Conclusions from Session 3:

Industrial Biorefineries

• A bit about Task XI on Industrial Biorefineries
• A quick summary of the messages from our keynote speakers
• Reflections about the ensuing discussion
Task XI on Industry-based Biorefineries
Sub-Tasks Being Initiated

1. Decision support systems & ex-ante research
   - Scenarios
   - TEA/LCA
   - Circularity metrics

2. Technology pathways towards net-zero emissions biorefineries
   - Decarbonization systems engineering
   - Mass and energy integration
   - Energy and GHG intensities

3. Circular bioeconomy and biomass-industrial symbiosis
   - Carbon circulation
   - Reduced wastes
   - Eco-industrial parks

4. Artificial intelligence for biorefinery transformation
   - Machine learning for prediction of biomass-to-bioproducts yields
   - Multi-criteria analysis methods
   - Sustainability metrics
Task XI on Industry-based Biorefineries
Decision Support Systems and Ex-ante Research

• Objective
  • Advance and share the knowledge on decision support approaches and tools.
  • Better understand the complex decision-making needs of industry and government related to setting bioeconomy strategies.
  • Demonstrate the resolution of complex bioeconomy decisions critical to industry, especially considering the link with ex-ante research.

• Key Activities
  • Review decision making methodologies and decision support tools, and establish harmonized DSS and Ex-Ante approaches/methods.
  • Synthesize industrial case studies in the area of DSS and Ex Ante.

• Subtask Managers
  • Dr. Paul Stuart, Polytechnique Montréal, Quebec, Canada
  • Dr. Marzouk Benali, Natural Resources Canada, CanmetENERGY in Varennes, Quebec, Canada
Task XI on Industry-based Biorefineries
Technology Pathways for Negative and/or Net-Zero Emission Biorefineries

• **Objective**
  - Technology Pathways embracing any technical attribute (new processing technology; new product pathway; new CCU/CCS strategy or implementation of renewable energy) and novel concepts that lead to overall net-zero/negative emissions in integrated biorefineries.

• **Key Activities**
  - Initial meetings held to explore the key elements related to the Sub-Task objective
  - Review emerging technologies for combined resource and energy efficiency with overall impacts on GHG emissions in biorefineries
  - Evaluate and adapt available tools and methodologies for energy efficiency and renewable energy systems integration
  - Synthesize industrial case studies (conceptual and demonstrated) in at least three different industrial sectors

• **Subtask Managers**
  - Dr. Bettina Muster-Slawitsch, AEE-Institute for Sustainable Technologies, Austria
  - Dr. Sarah Meitz, AEE-Institute for Sustainable Technologies, Austria
Task XI on Industry-based Biorefineries
Circular Bioeconomy and Biomass-Oriented Industrial Symbiosis

• **Objective**
  - *Focus on systems analyses to identify optimized solutions based on carbon circularity approaches, sharing information on strategies and methodologies to assess the potential for establishing industrial symbiosis involving biorefineries in industrial plants.*

• **Recent Activity**
  - Sub-Task goals based on a ½-day workshop where strong interest was shown for this topic
  - Proposal has just been approved by the IETS ExCo, and the 1st meeting is being organized

• **Subtask Managers**
  - Dr. Jorge Costa, Instituto Superior de Educação e Ciências - ISEC (PT)
  - Dr Isabel Cabrita, Instituto Superior de Educação e Ciências - ISEC (PT)
Task XI on Industry-based Biorefineries
The Monday Task XI Workshop was a Great Success...

• Task XI on Industry-based biorefineries has recently initiated or is about to initiate **3 Sub-Tasks** – and the goal of the meeting on Monday was to describe these, and attract **great people and projects**

• We were overwhelmed by the response to the workshop: **25 attendees**, and **25 presentations**

• It was the **opportunity to join** one or more of the Sub-Tasks…
Task XI on Industry-based Biorefineries
The Monday Task XI Workshop was a Great Success...

You are welcome to join the party!

<table>
<thead>
<tr>
<th>Agenda Item</th>
<th>Facilitator - Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>8h30-9h00 Overview of Task XI Roundtable Introductions</td>
<td>Paul Stuart Polytechnique Montréal (Canada)</td>
</tr>
<tr>
<td>9h00-10h00 Project Presentations</td>
<td>invited Speakers (see table below)</td>
</tr>
<tr>
<td>10h00-10h30 Questions and Discussion</td>
<td></td>
</tr>
<tr>
<td>10h30-11h30 Project Presentations</td>
<td>invited Speakers (see table below)</td>
</tr>
<tr>
<td>11h30-13h00 Lunch together at Wijkanders <a href="https://rijkanders.se/en/restauranger/">link</a>]</td>
<td></td>
</tr>
<tr>
<td>13h00-14h00 Project Presentations</td>
<td>invited Speakers (see table below)</td>
</tr>
<tr>
<td>14h00-14h30 Questions and Discussion</td>
<td></td>
</tr>
<tr>
<td>14h30-15h30 Project Presentations</td>
<td>invited Speakers (see table below)</td>
</tr>
<tr>
<td>15h30-16h30 Overview of 3 Task XI Sub-Tasks</td>
<td>Sub-Task Managers: (1) Jorge Costa, Circular Bioeconomy (2) Bettina Muster, Net Zero (3) Paul Stuart, DSS Ex-Ante</td>
</tr>
<tr>
<td>16h30-17h00 Sub-Task Selection</td>
<td></td>
</tr>
</tbody>
</table>
Task XI on Industry-based Biorefineries
The Roll-Out this Afternoon…

• 4 Keynote Speakers x 20 minutes
• Some directed questions by none other than…
  • Importance of industry-based biorefineries to energy futures and meeting climate targets, ie Beyond Net Zero objectives for industry
  • Importance of systems analytics for complex decisions relative to industry-based biorefineries for sustainability
  • The importance of biomass and its sustainability relative to meeting climate targets
  • What system boundaries should be considered in addressing bio-based biorefineries to evaluate Net Zero, circularity etc?

• A final questions to the speakers:
  • Related to your sub-task theme, what is the single critical issue you recommend be addressed?
IETS Conference Session on Industrial Biorefineries
The Line-Up this Afternoon…

- Bettina Muster-Slawitsch, AEE Institute of Sustainable Technologies (Austria)
  - “Approaches towards Net-Zero Biorefineries”
  - Technology pathways towards net-zero/negative emission biorefineries
- François Maréchal, École Polytechnique Fédérale de Lausanne (Switzerland)
  - “Designing biorefineries with a holistic and systemic approach”
  - The circular bioeconomy and industrial symbiosis
- Andrea Ramirez, Delft University of Technology (Netherlands)
  - “Ex-ante technology assessment of novel routes for production of chemicals”
  - Decision support systems and ex-ante research for assessing biorefineries
- William Mackintosh, RISE Research Institutes of Sweden - KTH (Sweden)
  - “Enabling upscaling of Biorefineries from R&D to commercial scale through investment in hardware, software and digitalisation: Case study Swedish Biorefinery Arena project”
  - Adoption of digitalization in the bio-based industries for decarbonisation

In some fortuitous way, the themes that were presented, “built on each other” to see the evolution of systems engineering as it may be used in biorefinery design…
Can new biorefinery products enhance the pathway towards net-zero/negative emissions?
How can net zero or negative emissions be reached in biorefineries?

Case study context to address this: Brewery
- Energy needs fulfilled including solar energy, malt fermentation...
- Digestate is landspread

Can the brewery do better, and achieve net zero?
- Spent grain valorization in a new (economically-viable) biorefinery concept
- "Oscillatory reactor" for protein solubilisation
- New digestate treatment and fate of the components – worth more and lower impact

Critical analysis:
- Combined resource/energy analysis and innovation with “a climate positive vision”
- Process innovation, use of system concepts, sources of renewable energy
Task XI on Industry-based Biorefineries
François Maréchal
“Designing biorefineries with a holistic and systemic approach”

biorefineries as a circular renewable energy hub
François started his presentation by “a review of Mother Nature”, for inspiration to design biorefineries – photosynthesis inspires the design approach.

A design process considering flowsheet super structures, system integration, and then performance of many options including capital/operating costs as well as environmental.

Case studies: ethanol production from lignocellulosic biomass, through to synthesis of a biochemical fractionation platform leading to a multiplicity of biofuels – considering different energy integration configurations and CCS.

Critical analysis:
• Using a systematic approach and systems engineering, we can effectively screen a large number of candidate biorefinery designs.
Task XI on Industry-based Biorefineries
Andrea Ramirez Ramirez
“Ex-ante technology assessment of novel routes for production of chemicals”

Possible pathways to make Ethylene (at different TRL)
Task XI on Industry-based Biorefineries
Andrea Ramirez Ramirez
“Ex-ante technology assessment of novel routes for production of chemicals”

• Use ex ante approach to assess the combination of technologies, their scale-up, value chains, systems – at the early design stage when we have lots of flexibility, but must see the future to make the right decision
  • “A TETRIS-like problem”

• The case study selected was the production of polyethylene, and the different ways this can be done in a net zero configuration…

• The electrochemical conversion of CO₂ after capture from cement plant and bioethanol plant was considered for a deeper dive, and the impact of the contaminants in the CO₂ stream – “very energy intensive, very costly”

• Port of Rotterdam: 45 chemical facilities and 5 biorefineries – highly integrated/symbiotic – try integrating a new process into this…

• Critical analysis:
  • By “seeing the future” using systems analysis (and evaluating the system at different ecosystems/scales) we can step back to the lab and change the direction of the process concept being developed that meets the needs of the TETRIS-like problem
Task XI on Industry-based Biorefineries
William Mackintosh
“Enabling upscaling of Biorefineries from R&D to commercial scale through investment in hardware, software and digitalization: Case study Swedish Biorefinery Arena project”
Task XI on Industry-based Biorefineries
William Mackintosh
“Enabling upscaling of Biorefineries from R&D to commercial scale through investment in hardware, software and digitalization: Case study Swedish Biorefinery Arena project”

• Introduction of the new RISE “Biorefinery Arena”, emphasizing its digitization and its digitalization
  • “An open flexible pilot hall dedicated to biorefinery development”

• RISE asked industry: What do you really need?
  • “Last but not least, a system that can imitate biorefineries at the pilot scale”
  • Walked through the impressive investment in the different testbeds, including industrial biotech

• The data management scheme (digitization) strategy was described

• Digitalization: How will we use the data? Example presented of research with Chalmers on hybrid models maximizing the value of limited lab test results
  • “Minirefine” testbed at RISE Södertälje to exploit this concept further

• Critical analysis
  • Digitalization techniques will be increasingly used with testbed results to minimize cost/testing requirements, scale-up – and even to integrate into a simulated complete value chain
Task XI on Industry-based Biorefineries: Discussion...

Thore: What is sustainable biomass?

- 500 scientists signed a letter that biomass should be left in the forest, and another 500 signed that it should be used for the bioeconomy
  - “Hardwoods are the new softwood”, and this is an important opportunity
  - Much of the biomass to be used in the biorefinery will be residues from existing harvesting operations
  - Forest biomass should be used for the bioeconomy, but considered to be a limited resource whose use should be optimized – especially to help address GHG emissions reduction objective
  - What should we do with wood, ie a heating source or for bioproducts?
  - For example – biomass should not be used as an energy source in favour of solar and wind energy

- Critical analysis
  - We can use systems engineering to assess many of the issues identified by the expert panel relative to the sustainable use of biomass
Task XI on Industry-based Biorefineries: Discussion...
Thore: What are “really” negative emissions from processes? What are the right system boundaries?

• Without offering a simple question to a complex question, this should be addressed in a responsible manner depending on the definition of net zero and context of the analysis

• There are many complexities related to, for example, circularity and life of long-life carbon products

• A global perspective is needed, considering the climate change contribution from all emissions from a plant, eg anthropogenic carbon, also biogenic carbon, nitrogen gases, etc
Task XI on Industry-based Biorefineries: Discussion...

Related to your sub-task theme, what is the single critical issue you recommend be addressed?

• Understand complexities of the system being analyzed, and don’t oversimplify the modeling approach
• We must define the system boundaries well for the correct analysis and solutions
• Make the systems analytics based case studies available to a broad audience, so they can be interpreted and considered in decision-making
• Critical analysis
  • These are methodological issues related to “proper” systems engineering – the sort of subjects we will undoubtedly “get to” in each of the Task XI Sub-Tasks
Task XI on Industry-based Biorefineries: Discussion...
Aggregating the Critical Analyses Related to Task XI

• Combined resource/energy analysis and innovation with “a climate positive vision” can lead to real-world successes

• Using a systematic approach and systems engineering, we can effectively screen a large number of candidate biorefinery designs

• By “seeing the future” using systems analysis (and evaluating the system at different ecosystems/scales) we can step back to the lab and change the direction of the process concept being developed that meets the needs of the TETRIS-like problem

• Digitalization techniques will be increasingly used with testbed results to minimize cost/testing requirements, scale-up – and even to integrate into a simulated complete value chain

• These share common recommendations of how to apply systems engineering in a proper way – highlighting the opportunity for a “common” annual Task XI Intra-Task meeting
Merci - Thank You!

Paul Stuart  
Professor  
Product and Process Design Laboratory  
Department of Chemical Engineering  
Polytechnique Montréal, Quebec, Canada  
Telephone : +1(514) 891-3506  
Email: paul.stuart@polymtl.ca  
https://www.polymtl.ca/en/

Marzouk Benali  
Senior Research Scientist  
Industrial Systems Optimization  
Natural Resources Canada/CanmetENERGY  
Telephone (Mobile): +1 (514) 241-5915  
Email: marzouk.benali@nrcan-rncan.gc.ca  
www.nrcan.gc.ca