Emerging Trends in Sustainable Manufacturing: New Opportunities Economic Growth

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Industrial Revolutions
Characteristics of Next Generation Manufacturing

• Intelligent/Smart Manufacturing Platform
• Sustainable Manufacturing Foundation
• Value Creation for All Stakeholders
• Broader Vision for Future State
  ➢ Sustainable industrial growth
  ➢ Improved societal wellbeing (e.g., healthcare and safety)
  ➢ Greater environmental/planetary protection
  ➢ Continued education and training
Global Challenges to Society, Environment and Economy

- Water Pollution
- Air Pollution
- Landfills and Wastes
- Ecological Footprint
- Global Warming
- Emissions and Toxicity
- Population

CO2 emissions:
- North America
- Europe
- Asia
- Middle East & North Africa

Global average temperature:
- Fahrenheit
- 60.5°
- 59.5°
- 58.5°
- 57.5°
- 56.5°

World population:
- 9.0 billion
- 8.0 billion
- 7.0 billion
- 6.0 billion
- 5.0 billion

Kentucky Association of Manufacturers Conference:
- May 8-9, 2018
- Lexington Center
Sustainability as the Basis for Sustainable Growth and Value Creation

- Sustainability is a *global phenomenon*
- Sustainability *IS NOT* Sustainment, but is the basis for *sustainable growth and value creation*

- Designing *sustainable products* and developing *sustainable manufacturing processes* have been a major research focus in *sustainable manufacturing*
The Foundation of Sustainable Development

Sustainable Development

- Economy
- Technology and Human Resources
- Society
- Environment
- Education & Training
- Innovation
- Creativity
Sustainable manufacturing at *product, process and systems* levels must:

- demonstrate reduced *negative environmental impact*,
- offer improved *energy and resource efficiency*,
- generate *minimum quantity of wastes*,
- provide *operational safety*, and
- offer improved *personnel health*

while maintaining and/or improving the *product and process quality* with the overall *life-cycle cost benefits*.

*Source:* Jawahir et al. (2014) – Adapted from US Department of Commerce (2009)
Sustainable Manufacturing: Basic Elements

Expectations:

- Reducing *energy consumption*
- Reducing *water use*
- Reducing *waste*
- Reducing *material utilization*
- Enhancing *product durability*
- Increasing *operational safety*
- Reducing *emissions and toxic dispersion*
- Reducing *health hazards/Improving health conditions*
- Consistently improving *manufacturing quality*
- Improving *recycling, reuse and remanufacturing*
- Maximizing *sustainable sources of renewable energy*
Companies pursue sustainable manufacturing for six main reasons:

- Economic gains
- Social commitment to their community and to stakeholders
- Compliance with regulatory requirements by using fewer resources and hazardous chemicals
- Meeting consumer expectations
- Awards and media attention
- Hiring gains by being a successful sustainable manufacturing company.

Elements of Sustainable Manufacturing

Sustainable Manufacturing

Systems

Products

Processes
Circular Economy as an Emerging Solution

Current Practice: Take – Make – Use – Dispose

“Today’s goods are tomorrow’s resources at yesterday’s prices”

Walter Stahel, Founder-Director of the Product-Life Institute
Closed-loop Sustainable Manufacturing and Circular Economy (CE)
Holistic and Total Life-cycle Approach

Emphasis on all four product life-cycle stages
Closed-loop Material Flow – The 6R Approach

3R CONCEPT

MATERIAL PROCESSING

MANUFACTURING

USE

REMANUFACTURE

REUSE

RECOVER

RETIRED

TREATMENT & DISPOSAL

REDESIGN

RECYCLE

ECOSYSTEM & ENVIRONMENT

Source: Jawahir et al. (2006)
From Lean to Green to Sustainable Manufacturing

**Innovation Elements**
- Remanufacture
- Redesign
- Recover
- Recycle
- Reuse
- Reduce

**Sustainable Manufacturing**
(Innovative, 6R-based)

**Green Manufacturing**
(Environmentally-benign, 3R-based)

**Lean Manufacturing**
(Waste Reduction-based)

**Traditional Manufacturing**
(Substitution-based)

**Stakeholder Value, $**

Source: Jawahir and Dillon (2007)
Evolution of Sustainable Manufacturing

Exponential Increase in Value for all Stakeholders by Managing Embodied Energy and Material Flow in Closed-Loop Life cycles

6R-based approach enables a ‘Circular Economy’
Case Study: Life-cycle Cost Modeling for Sustainable Value Creation

Materials used in 787 body
- **Fiberglass**
- **Carbon laminate composite**
- **Carbon sandwich composite**
- **Aluminum/steel/titanium**

**Total materials used by weight**
- **Steel** 10%
- **Titanium** 15%
- **Aluminum** 20%
- **Composites** 50%
- **Other** 5%

**By comparison**, the 777 uses 12 percent composites and 50 percent aluminum.
Aero-engine Materials and Recent Lightweight Trends

Alloys melted by Timet:
- Fan & Compressor
  - 6-4 Titanium
  - 6-2-4-2 Titanium
  - 6-2-4-6 Titanium
  - 8-1-1 Titanium
  - 17 Titanium

- Fasteners, Externals
  - 6-4 Titanium
  - 55Nb Titanium
  - 3-2.5 Titanium
  - 6-2-4-2 Titanium
  - 425 Titanium
  - 17 Titanium

Alloys melted by SMC:
- Compressor
  - INCOLOY 907/909
  - INCONEL 718
  - UDIMET D979

- Combustion
  - NIMONIC 263
  - NIMONIC PK33
  - INCONEL HX
  - Alloy 230
  - INCONEL 718
  - UDIMET L605

- Turbine
  - INCONEL 718
  - Waspaloy
  - NIMONIC PE16
  - INCONEL 625
  - NIMONIC 75
  - NIMONIC 80

- Exhaust
  - INCONEL 625

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The automotive industry started to use aluminum primarily to **reduce the weight** of the vehicles.

Components such as piston, cylinder heads, car hood, doors, frames, wheel rims & radiators etc., are being substituted with aluminum, thus reducing fuel consumption, and thereby the Green House Gases (GHG). This also **improved vehicles speed and efficiency and reduced the pollution levels**.

*Source: Alcoa*

*Source: Kilometer Magazine (Audi A6 – 3.2L)*
Product/Process Innovation in Sustainable Machining

Problems associated with cutting fluid applications

- Indiscriminate use of cutting fluids
- Surface integrity and product life
- Operator health
- Machining cost
- Energy consumption
- Chip recyclablility

Conventional Flood Cooling

Sustainable Machining

- Dry machining
- Near-dry (MQL) machining
- Cryogenic machining
**Sustainable Products from Sustainable Processes**

*Cryogenic processing* (machining, burnishing, forming, friction-stir processing, grinding, etc.) of a range of aerospace, automotive and biomedical alloys for achieving

- **enhanced product quality, life performance and sustainability**
- **improved process sustainability**

Materials tested include:

- AA 7075-T651
- AA 7050-T7451
- Inconel 718
- Ti-6Al-4V
- Ni-Ti- SMA
- AZ31B Mg
- Co-Cr-Mo
- AISI 52100
- AISI 4140
- AISI 316L
- AISI 304
- AISI 419
- Porous tungsten
- CFRP Polymer
Concluding Remarks

• Next generation manufacturing requires visionary thoughts, long-lasting public-private partnerships and collaborations, greater research and educational programs, and stronger commitment from all stakeholders.

• Smart and sustainable manufacturing concepts are transformative, and offer a strong basis for implementing next generation manufacturing with visionary Industry 4.0 concepts and perspectives.

Our collaborative efforts for more impactful advanced manufacturing technology and workforce development can help make a difference!
16th Global Conference on Sustainable Manufacturing

Lexington, Kentucky, USA
October 2-4, 2018