Materials for Energy Efficiency / Energy Efficient Materials

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Agenda

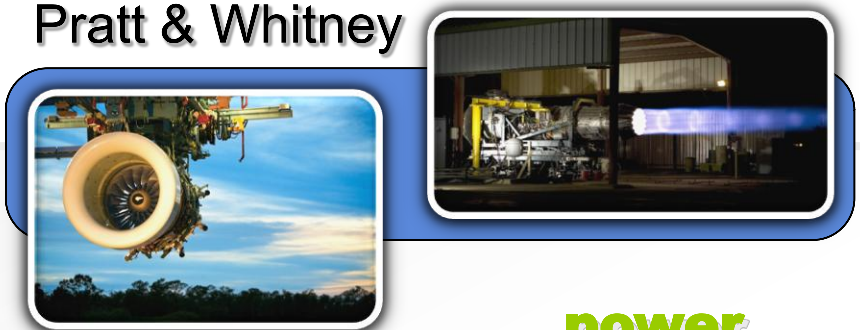
- UTC Overview
- UTC Examples of the Impact of Materials Science
  - Elevators
  - Membranes
  - Catalysts
- Materials Processing and Energy
  - Additive Manufacturing
  - Machine Modeling
  - Materials Design/Manufacturing

United Technologies

Business units

aerospace systems

Pratt & Whitney



Sikorsky

Hamilton Sundstrand

power solutions

UTC Power

Carrier

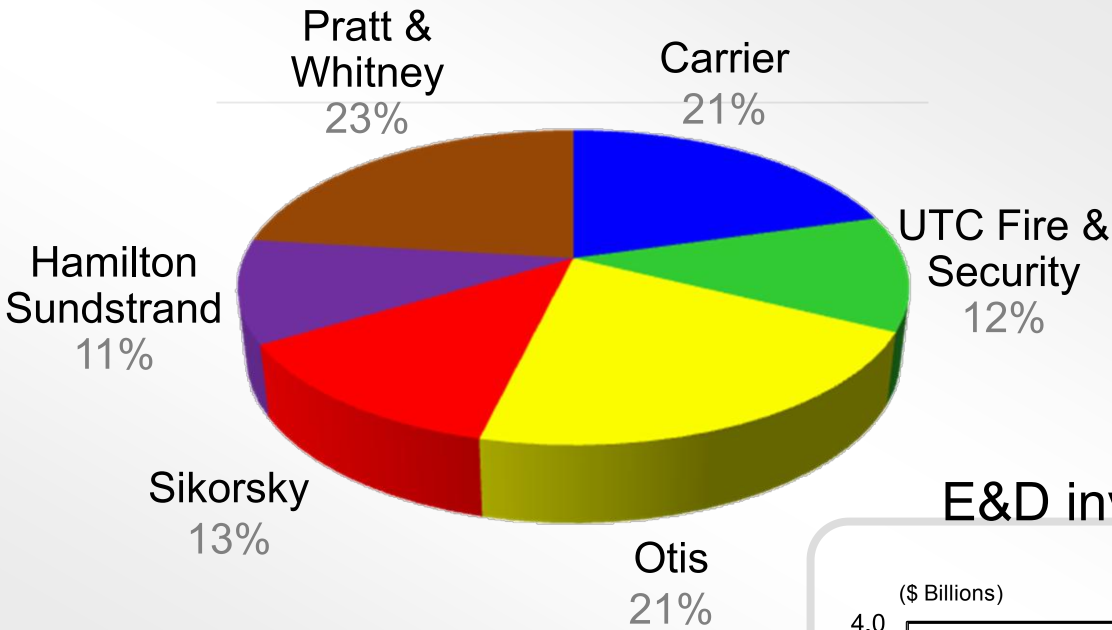
building systems

UTC Fire & Security

Otis

United Technologies - 2011 Revenues: $58.2 billion

Business unit revenues

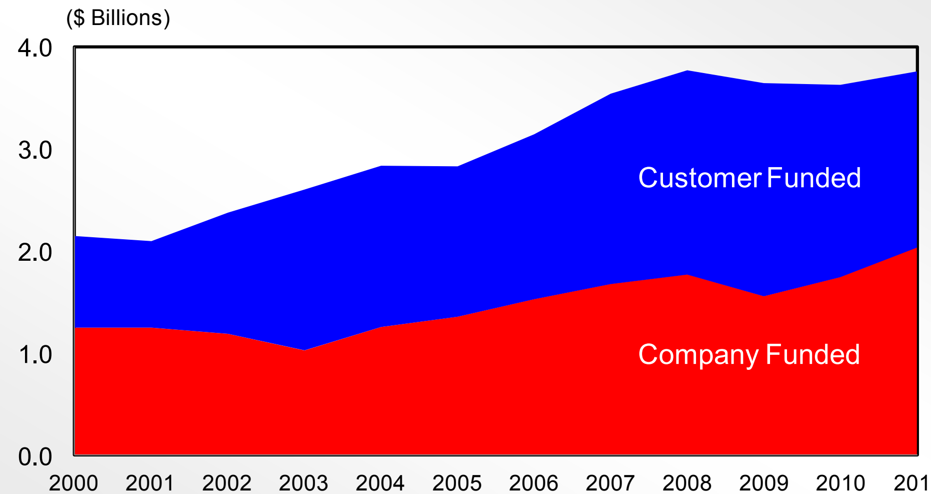


Segment…

54% Commercial & Industrial

46% Aerospace

E&D investment…$3.8B in 2011



UTC Sustainability Roadmap

Operations

UTC launches the **2015 Sustainability Goals** and establishes a LEED requirement for new construction

Products

UTC energy efficient products

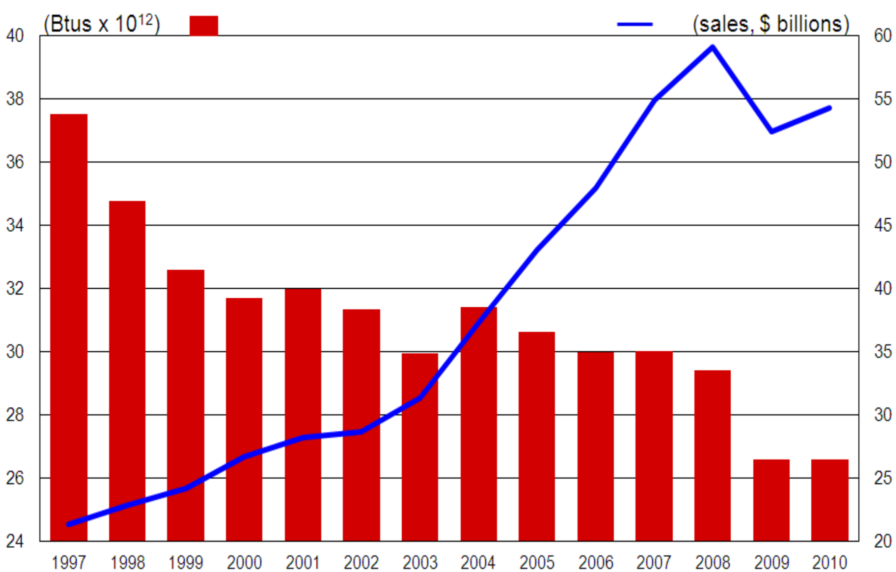
- Otis launches the Gen2® elevator system
- UTC Power introduces 400 kW PureCell® system
- Pratt & Whitney flight tests PurePower™ PW1000G engine with Geared Turbofan technology

Advocacy

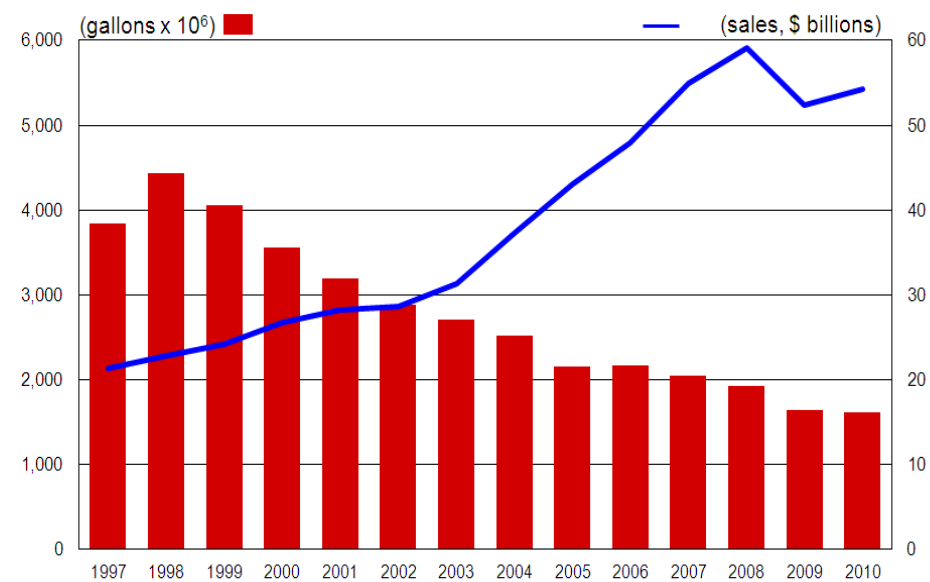
UTC is leading voice in advocacy programs

- U.S. Green Building Council (1993)
- World Business Council for Sustainable Development's Energy Efficiency in Buildings project (2006-2009)

Energy Use 1997-2010



Water Use 1997-2010



Materials Science – Enabling Technology

“The hallmark of progress in every age has been the way ‘materials engineers’ worked to improve the usefulness of materials”

- Iron and bronze
- Aluminum and stainless steel
- Plastics and synthetic fibers
- Nanostructured materials

“Materials have enabled advancements in railroads, automobiles, aircraft, telecommunications, defense, and medicine, even if materials did not, by themselves, set the pace of innovation”

Of interest: “The Advanced Materials Revolution”,
Sanford L. Moskovitz, Wiley, 2009

UTC's Basis of Competition is Technology

"Everyday, UTC engineers and scientists around the world work to overcome two basic forces of nature – gravity and weather"

former CEO George David, 2006

"UTC competes on the basis of its technology. Our operating system matters, our customer interactions matter, but in the end people buy products, services and solutions from us because they run faster, operate hotter, weigh less, make less noise, last longer, and use less energy."

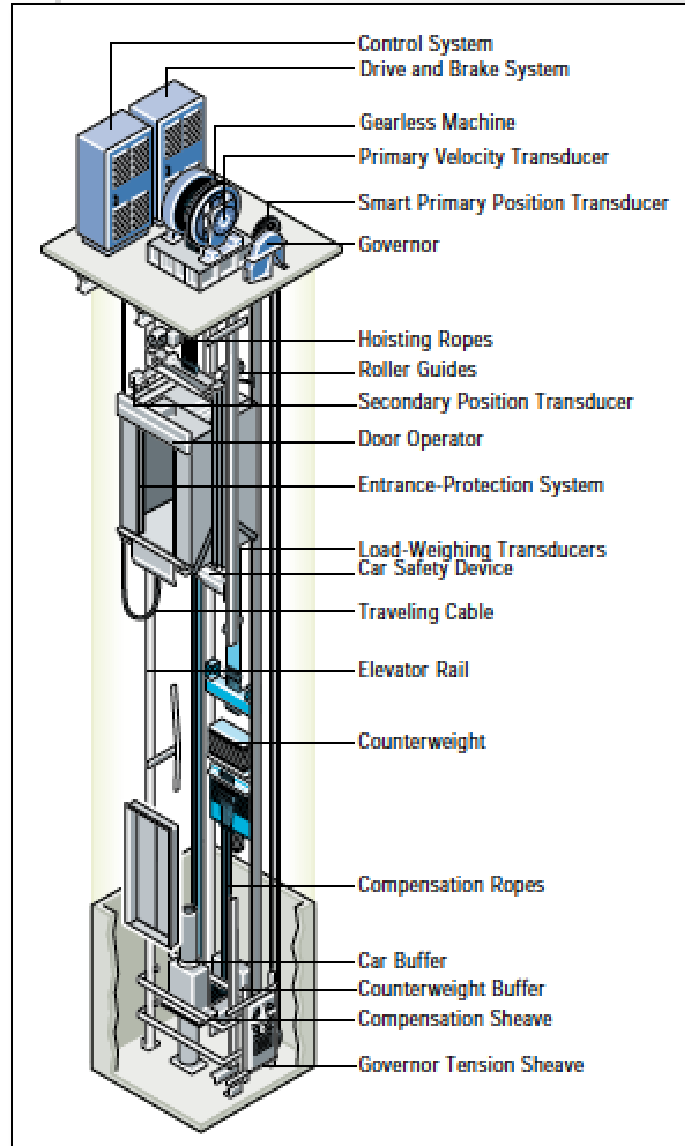
Fundamental drivers for materials technology insertion at UTC

Durability	Weight
Cost	Temperature
Embodied energy	Operating energy
Enhanced features	

SOME EXAMPLES

Elevators

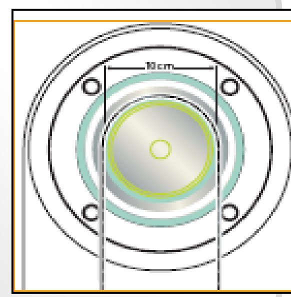
- Cost reduction
- Weight reduction
- Material systems for brakes and safeties
- Electrical efficiency
- Super hi-rise lifting systems



Elevator Systems Enabled By Materials Technology

Conventional rope systems require

- Large machine size due to rope torque
- Rope diameter drives turning radius drives sheave diameter
- Lubricant systems



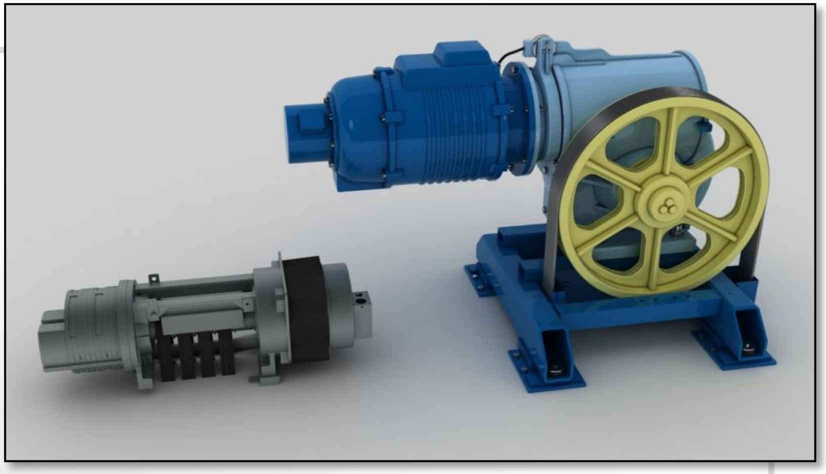
Otis Gen2® Elevator System

- Flat polyurethane-coated steel belts
- 3 mm x 30 mm belt
- Eliminates lubricants

Elevator Systems Enabled By Materials Technology

Gen2® Elevator System

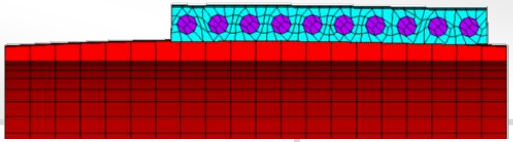
- Up to 70% reduced machine volume
  - Reduced torque from smaller radius sheave (480 mm to 100 mm)
  - 12mm dia rope vs. 1.6 mm dia. cord in flat belt
  - Improved packaging; machine roomless



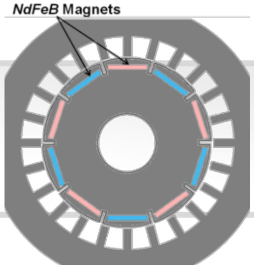
- 75% machine weight reduction
- Power consumption reduced by 50%

Gen2 ® Elevator Material Challenges

Material interactions in CSB cords



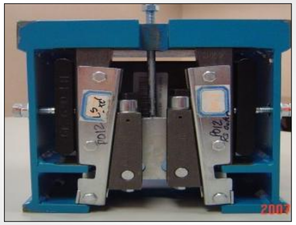
Advanced magnetics for motor drives



Materials for power electronics

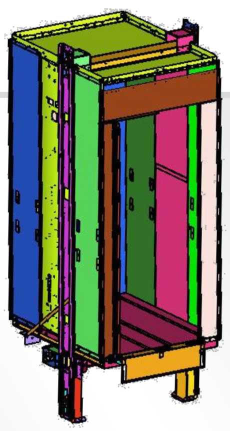
Gen2® regenerating drive system achieves 75% improved energy efficiency

Rail interactions and lifting

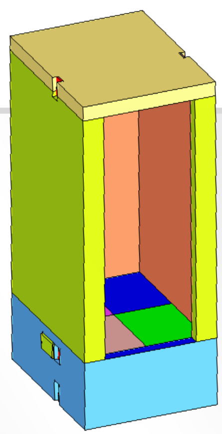


Elevator Topology Optimization

- Material saving
- Reduced distinct parts
- Reduced operations



Baseline product



Design space and load/BCs (10 load cases)

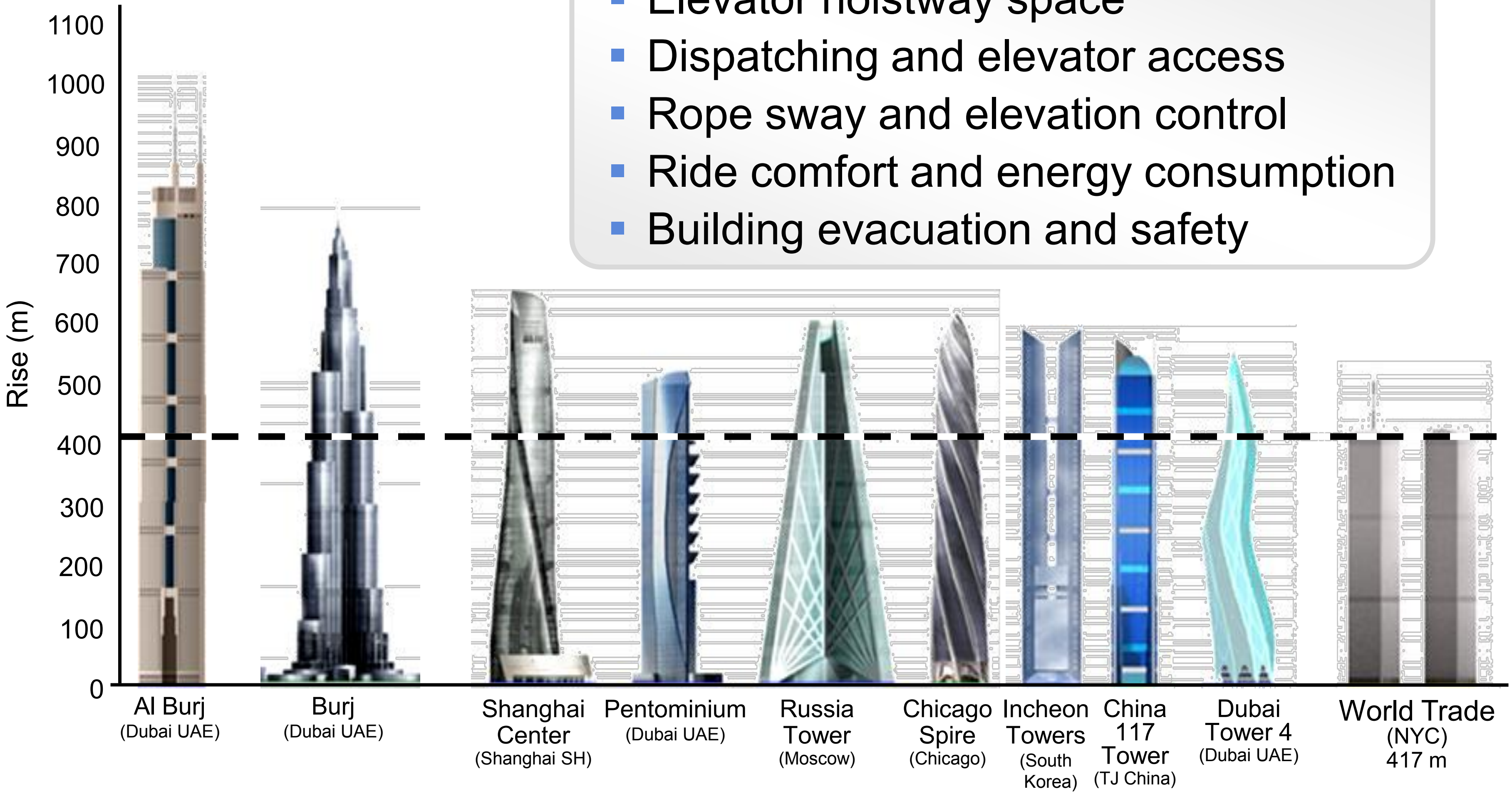
Optimal topology (stress, deflection and frequency constraints)

Engineering interpretation CAD drawing

Otis…Ultra High Rise Buildings

Technology challenges…

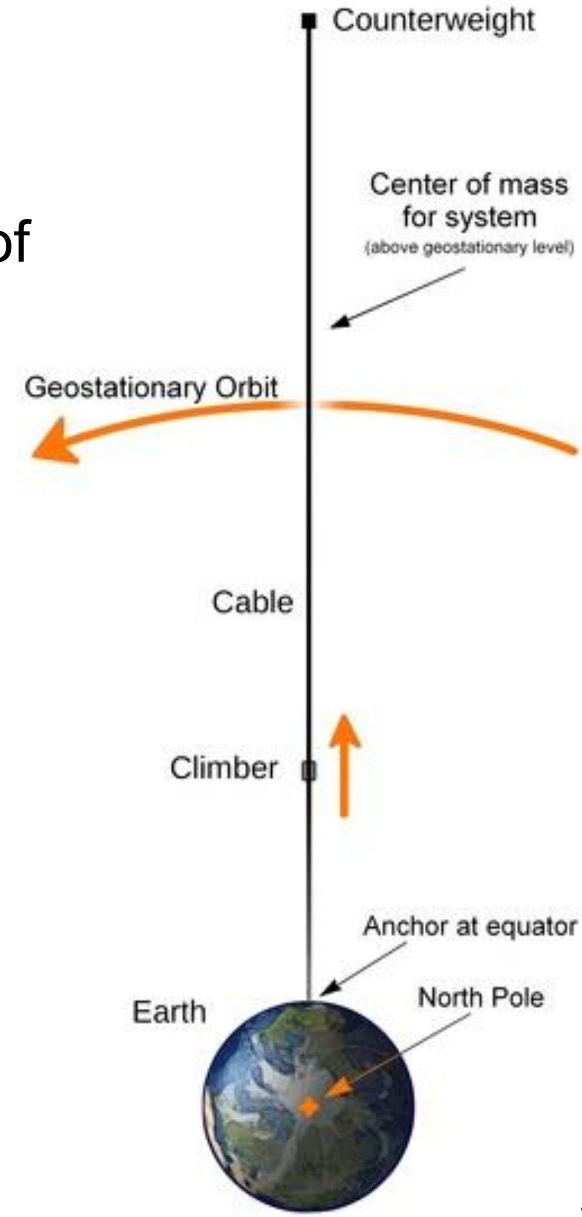
- Elevator hoistway space
- Dispatching and elevator access
- Rope sway and elevation control
- Ride comfort and energy consumption
- Building evacuation and safety



Emerging ultra high rise buildings have needs beyond the capabilities of many of the components we produce today.

Where Does It End - The Space Elevator

- A cable anchored to the Earth's equator, reaching into space. (Tsiolkovsky, 1895)
- A counterweight at the end keeps the center of mass above the level of geostationary orbit.
- Inertia ensures cable remains stretched
- Above the geostationary level, climbers have upward centrifugal force.
- The cable must be made of a material with a large tensile strength/density ratio > 100,000 kN/(kg/m).
- Optimize EM energy harvesting versus statics / potential differences.



Membranes and Catalysts

World Market (MM $US)

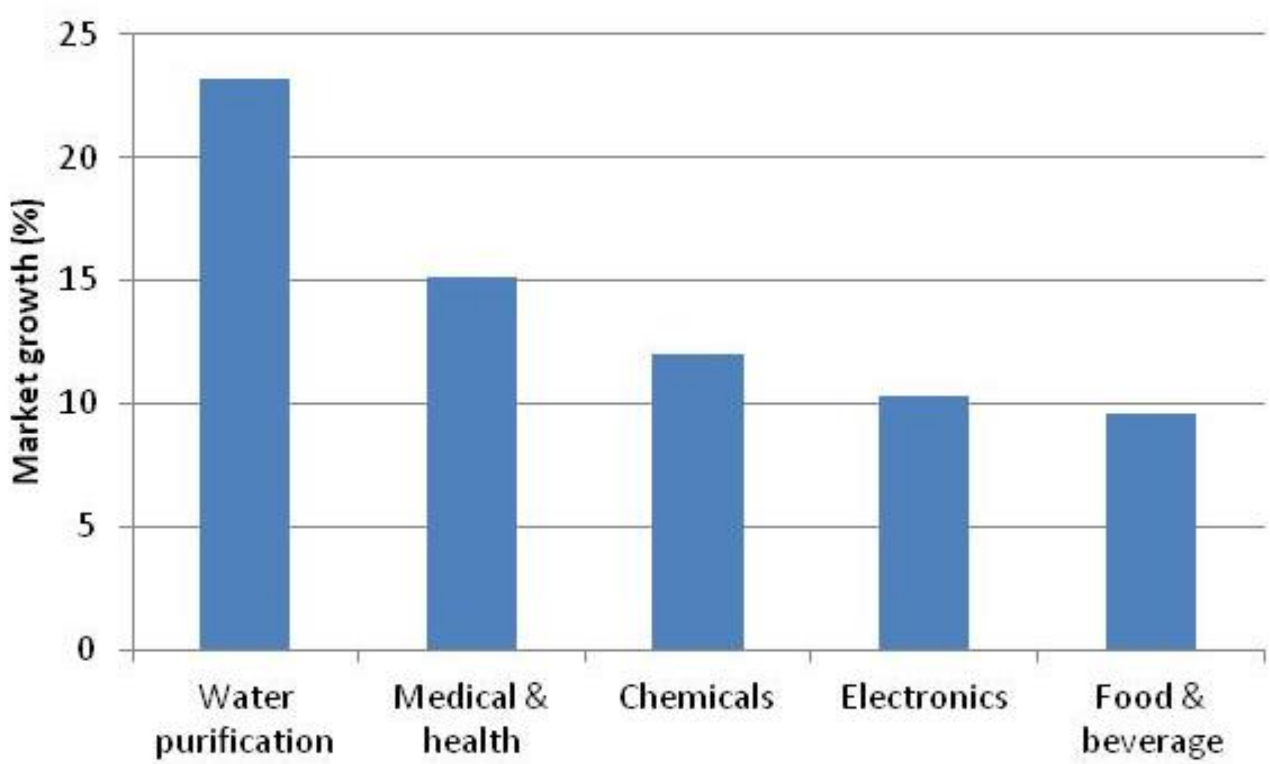
Process	2002	2004	2006	2008
RO / NF	1716	1934	2222	2571
Ultrafiltration	1441	1653	1927	2265
Microfiltration	2091	2449	2928	3517
Liquid Separations	1786	2138	2605	3200
Gas Separations	453	547	679	846
Total	**7487**	**8721**	**10361**	**12399**

Source: Profile of the International Membrane Industry, Elsevier Ltd.,3rd Ed.

Global membrane separation technologies market to reach US $16 Billion by 2017 (Global Industry Analysts, Inc.)

Membranes Market Overview

Market growth between 2003 - 2008



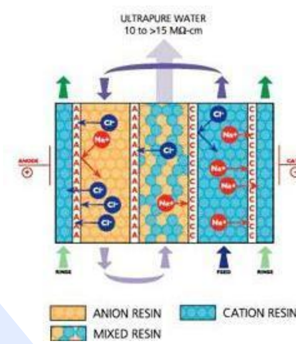
Key drivers are energy efficiency and environmental footprint

Source: Profile of the International Membrane Industry, Elsevier Ltd.,3rd Ed.

Membrane Technology Development

Materials

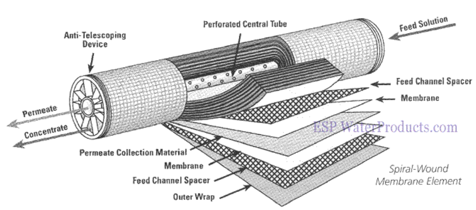
Polymers
Ceramics
Metals

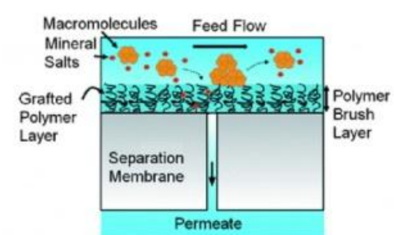


Flat sheets
Pleated papers
Tubular/hollow fiber

Pressure-driven
Concentration-driven
Electrical potential

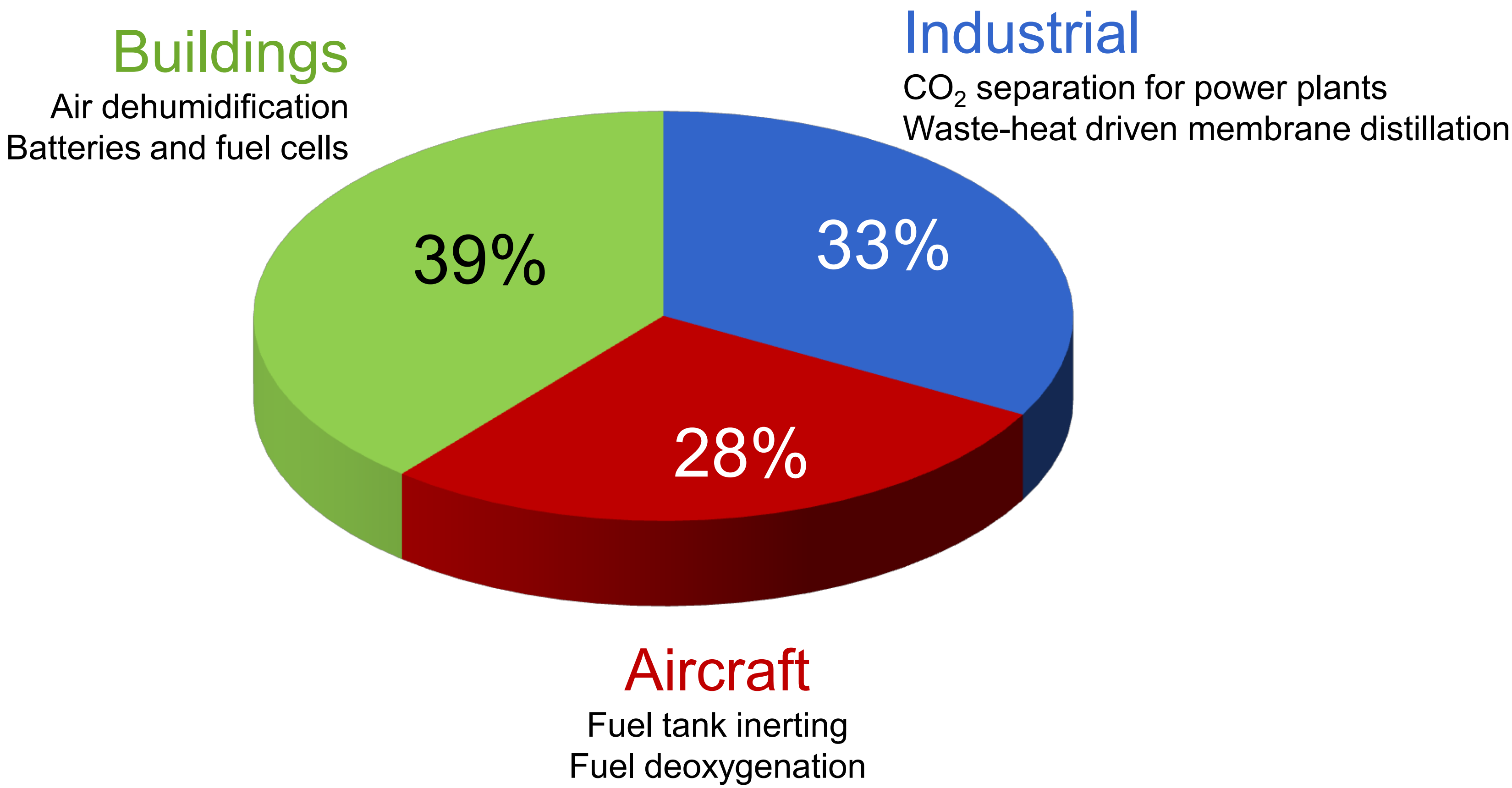
Structure





Process

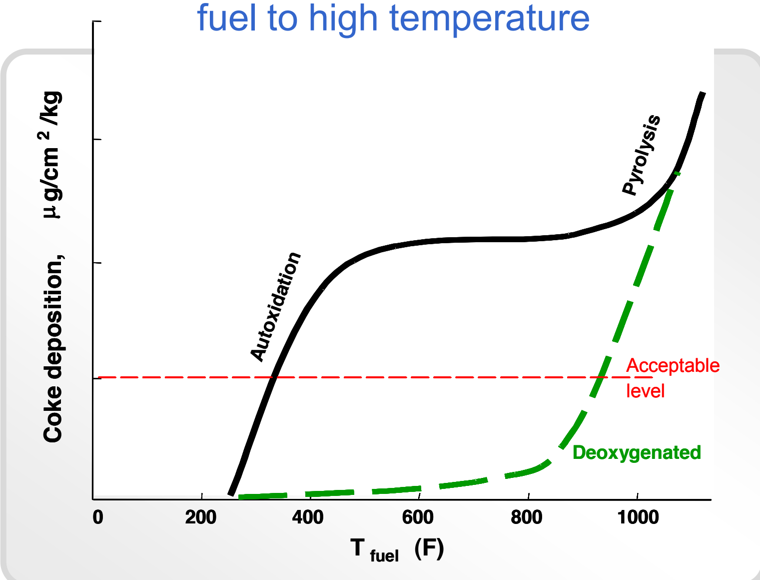
Membrane and Catalyst Applications at UTC



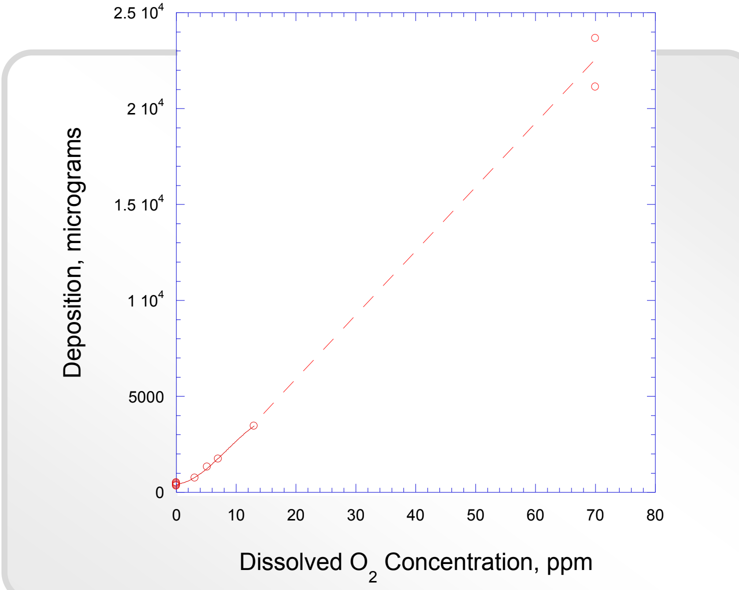
Principles of FSU Operation

Membrane-based deoxygenation prevents coke formation

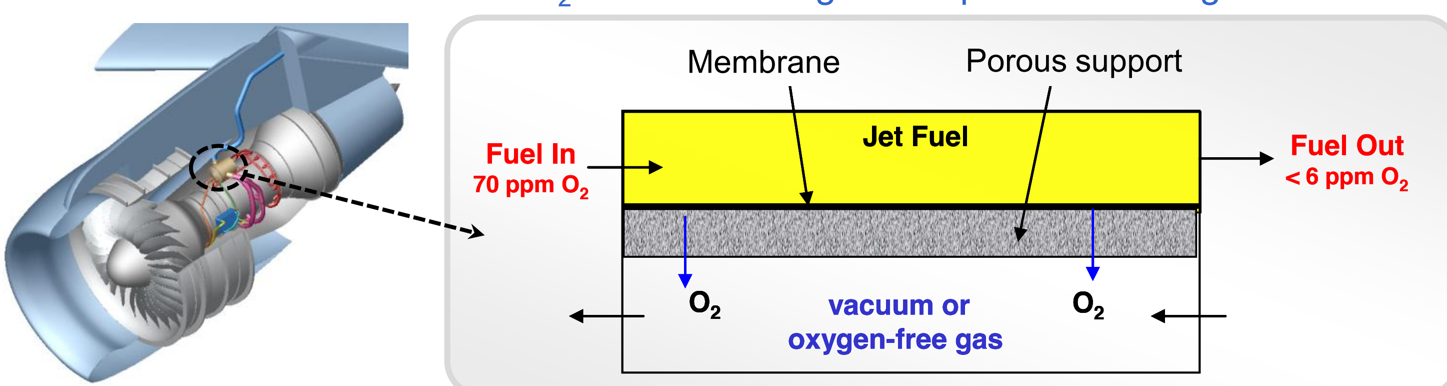
Coke formation prevents heating jet fuel to high temperature



Deposition as a function of oxygen level (20 mL / min flow rates)



O_2 concentration gradient provides driving force



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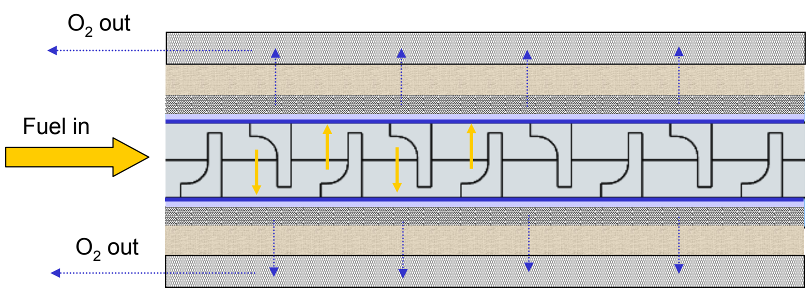
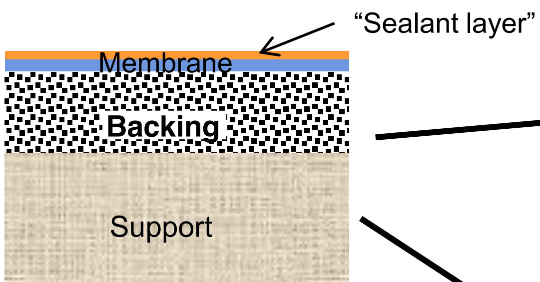
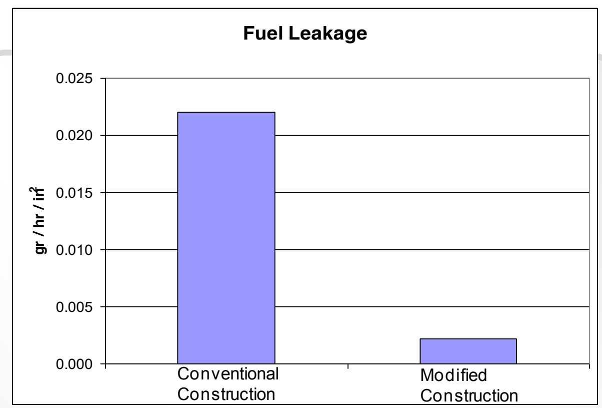
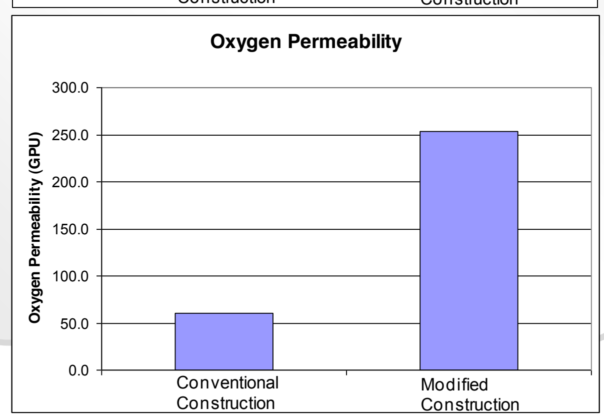
Membrane-based deoxygenation prevents coke formation



Bottleneck: oxygen transport from bulk flow to membrane surface







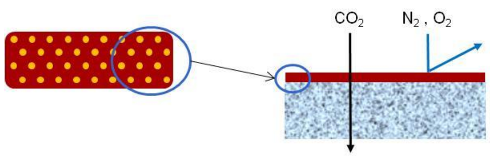
10X lower fuel leakage

5X higher oxygen permeance

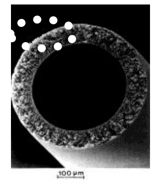
2X lower membrane mfg. cost

40% less membrane needed

CO_2 Separation Membrane – Simulation Study

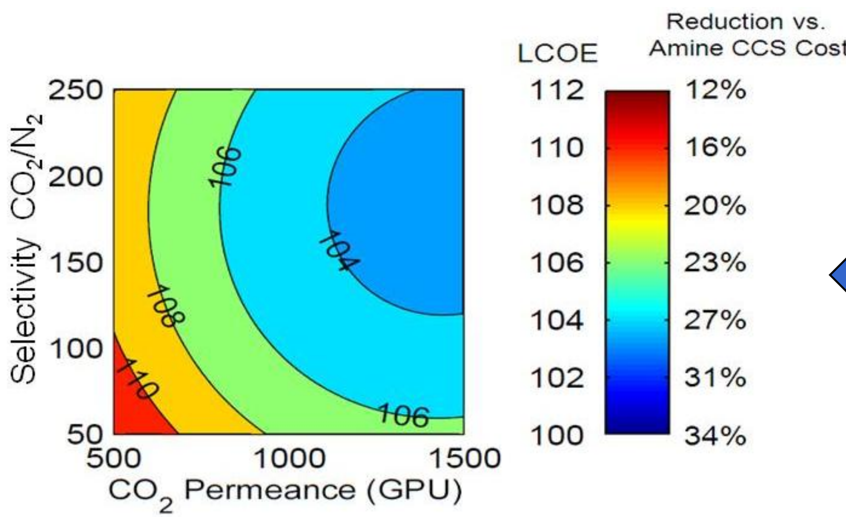


Synthetic analogue/
polymer thin-film

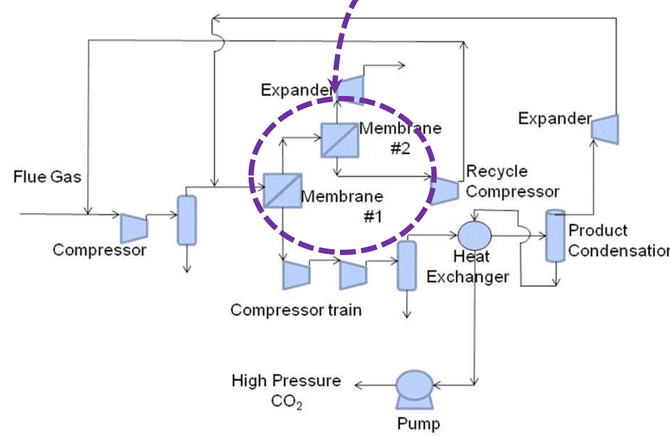


Porous substrate

Membrane
module

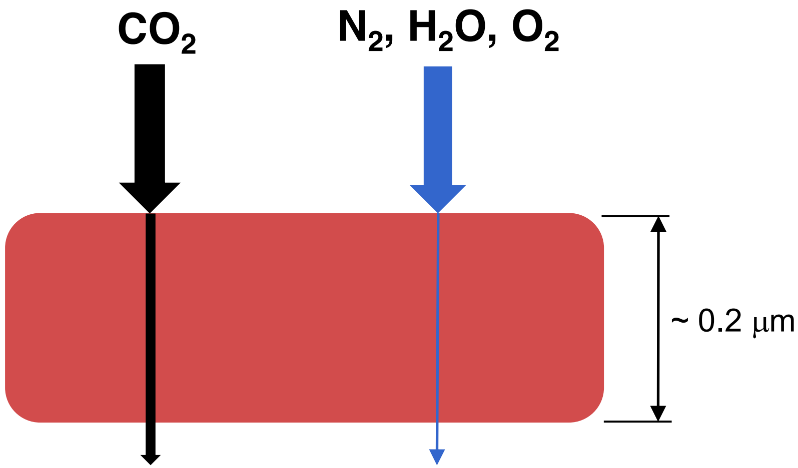


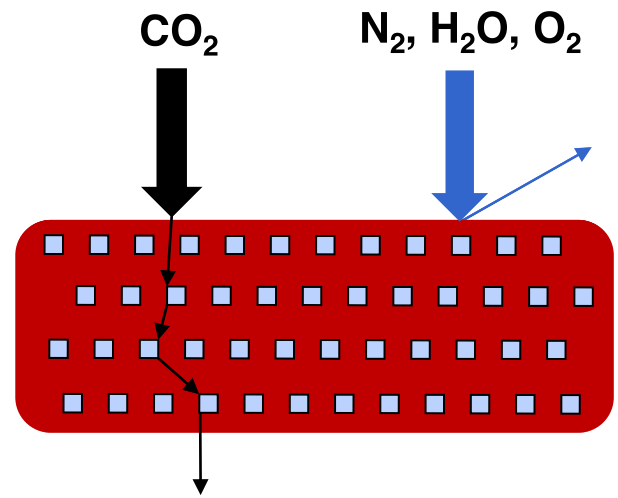
Membrane properties mapping



Simulated separation system (simplified)

CO_2 Separation Membrane



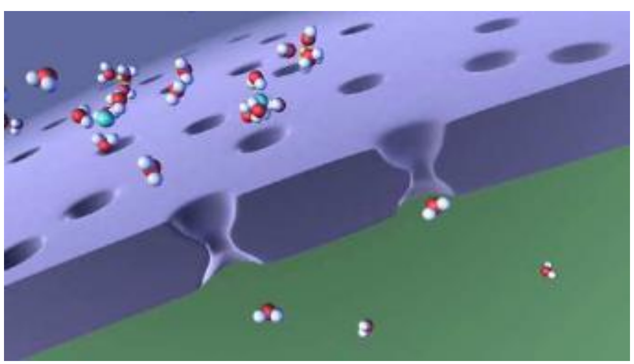


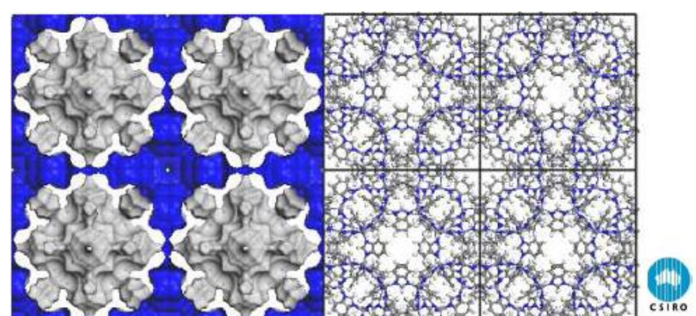
Current:

- Thin, dense polymer films with preferential CO_2 affinity
- Low selectivity for CO_2

Desired:

- CO_2 transport facilitated by “carriers” within a barrier film
- Fast and reversible interaction sites

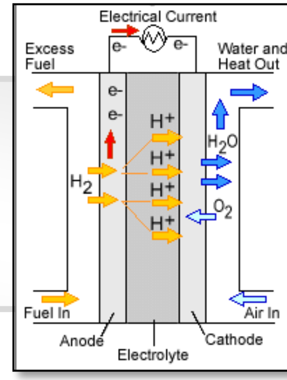




PEM Fuel Cells Membrane Attributes and Challenges

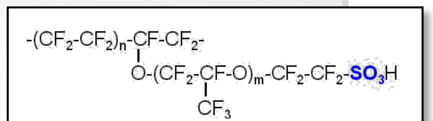
Function

- Transport protons
- Separate the reactants (H_2, O_2)

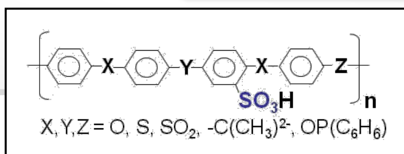


Available membranes

- PerFluoro Sulphonic



- Hydrocarbon

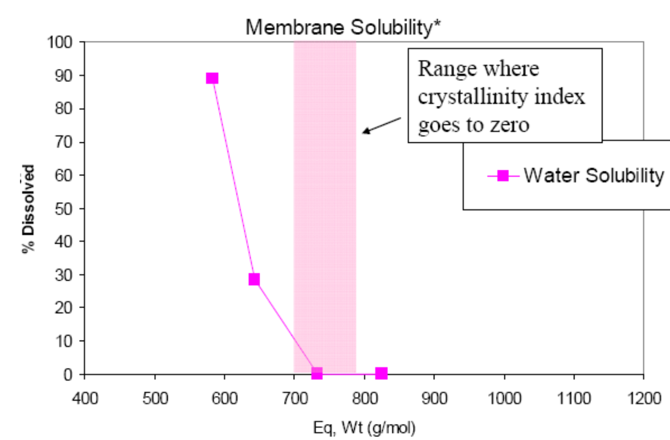


Desired attributes

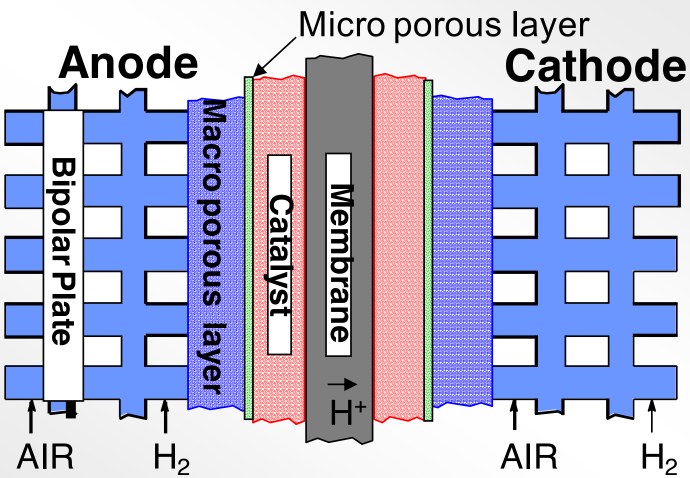
- High proton conductivity
- Low gas cross-over
- High chemical / mechanical durability

Challenges

- Sufficient proton conductivity at low RH
- Stability at high temperature operation
- Trade-offs in durability and performance
- Cost



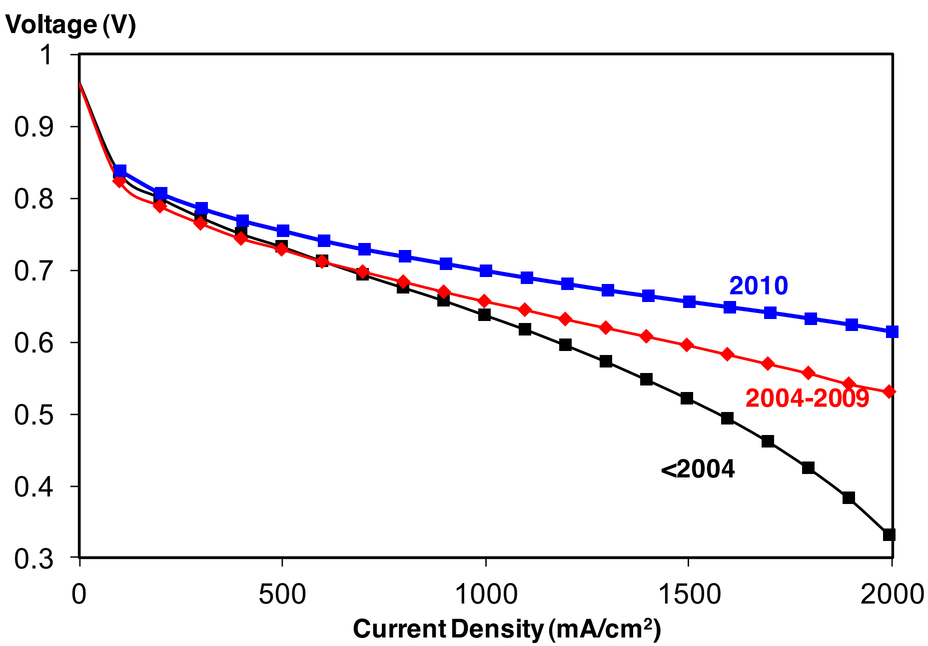
PEM Fuel Cells



Membrane critical to fuel cell life and performance

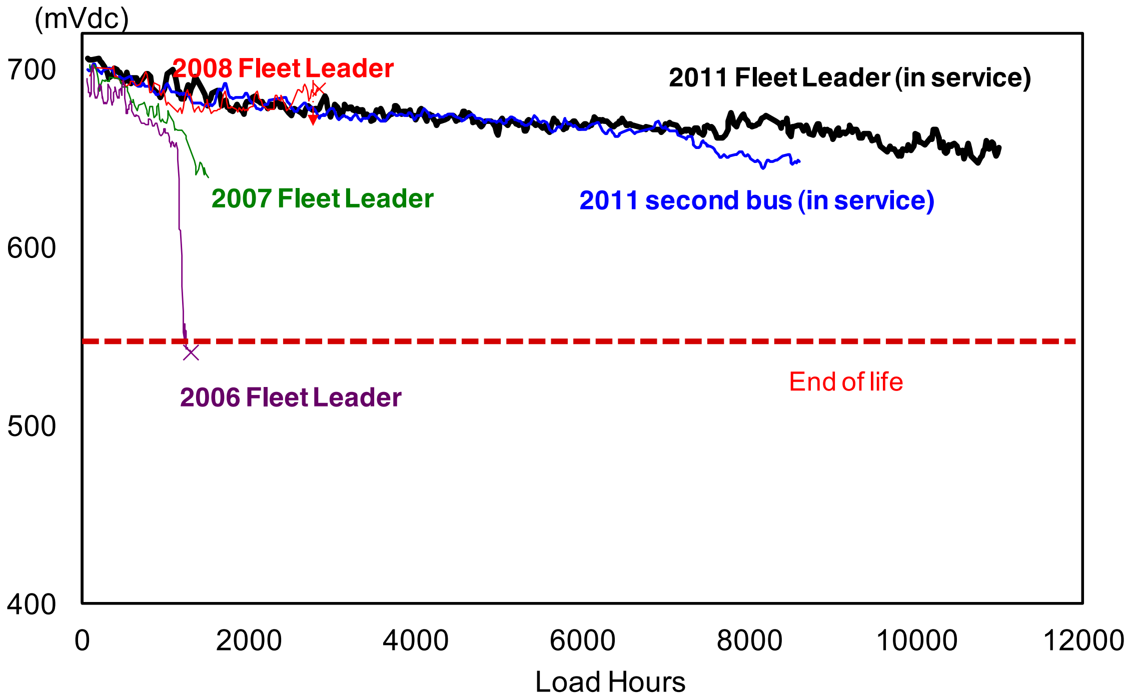
- Chemical stability
- Mechanical strength

Improved performance resulting in higher power densities



UTC Power
A United Technologies Company

UTC Power – Fuel Cell Bus Durability



Fleet statistics

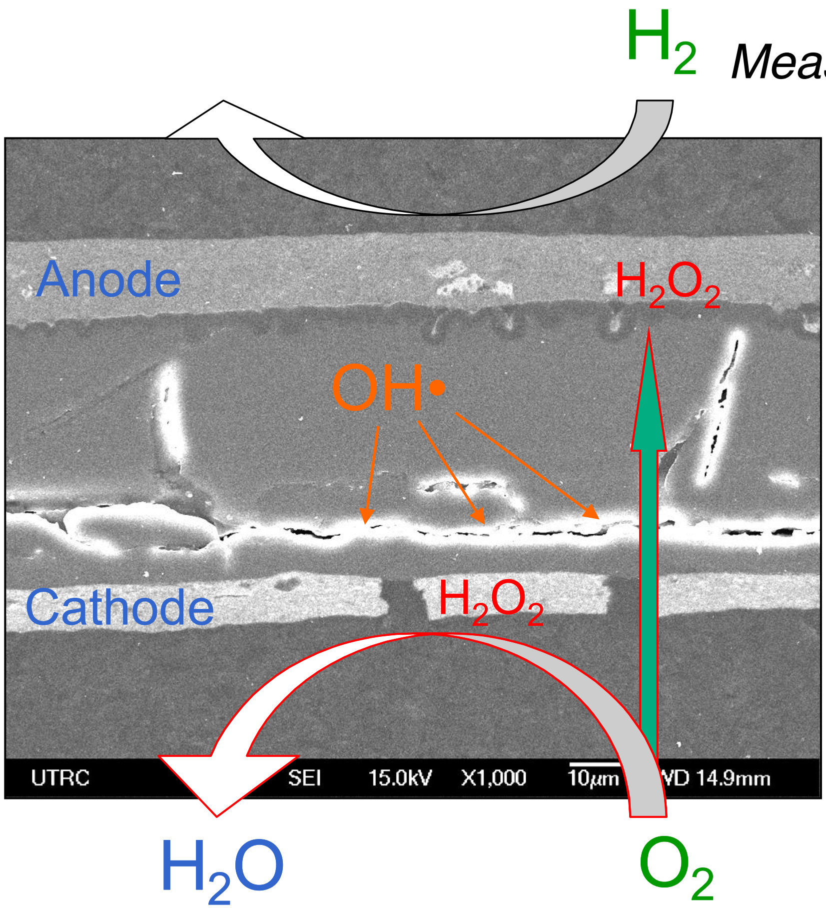
17 bus fleet
750,000 miles
70,000 hours
18,500 start-stops

Best in class PEM fuel cell durability enabled by improved systems understanding and advanced cell materials

UTC Power
A United Technologies Company

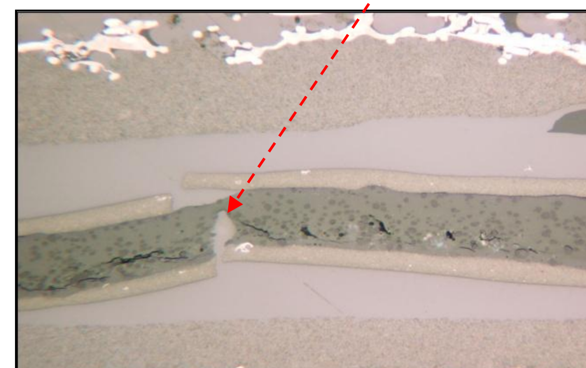
Membrane Durability: Critical Fuel Cell Enabler

Membrane failure limits stack life (e.g. 10,000 vs 40,000 hours)



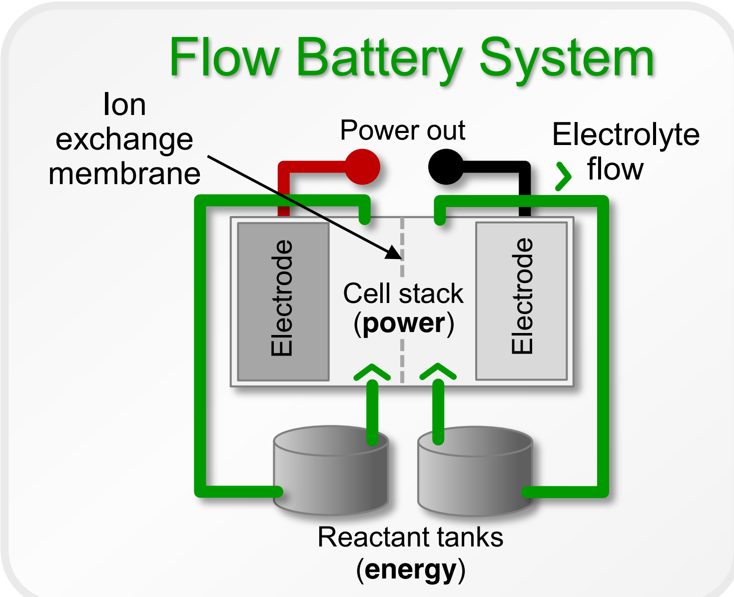
Measure in PEMFC effluent (FER) → F^-

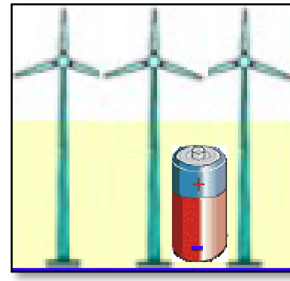
Radical formation → *Attack of polymer weak sites* → *Material properties degrade* → *Localized stress promotes cracks, fissures* → *Crossover failure occurs*



- Chemical degradation
- Mechanical degradation

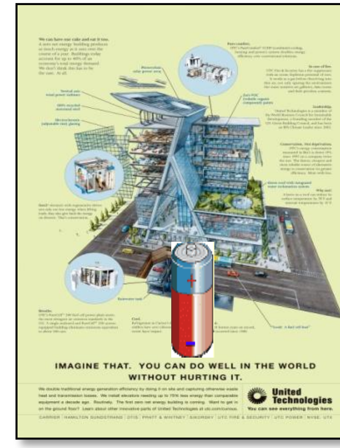
Flow Batteries



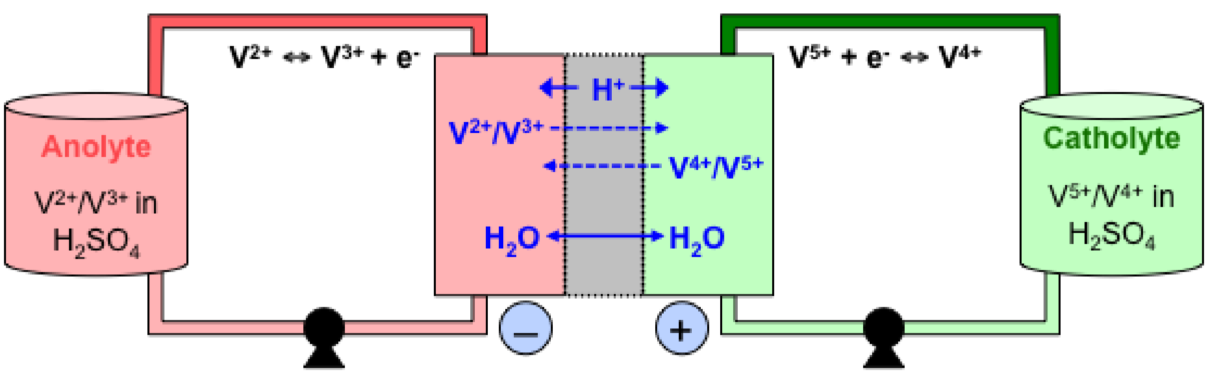


Renewable Energy
Smoothing & time-shifting

Remote & Off Grid
Minimize fuel usage

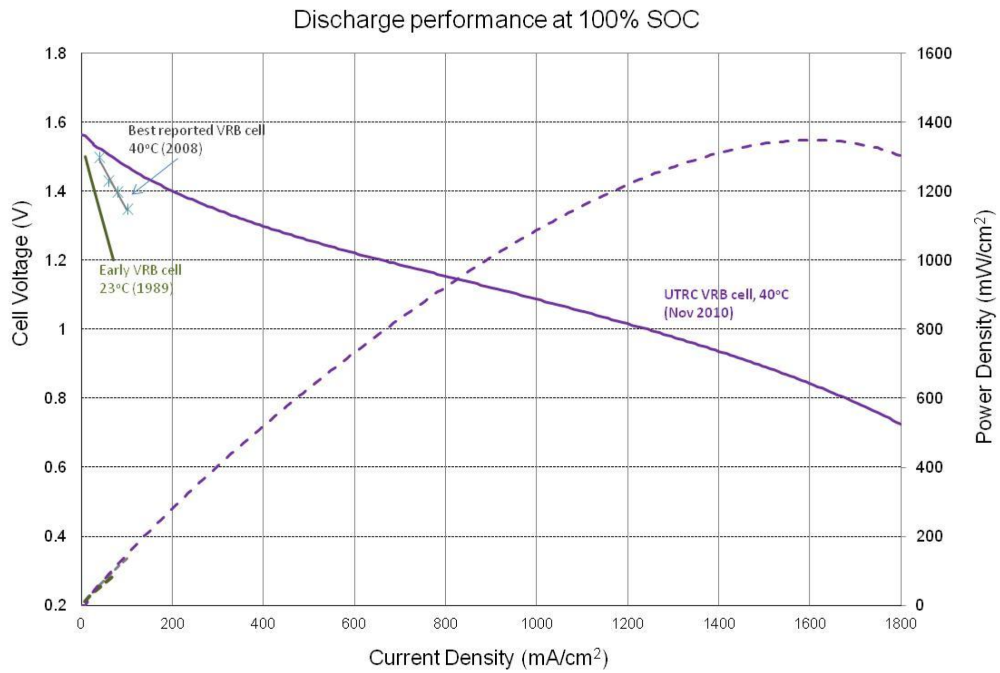


Commercial Buildings
Bill reduction & UPS



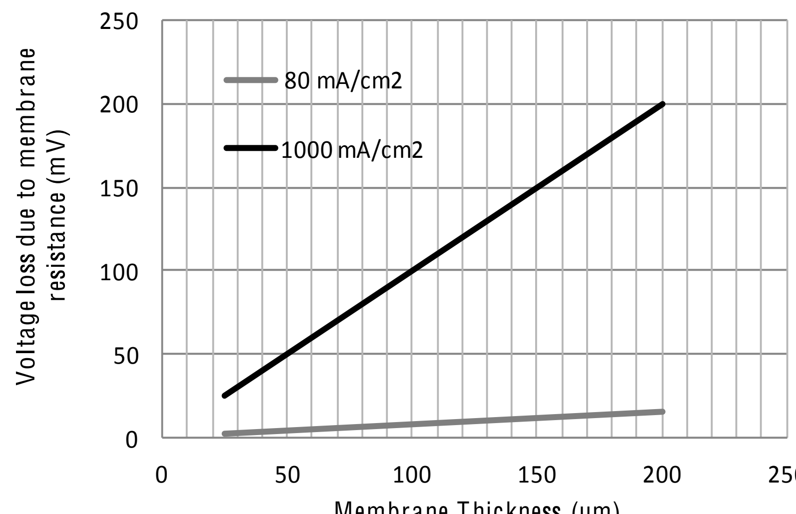
Transmission & Distribution
Infrastructure deferral

Flow Battery Performance



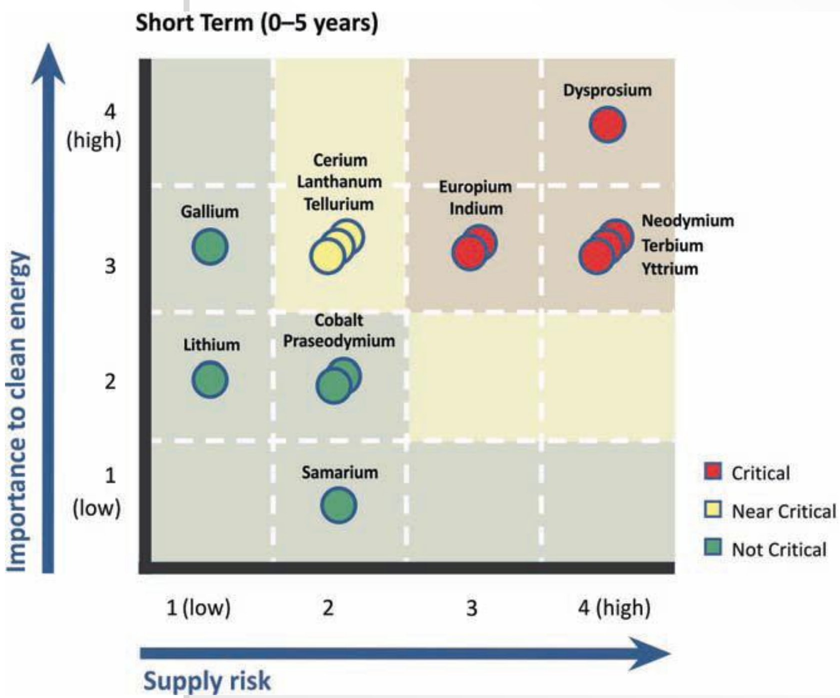
Lower membrane resistance enables higher power density operation

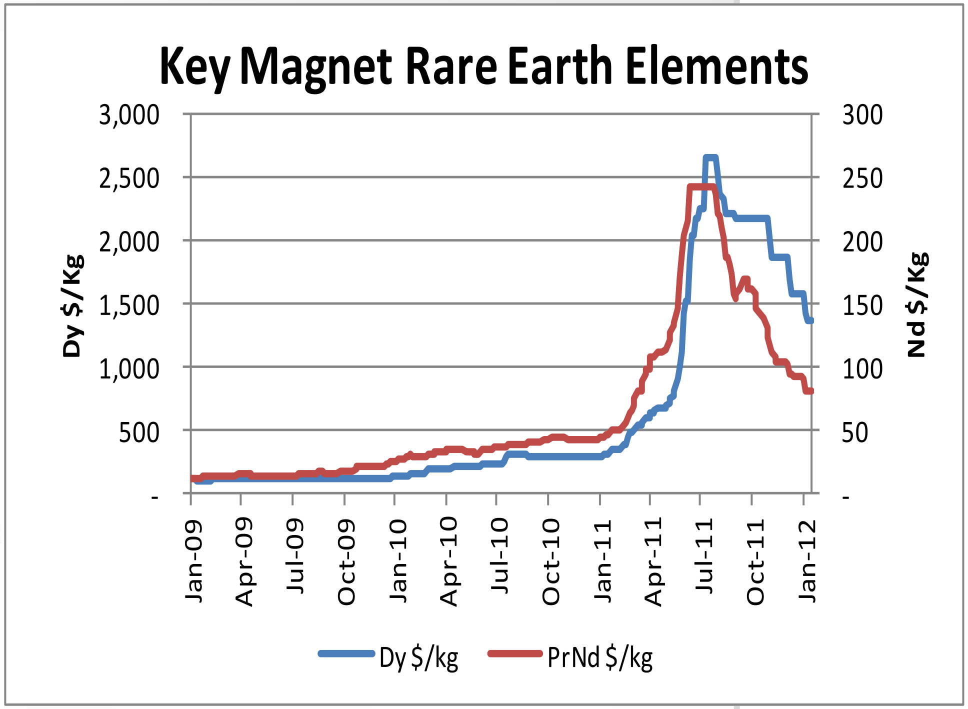
If crossover limitations addressed, thin membranes are advantageous.



The Skyrocketing Price of Rare Earths

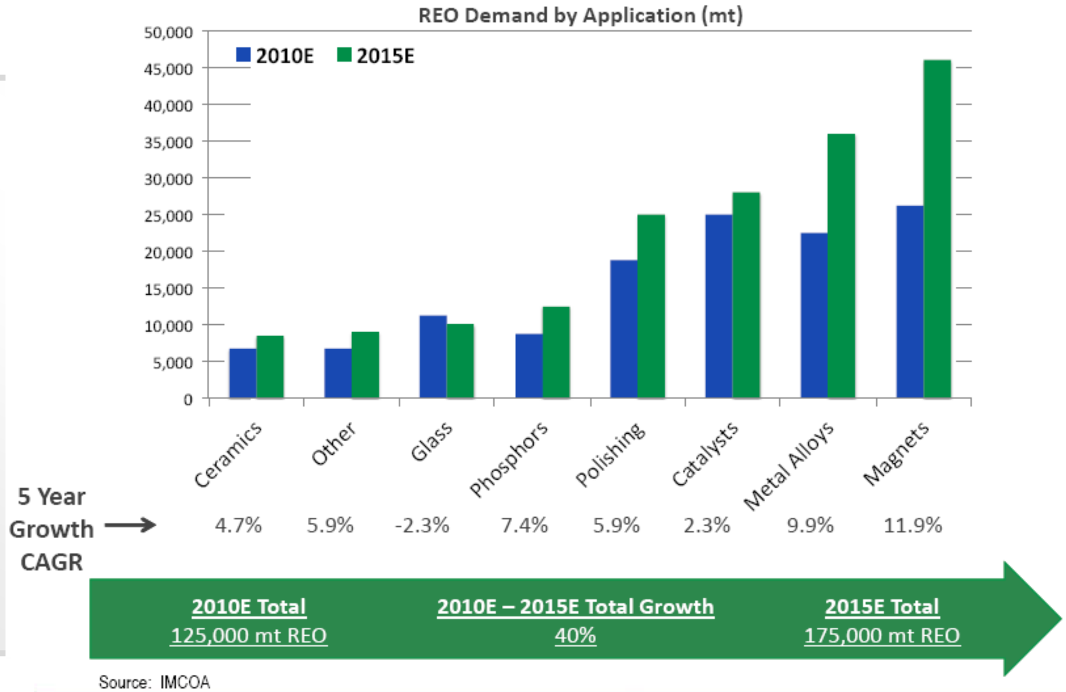
Cost increase begs a response





Demand for Rare Earths

Magnets are largest share of RE market and share expected to increase



UTC RE areas of Concern

- Magnets (Otis, Carrier, HS, Clipper)
- Coatings (PW)
- Alloys (PW, SIK)

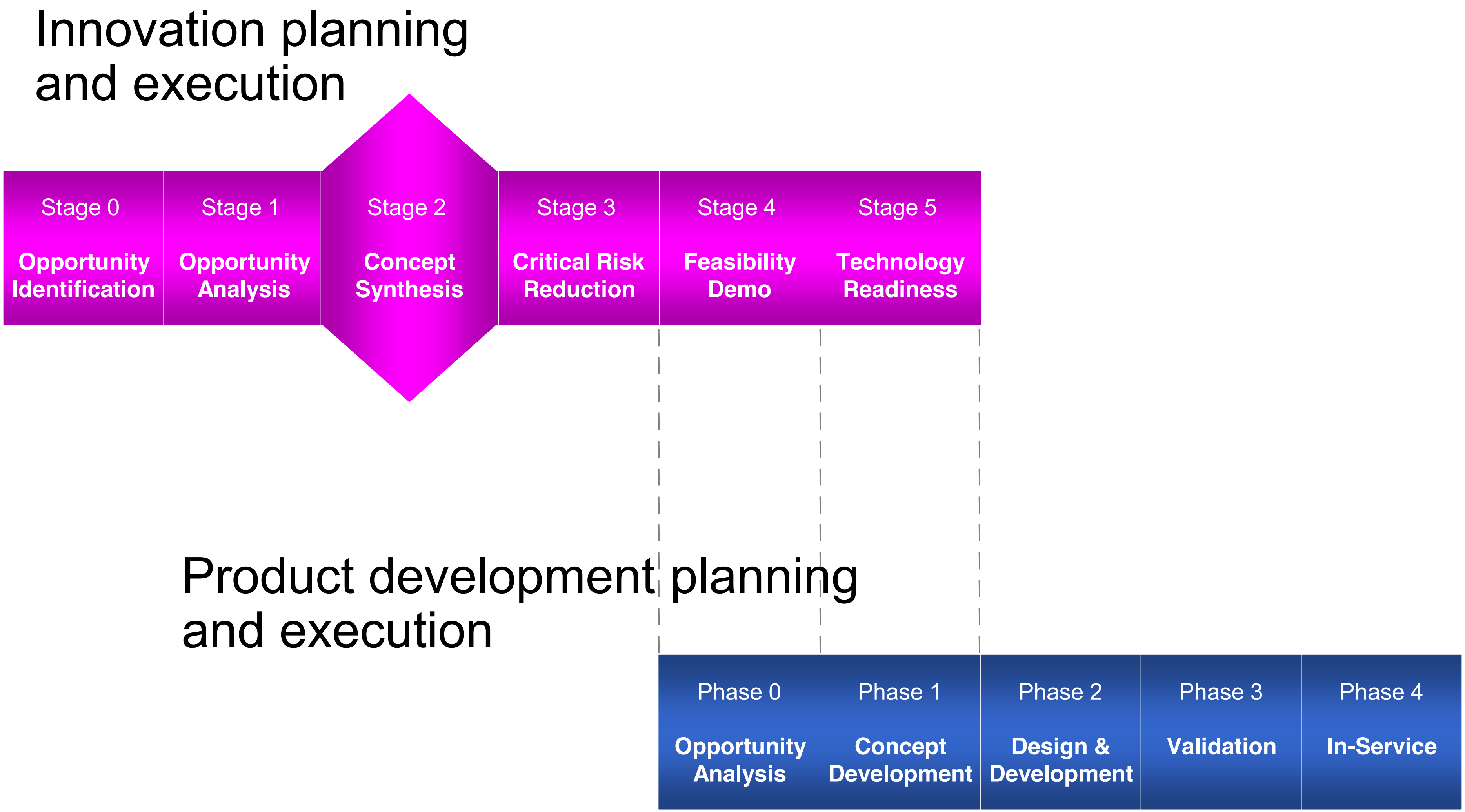
Primary focus Area

Data from: http://w
Presentations/Inve

Materials Processing and Energy

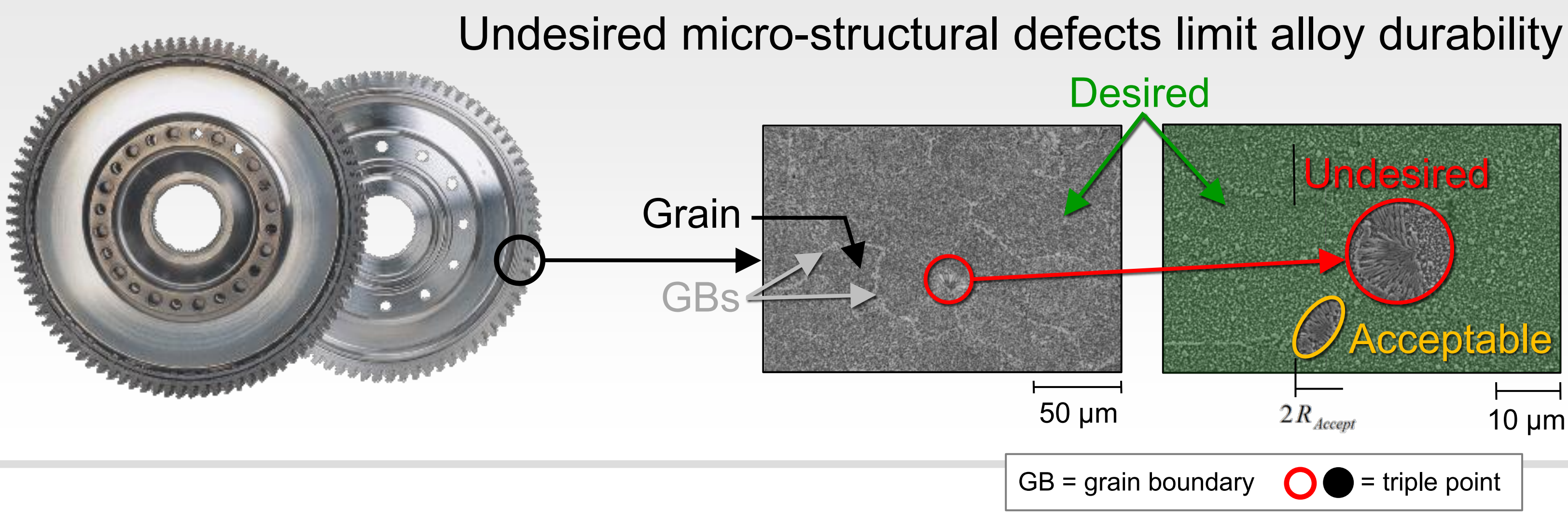
MANUFACTURING PROCESS ADVANCES

Innovation Process



Superalloy Fan-Type growth modeling

Problem...

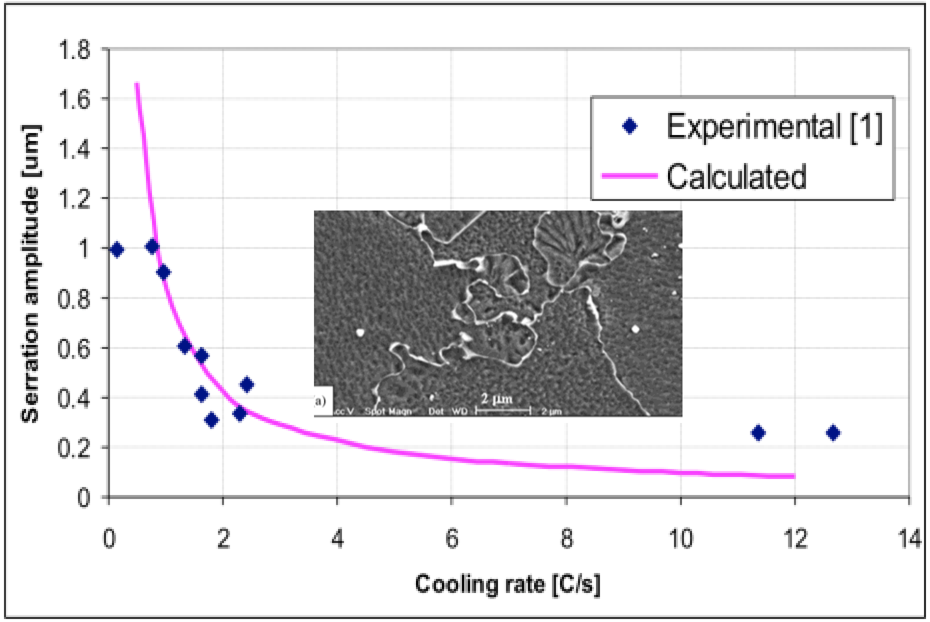


γ' Fan-Type (FT) growth in Ni-based superalloys reduces low cycle fatigue (LCF) life

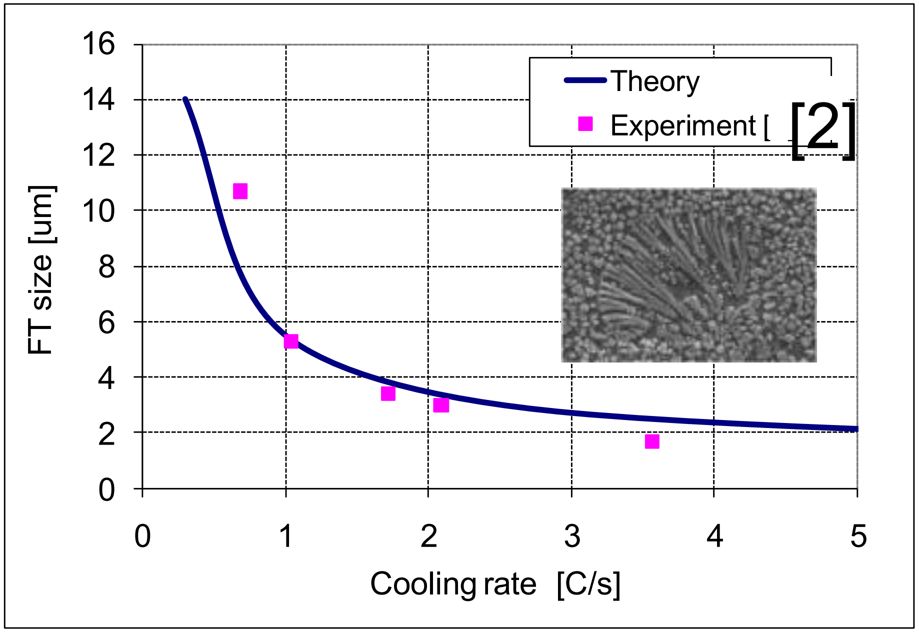
Superalloy Fan-Type growth modeling

Model predictions quantitatively agree with experiment

GB serration amplitude



FT size



[1] D.Furrer, Ph.D. Thesis

[2] Mitchell R.J. On the formation of serrated grain boundaries and fan type structures in an advanced polycrystalline nickel-base superalloy // journal of materials processing technology 209 (2009) 1011–1017

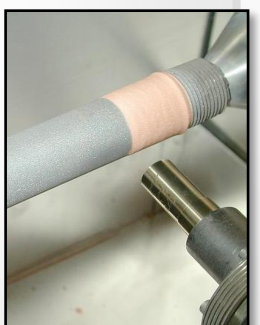
Advanced Manufacturing

ATOM…

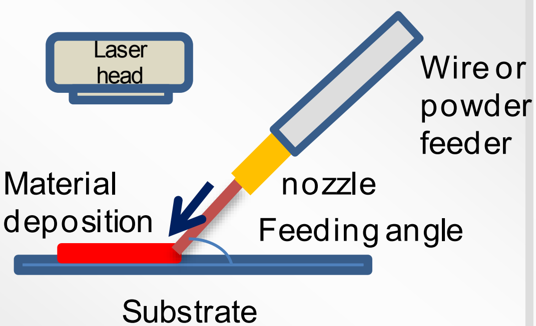
Additive Topology Optimized Manufacturing

Integrating Topology Optimization (TO)
with Additive Manufacturing (AM):

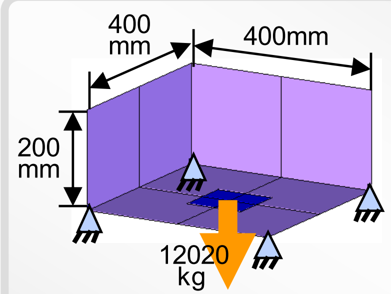
- Enables unlimited complexity (flexibility) in design
- 50% Reduction in time to market
- 35% Reduction in production cost
- > 50% Reduction in energy
- > 70% Reduction in raw materials consumption
- Provides an alternative to castings or forming



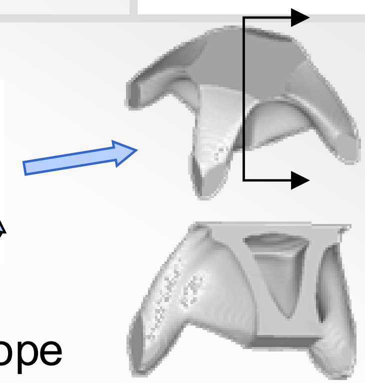
Forming
cold spray



Casting - Laser melting AM



Design envelope

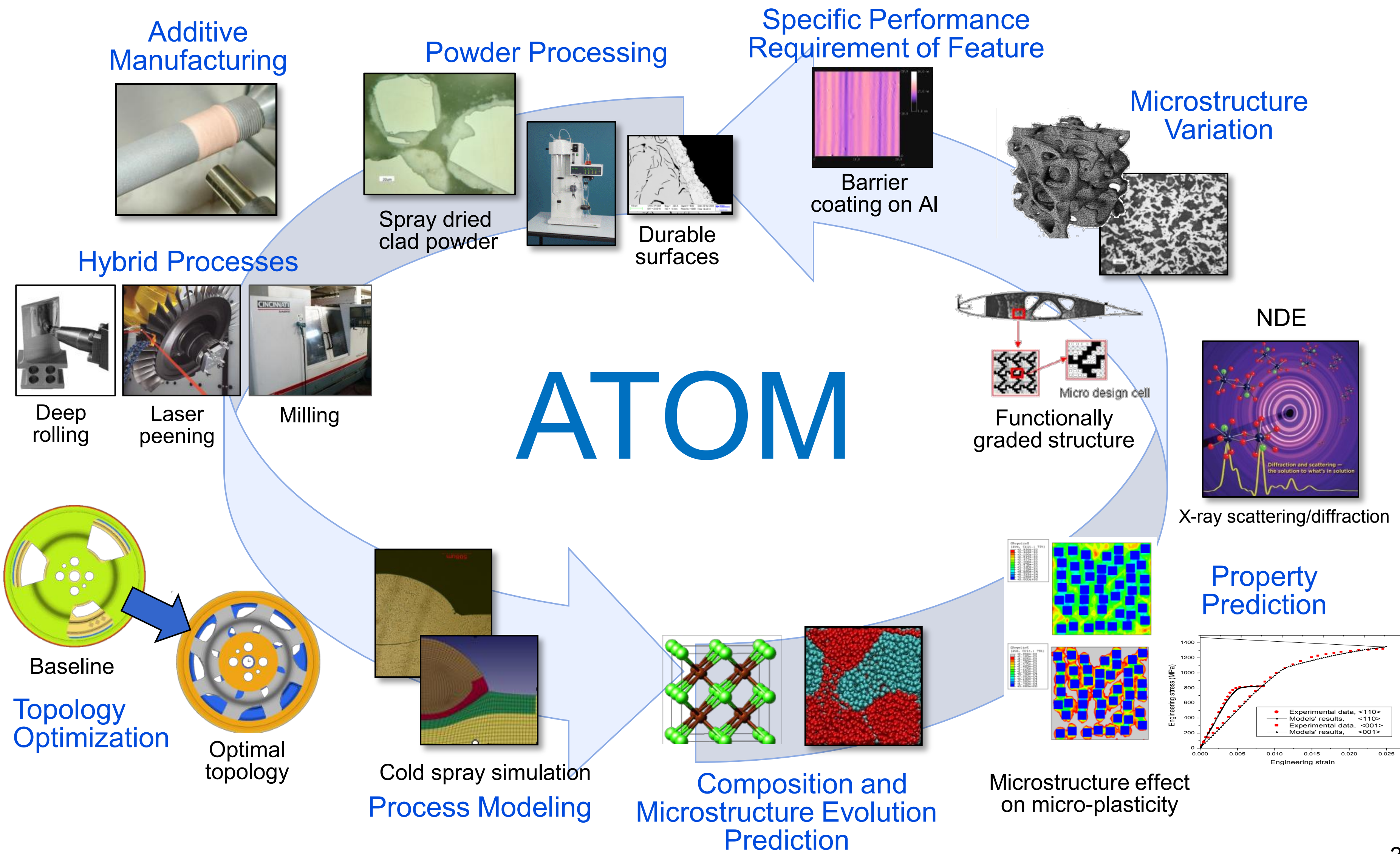


Optimized topology

ICME Approach to ATOM

Additive manufacturing with topology optimization for hierarchical structures

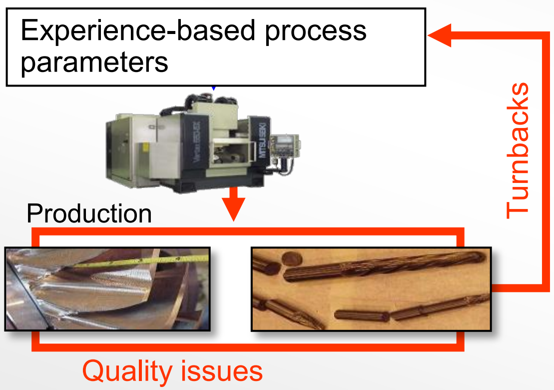
Achieve revolutionary freedom in part design for multifunctional properties

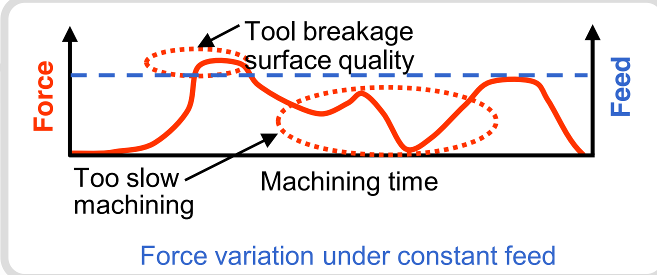


Physics-based Models

Optimizing machining processes

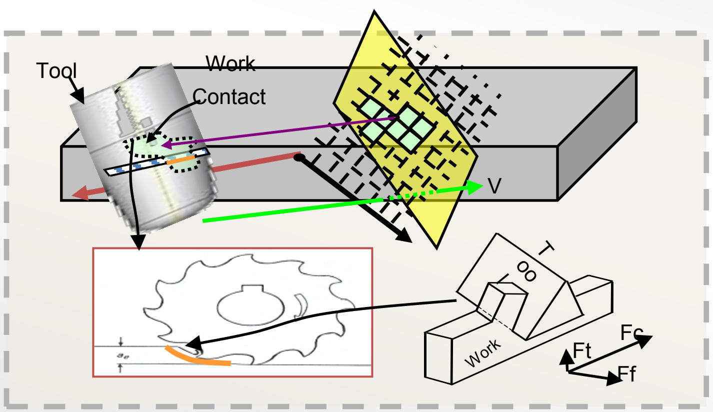
Traditional process development…

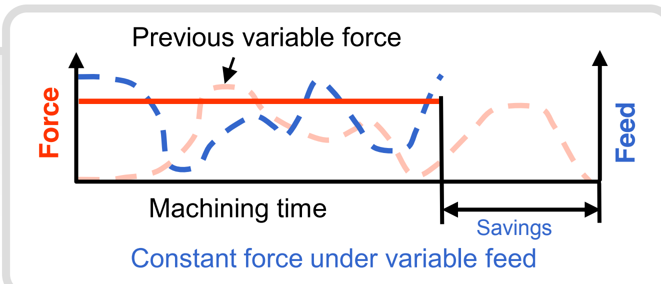




- Long process development time
- High development cost
- High process variations
- Long cycle-time and increased cost

Model-based approach…



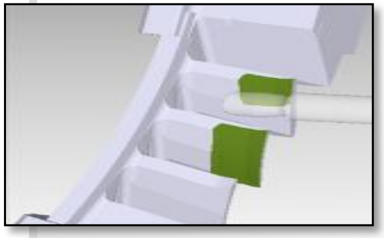


- Reduced time and cost
- Less process variation

Cycle-time and Cost Reduction

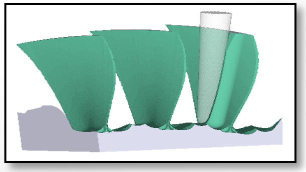
Integrated Bladed Rotor process development…

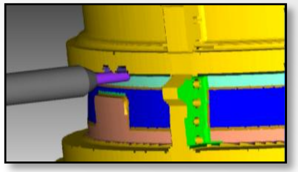
Technology enabler for small IBRs



Super abrasive machining model

P&W machining…

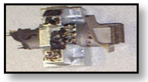


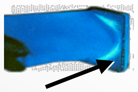


Multi-axis milling model

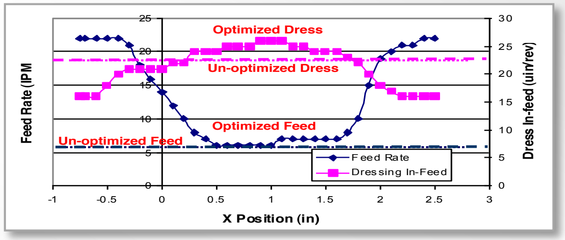
~ 30% time saving at suppliers

P&WC blade and vane…



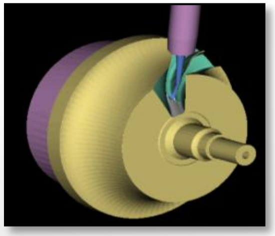


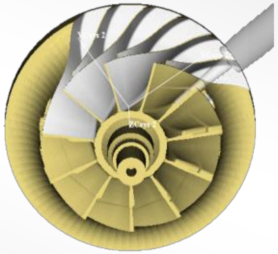
Coating cracks



Blade grinding optimization
~ 40% time savings

HS 787 impeller machining…

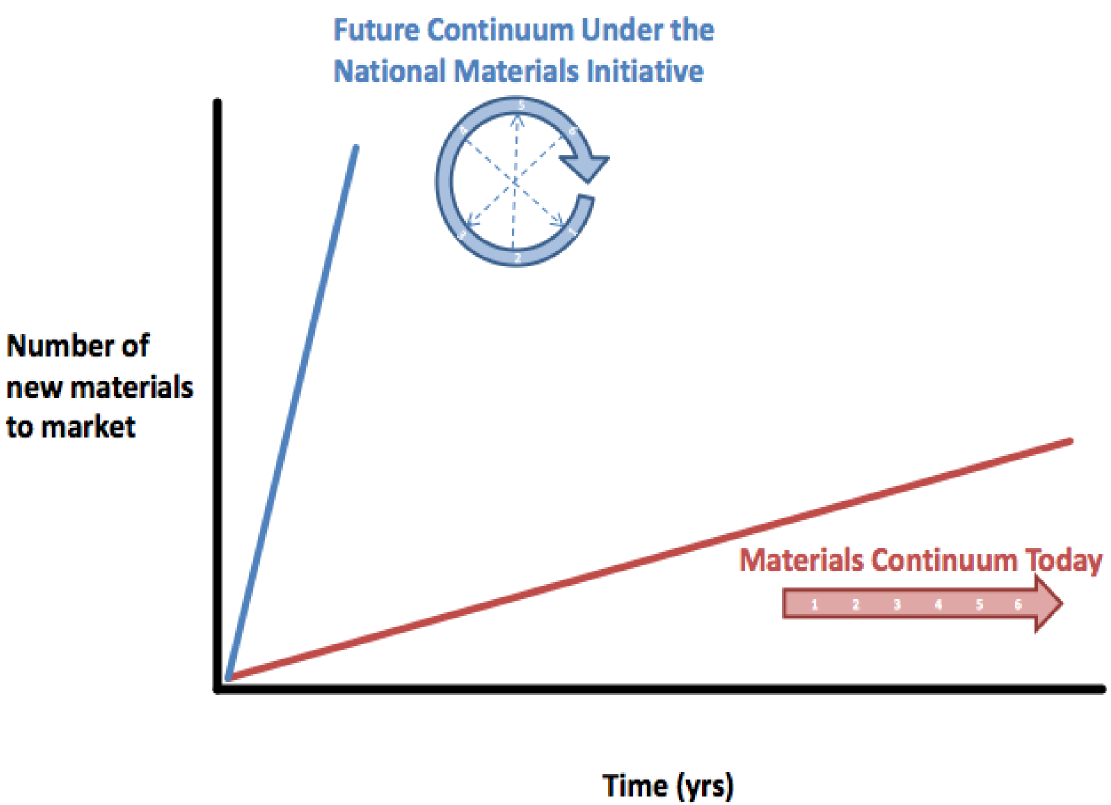


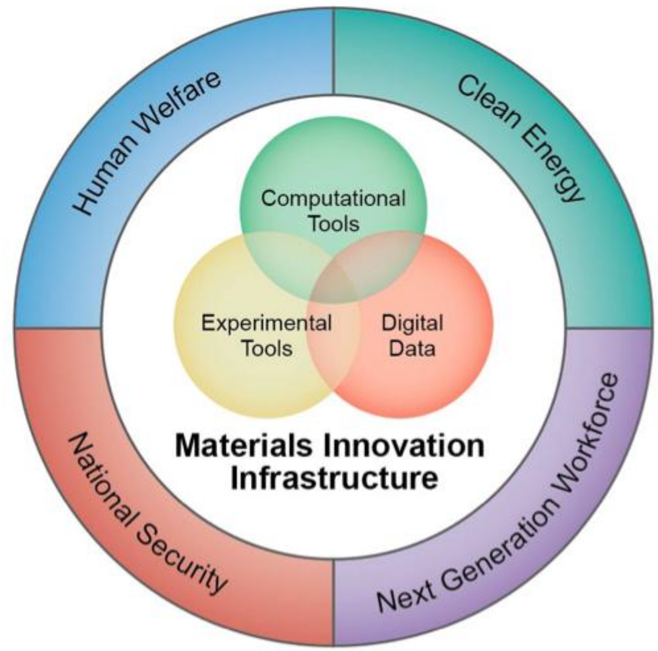


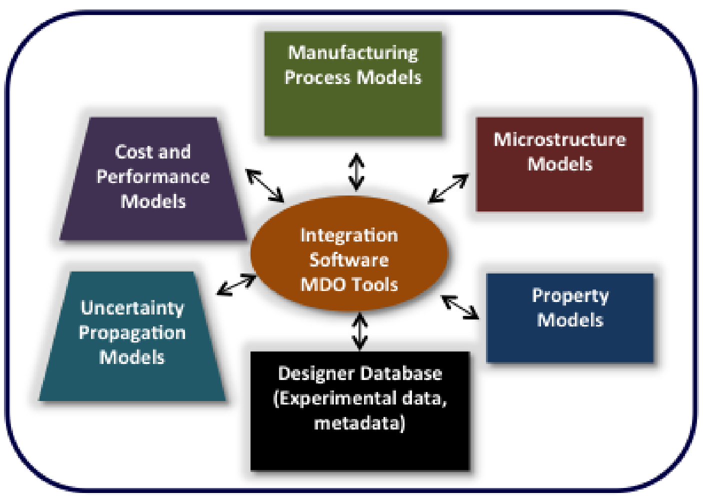
~ 40% time saving

Integrated Computational Materials Engineering

Materials genome initiative



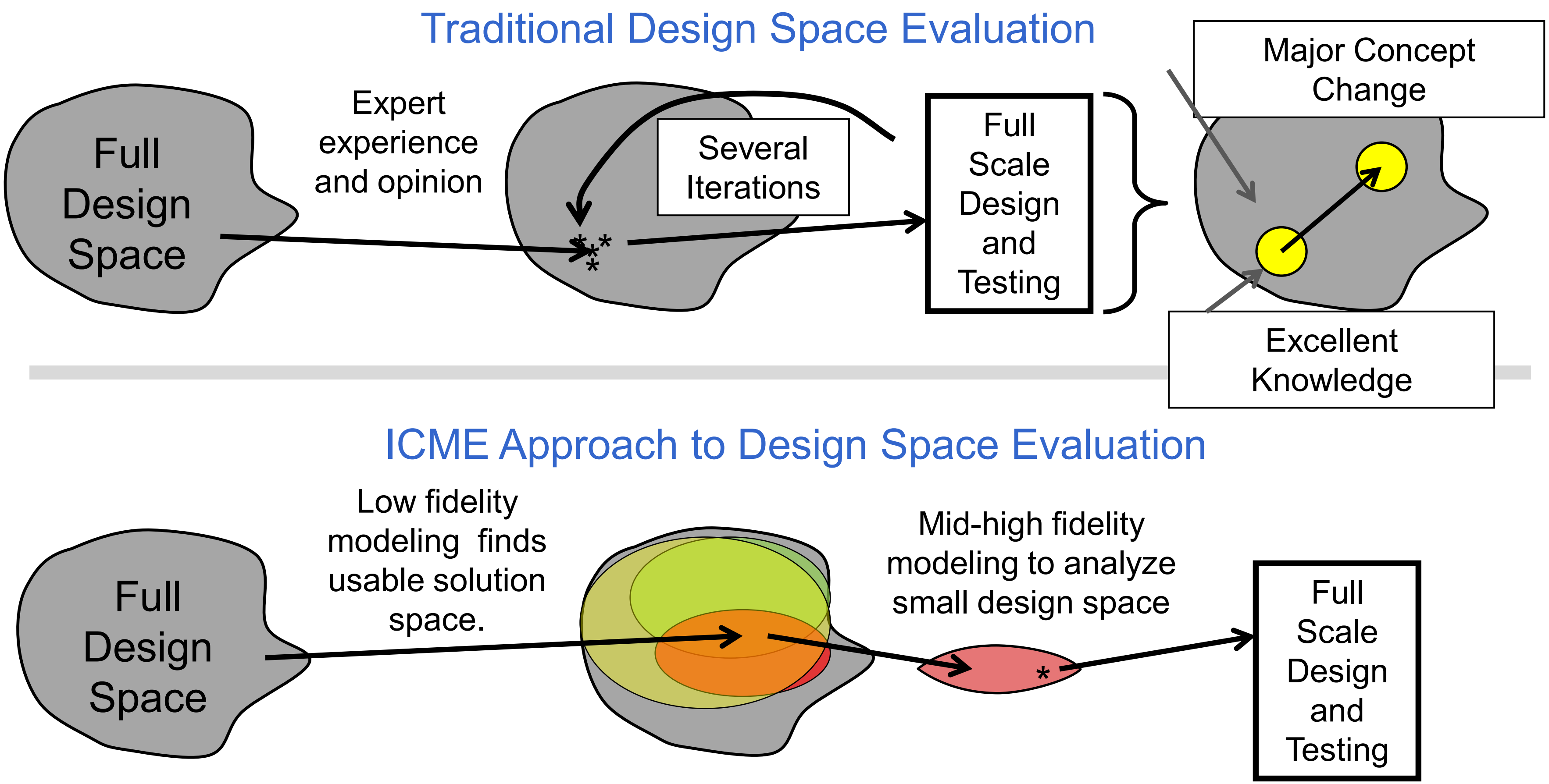




Optimization from ICME Perspective

Integration is key

- Computation working together at many levels (multi-scale)
- Experimentation still required
- Effective use of data



Invention and Innovation

"Invention and innovation are complements. In the short run, this complementarity is not perfect; it is indeed possible to have one without the other.

But in the long run, technologically creative societies must be both inventive and innovative.

Without invention, innovation will eventually slow down and grind to a halt, and the stationary state will obtain.

Without innovation, inventors will lack focus and have little economic incentive to pursue new ideas."

"The Lever of Riches: Technological Creativity and Economic Progress" John Mokyr, Oxford, 1990.