Sustainability Planning and Assessment – *Essential* Part of Biorefinery Design

Biorefinery Course
Amsterdam, The Netherlands

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Last century: Disrupted Cycles

- Metals/Minerals
- Biomass
- Petroleum

Refineries / Biorefineries

Blended Products

- Demand

Releases to Environment

Product Recovery
Reuse
Recycle

Fibres

- Fuels
- Chemicals

Energy

Feed

Enzymes

Other Renewable Energy

CO₂

“Recycled” Feedstocks

21st Century – Back in balance
Biorefineries are considered to be “part of the solution”

IEA Task 42 Biorefineries

- Biorefinery is the sustainable processing of biomass into spectrum of marketable products and energy.

- **Key Concepts**: Integration (technologies, feedstock to end-products) … Multiple products … **Sustainability**
  - Zero waste, efficient use of renewable resources, Profitable, create employment, supported by public, etc.
Biological Resources Provide ECOSYSTEM SERVICES +

Food

Animal Feed

Biobased Products

Biobased Products

Oils and Inks; Dyes and Pigments; Paints and Varnishes; Detergents and Cleaners; Industrial Adhesives; Biopolymers and Films; Composite Materials, etc.

Solid: Coke, Lignin, Bagasse

Liquid: Ethanol, Methanol, Biodiesel

Gaseous: Syngas, Methane, Hydrogen

Activated Carbon; Oxy Fuel Additives; Phenols and Furfural; Specialty Chemicals; Fatty and Acetic Acids; Industrial Surfactants; Agricultural Chemicals

Fuels, Energy

Biomaterials

Restorative Services

Pollution Control; Bioremediation; Soil Amendments; etc.

Health Products & Services

Biochemicals

* Figure adapted from Kamm
1. What is Sustainable Development?
2. Sustainability Planning
   - Approach: Strategic Sustainable Development to define sustainability goals and provide a framework for assessment
3. Sustainability Assessment
   - Status & review of tools
   - Early lessons learned in biorefinery design
4. Conclusions – *where we go from here*
1. Definition of Sustainable Development (SD)

Brundtland Commission (1987) defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their needs.”

- Our Common Future – World Commission on Environment and Development
- 1980s: technological advances of last decades resulted in high economic growth and improved standard of living but at the same time …
  - there were some serious environmental problems, and
  - a large divide between developed and developing nations.
How do we operationalize sustainable development? Put it into practice?

- Moving from Brundtland Definition (ends-oriented definition) to “means-oriented” definition of SD
- Development should support the natural and social systems on which it depends.

Respecting Interconnectivity - where progress in one dimension doesn’t make matters worse in another dimension.
Understanding the relationship between the 3 dimensions

Source: Dr. Carlos Licón, Utah State University, Evaluation Model of Sustainable Development Possibilities (2009)
2. **Sustainability Planning**

“What is our goal with respect to sustainability?”

- Propose a “relatively simple” systematic approach of backcasting from sustainability principles

- Start from fundamental principles

- Strategic Sustainable Development
Strategic Sustainable Development

Overall System

*the ecosphere – the anthropocene*

Success Level

(overarching principles)

Strategy Level

Actions

*concrete measures to meet desired outcomes*

Tools & Metrics

*assessing, managing & monitoring actions*

Focus of today:
Sustainable Biorefinery Design

- LCA
- LCC
- Social Impact Assessment
- Multi-Criteria Analysis
- Genuine Progress Index
- carbon footprint
- water footprint
**Fundamental Sustainability Principles**

Q: How do we influence natural cycles?

1. Relatively large flows of materials from the Earth’s crust

2. Introduce persistent compounds foreign to nature

3. Physically inhibit ability of nature to run cycles

4. Barriers to people meeting their basic needs worldwide

Source: The Natural Step Canada
Goal: To align with the 4 fundamental principles. That is, to reduce and eventually eliminate our contribution to:

1) the ongoing build-up of substances taken from the earth’s crust (e.g. metals, fossil fuels, etc.)
2) the ongoing build-up of substances produced by society (e.g. CFCs, CO$_2$, etc.)
3) the ongoing degradation of natural systems by physical means (e.g. permanent deforestation, etc.)
4) the conditions that undermine people’s capacity to meet their basic needs (economic and social)
The Natural Step – ABCD Process
Backcasting from Principles

Source: The Natural Step Canada
Good starting point for sustainable design

#1: Define what you want to achieve with respect to sustainability

- The Natural Step can be easily used to develop a sustainability framework in a short period of time (i.e. few months)
- Need a common sustainability language and common goals
  - *affordable course:*  http://www.naturalstep.org/elearning
- Adopt a “cradle to cradle” perspective – all life cycle stages
- Engage stakeholders in the different parts of the value chain
  - capture different interests, perspectives, backgrounds
  - “growing collective” – adding members over time
- Establish a dedicated communication and coordination function

Case Study: Experience using the Natural Step Framework for Strategic Sustainable Development of Canada’s Flax Industry by M. Wellisch, M. Beckie, L. Braun and S. Brooks
Metals & Minerals

Biomass

Petroleum

CO₂

Reduction of Rates of Extraction

Sustainable Production (Transformation)

Biobased Products

• Energy
• Fuels
• Chemicals
• Fibres

• Food
• Feed
• Health

Sustainable Consumption

Final Products

Use

Recycled Feedstocks

Benign Emissions

Disposal

Recycling

Closing the Cycles
3. Sustainability Assessment Evaluating Biorefinery Systems

Status:

- Integrated analysis of 3 dimensions of SD (economic, environmental and social) are just emerging
- Biorefinery systems:
  - Many Life Cycle Assessments LCAs (environmental) conducted of first generation biofuel systems
  - Few LCAs completed on more advanced (complex) systems
  - Most LCAs focus on only 2 parameters: non-renewable energy use and greenhouse gas emissions
  - Most LCAs estimate potential environmental loadings *(they do not measure environmental impacts)*

- Current situation: “energy and GHG analysis” of biorefinery systems, but not a comprehensive environmental or sustainability assessment
Simplified 1st generation Biofuel Biorefinery

Example:
1 – agricultural crop, forest
2 – black liquor (pulp mill)
3 – municipal solid waste

Lessons from the evaluation of 1st generation biofuel facilities

- Not all biofuels are created equal!
  - Type of feedstock (primary vs tertiary)
  - Process energy use (amount and type of energy)
  - Co products and byproducts (their uses, economic value, allocation of GHG emissions)

- Zah et al. (2007) only found 2 biofuel pathways that were better than their petroleum counterparts in all environmental categories. Impacts such as eutrophication, acidification and smog were greater for some biofuels than for gasoline/diesel. Most of these other environmental emissions were attributed to agricultural production (feedstock stage).

- Blenders want fungible or “drop-in” bioproducts.

- Consumers want to know that what they are doing is the “right thing”, i.e. not causing harm elsewhere.
Example: ADEME (France)

- Not all bioproducts are equal!
- In general, bioproducts use less non-renewable energy and emit fewer GHG emissions than their petroleum-based counterparts.
- No bioproduct is better in all environmental categories than another.
- Agro-based materials used in vehicle manufacture rate very high with respect to GHG reduction as they lower fuel consumption over a vehicle’s lifetime.
  - Help users of products reduce their footprint
- LCAs are not easily compared; review of methodological choices made in bioproduct LCAs was commissioned by ADEME
  - (Dec 2009) “Study for a Simplified Methodology Adapted to Bioproducts”
Environmental Assessments of “Product-Focused” Biorefineries

- Relatively fewer studies carried out.
- Example: IFEU (Heidelberg, Germany)
  - Modelling multi-product systems = complex
  - General tendencies: Lower use of non-renewable energy and lower GHG emissions
  - “Not always the case”; it depends on the specific “feedstock – conversion – product” configuration
- Four important factors:
  1. type of feedstock;
  2. how bioproducts are used;
  3. how co-products are used; and
  4. final product recycling, reuse and disposal patterns.
More complex biorefinery systems

Economic and Social Aspects

- Economics influenced by:
  - Use of existing infrastructure
  - Feedstock costs
  - Value/demand for co-products
  - Supportive policies & incentives

- Social Assessment - IPiEO (Warsaw, Poland) conducted a project under BIOPOL. Interviews of 8 demo or commercial scale biorefineries showed that they can:
  - retain and provide new employment opportunities;
  - revitalize existing industries;
  - promote regional development, especially in the R&D area.
Considerable work is underway!  

**different picture in 5 years time**

- International “standardization work”
  - Sustainability Principles, Criteria & Indicators – Bioenergy, Biofuels
  - OECD Best Practices for Evaluation of Bioproducts
  - UNEP Guidelines for Social Life Cycle Assessments of Products
  - Environmental Product Declaration (2012 ?)

- EU Biorefinery projects underway
  - FP7 – EuroBioRef, BIOCORE, SUPRA BIO,
    - Mandatory sustainability assessments
  - PROSUITE (Utrecht University) – open source software for sustainability assessment
4. Conclusions

- Sustainable design is expected by today’s society.
- Tools are available for sustainability planning and assessment … and several are in the pipeline for biorefinery applications.
- Biorefineries have the potential to play important roles in the development of a more sustainable economy.
  - Build on the use of renewable vs non-renewable resources, fewer GHG emissions, regional economic development, intergenerational equity, etc.
- However, the increased use of biomass for energy and materials requires land and water, and competes with ecosystem services and other human uses.
- The sustainable co-existence and positive contributions of biorefineries need to be shown – i.e. planned, evaluated and communicated.
Next Steps re: Sustainability Assessment - Knowledge Management

- More biorefinery applications!
  - Limited application of modelling and assessment tools due to budget constraints, lack of awareness of tools, absence of requirement, etc.
  - Identify and address hurdles (e.g. $, commitment)

- Build knowledge base and capacity
  - Databases
  - Integrated analysis
  - Interpretation

- Communicate for the 21st century
  - Science communicators
  - Value, risks, timeline, investment …

Life Cycle Costing
Social LCA (s-LCA)
Life Cycle Analysis
Process Modelling Software
Process & Communication Tools – stakeholder engagement
Thank You! / Dank u wel!

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Various life cycle stages of biorefinery systems
Three Groups of Biomass Feedstocks

- **Primary** = original starting material (valuable structure or complex carbohydrate chemistry); full environmental impacts related to production are accounted for.
- **Secondary and Tertiary** = pre-processed; lower cost; limited supply; environmental impacts related to production have already accounted for.

Primary feedstock issues include:
- Cost (farmer vs. processor)
- Jobs (local feedstock vs imported)
- Yields, land area, feedstock cost
- Emissions related to inputs (fertilizers, pesticides, etc.) are allocated to the biorefinery products
- GM crops
- Competition for land and/or water
- Land use change (e.g. indirect effects, loss of carbon, biodiversity)
- etc.
Biomass Feedstocks

Environmental Aspects

Biofuel LCAs:
- Estimate potential non-renewable energy use, greenhouse gas emissions
- Less information available on acidification, eutrophication, etc.
- In biofuel LCAs, the biomass feedstock stage can be the major source of environmental impact
  - “worst case” - primary feedstocks involving land use change in areas of rich biodiversity and high carbon stocks
  - “best case” – tertiary feedstocks (i.e. diverting waste from landfills and converting it into energy or fuel)
- Tradeoffs - use of nitrogen fertilizers and pesticides to produce a consistent, high yielding and affordable biorefinery crop has environmental impacts
Design Considerations

- Don’t neglect or underestimate feedstock development + production
- Example: Agriculture: seed supply, production, harvest, collection, cleaning, storage
- Balancing whole crop utilization, whole tree harvesting with residue/nutrient balances
- Agriculture: understanding the influence of crop rotation
- Opportunities for further feedstock development
  - New high yielding, low input crops that are easy to transform
  - Improving drought tolerance, water and nutrient efficiency of plants (i.e. use few inputs)
  - Green biotechnology – e.g. designing feedstocks that produce valuable compounds; designing crops that will be easier (require less energy or chemicals) to break down feedstock

Biomass Feedstocks

Breeding
Agronomy/Forestry

Crop Production
Harvest, Collection
Systems design (continuous) - combinations of technologies and operations that can “deal with” feedstock variability
- Separation / Fractionation; Thermochemical; Biochemical

Resilient systems – systems able to respond to change

Efficient transformation of biomass into Multiple BioProducts
- Derive value from all products
- System optimization (vs. focus on one product with “consequential byproducts”)

There are different ways of allocating benefits and impacts to biorefinery products
Lessons Learned

- Bioproduct selection
  - **Pull = product value and demand + sustainability goals**
  - **Push = policies and incentives (biofuel mandates, green energy premium, bioproduct procurement, etc.)**

- Not all bioproducts will have the same demand, benefits or impacts
  - Production cost, profitability
  - Environmental impacts
  - Industry acceptance of new products
  - Societal needs

- **What are your sustainability goals?**
Biomass / fossil product group comparison in terms of the “consumption of primary non-renewable energy” impact per functional unit and per unit surface area of cultivated land (Source: ADEME, 2004)
Lessons Learned

- Siting of facilities: locating near feedstock, co-locating with other industries (e.g. heat/power, process streams), mobile operations
- Conversion of existing facilities
- Energy balance / minimizing fossil fuel input; targeting “zero net energy”; purchasing only renewable energy
- Minimizing the “rucksack” or associated burden of all inputs (e.g. energy, chemicals, microorganisms, etc.)
- Estimating emissions of facilities and transportation activities to air, water, soil, etc.; targeting “zero waste”
- Good indoor air quality and low occupational H&S risks
- Contribute to a healthy community (e.g. avoid odours, excessive noise, spills; provide opportunities for dialogue, education, etc.)
Product Use - Lessons Learned

- Cradle to gate OR Cradle to grave?
- Many bio-based products are intermediate (vs final) products
  - what products are substituted, in what quantity
  - Impact of bioproduct on final product performance, longevity
- Bio-based content of final product (USDA Biopreferred Program)
- How is the final product used (e.g. in what way, for how long) can effect the net impacts
  - Example: materials using strong, light weight natural fibres
  - Bioenergy/biofuels applications have a very short lifespan VS. other bioproducts could have a lifespan of years or decades
Product Disposal – Lessons Learned

- Product “return to the environment” stage
- Design with the end in mind - “cradle to cradle”
- For each final product, need to know the pattern of recovery, reuse, recycling and disposal in final market
- In general, there is potential for greater separation, reuse as tertiary feedstock, etc.
- Compostability and biodegradability of final product?
- Energy recovery opportunities?

Closing the loop
Cascading from higher value to lower value products

Product Disposal
Environment
Beneficial (vs not harmful)
Sustainable Design
“Good Practices”

1. Acknowledge the Starting Point
   - Planet Earth is already damaged at some points and being increasingly stressed through population growth and the desire for higher standards of living.

2. Set sustainability goals with stakeholders
   - What is it that you want to achieve with respect to sustainability? (e.g. what does alignment with 4 sustainability principles look like for you?)

3. Don’t assume biorefineries or bioproducts are benign or automatically better than their conventional counterpart.
Influence Design from the start

- Evaluation of technical feasibility
- Techno-economic viability
- LCA
- Siting studies
- Socio-economic assessment
- Environmental Approval (facility)
- Public consultation
- Market studies
- Concept
- R&D
- Pilot
- Demonstration
- Pre-Commercial
- Investment $
More “good practices”

4. Start early – Influence design *from the start*!

5. Adopt a Life Cycle Thinking approach
   - LCT is key to avoid: shifting problems from one life cycle stage to another; creating new problems; and addressing only “flavour of the month”

6. Use an inclusive, multi-disciplinary team approach
   - More than technical knowledge is needed

7. Identify the stakeholders and their respective roles with respect to biorefinery development
   - e.g. involve stakeholders in defining goals, communication, participatory technology assessment, etc.

8. Pass on your sustainability learning to the next stage of development (e.g. bar code)