

Tutorial on the SMART-CN Education Modules for Incorporation in the Advanced Undergraduate or Graduate Engineering Curriculum

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**Paper 217 (g) in Graduate or Special Topics Courses: Course Development
and Best Practices**



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Outline

- Introduction
- Sustainable Manufacturing
- The SMART – CN
- SMART – CN Education Vision
- Modules Development
- Future Modules



Introduction

Perception of sustainable development by lecturers showed that only 34% believed their understanding was satisfactory and 24% suggested that it was good (Cotton et al., 2007)

In the same survey, over 50% of respondents wanted to include sustainable development related material in their teaching in following years.

Engineering Education has been facing challenges to integrate sustainability education in the curriculum due to:

- The wide array of topics in sustainability
- Absence of differentiation of sustainability rhetoric from engineering scope
- Lack of a uniform method of delivery

Sustainable Manufacturing

- Manufacturing is one of the most vital wealth-producing sector of the economy
- Sustainable manufacturing is one way of achieving sustainable development

“Sustainable manufacturing is defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers.” – **US Department of Commerce**¹

“Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community, and product safety.” – **US Environmental Protection Agency**²

“Sustainable manufacturing includes the manufacturing of “sustainable” products and the sustainable manufacturing of all products.” – **National Council for Advanced Manufacturing (NACFAM)**³

¹ http://www.trade.gov/competitiveness/sustainablemanufacturing/how_doc_defines_SM.asp

² <http://www.epa.gov/sustainablemanufacturing/index.htm>

³ <http://www.nacfam.org/PolicyInitiatives/SustainableManufacturing/tabid/64/Default.aspx>



The SMART - CN

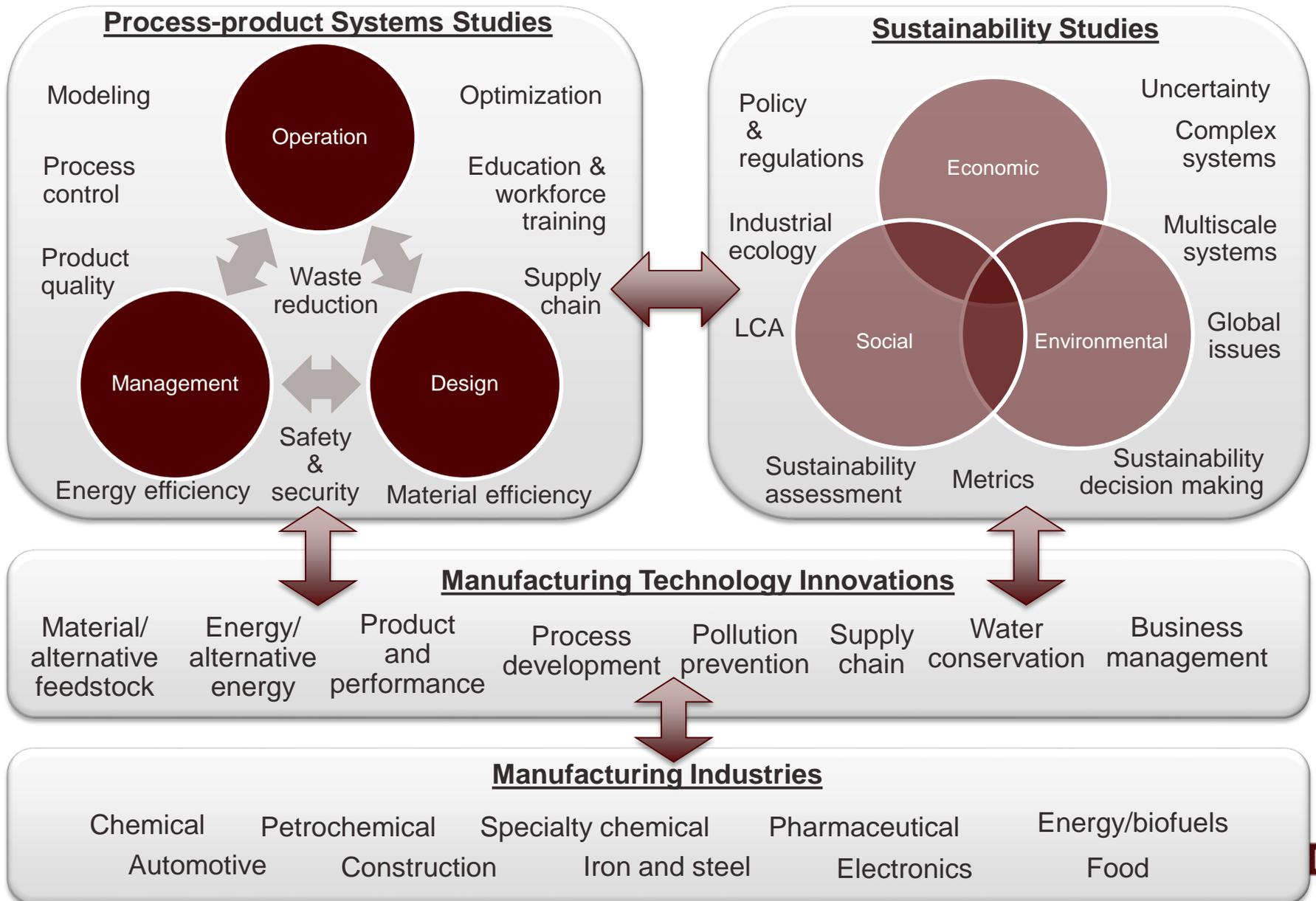
Sustainable Manufacturing Advances in Research and Technology Coordination Network (NSF RCN-SEES: SMART CN) aims to bridge the gap between academic knowledge discovery and industrial technology innovation for manufacturing sustainability

One of the key aims of the project is to conduct education and outreach to a wide range of stakeholders

- Sustainable manufacturing covers wide variety of topics extending beyond traditional textbook
- These topics combine several ideas and rationales found embedded in certain core concepts
- A lecturer needs to choose and construct a set of topics suitable for the sustainability assessment of a particular system
- Education is difficult because this area is still research oriented and few functional books have been written at the undergraduate level



Coordinated Research and Education on Sustainable Manufacturing



The SMART - CN

Sustainable Manufacturing

Multiscale Framework Required for Information Exchange

Technology
Development

- New Product Development
- Alternative Feedstock and Materials
- New Pathways and Processes

Process and
Systems
Management

- Process Design
- Plant Operations
- Materials and Energy Management

Enterprise
Management

- Supply Chain Management and Logistics Optimization
- Information Management
- Enterprise Framework

Education/Outreach



The SMART – CN

Themes identified as challenges to sustainable manufacturing in SMART CN Workshop, Cincinnati, OH, 2013

- Standards and platforms for information exchange
- Clear definition, semantic understanding
- Pervasive adoption of sustainable practices
- Comprehensive characterization and quantification of manufacturing processes including metrics
- Comprehensive, interoperability in life-cycle assessment
- **Cross-discipline sustainability education**
- Model-based assessment and control for sustainability
- Data access for sustainability
- Optimized product design, including sustainability
- Systematic sustainability achievement



SMART – CN Education Vision

Sustainable Manufacturing

Multiscale Framework Required for Information Exchange

Technology
Development

Process and
Systems
Management

Enterprise
Management

- **New Product Development** – Thermodynamics, chemistry, molecular modeling
- **Alternative Feedstock and Materials** – Chemical properties for new feedstock, seamless integration into design software
- **New Pathways and Processes** – catalysis, reaction pathway synthesis, environmental releases

Learning criteria for students/workforce: Identify (develop if necessary) indicators and metrics for assessment and management of sustainable technologies



SMART – CN Education Vision

Sustainable Manufacturing

Multiscale Framework Required for Information Exchange

Technology
Development

Process and
Systems
Management

Enterprise
Management

- **Process Design** – process integration, process intensification, process optimization
- **Plant Operations** – advanced control systems, process safety, environmental control systems
- **Materials and Energy Management** – can be integrated into process design area through the integration and intensification methods

Learning criteria for students/workforce: Identify (develop if necessary) technologies, indicators and metrics for assessment and management of process systems. Incorporate this knowledge into various stages of design and operations



SMART – CN Education Vision

Sustainable Manufacturing

Multiscale Framework Required for Information Exchange

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Management

- **Supply Chain Management and Logistics Optimization** – life cycle assessment (for environmental impact assessment), optimization (for logistics, cost), life cycle optimization (for both economic and environmental assessment of supply chain)
- **Information Management** – tools, data, information related to success stories, case studies for enterprise managers
- **Enterprise Framework** – systems analysis for studying impacts of entire supply chain

***Learning criteria for students/workforce:** Identify (develop if necessary) methodologies for systematic analysis of sustainability of enterprise. Crucial to include all aspects of sustainability, such as economic, environmental, and social. Can be expanded to include cross-cutting areas such as safety.*



Course Type 1 – Integrating into Existing Coursework

- The approach for this course is to develop modules which **COMPLEMENT** existing engineering discipline course curriculum with sustainability approaches.
- Instructors may choose to incorporate the case studies in these modules into the individual courses.
- Social criteria is not included in this section. It is expected to be incorporated into existing liberal arts coursework that students have to take in their degree.

Thermodynamics
Mass Transfer
Heat Transfer
Reaction Engineering
Transport Phenomena



Molecular modeling
Green chemistry
Environmental impact potential
Resource use
Energy use

Engineering Design



Process integration
Process intensification
Process safety
Metrics/Indicators/Indices

Process Control and Optimization



Environmental control variables
Optimum points for economic and environmental issues

Supply Chain/Operations Management

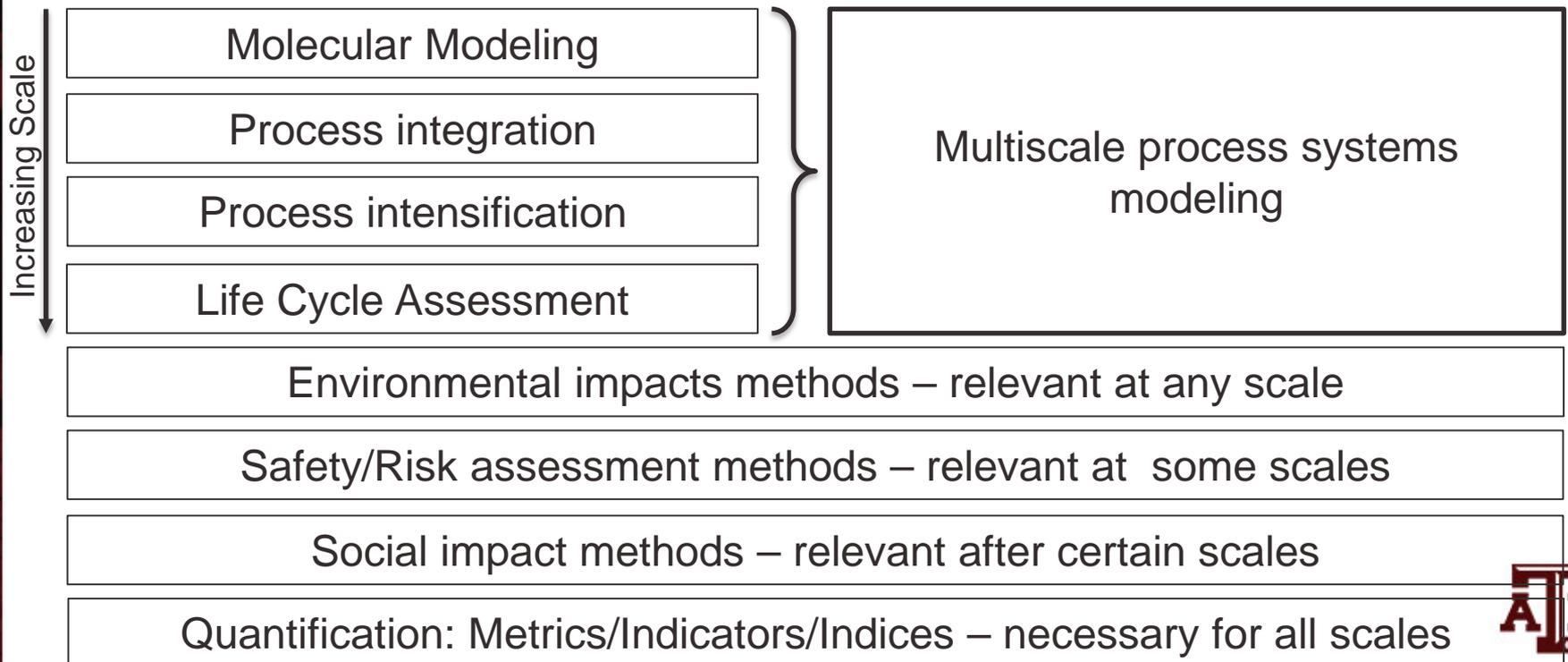


Life Cycle Assessment
Supply Chain Optimization



Course Type 2 – Introducing New Coursework

- The approach in this course type is to **ADD** a topic to existing engineering discipline courses, at par with engineering design.
- Suggested title: “Sustainability approaches in Engineering”.
- Single instructor, or a group of instructors, specializing in the individual areas.
- Requires coordination among the instructors to time and devise homework/exams.
- Introduction of certain social aspects require interdisciplinary coordination from social sciences instructors.



Course Type 3 – Short Courses Directed towards Specific Manufacturing Sector

- The approach for this course is to **CATER** to the needs of existing industry professionals to understand, integrate, and measure sustainability approaches in their sector.
- This may be a classroom instruction course, **Massive Open Online Course (MOOC)**, or standard slideshow based course
- Developing this will require the following knowledge and dissemination plan:

Knowledge of Industrial Sectors

(can be categorized based on NAICS/SIC codes)

Knowledge of Sustainability Implementation Areas

(for example, petroleum refineries need to be profitable, safer, low emission, and built in areas such that environmental justice is not violated)

Develop Specific Module Based on the Knowledge of The Sustainability Implementation Area

- Course module takes an existing refinery, follows it through the various stages of design to implementation (Front End Engineering Design, Site Selection, HAZOP/HAZID studies, Environmental Permits and Regulations, Construction and Management, Operations)
- Plugs in the sustainability criteria knowledge (through modules) into the stages of design
- Identify a set of key indicators and metrics required to assess sustainability over the life cycle of the sector

Example: Petroleum Refining Manufacturing Industry



Course Type 1- Structure

Outline/Overview (Word® document)

- **Introduction** (*max 500 words, excluding figures*)
Key aspects of module, e.g. “What is LCA?”, “Why is LCA needed?”, “Overview, framework for LCA”
- **Rationale: <Life Cycle Assessment> for ensuring Sustainable Engineering** (*max 300 words*)
e.g. Why do we need LCA for sustainable engineering/manufacturing?
- **Course Content: <LCA theory, methods, tools and databases>** (*max 3000 words to ensure most important information is provided in the text, excludes figures, use of appendices for additional information*)
- **Connections to Existing Core Curriculum** (*max 200 words*)
e.g. Which areas in existing courses can LCA fit into? Who should know about LCA?
- **Case study** (*max 300 words, short description*)
- **References and Websites for Further Reading**
- **Appendices**



Course Type 1- Structure

Classroom Presentation (Powerpoint® slides)

- ~ 40-50 slides, including case study
- Ready for use by instructor, specific delivery instructions (e.g. when to administer a certain case problem) provided in the notes
- Can also be used by individuals seeking self-study options

Case Study (Word® document)

- No word limits
- Case study can be describing a single problem with multiple example options
- The solutions are provided in most cases, with specific instructions on the solution methods used

Supporting Material

- All supporting material provided (spreadsheets, solution manuals, computer programs, design files)



Module Categories

Methods for Sustainable Manufacturing

Focus on the method of assessment of sustainability

Sustainable Manufacturing Processes

Focus on the process(es) for manufacturing

Dedicated Assessment Tools

Assessment platforms for Sustainable Manufacturing

Modules

Module Name	Developer/ University	Module Content
Assessment of the Presidential Green Chemistry Award Winners using Green Chemistry Metrics	Christopher L. Kitchens/Clemson University	<p>Method Topic: This module evaluates the work that has received the Presidential Green Chemistry Challenge Award using green chemistry metrics, principles, and design strategies.</p> <p>Assessment Tools: The first part is to perform a critical review of the awarded technology. The second part of the assignment requires students to contact the award winners by whatever means necessary, and interview them on 1) what the PGCC Award has meant to them and their career and 2) what personal benefit have they gained from working the award winning technology</p> <p>Supporting Documents: Sample interview responses, assessment of Ibuprofen production by green technology, awarded Green Chemistry award in 1997</p> <p>Learning Outcomes: Develop an appreciation of the Green Chemistry pathways and challenges through a case study based approach on the awarded winners</p>



Modules

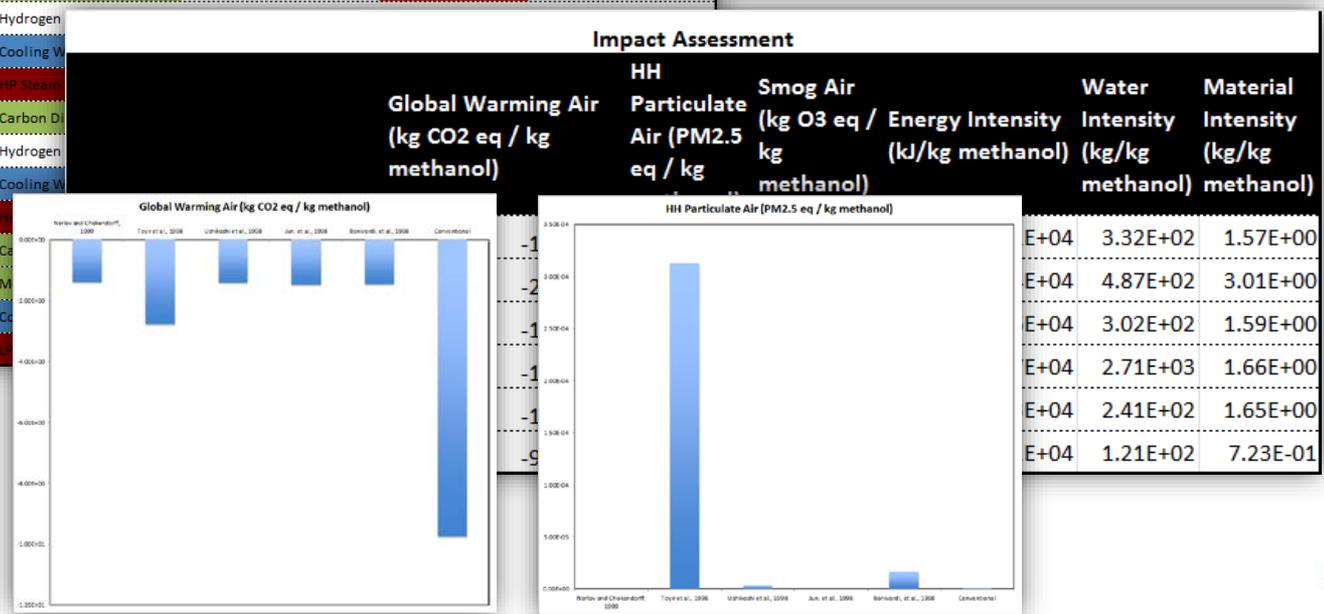
Module Name	Developer/ University	Module Content
Life Cycle Assessment for Sustainable Manufacturing	Debalina Sengupta, Texas A&M University	<p>Method topic: Provides overview of life cycle assessment methodology as outlined in the ISO standards, Emphasize the utility for the LCA methods for manufacturing sustainability</p> <p>Assessment tools: Case study for a chemical production process choice for methanol, assignment set</p> <p>Supporting documents: spreadsheet tool demonstrating case study</p> <p>Learning Outcomes: Understand the role of process engineers in providing effective inventory data for LCA, conduct screening level LCA studies for sustainable manufacturing</p>



LCA Module Example

Inventory of Inputs and Outputs			
Process	Input Streams	Flow Rate (Kg/hr)	Flow Rate (kg/kg methanol)
Nerlov and Chokendorff, 1999	Carbon Dioxide	75,540	1.38E+01
	Hydrogen	10,380	1.90E-01
	Cooling Water	18,160,000	3.32E+02
	HP Steam	776,000	1.42E+01
Toyir et al., 1998	Carbon Dioxide	151,400	2.76E+01
	Hydrogen	13,870	2.53E-01
	Cooling Water	26,740,000	4.87E+02
	HP Steam	1,205,000	2.20E+01
Ushikoshi, 2002	Carbon Dioxide	76,450	1.40E+01
	Hydrogen	10,420	1.90E-01
	Cooling Water	16,510,000	3.02E+02
	HP Steam	693,000	1.27E+01
Jun, et al., 1998	Carbon Dioxide	79,740	1.46E+01
	Hydrogen		
	Cooling Water		
	HP Steam		
Bonivardi, et al., 1998	Carbon Dioxide		
	Hydrogen		
	Cooling Water		
	HP Steam		
Conventional Process	Carbon Dioxide		
	Hydrogen		
	Cooling Water		
	HP Steam		

TRACI Characterization Factors			
Compound	Global Warming Air (kg CO ₂ eq / kg substance)	HH Particulate Air (PM2.5 eq / kg substance)	Smog Air (kg O ₃ eq / kg substance)
Carbon Dioxide	1	-	-
Methanol	25	-	-
Carbon Monoxide	-	3.56E-04	5.56E-02
Methanol	-	-	6.72E-01



Modules

Module Name	Developer/ University	Module Content
Sustainability Metrics and Sustainability Footprint Method	Debalina Sengupta, Texas A&M University	<p>Method topic: Provides overview of methods to compute sustainability metrics. It also gives a method compute overall sustainability by aggregating metrics.</p> <p>Assessment tools: Two case studies are presented on automotive shredder residue treatment method and on automobile fender formulation.</p> <p>Supporting documents: spreadsheet tool demonstrating case study</p> <p>Learning Outcomes: Understand the metrics used for measuring sustainability, compute these metrics, and then use the sustainability footprint method to decide which is the best option among these.</p>



Modules

Module Name	Developer/ University	Module Content
Sustainable process design	Jeffrey R. Seay, Assistant Professor, University of Kentucky	<p>Method Topic: Introduces the concept of green chemistry for green design of processes, gives three methods for assessing “greener” processes: The WAR Algorithm for computing the potential environmental impact (PEI) of a process, Life Cycle Assessment for assessing environmental and other impacts, and inherently safe process design.</p> <p>Assessment Tools: Case study for assessing sustainability of acrolein production, assignment set for pre-test on sustainability and five guided enquiry activities.</p> <p>Supporting Documents: Aspen Plus design files for acrolein production</p> <p>Learning Outcomes: Learn the theory for green chemistry, green engineering, and sustainability assessment methods</p>



Modules

Module Name	Developer/ University	Module Content
Sustainability Root Cause Analysis (SRCA)	Helen H. Lou, Professor, Lamar University	<p>Method Topic: Demonstrates Sustainability Root Cause Analysis (SRCA) as a tool to determine the bottlenecks for a system's progress towards sustainability. The framework is built on the combination of Pareto chart and the Fishbone diagram, in conjunction with a set of sustainability metrics (economics, environmental and safety).</p> <p>Assessment Tools: Three case studies with assignment set on steam reforming of methane, polygeneration, and LNG process</p> <p>Supporting Documents: ASPEN Plus design files for the case studies</p> <p>Learning Outcomes: Learn how to combine quality assessment method of Root Cause Analysis (RCA) and sustainability metrics to determine a sustainable manufacturing process</p>



Modules

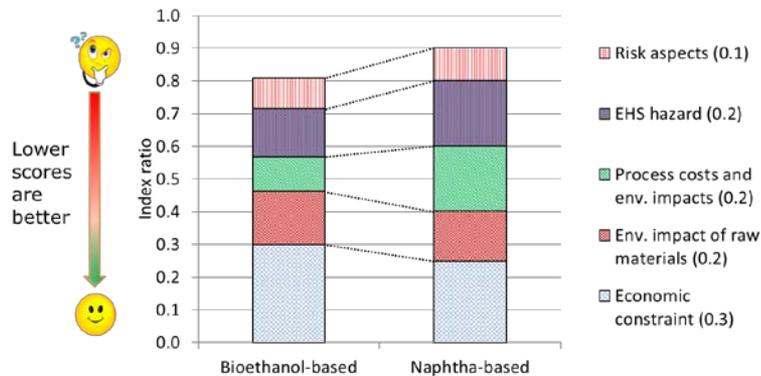
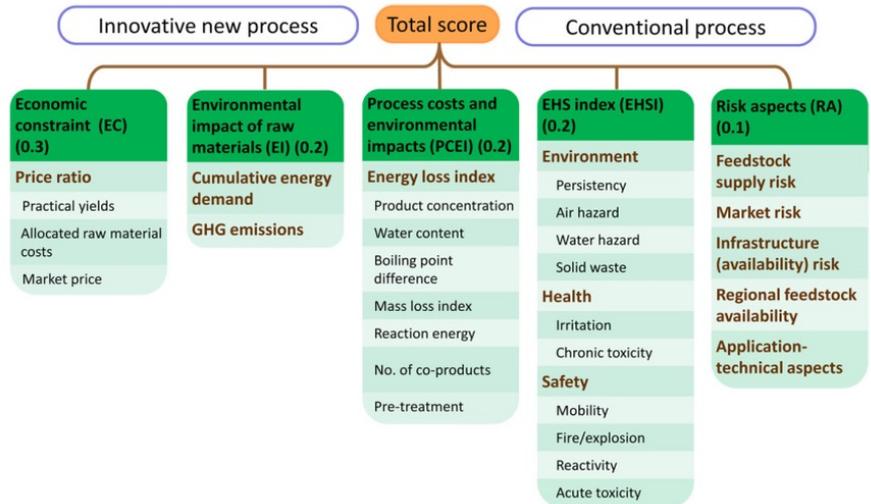
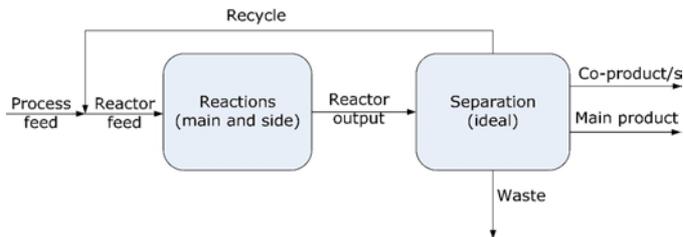
Module Name	Developer/ University	Module Content
Optimization and Uncertainty for Green Design and Industrial Symbiosis	Dr. Urmila Diwekar, Vishwamitra Research Institute and Dr. Yogendra Shastri, IIT Bombay	<p>Method Topic: Demonstrates the use of optimization methods for sustainable manufacturing. Incorporates systems theory as a valuable tool to enable the integration of multi-scale, multi-disciplinary components using an informational and computational platform.</p> <p>Assessment Tools: A case study on mercury waste management from coal power plants, divided into several sub-modules to demonstrate model formulation and solving.</p> <p>Supporting Documents: GAMS codes, solution files</p> <p>Learning Outcomes: Learn how to use optimization methods as a tool to formulate and solve issues related to sustainable manufacturing</p>

Modules

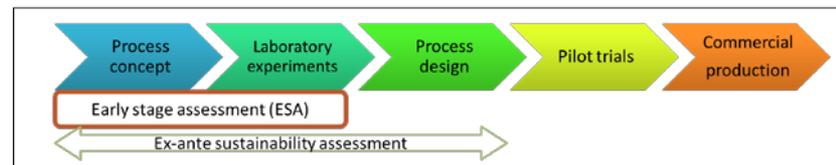
Module Name	Developer/ University	Module Content
Early Stage Sustainability Analysis Tool - EarlySim	Akshay Patel/SustAnalyze /Utrecht University	<p>Tool: This module provides an early stage chemical process assessment tool. The tool can be used for sustainability assessment in the areas of economic constraints, environmental impact of raw materials, process costs and environmental impact, EHS index, and Risk aspects.</p> <p>Assessment Tools: The module provides a link to a tool available online, instructions on how to use the tool and learning modules.</p> <p>Supporting Documents: Dedicated tool online access, Learning modules, walkthrough for case studies</p> <p>Learning Outcomes: Learn to analyze sustainability issues through a tool based learning environment</p>



EarlySim Tool



Index Ratio = 0.90
Bioethanol Score / Naphtha score



Modules

Module Name	Developer/University	Module Content
Atomic Layer Deposition Nano-Manufacturing Technology	Chris Yuan/University of Wisconsin, Milwaukee	<p>Process Topic: This module on atomic layer deposition (ALD) focuses on the study of energy usage and exergy efficiency, simulate reactions inside ALD system and analyze ALD deposition and emissions.</p> <p>Assessment Tools: A design of experiments based assessment of ALD process with sustainability considerations, Minitab example to run DOE</p> <p>Supporting Documents: Detailed process description, experimental requirements, and design of experiments description for sustainability assessment of ALD process</p> <p>Learning Outcomes: Learn details of ALD concept, manufacturing steps, model formulation for DOE, and benefits of sustainable manufacturing principles applied to ALD</p>

Modules

Module Name	Developer/ University	Module Content
Optimal Design and Operation of Reverse Osmosis Desalination	Mingheng Li/California State Polytechnic	<p>Process Topic: Specific energy consumption (SEC) in reverse osmosis (RO) desalination is considered for sustainability of the water treatment process. The module focuses on case studies that help in the optimal design for RO with the sustainability concerns in energy consumption addressed.</p> <p>Assessment Tools: GAMS program files</p> <p>Supporting Documents: Supporting documentation on RO, homework problems</p> <p>Learning Outcomes: Learn about RO water treatment as a means to provide desalinated water, understand the key sustainability issues with RO desalination, and</p>

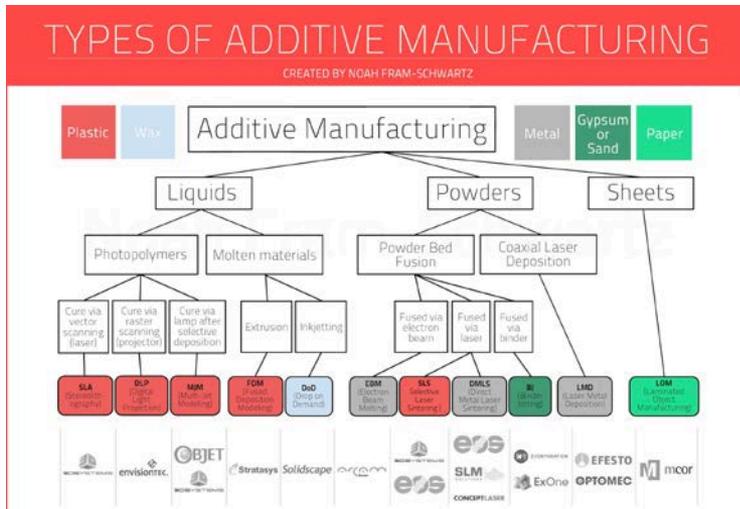
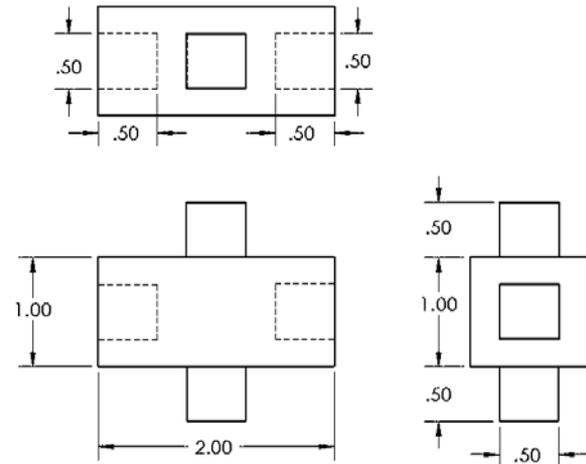
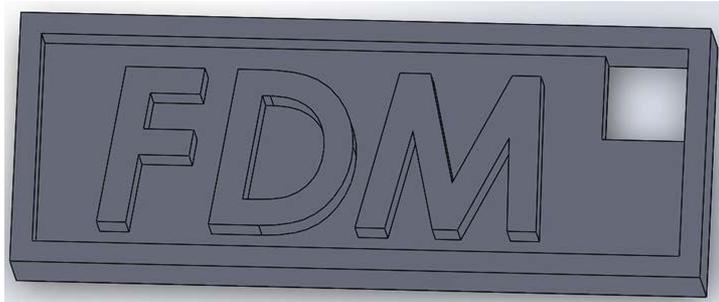


Modules

Module Name	Developer/ University	Module Content
Additive Manufacturing	Karl Haapala/Oregon State University	<p>Process topic: Provides a module that covers additive manufacturing as a means for sustainable manufacturing. This module explains the basics of additive manufacturing, and explores energy analysis as a metric to establish the benefits of AM.</p> <p>Assessment tools: Case study in the form of a hands-on laboratory that will educate students about the use of CAD and CAM tools in AM for developing a keychain.</p> <p>Supporting documents: CAD exercise file, Powerpoint presentations for different topics covered</p> <p>Learning Outcomes: Understand the basics of the new trend in additive manufacturing, have sustainability considerations in design, create effective low cost and low energy consuming manufactured goods.</p>



Additive Manufacturing Module Example



Think-Pair-Share

- What can be done to improve the efficiency of AM processes?
 - Process:
 - Problem:
 - Research:
 - Action:



Modules

Module Name	Developer/ University	Module Content
Sustainable Mitigation of Carbon Dioxide to Chemicals	Debalina Sengupta and Sherif Khalifa/Texas A&M University and Drexel University	<p>Process Topic: this module explores CO2 mitigation strategies through the utilization of CO2 into high value chemicals. A superstructure optimization model is formulated and solved for different scenarios.</p> <p>Assessment Tools: GAMS program files for several scenarios, homeworks</p> <p>Supporting Documents: Case study explanation files, background information documents</p> <p>Learning Outcomes: The module is intended to expand the knowledge on CO2 mitigation methods as a means to tackle climate change.</p>



Modules

Modules are made available through the following website:
Computer Aids in Chemical Engineering: <http://cache.org/super-store>



Future Modules

- Currently following modules are under development:
 - Tool:
 - Chemical Complex Analysis tool for Sustainability Analysis
 - Process Modeling and Life Cycle Analysis of 1,3-Propanediol from Fossils and Biomass: Instructor Materials
 - Process:
 - Sustainability of Battery Manufacturing
 - Characterizing and Managing Hydraulic Fracturing Water and Gas Production
 - Sustainable Shale Gas Monetization
 - Electrodialysis Membrane Distillation
 - Method:
 - Process Integration
 - Sustainability Cost Assessment for Manufacturing
 - Water-Energy Nexus
 - Biomass Feedstock Properties
- Help is sought in the academic community for knowledge dissemination and utilization of the modules



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