Sustainability – Macros and Micro level understanding is critical

View 1: “Triple Bottom Line”
- **People**
- **Planet**
- **Profit**

View 2: Human Health
- Health effects of pollution
- Air pollution
- Water pollution
- Health impacts

View 3: Environment
- Life Cycle Thinking is Essential for Achieving Sustainability
- Pre-Design: Material
- Resources: Raw Material (Extraction and Transformation)
  - Water, Land, Energy
- Minimize this Flow
- Avoid Landfill
- Post use: Reuse, Recycle, Reclaim, Reduce
- Use: Services, Remanufacture
- Production: Products, Processes
- Optimize this Flow
- Macro level
- Sustainability – Macros and Micro level understanding is critical

- **Productivity**
  - Research focus – Resource efficiency
  - For manufacturing

- **Quality**
  - Cost

- **Pollution Prevention**
  - Greenhouse gases
  - Deforestation
  - Landfill
  - Water pollution
  - Air pollution
Life Cycle Thinking is core to understanding sustainability

LCE is a multi-disciplinary approach and it is the core of sustainable manufacturing

Mapping Sustainability to Porter’s Five Forces

The Five Forces That Shape Industry Competition

- Threat of New Entrants
- Bargaining Power of Suppliers
- Rivalry Among Existing Competitors
- Threat of Substitute Products or Services
- Bargaining Power of Buyers

Five forces of industry competition
An engineer view on “Urgent” Research Needs

1. Performance of Sustainable manufacturing
   a. A framework for metrics and measurement

2. Aspects of measurement science
   a. Classification of metrics, resources, processes
   b. V&V and UQ of models

3. Smart interconnected devices and technologies
   a. Big data and Predictive analytics
   b. IoT and smart technologies
1) A Framework for Metrics and Measurements for Sustainability Performance

**What to measure**
- Indicators /metrics
  - Life cycle (cradle to cradle and cradle to grave)
- Metrology
  - Accuracy
  - Precision
  - Units
  - Uncertainty
  - Reference data
  - Reference materials
  - Measurement methods
  - Predictive tools
  - Information models
  - Standards
  - Measurement devices
- Voluntary
  - GHG protocol
  - ISO 14000
  - ISO 19011
  - ASTM E60
  - IPC 1752
- Regulatory
  - RoHS
  - REACH
  - ELV
  - WEEE
  - USEPA

**How to measure**
- Data availability /Generation

**How to document**
- Standards based
  - Global Reporting Initiative (GRI)
  - Corporate Performance Disclosure (CPD)
  - Dow Jones

**How to verify/validate**
- Compliant based
  - GRI
  - CPD
  - Dow Jones

**Measure performance**
- International
  - EU
  - ECHA
  - EMAS
  - ISO
- National
  - Federal
  - State
  - Regional
- Private/Public partnership

**How to model different flows**
- Information, Energy, Material
2. Aspects of measurement science

- terminology and metrics (ontology)
- resources (material) information model
- classifying manufacturing process (ontology)
Sustainable manufacturing terminology (ontology)

- extensible schema, to classify a wide range of terms
- terminology as an ontology, capturing relationships to other terms and concepts
- interactive visual interface

![Diagram of Sustainable manufacturing terminology (ontology)]

Search:

**Product Category**

Definition: Group of products that can fulfill equivalent functions.

Source: [link](http://sourceforge.net/projects/novis/?source=directory)

Links to related documents

Intelligent querying

Detailed description of selected term, with links

Interactive visualization of networked information

http://sourceforge.net/projects/novis/?source=directory
Typology of Resources and its representation
What is the “language” for material information similar to the “language” for shapes - geometry
We also need a good Manufacturing Process Classifications

- Clustering of similar processes
- Easier grouping for purposes of analysis
- Sustainability characterization through understanding complex relationships

Facets

We need to expand V&V for Data-Driven Models.
Smart Technologies for deploying sustainable manufacturing

• Smart interconnected devices and technologies:
  – IoT, IIoT – Standards and protocols
  – big data analytics, smart sensors, mobile devices
  – cloud infrastructure, cyber security

Decision
Business and User Goals
Manufacturing Business Intelligence (web, desktop, mobile apps), Dynamic production system, Operations

Integration
Rules Engine, Distributed and real-time computing, Apps, APIs, Web Services

Analytics
Predictive Models, Algorithms, Analytics engine, Model composition, Uncertainty quantification

Data
Structured, multi-structured, Streaming, DAQ, Data pre-processing, Descriptive analytics

Manufacturing Execution System, Manufacturing Operations Management
SCADA, PLC, HMI, DCS

Real time/On time
Years -> Months -> Weeks -> Days

Timeliness
Hours -> Minutes
Seconds or less

* Extraction, cleaning, annotation

SCADA Supervisory Control and Data Acquisition
PLC Programmable Logic Controller
HMI Human Machine Interface