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

Biorefinery Course

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September 13, 2010

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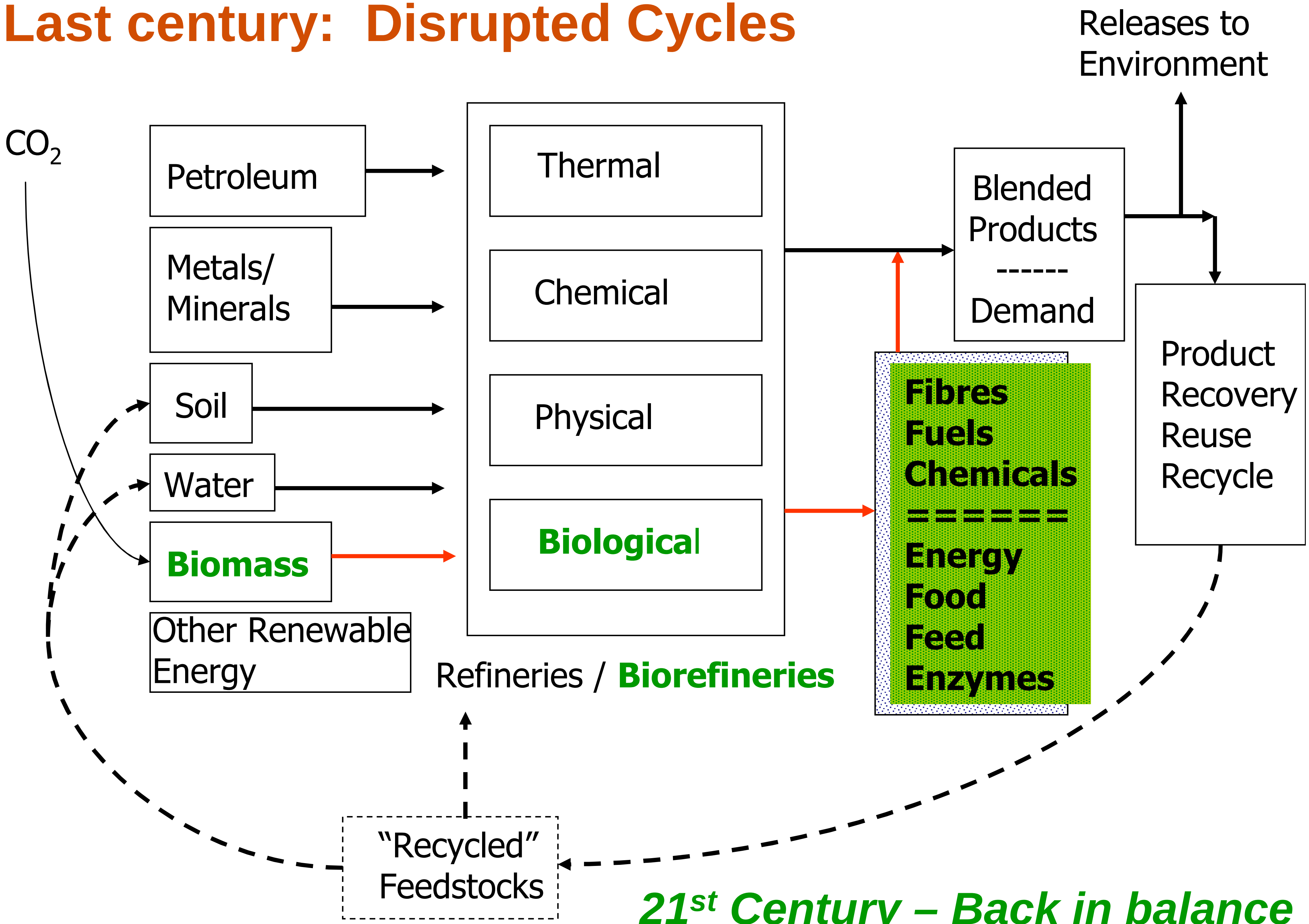
Canada

Last century: Disrupted Cycles



21st Century – Back in balance

Biorefineries are considered to be “part of the solution”

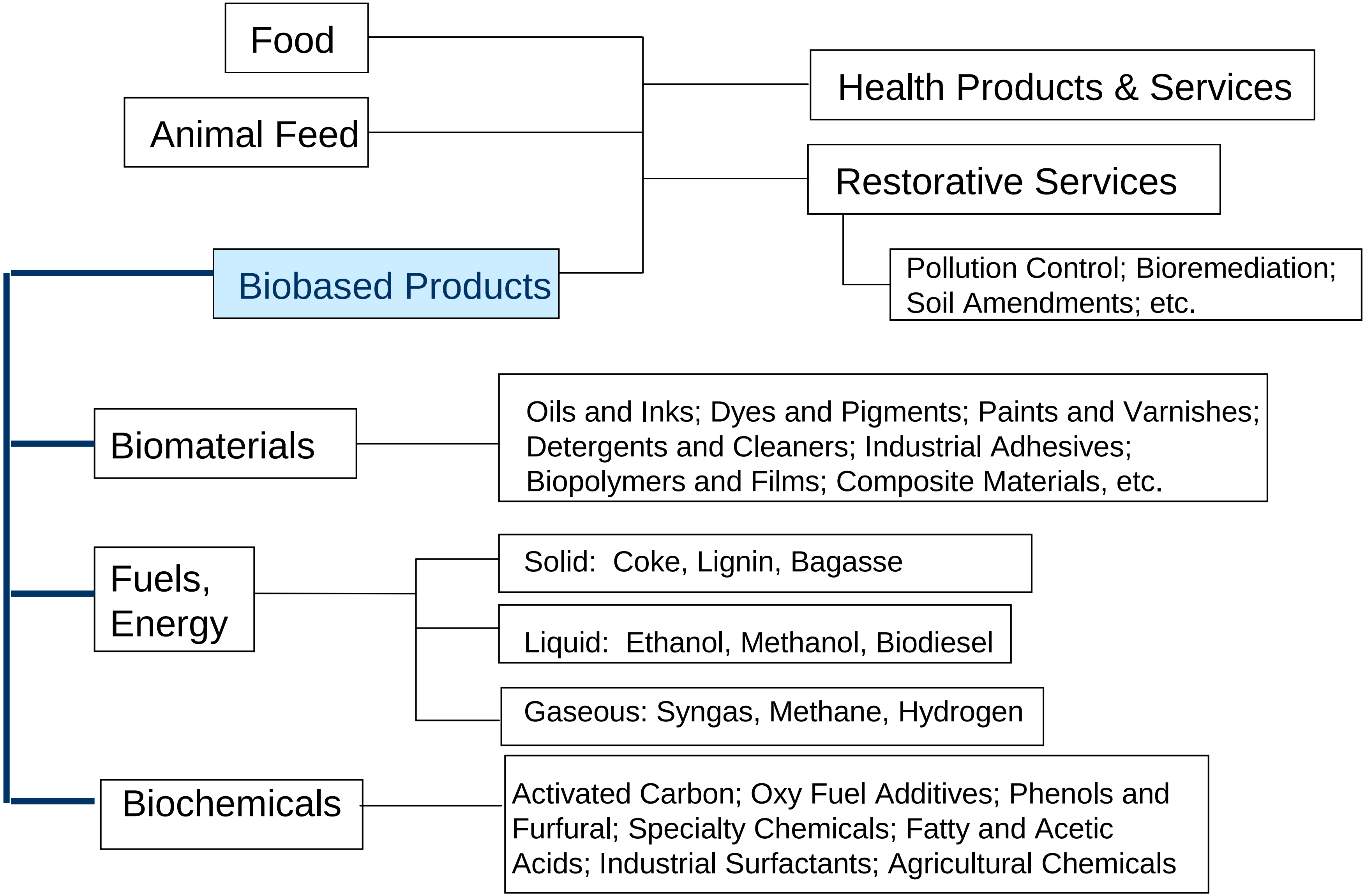
IEA Task 42 Biorefineries

- 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 +



** Figure adapted from Kamm*

Content

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"*

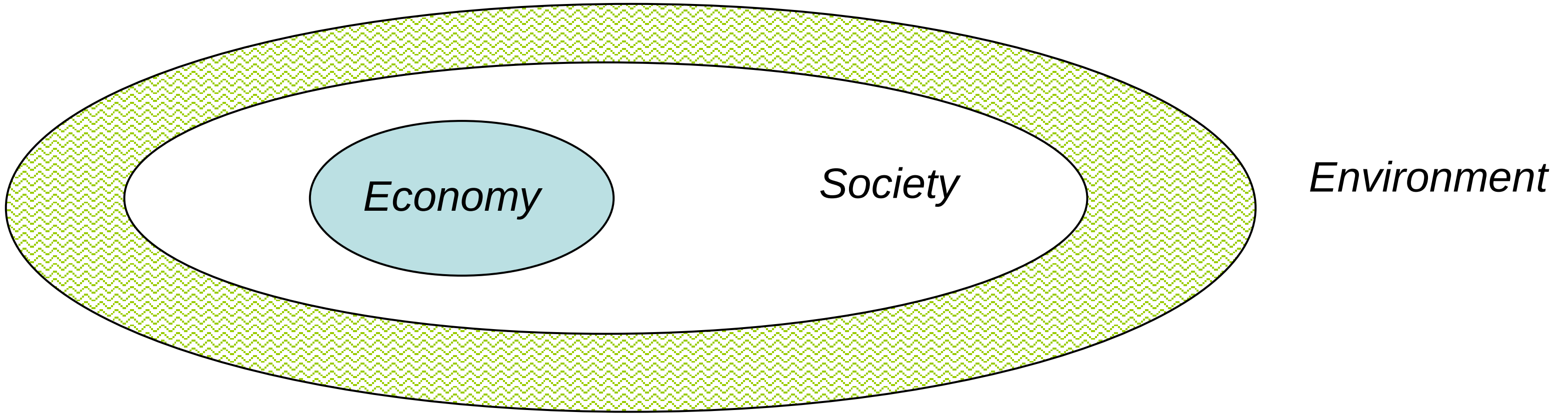
- Our Common Future – World Commission on Environment and Development
- 1980s: technological advances of last decades resulted in high economic growth and improved standard of living

  but at the same time …

  - there were some serious environmental problems, and
  - a large divide between developed and developing nations.

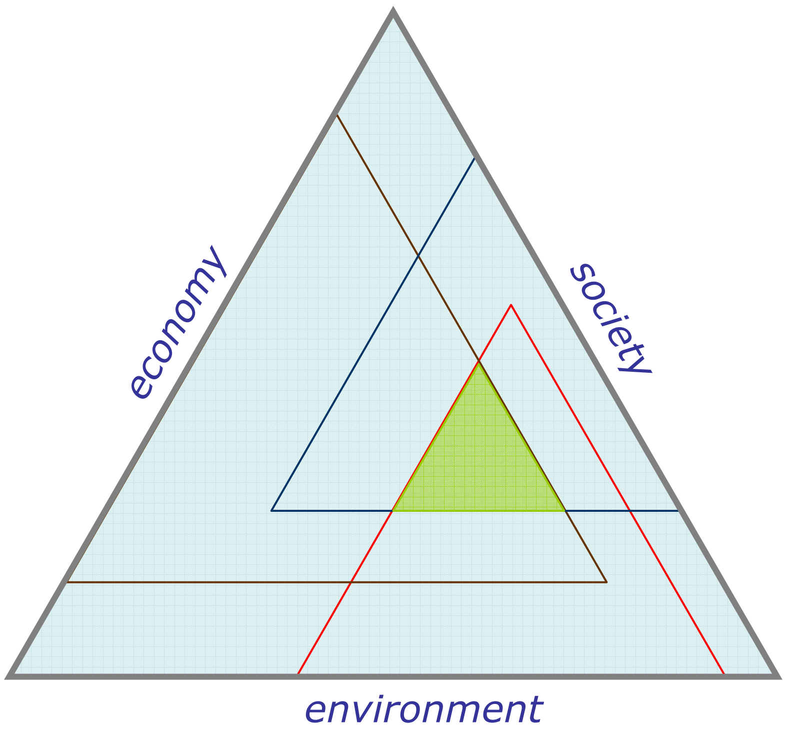
How do we operationalize sustainable development ? Put it into practice ?

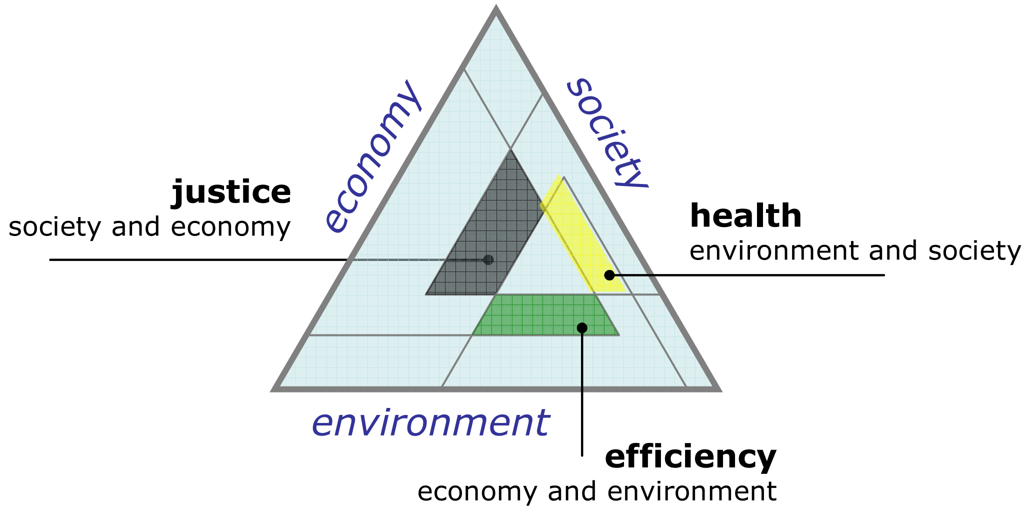
- Moving from Brundtland Definition (ends-oriented definition) to “means-oriented” definition of SD
- Development should support the natural and social systems on which it depends.

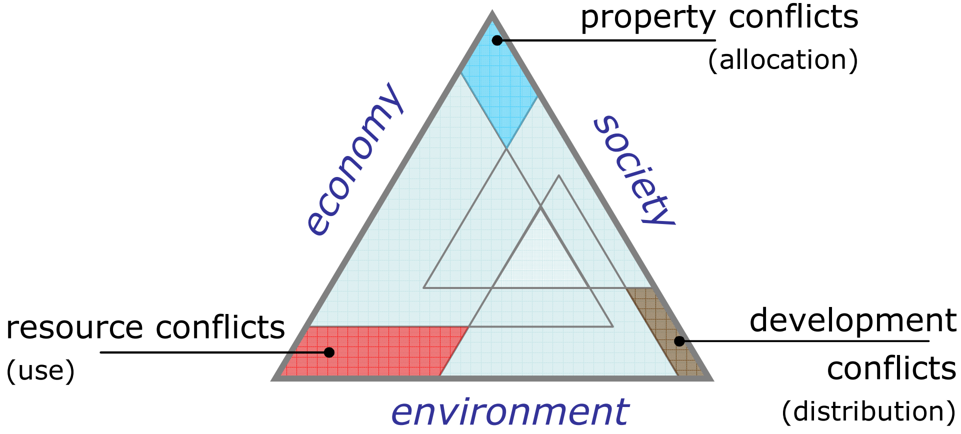


Respecting Interconnectivity - where progress in one dimension doesn’t make matters worse in another dimension

Understanding the relationship between the 3 dimensions







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

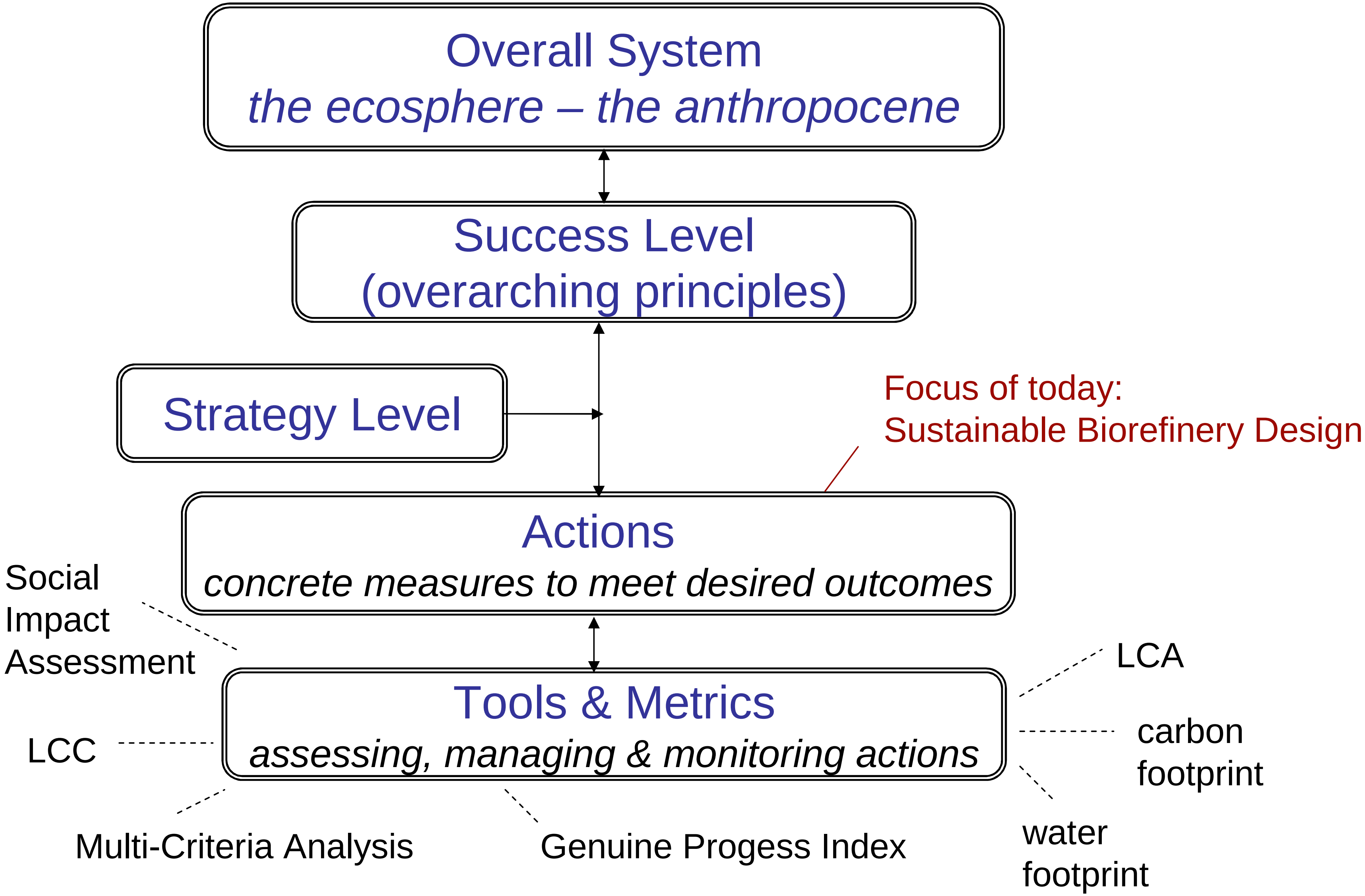
2. Sustainability Planning "What is our goal with respect to sustainability?"

- Propose a "relatively simple" systematic approach of backcasting from sustainability principles
  - The Natural Step http://www.naturalstep.org/

- Start from fundamental principles
  - Broman G, Holmberg J, Robèrt, K-H, Simplicity without Reduction – Thinking Upstream Towards the Sustainable Society, *Interfaces* 30: 13-25 (2000)

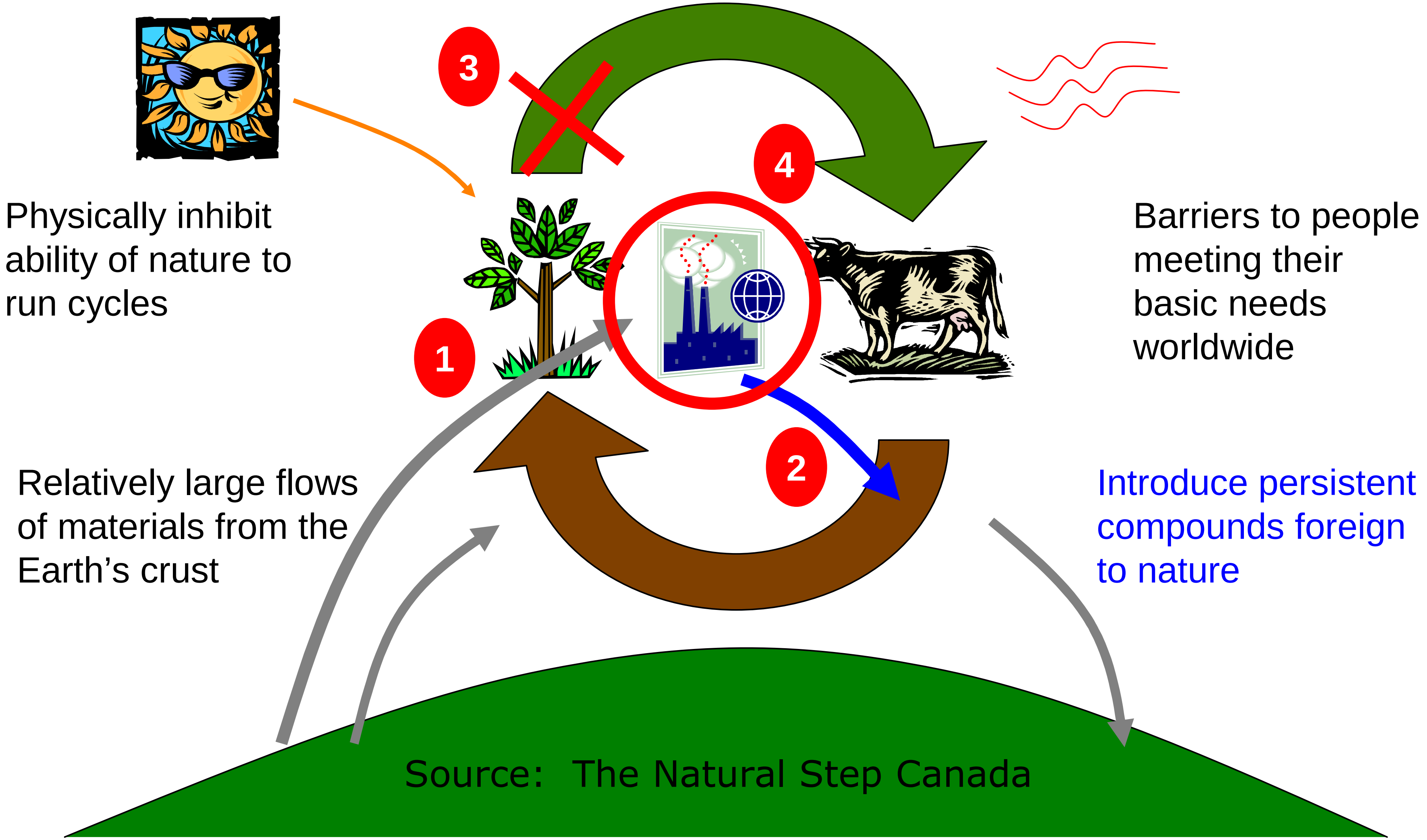
- Strategic Sustainable Development
  - Robèrt, K-H et al., Strategic Sustainable Development: Selection, Design and Synergies of applied tools. *Journal of Cleaner Production* 10:197-214 (2002)

Strategic Sustainable Development



Fundamental Sustainability Principles

Q: How do we influence natural cycles ?



Source: The Natural Step Canada

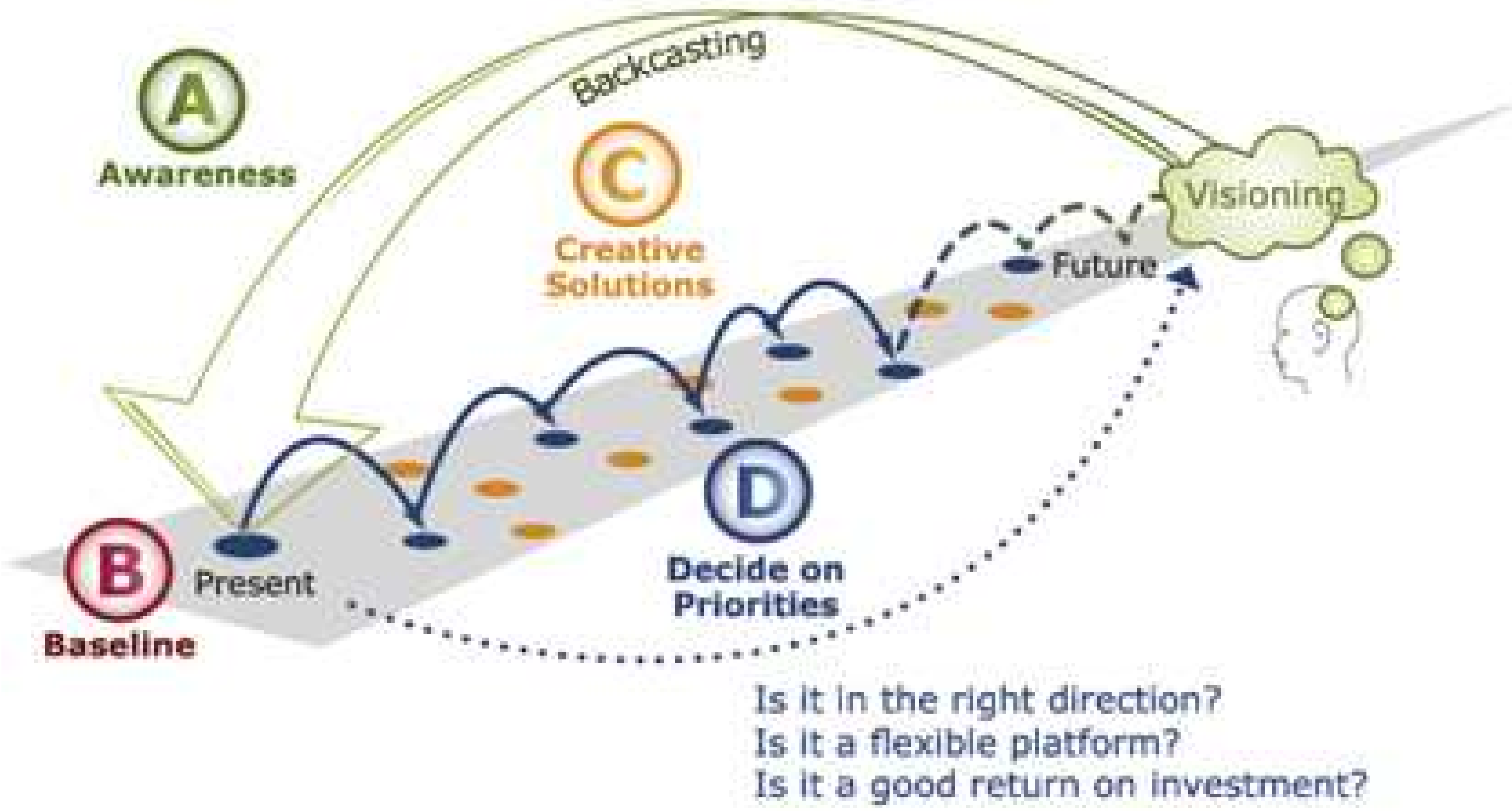
The Natural Step “4 System Conditions or Sustainability Principles”

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



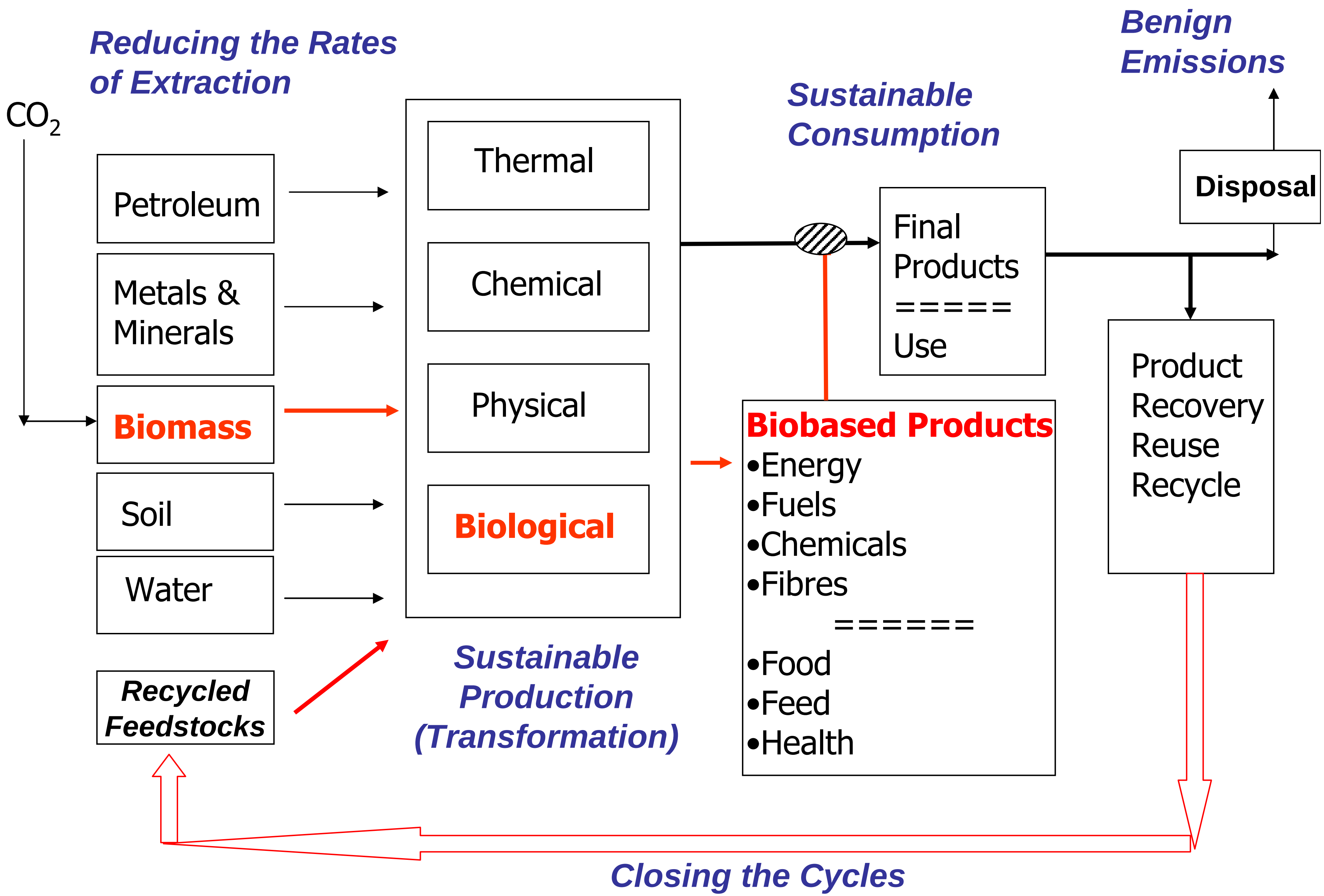
Source: The Natural Step Canada

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


Reducing the Rates of Extraction
CO_2
Petroleum
Metals & Minerals
Biomass
Soil
Water
Recycled Feedstocks
Thermal
Chemical
Physical
Biological
Sustainable Production (Transformation)
Sustainable Consumption
Final Products
=====
Use
Biobased Products
•Energy
•Fuels
•Chemicals
•Fibres
======
•Food
•Feed
•Health
Benign Emissions
Disposal
Product Recovery Reuse Recycle
Closing the Cycles

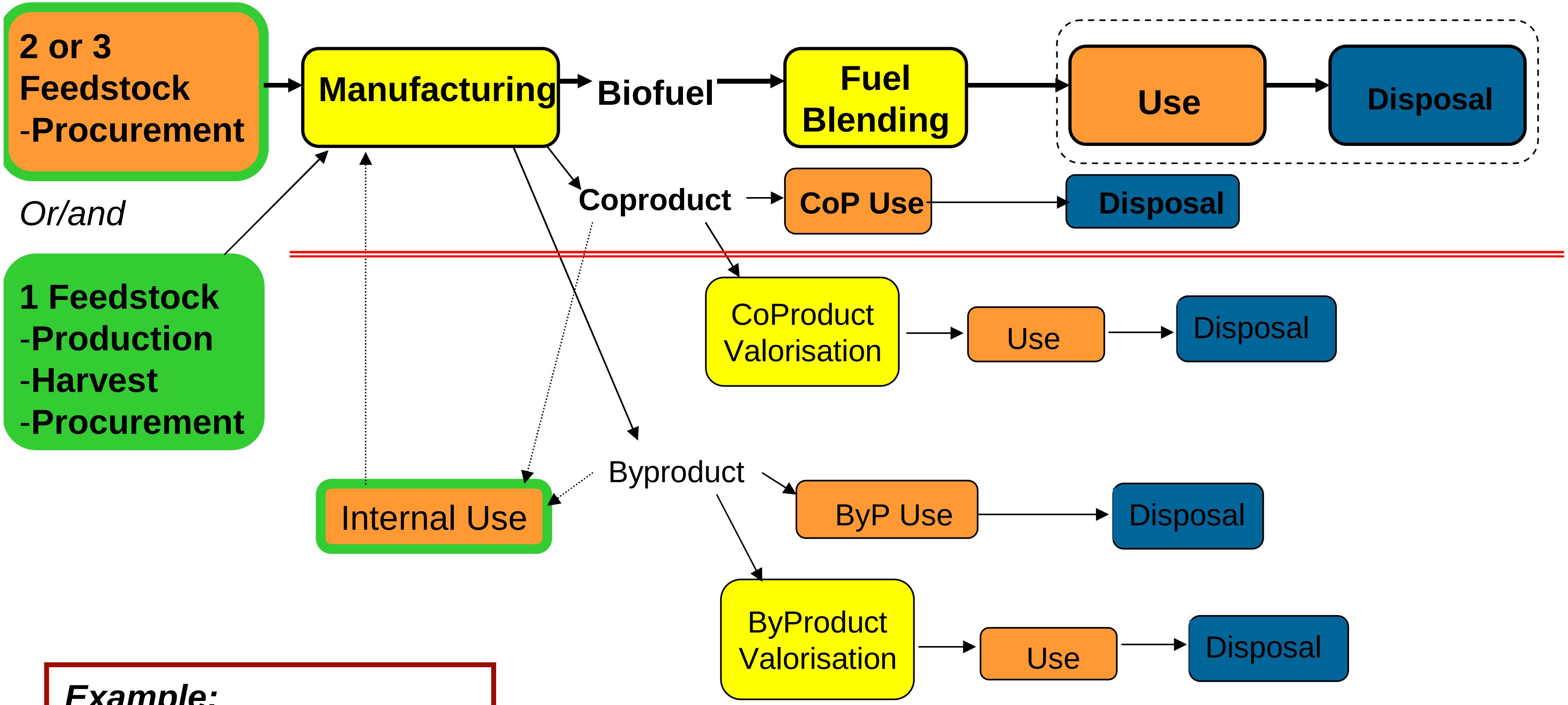
3. Sustainability Assessment Evaluating Biorefinery Systems

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

Biofuels, Bioprod. Bioref. 4:275–286 (2010)

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.

Environmental Aspects of Bioproducts – *other than biofuels*

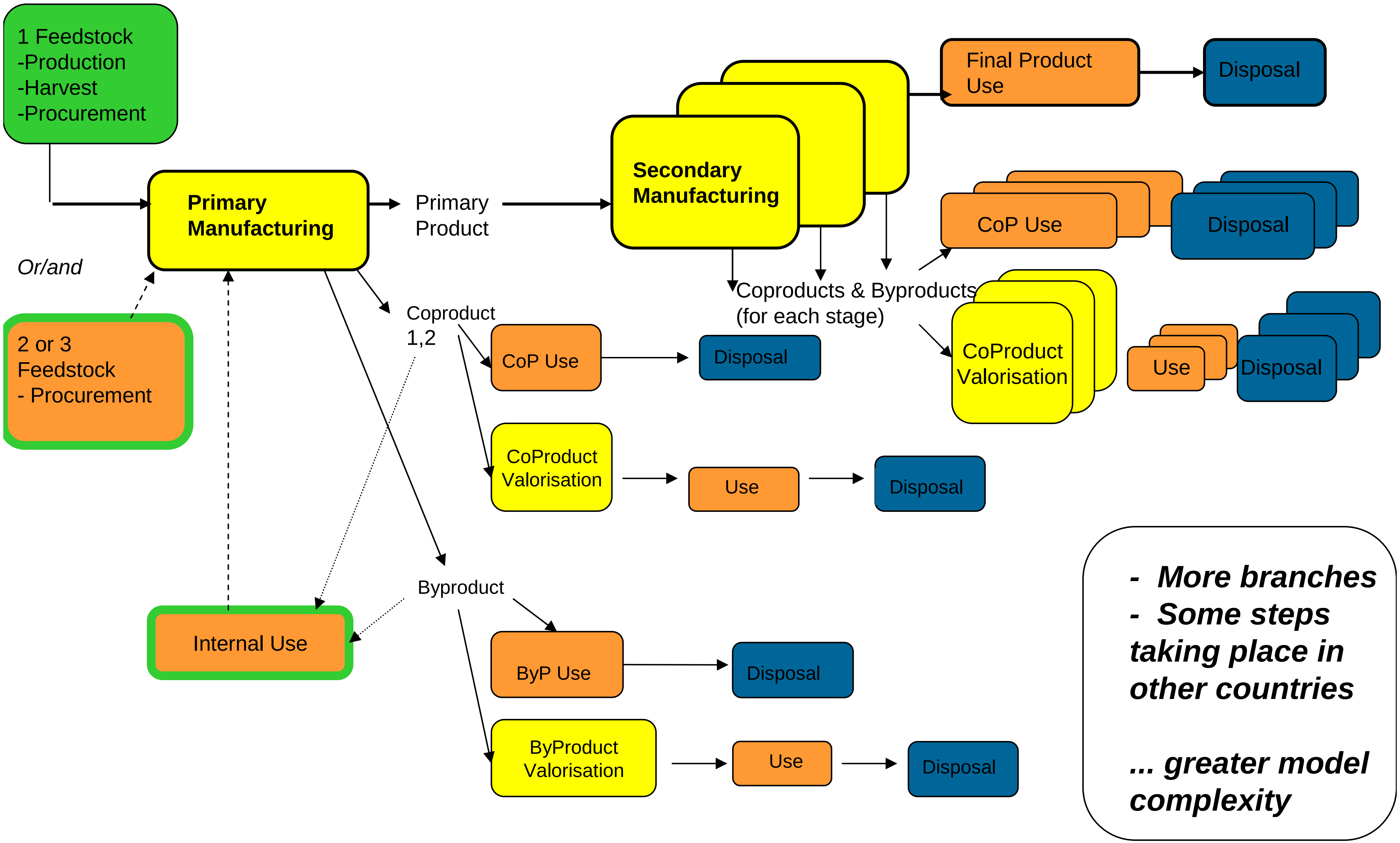
Example: ADEME (France)

- 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 <u>all</u> 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



Biofuels, Bioprod. Bioref. 4:275–286 (2010)

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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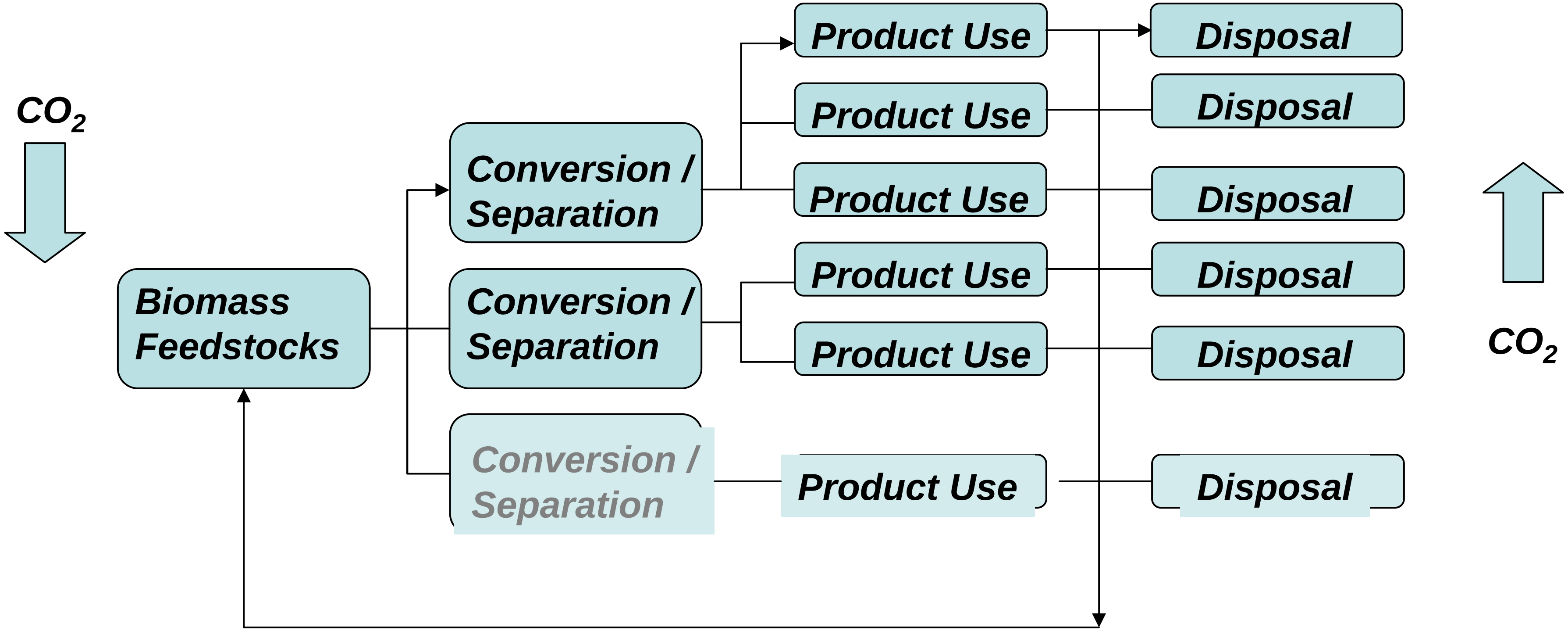
Additional Slides

- *Various life cycle stages of biorefinery systems*



Biomass Feedstocks

Lessons Learned

- 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 <u>already</u> 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.

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

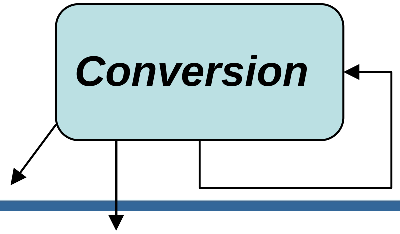
Biomass Feedstocks

Design Considerations

- Don’t neglect or underestimate feedstock development + production
- Example: Agriculture: seed supply, production, harvest, collection, cleaning, storage

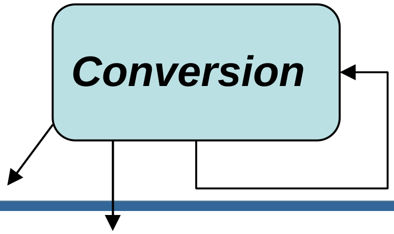
Breeding Agronomy/Forestry → Crop Production Harvest, Collection

- 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



Lessons Learned

- 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

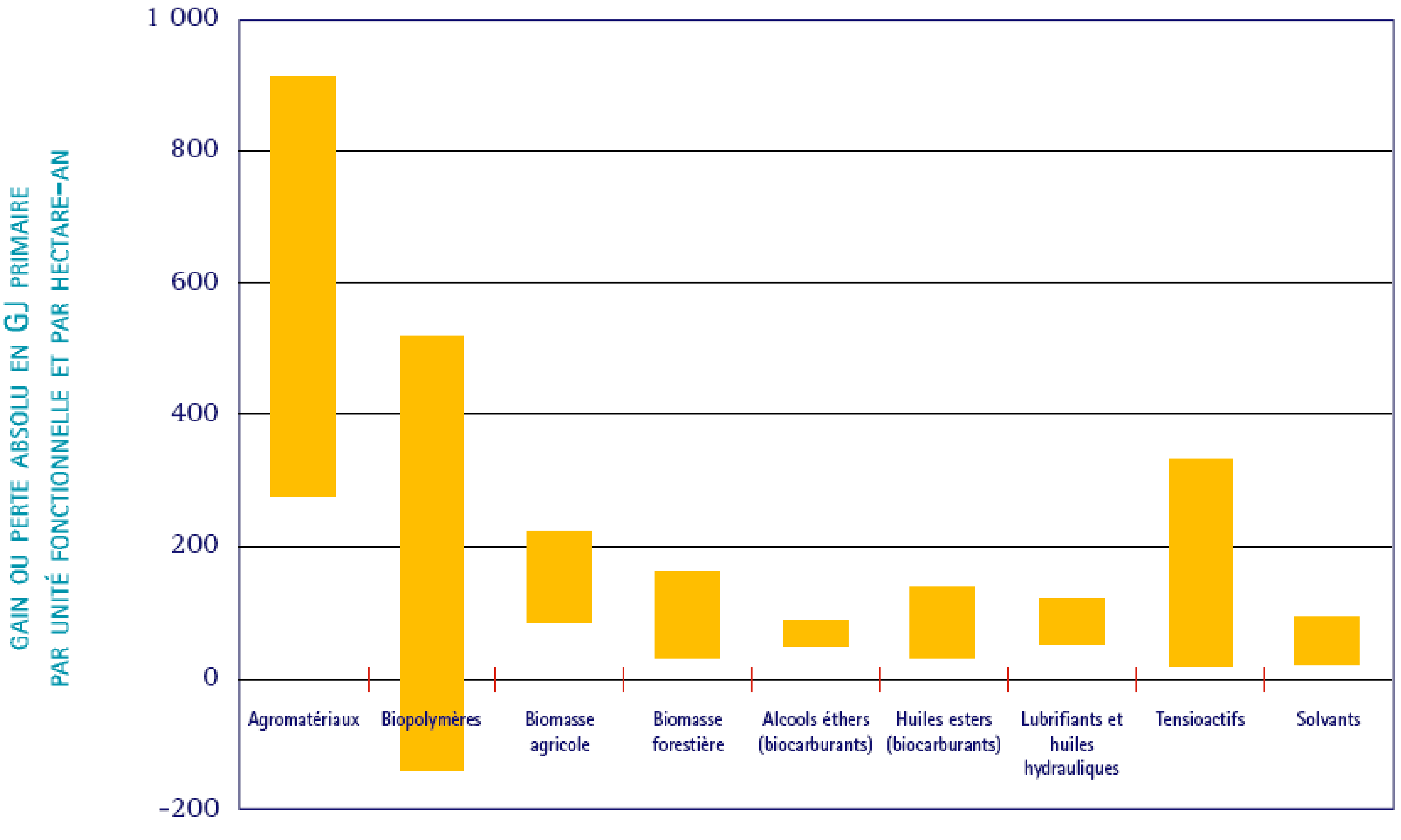


Lessons Learned

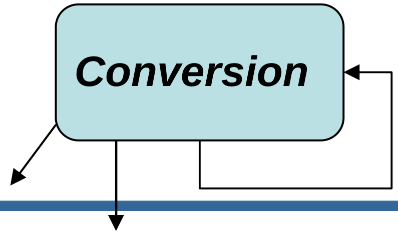
- Bioproduct selection
  - Pull = product value and demand + sustainability goals
  - Push = policies and incentives (biofuel mandates, green energy premium, bioproduct procurement, etc.)

  - 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)

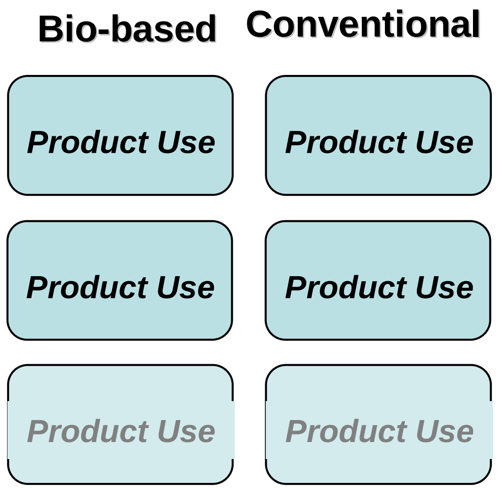


Lessons Learned

- 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.)

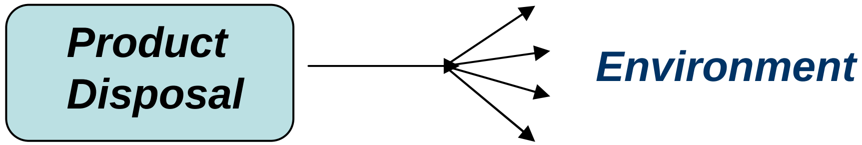
Product Use - Lessons Learned

- Crade 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

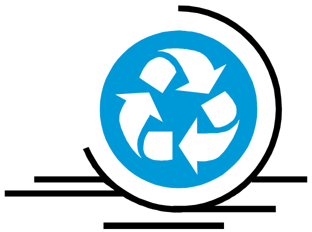


Product Disposal – Lessons Learned

- 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



Beneficial (vs not harmful)

Cascading from higher value to lower value products

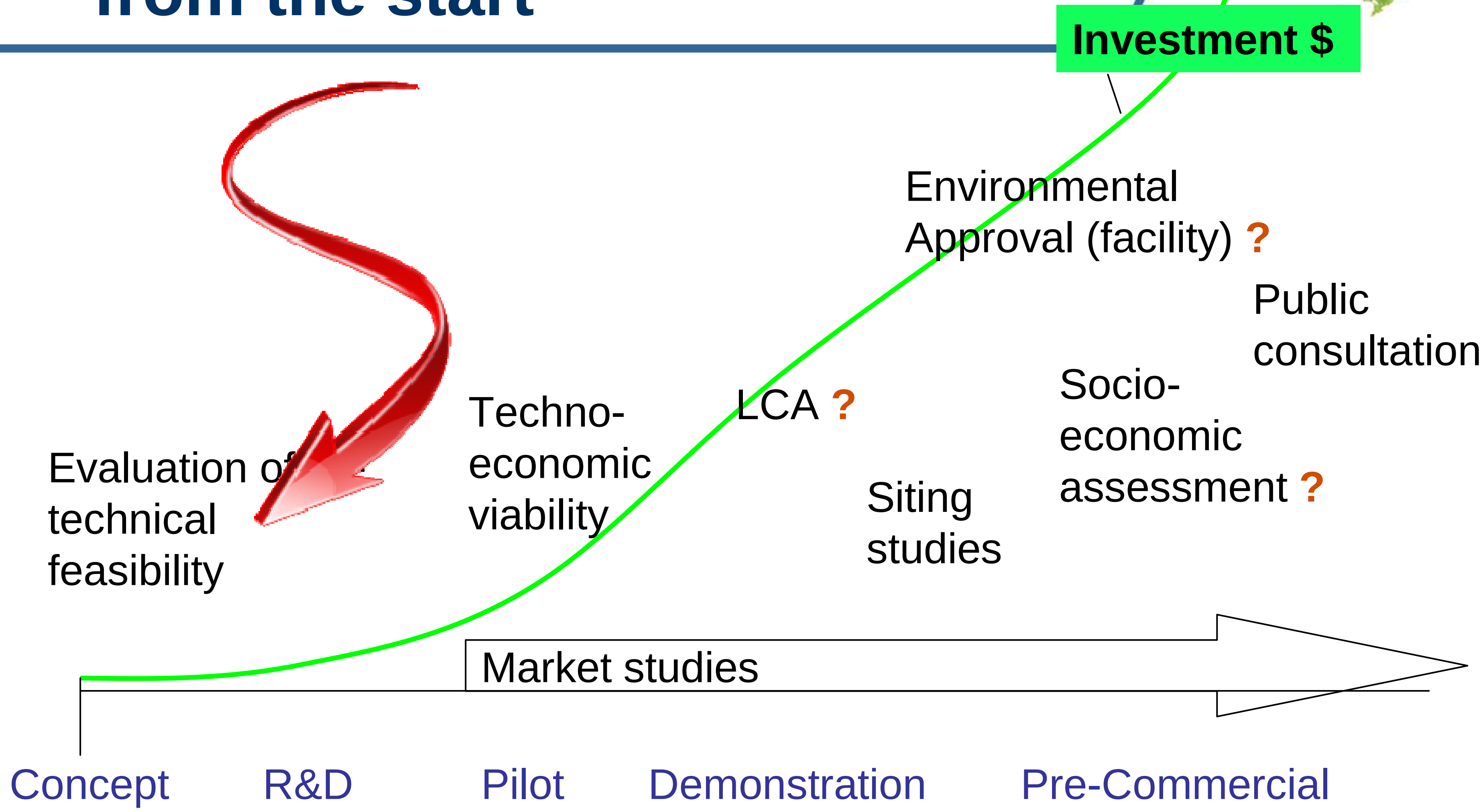
Sustainable Design
"Good Practices"

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



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)