Collaborative Mapping for Sustainability: Using Group Model Building to Identify Sustainability Factors in Early-Stage Technology Development

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Introduction

New materials and chemical process technologies are needed to address the current sustainability challenges faced by the world. As new technologies are developed, they must be evaluated not only for solving a specific challenge, but also to ensure that they do not create unintended negative environmental, social or economic consequences. In other words, we need new chemical technologies for sustainability, but also ones that are themselves more sustainable.

To explore ways of facilitating sustainability consideration in early-stage process technology development, we piloted a Group Model Building (GMB) workshop with a university research lab working to commercialize anaerobic digestion of organic wastes to generate higher value chemicals. This paper presents a case study of a pilot of GMB processes with a university research lab developing a new chemical process technology. The pilot attempts to answer the following research questions: **How does a GMB workshop shift participants' understanding of sustainability? How might this shift in understanding impact the technology design?**

Background

Sustainability is a broad concept that was defined by the 1987 Brundtland Report for the United Nations as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [1]. A three 'pillars' or 'dimensions' approach to sustainability considers environmental, economic, and social considerations in an integrated fashion [2]. The three dimensions are highly interrelated; given the overlap of considerations, sustainability challenges are complex and fundamentally systemic [1]. However, traditional technology process development has taken a linear, sequential approach to addressing sustainability, with early-stage research focussing on proof-of-concept, while sustainability evaluations such as life-cycle assessment or techno-economic assessments (LCA and TEA) tend to happen later in the development cycle once manufacturing processes, supplies and products have been fully specified [3]. There are calls for changes to the way chemical process development occurs to improve the incorporation of sustainability into design. Most recently, the Safe and Sustainable by Design (SSbD) framework, introduced by the European Commission in 2020 takes a precautionary approach to chemical and material innovation, attempting to integrate safety and sustainability considerations from the earliest stage of the innovation process [4], [5]. However, it does not specify the processes for such collaboration; new practices must be developed to facilitate the implementation of these frameworks.

Group Model Building (GMB) is a collaborative process for facilitating group learning as teams work together to generate descriptions of complex systems dynamics [6]. GMB brings together multiple stakeholders in a formal facilitation exercise to generate qualitative descriptions of systems dynamics. As summarized by Andersen et al.[7], GMB can be used to align mental models, create consensus about a policy or decision, and/or generate commitment with a decision. The process should be highly structured, with clear goals, pre-consultation with clients and well-designed facilitation in terms of room set up, appropriate selection of activities, and scripts [8], [9], [10].

GMB has been used to support sustainability assessments in areas as diverse as building materials assessment and selection [11], the environmental impacts of ultra-processed foods [12], watershed management [13], wetland management [14], and the socio-political acceptance of negative emission technology [15]. GMB has also been used in sustainable design. Laurenti et al. [16] used GMB to identify variables that are not typically considered in LCA exercises that could have a significant effect on the environmental impact of a product system. Watz and Hallstedt [17] developed GMB workshops with CLDs to enhance sustainable product development implementation in product development companies. They found that the method gave new insights among participants, including appreciation of system boundaries and the revelation of hidden dependencies. Watz et al. [18] then investigated the effect of CLD on early sustainable design decision making in a more comprehensive study, and found that participants improved their sustainability understanding of the products and identified improvement actions. Further, the GMB approach helped the group to align on their weighing of the identified sustainability factors.

Brychikov et al. [19] describe the use of Connection Circles as a systems thinking tool for postgraduate sustainability education. They reported a deepened understanding of the meaning of sustainability for a specific system. They argue that connection circles are a good first step for learning about a system and that the iterative discussion supported by the diagramming activity was a key part of this learning.

Methodology

Case Description: Technical background

The research team partnered with a chemical engineering lab at the University of Toronto that is developing a novel process to convert organic municipal waste into value added chemicals via anaerobic digestion (AD). AD is an established technology that has been deployed to convert organic waste (food, sewage or other) into biogas (primarily methane, ethane and propane) for many years [20] .

The technology was at an early stage of technology readiness. The lab was preparing the case for piloting at a municipal site and wanted to explore the sustainability benefits of the technology and to identify potential challenges in commercialization. Other partners in the project included the local municipality who would potentially host the pilot, an industrial partner who was already operating a municipal AD-biogas plant, and a potential end user for the MCFAs. Representatives from a local environmental agency also participated in the workshop.

The goal of the GMB workshop was set through consultation with the various stakeholders: to increase participants' understanding of sustainability, to anticipate sustainability related challenges in industrial implementation of the technology, and to identify missing information that was needed to inform the case for piloting the technology.

The GMB team began by educating themselves about the technology through literature review and interviews with the AD-MCFA team to generate a description of the technology and generated a first draft of a process life-cycle map. The process life-cycle map incorporated the full material life cycle, from municipal waste collection, through the existing AD-biogas plant to final material outputs including waste streams; the pilot technology could then be added onto the map as a parallel process option. The map was iterated over several weeks through review with members of the GMB and AD-MCFA teams to ensure accuracy and clarity.

The workshop was scheduled for 3 hours, with 27 participants from academia, industry, municipal government, and environmental organizations. The workshop began with a brief introduction to the three dimensions of sustainability - social, environmental and economic - including examples of each dimension. The co-facilitator then led the whole group through a review of the process life-cycle map, with the stakeholders most knowledgeable for each part of the map asked to provide context and information about that step.

The second activity was a role-playing exercise; people were assigned roles different from the ones they currently occupied (community member, facility operator, municipality, AD-MCFA technology developer, end-user) and put into groups of 4-5 to discuss the 3-dimensional sustainability considerations that are involved in introducing an AD-MCFA pilot at the existing facility.

The final activity was a connection circle exercise. Participants were grouped based on their current role (industry, end-user, AD-MCFA lab) and asked to brainstorm the key variables that mattered for the case and to write them on post-it notes, select 5-10 to arrange around the circle and then to draw positive or negative causal connections between them. The groups were invited to identify feedback loops (balancing or reinforcing). The workshop ended with a reflection activity via the post-survey.

Data collection included pre- and post-workshop surveys and 5 connection circle diagrams. Quantitative data were analysed using non-parametric statistical test, while qualitative responses were coded using the three dimensions sustainability framework.

Findings

As participants entered the workshop, they came in with varying understanding of sustainability. The definitions of sustainability generated by participants in the pre-survey were primarily focused on the environmental pillar with only a third explicitly mentioning social and/or economic aspects. Post-workshop results showed significant increases in understanding across all dimensions, particularly social sustainability and broader systems-oriented thinking.

Participants reported increased awareness of stakeholder perspectives, including community acceptance, supply chains and labour considerations. However, translation into concrete design changes remained limited.

The connection circle analysis showed that lab groups focussed more on technical factors, with some groups adding implied social factors related to process upsets, without explicitly identifying causes. The industrial team took a meso-level approach to considering the technology, considering the impacts of the technology on the area around the plant. The faculty/end user team considered how MCFA production would shift market supply and demand. Thus, their analysis primarily explored economic sustainability at a macroeconomic level as markets were disrupted.

Discussion

The GMB exercise worked well as a learning exercise, broadening participants' understanding of sustainability and surfacing new information about the technology and the context in which it would be deployed. Similar to the previous work, participants showed deepened understanding of sustainability in the dependencies between stakeholders and an increased understanding of system overlaps [17], [19]. Participants reported shifts in their mental models of the system and were able to identify new factors and considerations for advancing the technology.

The use of connection circles was an accessible way for the group to capture their thinking, in a relatively short timeframe. While every group was able to complete the connection circle exercise and identify causal relationships, there was insufficient time to make solid assessments of the feedback loops.

It was noted by the facilitation team that even with the multi-stakeholder workshop, the thinking was still quite technically focused when building the causal loops, focussing on the drivers of operational process performance. The findings suggest that GMB is most effective as an iterative process rather than a one-time intervention.

Implications for GMB Design

The importance of preparation: The facilitation team dedicated a lot of time to preparing for the workshop, following the recommended best practices for GMB [7], [9]. The pre-interviews and generation of the life-cycle map were highly valuable, helping to link together the combined perspectives of the participants and providing information that could be incorporated into the facilitation script.

Importance of facilitation: It is not realistic for people who only know part of a process to generate connection circles or causal loops without facilitation. The pre-interviews were conducted by a subset of 2-3 members of the facilitation team with engineering, sustainability and systems dynamics expertise; this combination helped to pull out the relevant information and was key for the generation of the process map. Even with prepared scripts, we found that the domain knowledge of the facilitation team had a big impact on the success of the workshop.

Importance of multiple stakeholders: The workshop was held at a useful time in the technology evolution, when the technology was well enough defined to have concrete conversations but still early enough that new issues could be raised. The ability to hear from stakeholders from across the process life cycle meant that all participants learned new information and considered new perspectives.

Considerations for future GMB design: The main design change would be to invest more time for the workshop, and more time for specific activities, most importantly having the second iteration of the connection circle exercise to include mixed groups.

While connection circles were a useful facilitation and learning tool for a group not familiar with CLDs, similar to Brychikov et al. [19] we found that they are only a first step in getting to more concrete causal models. Future workshops should use include the generation of CLDs and the weighing of parameters in hopes of identifying more concrete future actions and research questions for the technology development team, similar to previous work using CLDs for sustainable product design [18].

Conclusions

GMB shows promise as a method to bring sustainability considerations into early stages of technology development. Further work is needed to refine workshop design and to evaluate the longer-term impact of the GMB process on the development of the technology.

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Ethics Statement

This study was conducted in accordance with the Declaration of Helsinki and approved by the University of Toronto Health Sciences Research Ethics Board (Protocol #46380). Informed consent was obtained from all participants prior to data collection.

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