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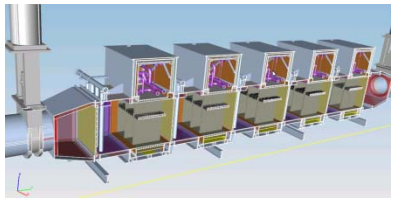

OTM Technology: Process Intensification and Modularization

Sean M. Kelly

Praxair

Modular Gasification-Based Energy Systems Workshop

Pittsburgh, PA

March 21st,2017

Modular might be a solution if…

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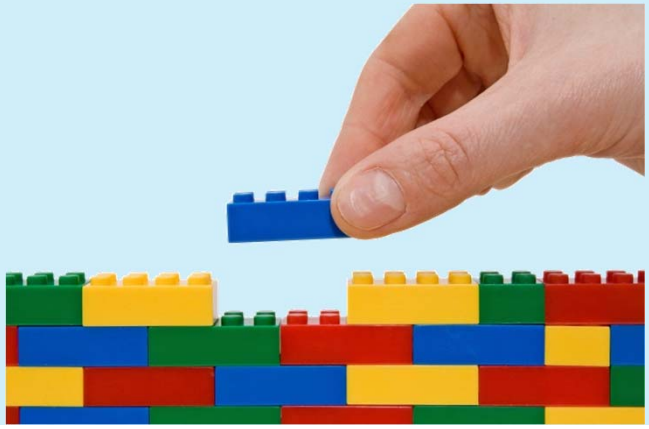
The technology is inherently small,
but it needs to scale larger.

and/or

The process is large,
but it practically needs to be smaller.



A strategy of integration and disintegration

What is Modularization?

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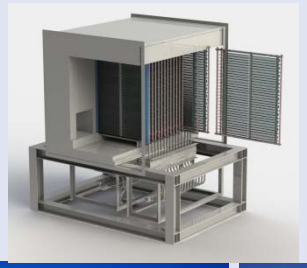
Modular Construction

- Well-known, available option
- Drastic reduction in field costs
- Scale is logistically limited
- Traditional process scaling rules apply
- <u>Large system → small modules</u>

ZETON

Modular Process

- Replicate over and over
- Massive parallel processing
- Linear process scale-up
- High volume manufacturing scaling rules apply
- <u>Small modules→ large system</u>



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Why modular? Reduced cost and increased flexibility

What is a “Module”?

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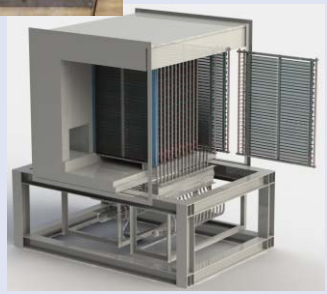
Integrated Process Units

- The “new” technology
- Smallest unit of process
- Numbered-up to achieve scale with lower risk
- Packaged into modules
- Maximize productivity and manufacturing efficiency

Modules

- Packaged process units
- Parallel operating unit in process
- Numbered-up to achieve scale with lower risk
- Minimize number for economy



Modular systems are comprised of process units in modules

The economies of scale…..

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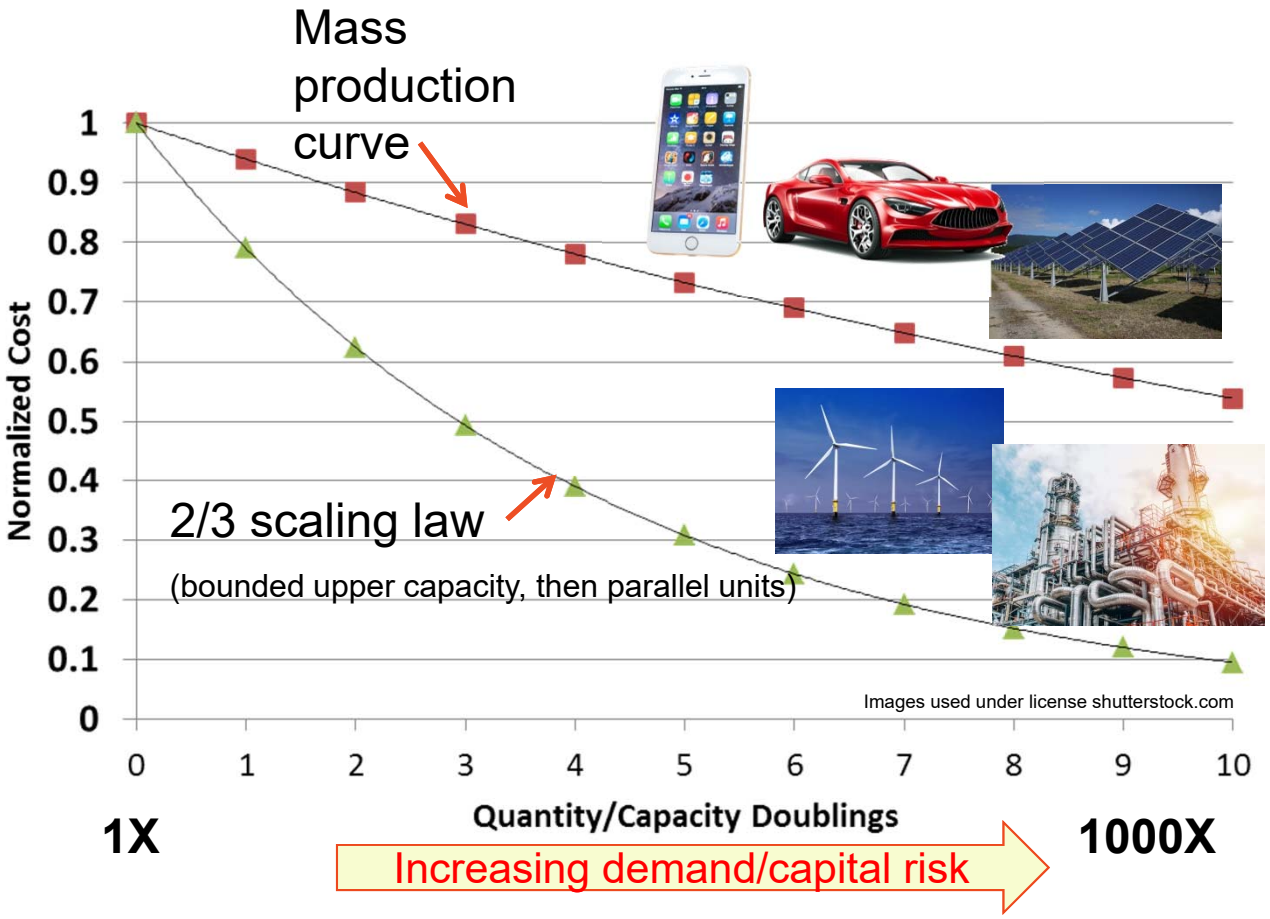

This curve always wins in consumer goods **"The right product at the right price"**

This curve always wins in the process industry **"The most for the money, period."**

What value for mass production in the process industry?

The economies of scale…..

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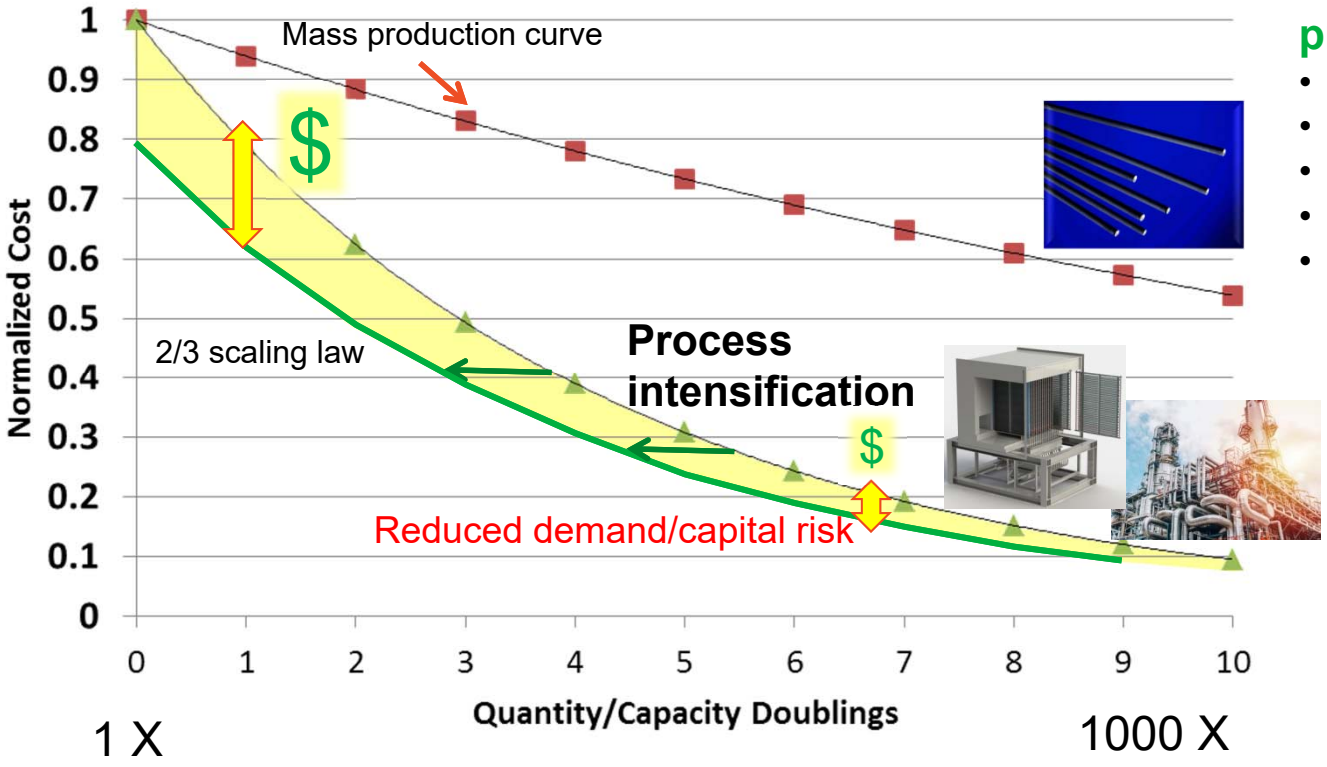

"New technology" must enable
process intensification

- **Combine processes**
- **Eliminate processes**
- **Smaller boxes**
- **More productive boxes**
- **Smarter, less labor input**

Integration of process intensified units shifts this curve to the left
Enables economics at smaller scale

Process intensification and mass produce to enable improved economics

OTM – A "New" Technology:

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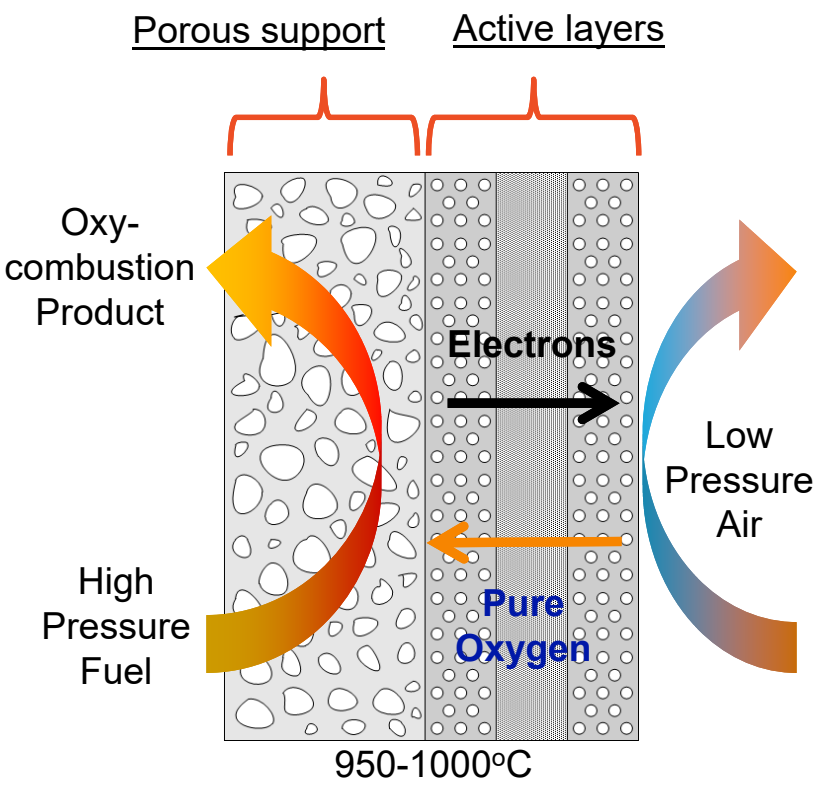
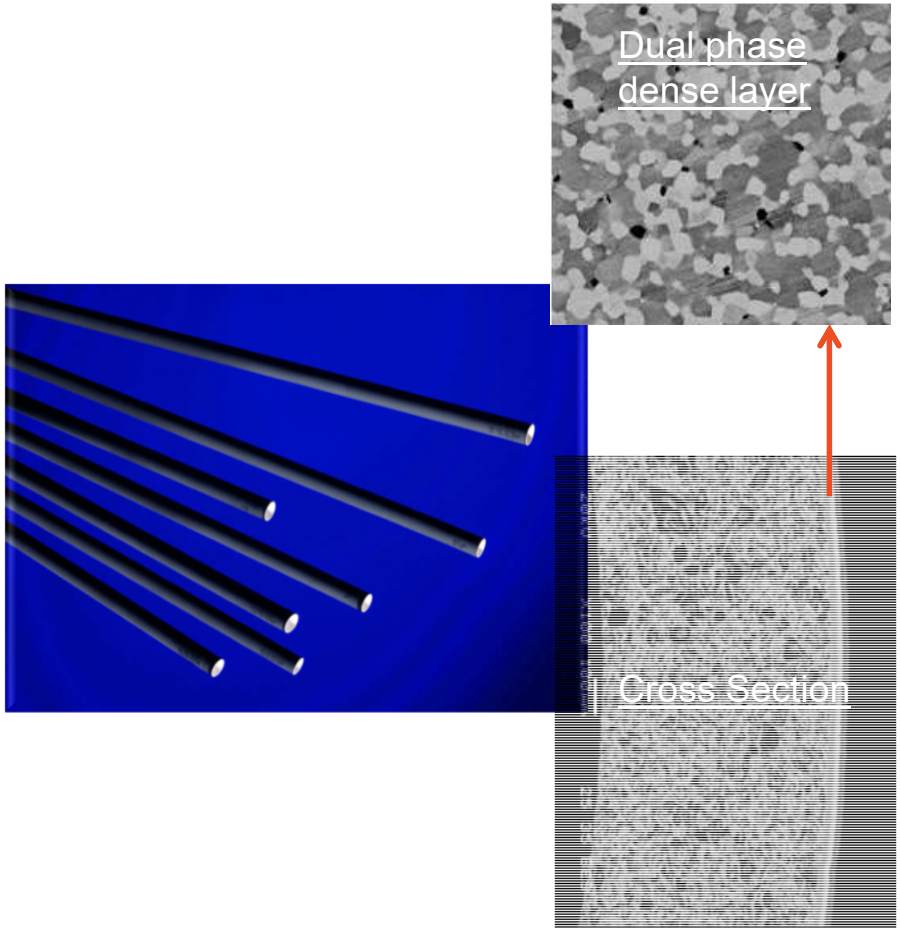
Oxygen Transport Membrane (OTM)





Process Intensification: Solid-state, pure air separation

Ceramic Membrane– Mass Produce 1,000's for a System

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Substrate extrusion

Coating

High temperature firing

Finished Multi-tube Assemblies

Seal assembly

Putting it all together…

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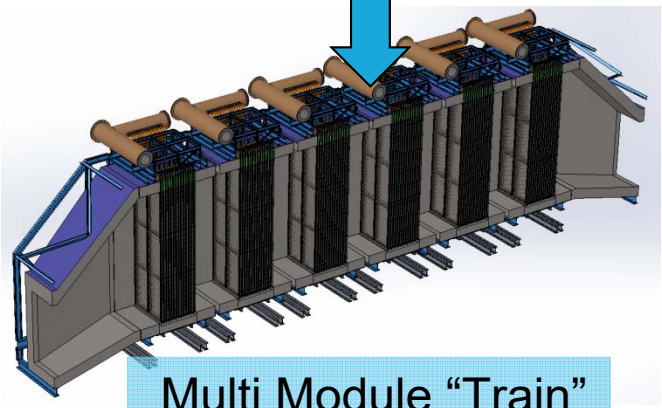
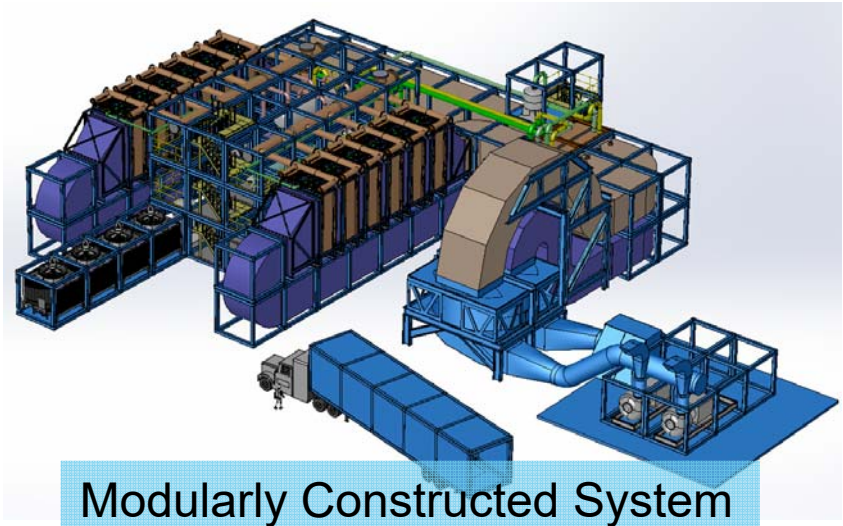
Ceramic Membranes

Panel Array

Furnace Module "Pack"



Multi Module "Train"



Modularly Constructed System

A process intensified, modular process utilizing modular construction

Lessons Learned

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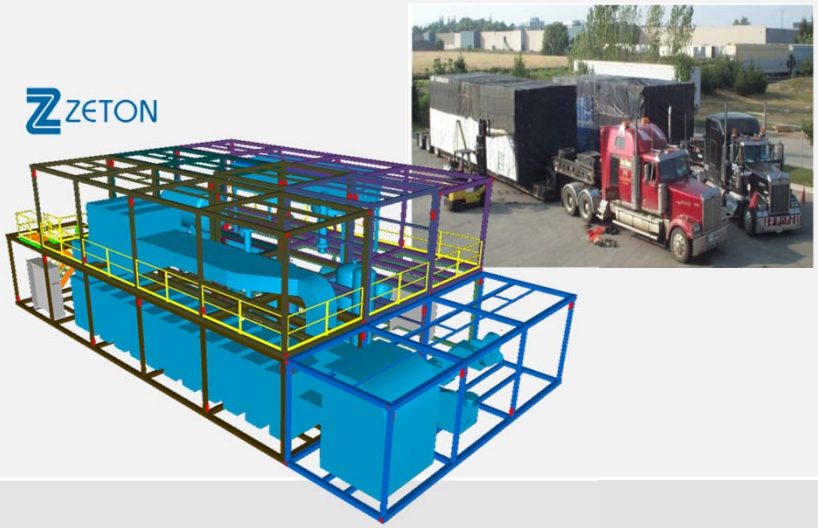
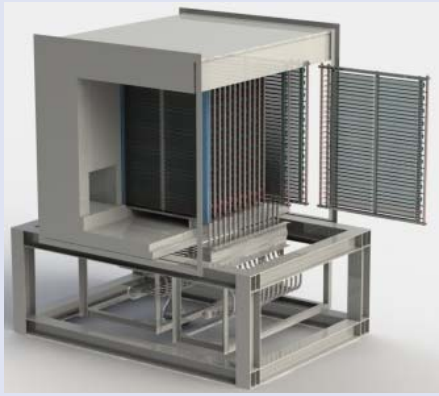
Modular Construction

- Size module for low total freight costs
- Maximize fab shop scope, build & check out
- Don't forget about serviceability / maintenance access



Modular Process

- Drive manufacturing efficiency/volume
- Fault-tolerant parallel units
- Largest module size→ reduce parallel trains
- Small plants low risk but always capital cost challenged



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Thank you!