactor behavior in co-current flow**
  - Balanced heat fluxes
  - Steady temperature increase
  - High conversion in both channels

Zanfir and Gavriilidis, CES 2003

CPR Design and Manufacturing







www.velocys.com

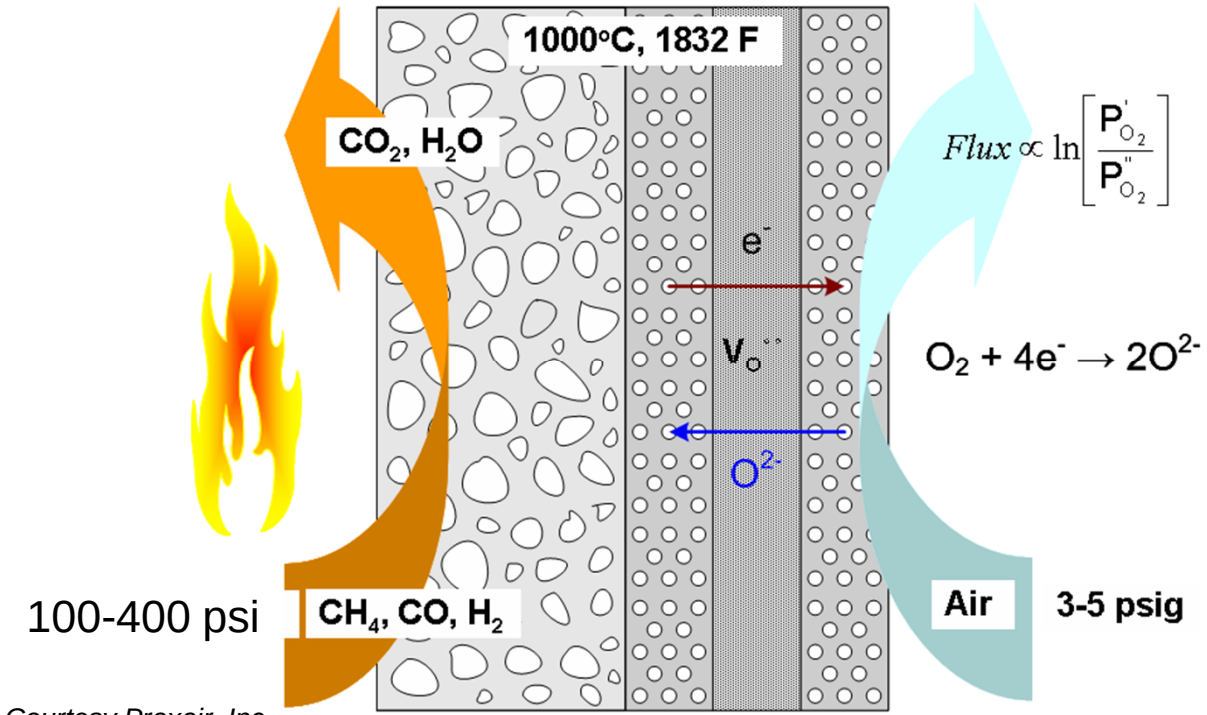
CPR
Catalytic Combustion Assisted Methane Steam Reforming

- **Claimed benefits**
  - Significant cost reduction
  - Lower operating temperatures

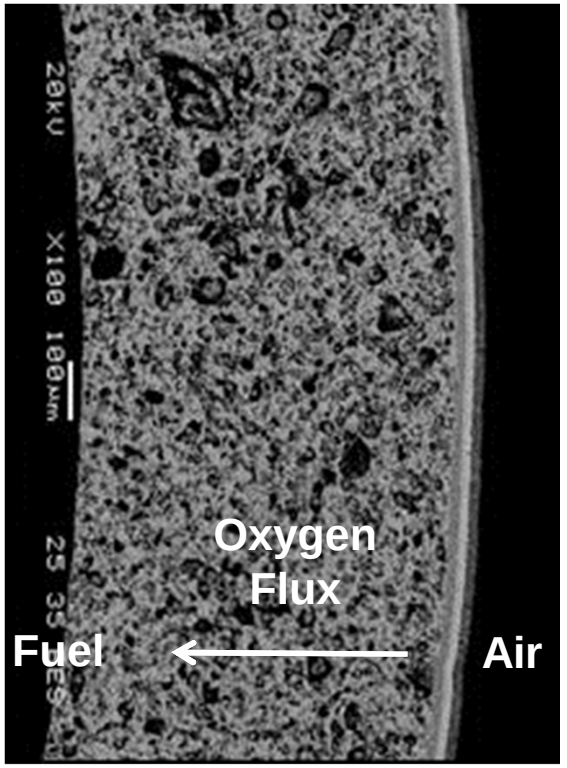
www.velocys.com

Oxygen Transport Membrane

- OTM enables oxygen production without air compression
- Potential for 75 % reduction in energy to produce oxygen
- Reduced Indirect CO2 emissions

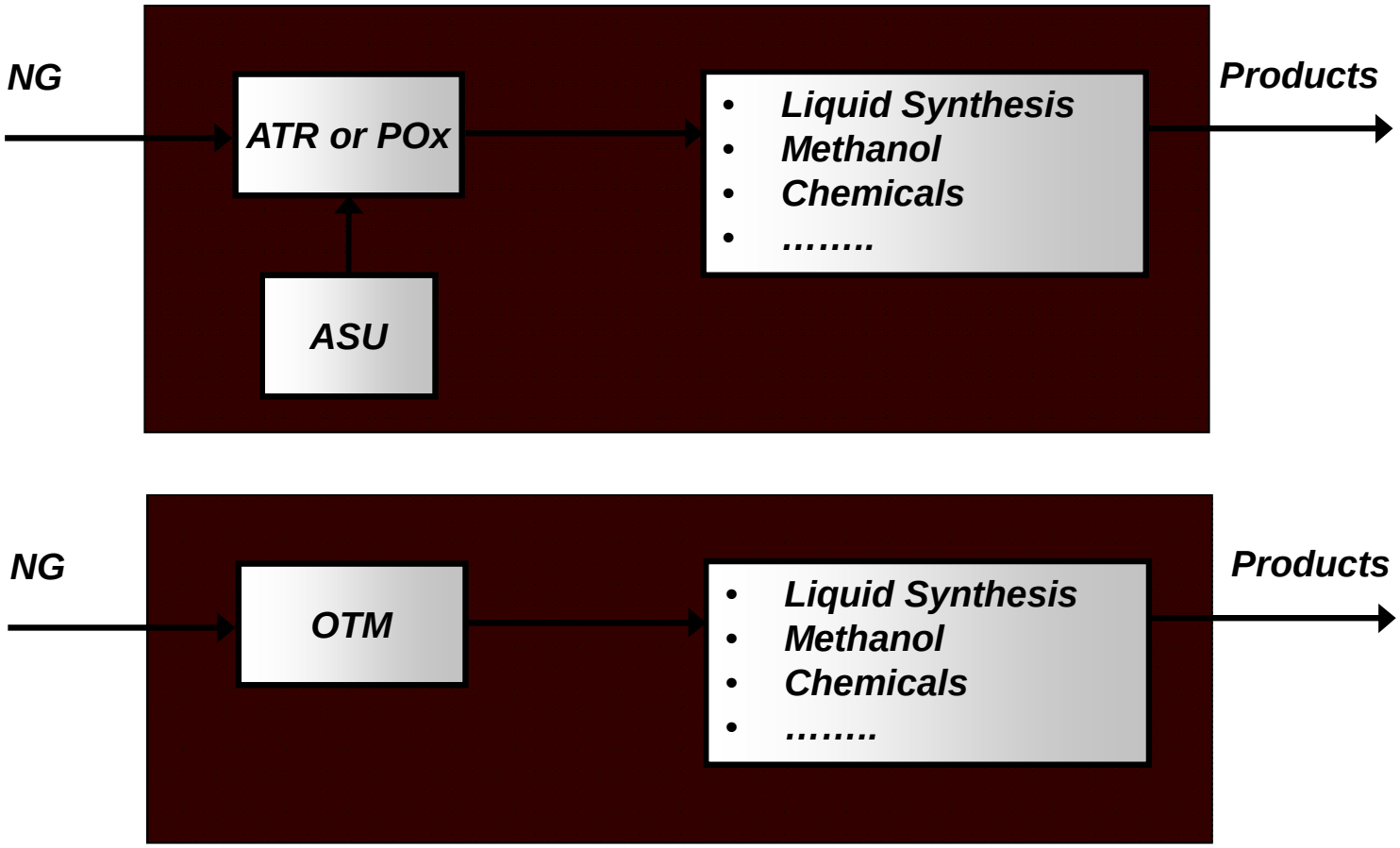


Courtesy Praxair, Inc.
www.praxair.com



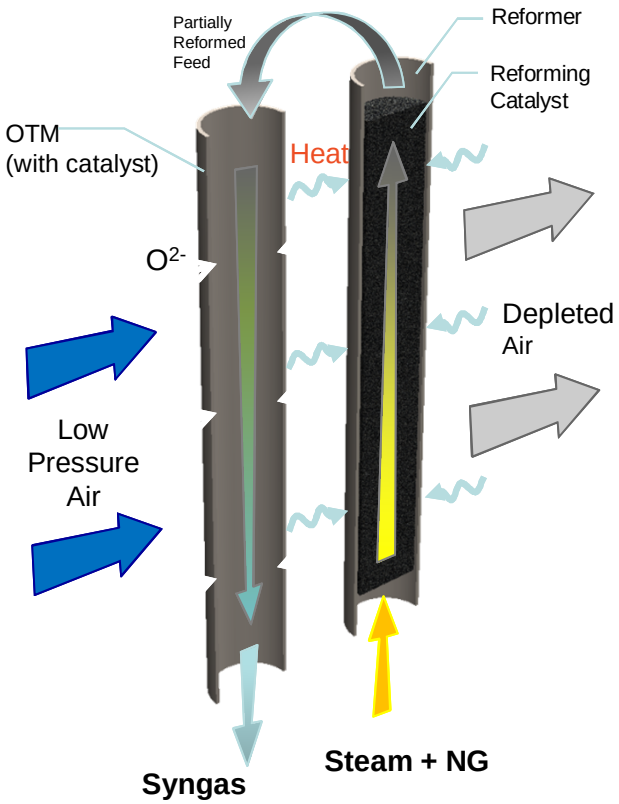
Oxygen Transport Membrane Reactors

- **OTM Reactors for Syngas Generation combines natural gas reforming and oxygen production form air in the same piece of equipment**



OTM Syngas Generator Design

OTM Autothermal Reformer



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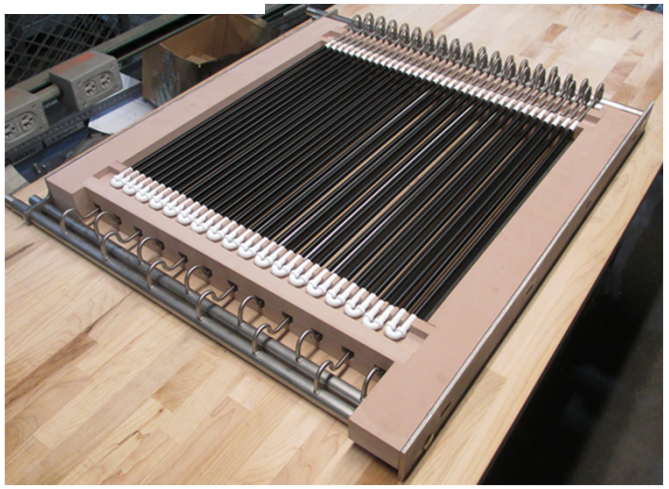
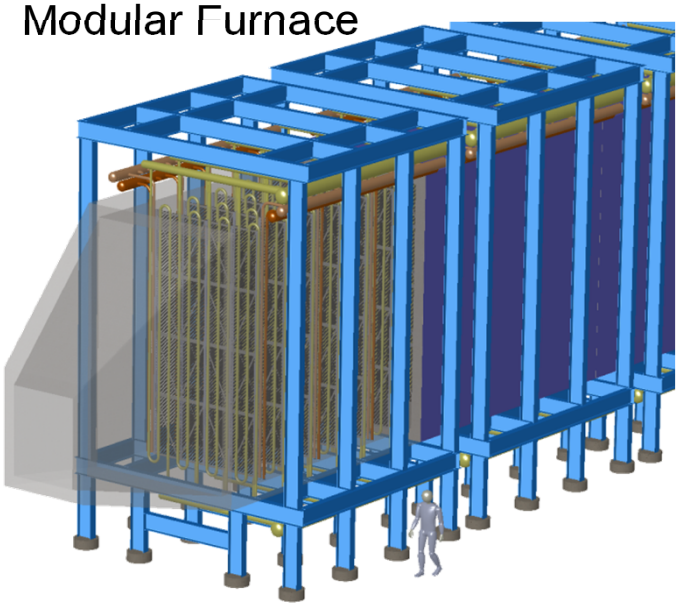
Panel Array

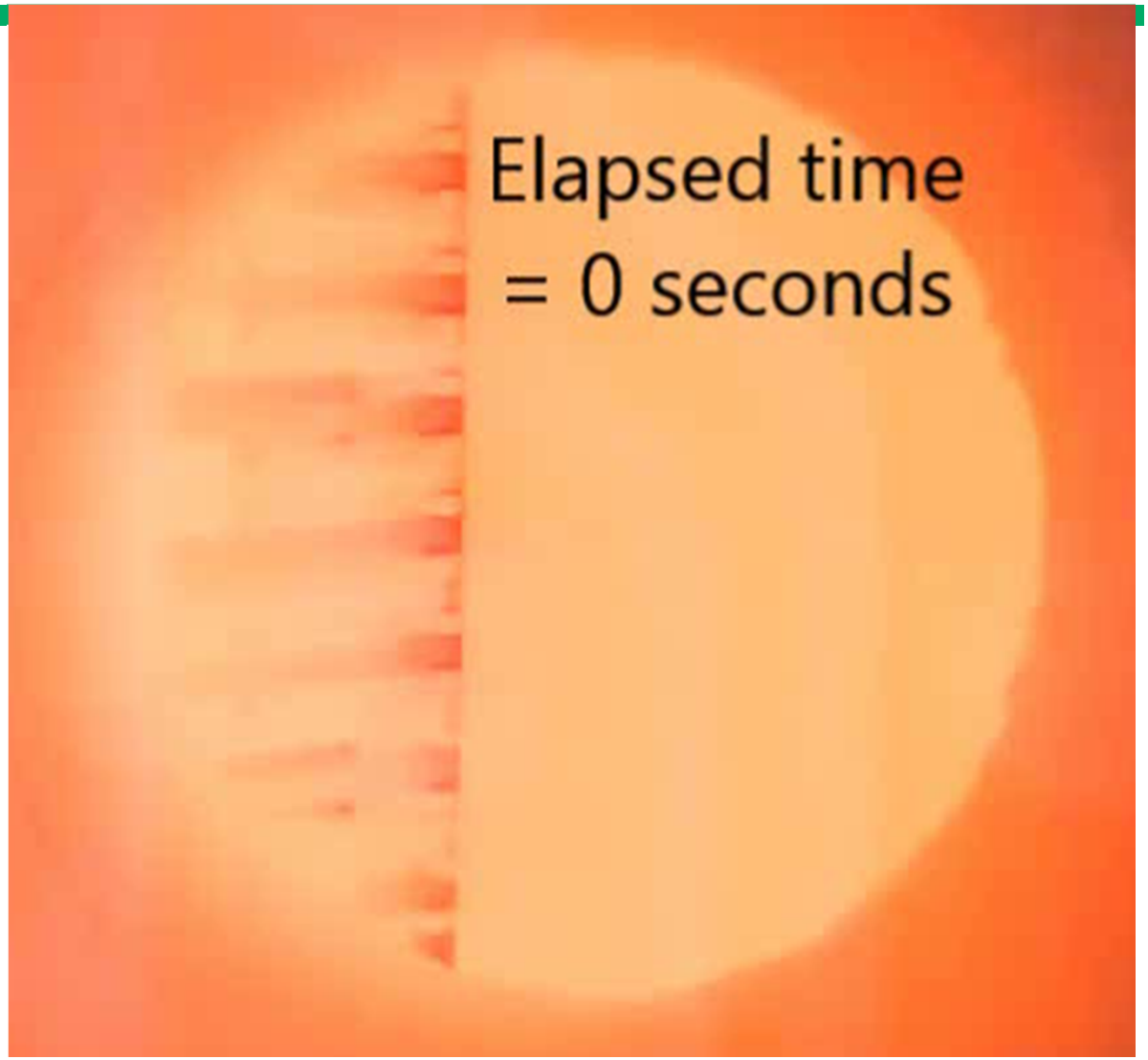


Modular Furnace



>20% reduction in capex versus ATR + ASU

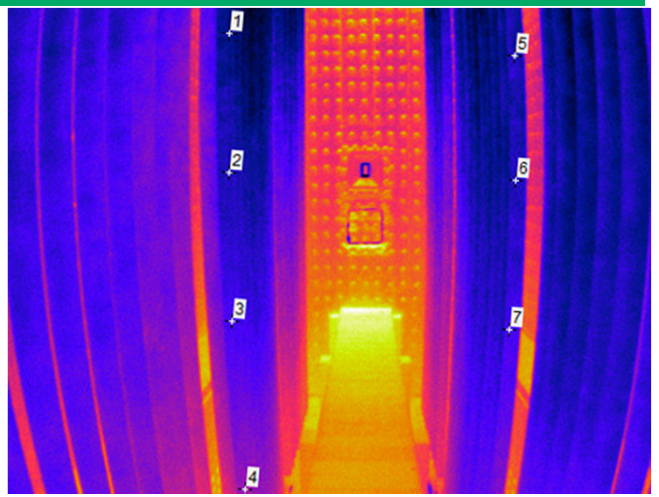
Panel Array Operation



Syngas module robust to thermal cycles, trips, and transients

SMR Furnace Balancing

- Reformer Tube Operating Temperature – trade off: tube life vs energy efficiency
- Better temperature monitoring
  - tube temperature spread reduction
  - higher reformer outlet temperature
  - higher conversion & thermal efficiency
  - avoids hot spots
  - better assets utilization
- Advanced instrumentation and online monitoring allows operating at higher temperatures leading to increase throughput and safe and reliable operation



http://www.landinst.com

www.GBHENTERPRISES.com

Concluding Remarks

- Process Intensification is thinking progressively about processes and viewing them integrally through the tasks they need to fulfil and the results they have to deliver
- Process Intensification apply to “new” as well as “old” equipment, technologies, and processes
- An important aspect of Process Intensification implementation relates to simplifying manufacturing, assembly and installation of new equipment and technologies