SUSTAINABLE MANUFACTURING:
TRENDS AND RESEARCH CHALLENGES

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ABSTRACT
Sustainability is the only answer for guaranteeing a future to our generations. Natural resources are not infinite and the capacity of regeneration of the environment has been in the last years overestimated. Manufacturing is from one side still one of the most important driving force of our economy but on the other side is one of the main cause of natural resource consumption and CO2 emissions.
The presentation, after having introduced some of the most important social and economical megatrends, will address the most probable technical evolution paths of Sustainable Manufacturing, highlighting the role of the research and innovation in this key area. Roadmapping activities at European level will be discussed.
Sustainable Manufacturing: Trends and Research Challenges

Prof. Marco Taisch

TMT Conference, Dubai, 10-12 September 2012

Sustainable Development

“the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland-Commission 1987)

The Triple Bottom Line
Agenda

1. Social Megatrends
2. Environmental Megatrends
3. Natural resources Megatrends
4. Energy Megatrends
5. The answer from the Manufacturing Industry

What would a future generation look like?

Population pyramids for 2000 and 2050

Population by age, sex and educational attainment

European Union 2000

Africa

MEN

WOMEN

European Union 2050

Africa

Global Education Trend (GET) scenario 1

Million people

1 - The GET scenario is not derived from a simple assumption. It is based on the country’s educational expansion historical trend.

Source: Sank K.C. et al. 2015.Projection of populations by level of educational attainment, age, and sex for 176 countries for 2000-2050 IZIA.
Changing middle class

The European environment | State and outlook 2010

Car ownership rates projections

The European environment | State and outlook 2010
Demand for most resources has grown strongly since 2000, a trend that is likely to continue to 2030.

1 Only cereals.
SOURCE: Global Insight; IEA; UN Environment Program (UNEP); FAO; World Steel Association; McKinsey analysis.

Clean and healthy place to live ...
Clean and healthy place to live ...

Source: http://rs.resalliance.org/2008/12/04/visualizing-the-great-acceleration-part-ii/
Drilling technology during 100 years

Source: Stichting Materials innovation institute (M2i) 2009

Rare earth elements

Rare earth elements

A ton of cell phones would have:

- 3.5kg of silver
- 340 g of gold
- 140 g of palladium
- 130 kg of copper

(Hagelüken and Meskers 2008).

The World’s Water Supply

Freshwater availability

- About 97.5% of all water on Earth is salt water.
- Only 2.5% of all the water on Earth is freshwater.
- Around 75% of freshwater is found in Antarctica and Greenland ice caps.
- Most of the remaining freshwater lies too deep underground to be accessible or exists as soil moisture.
- Only 1% of the earth’s fresh water is available for withdrawal and human use.

The grey band represents the difference between the amount of water extracted and that actually consumed. Water may be extracted, used, recycled (or returned to rivers or aquifers) and reused several times over. Consumption is final use of water, after which it can no longer be reused. That extractions have increased at a much faster rate is an indication of how much more intensively we can now exploit water. Only a fraction of water extracted is lost through evaporation.

50 percent
The number of people who don't have access to the quality of water available to the citizens of Rome 2,000 years ago

Source: GE Citing Blue Planet Run, Smolan, Erwitt

Water/Energy Nexus

1. About 6-18% of a city’s energy demand is used to produce, treat & transport water
   - At times 60% of this water leaks and never reaches the end user!
2. Higher technology to treat impaired water requires higher energy demand
3. Declining reservoir levels reduce hydro generating capacity
4. Power generation requires large quantities of water
   - >50% of global industrial water consumption is used to generate power
5. Energy exploration & production generates large quantities of wastewater

Source: GE
Oil: Hubbert Peak


Hubbert Peak

Every year for the past 30 years, the world-wide oil industry has pumped more oil than it has discovered.

In the last 5 years, 15 billion barrels of new oil were found world-wide.

During the same 5 years, how many billions of barrels of oil were pumped out of the ground?

135
“Technologies and best practices could save between 18% to 26% of current primary energy use in global industry” (1)

(1) IEA, Worldwide trends in Energy Use and Efficiency, Energy Indicators, 2005
Why Energy Efficient Manufacturing?
– The Global Perspective

77% of GHG emissions are CO₂ emissions

Global GHG Emissions 2005

Non-Energy-Related CO₂; 60%
Energy-Related CO₂; 38%
Other GHG Gases; 23%

Global CO₂ Emissions 2005 per Sector

Transport; 38%
Manufacturing; 25%
Households; 12%
Services; 4%
Other; 21%

40% of reduction potential in industry from energy efficiency

Technology for reducing direct CO₂ emissions from industry, 2006-2050

Recycling and Energy Recovery; 9%
Fuel and Feedstock Switching; 21%
CCS (Energy and Process); 30%
Energy Efficiency; 40%

GHG – Greenhouse gas, CCS – Carbon Capture and Storage
Source: IEA 2008d, World Resource Institute 2011; data from 2005

Source: IEA 2009a

Direct CO₂ emissions in industry by sector and region

- Environmental regulations
- Customer demands
- Rising energy prices

Exhibit 1. Despite the Economic Downturn, Consumers Still Care About Green Products

Because the forces driving the green movement haven’t changed...

- Energy prices are still volatile
- Concerns about product and food safety are still high
- Governments remain interested in environmental issues
- There’s a more compelling business case than ever for reducing costs
- The environment is not getting any cleaner on its own

...consumer demand for green products is still rising

Development of prices of natural gas for industry


Note: Data are from a survey of more than 2,000 European adults with an annual income equivalent to $50,000 or more.

Motivation for Sustainable Manufacturing

We, as a species, are depleting many resources at a very rapid rate

Fresh water efficiency ~ 40%
Car efficiency ~ 25%
Light bulb efficiency ~ 2%

We, as engineers and managers, can have a significant impact on sustainability
But what is really Sustainable?

**Toyota Prius**
- 104 gCO2/Km
- 4.7L/100Km

**Seat Leon**
- 100 gCO2/Km
- 6.2L/100Km

**WV Polo**
- 108 gCO2/Km
- 4.0 L/100Km

Which one is the most sustainable?

What about the production process? And beyond the environmental impact?
The Three Major Dimensions of Sustainability

New engineering focus

<table>
<thead>
<tr>
<th>Environmental sustainability</th>
<th>Social sustainability</th>
<th>Economical sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Materials</td>
<td>- work practices and adequate working conditions</td>
<td>- economic performance</td>
</tr>
<tr>
<td>- Energy</td>
<td>- diversity and equal opportunities</td>
<td>- market presence</td>
</tr>
<tr>
<td>- Water</td>
<td>- relations with the community</td>
<td>- indirect economic impacts</td>
</tr>
<tr>
<td>- Bio-diversity</td>
<td>- social policy compliance</td>
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<tr>
<td>- Emissions</td>
<td>- consumer health and safety</td>
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<td>- Waste</td>
<td>- human rights</td>
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<td>- Product and services</td>
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<td>- Compliance</td>
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<tr>
<td>- Transport</td>
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</tbody>
</table>

Future engineering focus?

Source: N. DUQUE CICERI 2011

So far...

Population increasing rapidly
Resource (minerals, water, oil, energy) consumption increasing too fast
Not enough supply! Prices will sky rocket!
We need to be much more productive
Engineers and managers should take a holistic perspective of products/services from design, manufacturing, operation, transportation, and recycling
## Value Chain for Sustainable Innovation

### Design
- Green Marketing
- LCA
- Environmental break even point
- Design for Assembly
- Design for Disassembly
- Design for Maintenance
- Packaging Design

### Industrialization
- GSCM
- Supply Chain Collaboration
- Closed loop supply chain
- Reverse Logistics
- Eco fleet

### Procurement
- Energy Efficiency
- Production Planning
- Quality Management
- New Technologies

### Production
- Combined Transport
- Transport Improvement
- Delivery Routes
- Logistic plants sharing

### Distribution
- Sensitization
- Communication
- Training

### Use
- Recycle
- Remanufacturing
- Reconditioning
- Repair
- Reuse

### Recycle
- Prevention
- Recycling
- Disposal technologies

### Information System
- EDI, ERP, CRM
- Knowledge management
- LCDA + Embedded technologies

### Organization and Human Resources
- Empowerment
- Sensitization, Corporate culture
- Commitment, Premium system
- Functional integration

### Planning and Control
- Supply chain integration
- Environmental monitoring
- Localization
- Servitization
- Certifications, Ecolabelling, Reporting
- Green Image, Environmental impact evaluation methods, Focus on environmental costs and benefits

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**THE FACTORY OF THE FUTURE**
The Strategy of the EU and the USA

The ActionPlanT Roadmap for Manufacturing 2.0

Main Components

Vision

- Based on 4 socio-economic and 4 ICT megatrends
- Proposes 5 ambitions for future enterprises
- Defines Manufacturing 2.0 vision with 5 R&D clusters

ICT Recommendations

- Takes a technology push view
- Expands 4 megatrends into 15 key ICT recommendations for implementation

Research Priorities

- 40 Research Priorities grouped according to 5 R&D clusters
- Integrated in the EFFRA FoF Roadmap

(C) ActionPlanT 2012
ICT Megatrends & Recommendations
Technology Push Perspective

Collaboration
- OEM – subcontractor collaboration through cloud paradigm
- Trends of contract manufacturing and ‘product as a service’
- Customer involvement in product design

Mobility
- Proliferation of mobile devices
- ‘On-the-go’ and ‘Always-on’ users
- New businesses (manufacturing apps & manufacturing app store)

Connectivity
- Sensors, controllers, embedded devices a commonplace
- ‘Intranet of Things’ to ‘Internet of Things’
- Bidirectional interaction with real-world objects

Intelligence
- Data analytics and forecasting on-the-fly
- Leveraging cheaper storage and low cost processors
- Better visualization & intelligence on manufacturing data

Human–centric Manufacturing

Ambitions for Manufacturing Enterprises

On-demand
- Accommodate changing demands & deliver customized products
- Make supply networks agile, interoperable, and manageable

Optimal
- Deliver high quality products that are durable and competitively priced
- Focus not only on the design but also on after-sales services

Innovate
- Faster introduction of collective innovation
- Short turnaround – from laboratory prototype to full-scale production

Green
- Reduce energy footprints on shop floors and increase End-of-Life (EoL) use
- Be compliant with new regulations

Human-centric
- Change perception from being production-centric to human-centric
- More accommodating towards needs of the workforce and customers
Beyond the Shop Floor
A Manufacturing 2.0 Enterprise

Agile Manufacturing Systems & Processes

- RP1.1 – Software for flexible and reconfigurable machinery and robots
- RP1.2 – Professional service robots and multimodal Human-Machine-Robot collaboration
- RP1.3 – Adaptive process automation and control for a sensing shop floor
- RP1.4 – Dynamic manufacturing execution environments for smarter integration
- RP1.5 – Monitoring, perception and awareness at the shop floor
- RP1.6 – M2M cloud connectivity for Manufacturing 2.0 enterprises
- RP1.7 – Mass customisation and integration of real-world resources
- RP1.8 – Intuitive interfaces, mobility and rich user experience at the shop floor

Seamless Factory Lifecycle Management

- RP2.1 – Integrated factory models for evolvable manufacturing systems
- RP2.2 – Intelligent maintenance systems for increased reliability of production
- RP2.3 – Integrated High-performance computing in Factory Life Cycle Management
- RP2.4 – Energy monitoring and management in Manufacturing 2.0 enterprises
- RP2.5 – Multi-level simulation and analytics for improving production quality and throughput
- RP2.6 – Services for continuous evaluation and mitigation of manufacturing risks
- RP2.7 – On-demand modular and replicative models for faster factory initialisation
- RP2.8 – Mobility suite for comprehensive factory performance management
People at the forefront

- RP3.1 – Enhanced visualisation of complex manufacturing and production data
- RP3.2 – New ICT-facilitated initiatives to engage younger generation in manufacturing
- RP3.3 – Advanced Information Models for knowledge creation and learning
- RP3.4 – ICT support to worker-process interaction and collaborative competence development
- RP3.5 – Next generation of recommendation systems for European workforce
- RP3.6 – Tools for worker behaviour tracking, monitoring, and analysis
- RP3.7 – Plug & Play interfaces for factory workers in dynamic work environments
- RP3.8 – Linked organisational knowledge for connected enterprises

Collaborative Supply Networks

- RP4.1 – Cloud-based Manufacturing Business Web for Supply Network Collaboration
- RP4.2 – End-of-Life (EoL) applications in a network of remanufacturing stakeholders
- RP4.3 – Mobile store and applications for an agile and open supply network
- RP4.4 – Connected objects for assets and enterprises in the supply networks
- RP4.5 – Complex Event Processing (CEP) for state detection and analytics in supply networks
- RP4.6 – Collaborative Demand and Supply Planning, Traceability, and Execution
- RP4.7 – Digital Rights Management (DRM) of products and code in supply networks
- RP4.8 – Multi-Enterprise Role-Based Access Control (mRBAC) in Manufacturing 2.0 enterprises
Customers in-the-loop

- RP5.1 – Manufacturing intelligence for informed product design
- RP5.2 – Solutions for energy-efficient product life cycles
- RP5.3 – Collaborative design environments for SME involvement
- RP5.4 – Crowd sourcing for highly personalized & innovative product design
- RP5.5 – Product servicing and recycling simulation for increased sustainability
- RP5.6 – ICT- and market-based costing and manufacturability assessment
- RP5.7 – Data collection and anonymization during product usage
- RP5.8 – Mobile maintenance and servicing cockpit for extended business offerings

Acknowledgements

- Prof. Vittal Prabhu, Penn State University
- Prof. Marco Garetti, Politecnico di Milano