STRUCTURED ABSTRACT: Using Collaborative 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. We present a case study of our pilot GMB approach with this research lab that is developing a new chemical process technology. This early study on the GMB pilot attempts to answer the following research questions: **How does a GMB workshop shift participants' understanding of the social, environmental, and economic dimensions of sustainability? How might this shift in understanding impact the technology design?**

Method

Group Model Building (GMB) is a collaborative process for facilitating group learning as teams work together to generate descriptions of complex systems dynamics [6]. In this pilot, 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). 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.

Day of the Workshop:

Part 1.

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, which had been developed over months by the research team in consultation with individual stakeholder groups. At the workshop, stakeholders who were most knowledgeable for each part of the map were asked to elaborate on the context and information about that step.

Part 2.

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.

Part 3.

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 tests, while qualitative responses were coded using the three dimensions sustainability framework.

Findings

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 awareness 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 and its impact 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. 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.