Energy Efficiency:
Materials and Manufacturing Processes

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UTC Reminder

A couple of examples: elevators and membranes
Materials Processing and Energy
United Technologies

Business units

UTC Aerospace Systems

Otis

Pratt & Whitney

UTC Climate, Controls & Security

Sikorsky

OTIS

Commercial Aerospace

Commercial & Infrastructure

Military Aerospace
UTC Sustainability Roadmap

Established first sustainability goals 1997
Major cogeneration implementations 2005-2010
2015 Sustainability Goals include LEED requirement for new construction
Energy efficient mfg processes

UTC energy efficient products
Otis Gen2® regenerative elevator system
Pratt & Whitney PurePower™ PW1000G engine with Geared Turbofan technology
Carrier 23XRV Evergreen® chiller with Foxfire compressor – worlds most efficient water cooled chiller

UTC is leading voice in advocacy programs
U.S. Green Building Council (1993)
WBCSD Energy Efficiency in Buildings (EEB 1.0) (2006-2009)
EEB 2.0 2012 - 2014
Alliance to Save Energy Commission on Energy Productivity (2012-2013)

Energy Use 1997-2012

Water Use 1997-2012
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, take less energy to make and use less energy.”

Fundamental drivers for materials technology insertion at UTC

<table>
<thead>
<tr>
<th>Durability</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Cost</td>
<td>Temperature</td>
</tr>
<tr>
<td>Enhanced features</td>
<td>Embodied energy</td>
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<tr>
<td>Operating energy</td>
<td></td>
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</table>
UTC Reminder

A couple of examples: elevators and membranes

Materials Processing and Energy
Elevators – Competitive Drivers

- Cost reduction
- Weight reduction
- Safety
- 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
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
Emerging ultra high rise buildings have needs beyond the capabilities of many of the components we produce today.
Membrane Technology Development

Materials
- Polymers
- Ceramics
- Metals

Structure
- Flat sheets
- Pleated papers
- Tubular/hollow fiber

Process
- Pressure-driven
- Concentration-driven
- Electrical potential
Membrane Applications for Energy and Sustainability

World Wide Energy Consumption

Buildings
- Air dehumidification
- Flow Batteries
- Fuel Cells

Industrial
- Gas Separations
- CO₂ separation for power plants
- Waste-heat driven distillation

Aircraft
- Fuel tank inerting
- Fuel deoxygenation

Automotive
- PEM Fuel Cells
Principles of FSU Operation

Membrane-based deoxygenation prevents coke formation

O₂ concentration gradient provides driving force
Principles of FSU Operation

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
Efficiency benefits
PEM Fuel Cells Membrane Attributes and Challenges

Function
- Transport protons
- Separate the reactants (H₂, O₂)

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

higher power densities
Improved performance resulting in
Mechanical strength
Chemical stability
Performance
Membrane critical to fuel cell life and

H₂ | AIR
---|---
| | Membrane
| Catalyst
| Macro porous layer
| | Bipolar Plate
Anode
Cathode

Current Density (mA/cm²)
Voltage (V)

UTC Power
Flow Batteries

Flow Battery System

- Ion exchange membrane
- Power out
- Electrolyte flow
- Reactant tanks (energy)
- Cell stack (power)

Renewable Energy
Smoothing & time-shifting

Commercial Buildings
Bill reduction & UPS

Remote & Off Grid
Minimize fuel usage

Transmission & Distribution
Infrastructure deferral

Flow Batteries

![Flow Battery Diagram](image)

- Anolyte: $V^{2+} \leftrightarrow V^{3+} + e^{-}$
- Catholyte: $V^{5+} + e^{-} \leftrightarrow V^{4+}$
- $V^{2+}/V^{3+}$ in $H_2SO_4$
- $V^{5+}/V^{4+}$ in $H_2SO_4$

Electrolyte flow
Ion exchange membrane
Cell stack (power)
Reactant tanks (energy)
Flow Battery Performance

Lower membrane resistance enables higher power density operation

If crossover limitations addressed, thin membranes are advantageous.
Agenda

UTC reminder
A couple of examples: elevators and membranes
Materials processing and energy efficiency
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

Design envelope

Optimized topology
Additive manufacturing with topology optimization for hierarchical structures

Achieve revolutionary freedom in part design for multifunctional properties

ICME Approach to ATOM

Additive Manufacturing

Powder Processing

Specific Performance Requirement of Feature

Microstructure Variation

Hybrid Processes

Spray dried clad powder

Durable surfaces

Barrier coating on Al

Cold spray simulation

Functionally graded structure

X-ray scattering/diffraction

NDE

Property Prediction

Baseline

Optimal topology

Composition and Microstructure Evolution Prediction

Microstructure effect on micro-plasticity

Hybrid Processes

Deep rolling

Laser peening

Milling

Cold spray simulation

Process Modeling

Optimal topology

Baseline

Topology Optimization

ATOM

Additive Manufacturing

Microstructure effect on micro-plasticity

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Topology Optimization

ATOM
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

Experience-based process parameters

Production

Quality issues

Force variation under constant feed

Constant force under variable feed

Previous variable force

Savings
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&W blade and vane...
- Coating cracks
- Blade grinding optimization
- ~ 40% time savings

HS 787 impeller machining...
- ~ 40% time saving
Additive Manufacturing Methodologies

**DMLS – Direct Metal Laser Sintering**
Laser fuses powdered material by scanning cross-sections generated from a 3D CAD file on the surface of a powder bed.

**EBM - Electron Beam Melting**
Electron beam melts powdered material in a layer-by-layer process in a high vacuum to build the physical part.
Additive Manufacturing

Reduced product life-cycle energy consumption

Materials
- Materials with high embedded-energy content

Manufacture
- Net shape manufacture reduces material scrap/waste

Transport
- Minimizes inventory with on demand part manufacture

Use
- Increase potential for multi-functional can improve product performance

Conventional method

Ingot → Milling → Machining → Finished
- ~1.5 kWh/kg
- ~9.9 kWh/kg removed
- 33:1 raw stock: finished part \(^1\)

Additive Manufacturing method

Ingot → Powder → EBM → Finished
- ~1.3 kWh/kg
- ~17 kWh/kg
- 1.5:1 raw stock: finished part \(^2\)

Note: Energy estimates reference [2]
## Materials and Manufacturing Science Needs

### DMLS Process Modeling & Monitoring

<table>
<thead>
<tr>
<th>Gap</th>
<th>Unique problem</th>
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<tbody>
<tr>
<td>Powder packing, Laser-powder interaction</td>
<td>Laser absorption and reflection of powder</td>
</tr>
<tr>
<td>Powder sintering and melting</td>
<td>Solid sintering $\rightarrow$ liquid melting</td>
</tr>
<tr>
<td>Solidification</td>
<td>Rapid cooling</td>
</tr>
<tr>
<td>Macro/micro grain prediction</td>
<td>Eutectic and secondary phases</td>
</tr>
<tr>
<td>Chemical segregation defect</td>
<td>Freckle and white spot, carbide</td>
</tr>
<tr>
<td>Inclusion defect</td>
<td>Oxidation, nitride</td>
</tr>
<tr>
<td>Other defect (porosity, cracking)</td>
<td>Scanning pore, partially melted powder, HAZ cracking</td>
</tr>
<tr>
<td>Design &amp; Mfg</td>
<td>Balling and warping</td>
</tr>
<tr>
<td>Process monitor and control</td>
<td>short tiny pulse and fast speed</td>
</tr>
</tbody>
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MPE # 51503 Preliminary Report

![BSESEM Image]
Final thoughts…

We are moving beyond product architecture, i.e. how it does what it does, to how the materials and processes from which it is constructed combine to enable it do what it does more efficiently

Chemistry

↑ Physics

↓ Electronics / Computer Science

↑ Bioscience

↓ Materials and Manufacturing Science
References
