Waste for feedstock recycling: Challenges and opportunities

Digital workshop, June 15, 2020

Workshop Report

IEA Bioenergy: Task 36: June, 2020

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Preface

This report summarizes the results of a digital public workshop of June 15, 2020, organized by members of the US Department of Energy (USDOE) and Office of Energy Efficiency and Renewable Energy (EERE), within the framework of IEA Bioenergy Task 36. The purpose of this workshop was to explore several facets of producing higher value biochemicals and bioproducts from waste streams.

IEA Bioenergy Task 36, Material and Energy Valorisation of Waste in a Circular Economy seeks to raise public awareness of sustainable energy generation from biomass residues and waste fractions including MSW as well as to increase technical information dissemination. This workshop represents one of several workshops that focuses on resource and energy recovery from waste, which is critical in the transition from a linear to a circular economy. As outlined in the 3-year work programme, Task 36 seeks to understand what role energy from waste and material recycling can have in a circular economy and identify technical and non-technical barriers and opportunities needed to achieve this vision.

Past workshops in this 3-year work programme have explored opportunities for nutrient recovery, especially nitrogen and phosphorus from waste (Stockholm, May 2019) as well as technology pathways for energy recovery from waste (Brisbane, November 2019). See appendix B for links to these workshop reports. Whereas the Brisbane workshop focused on energy products from waste, the focus of this workshop was to investigate the potential for a more diverse range of products from processes using waste as a feedstock. See http://task36.ieabioenergy.com/ for links to the workshops.

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Abbreviations, Acronyms, and Definitions

GHG: greenhouse gas

ISPR: in-situ product recovery

LCA: life-cycle assessment

OFMSW: organic fraction of municipal solid waste

PFA: Perfluoroalkoxy alkane

TEA: techno-economic analysis

VFA: volatile fatty acid(s)

WTE: waste to energy

Upcycling: converting a plastic or waste stream of a specific economic value to one that is of higher value, e.g. converting a monomer worth $500/tonne to a monomer worth $2,000/tonne.

Introduction

Global recycling rates vary considerably but are typically below 40%, and the streams that are not recycled are most commonly landfilled or incinerated (most often with energy recovery in developed countries). The variation is illustrated in Figure 1 which present the situation on recycling of plastic packaging in the EU member states.

Figure 1 Official statistics for recycling of plastic packaging in the member states of EU. Source: Eurostat

The EU and other nations across the world have set aggressive targets for plastics recycling by 2030 and is introducing a tax on virgin plastics from January 1st, 2021. In Europe alone, there is a net deficit of 11 million tons of recycling capacity for plastics1. This would require a major expansion of recycling infrastructure or the development of pathways to recapture and reuse these plastic waste streams and keep them "in-the-loop." Other plastics streams, such as composites, are considerably more difficult to recycle and energy recovery from these streams is often the best option in the waste management hierarchy.

Plastics recycling is also a significant energy efficiency opportunity. Approximately 6% of the world's crude oil is used to make plastics and by shifting to energy efficient recycling strategies, the world can reduce the amount of energy that is devoted to the manufacturing of virgin plastics.

Organic waste streams such as the organic fraction of municipal solid waste (food waste, yard waste, contaminated paper, etc.), residues from wastewater treatment, and manure also represent opportunities for keeping carbon "in-the-loop." In many nations some or all of these waste streams have been banned from landfills and from land application (e.g. compost) necessitating novel management strategies and/or processes. In countries which have not yet banned these practices,

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[1] Stapf, D. (2020, September 16). *Trends and Drivers in Alternative Thermal Treatment of Waste.* IEA Bioenergy Task 36.
http://task36.ieabioenergy.com/publications/report-trends-and-drivers-in-alternative-thermal-conversion-of-waste/

landfill availability is becoming limited and there is recognition that these organic waste streams decompose to form methane – which is more than 20 times more greenhouse-intensive than CO_2. Diminishing or constant public acceptance of landfills is also a driver as is opposition or acceptance of technologies such as incineration

Historically, technologies such as incineration and anaerobic digestion have been used primarily as waste management strategies, with energy recovery integrated in more recent times. Looking forwards, and in order to realize a vision of a circular economy, new approaches to find higher values for these waste streams are needed. In the near term, utilizing these waste streams as feedstocks for biochemicals and other bioproducts could represent an attractive economic opportunity and simultaneously help solve some of the environmental challenges associated with these streams.

A significant challenge with producing biochemicals and bioproducts is market size and market development, especially with limited incentives to use recycled materials. For many specialty chemicals and products, a small number of commercial plants can fully saturate the market. While this may open up additional end markets, market saturation can quickly erode prices and economic sustainability for these approaches. For molecules that seek to replace incumbent molecules, such as lactic acid for plastics production, the time to develop the market is quite significant. To manage some of these challenges, this workshop sought to explore if there are particular “platform” molecules that represent attractive targets from which many subsequent products and chemicals can be synthesized.

WORKSHOP OBJECTIVES

The purpose of this workshop was to explore several facets of producing higher value biochemicals and bioproducts from waste streams. Discussion questions include:

- What waste streams are most underutilized and/or represent the best opportunity feedstocks in these type of applications?
- Why are these waste streams currently underutilized and is it anticipated that this lack of beneficial utilization will persist into the future?
- What are attractive intermediate or platform molecules that can be produced from waste and can serve a variety of end markets?
- What are technical and non-technical barriers towards producing these platform molecules from waste?
- Which technologies are most appropriate for mixed or aggregated waste streams?

For each of these questions, and given the international audience, the workshop also seeks to understand the national and local factors that underpin particular answers.

Workshop Structure

KEYNOTE SPEAKERS

Dr. Zia Abdullah, Biomass Program Manager, National Renewable Energy Laboratory

Dr. Abdullah, biomass program manager at NREL, gave the first keynote on organic waste as a feedstock for recycling, highlighting waste as a feedstock for the production of fuels and chemicals. In his presentation, Dr. Abdullah focused on several organic waste streams: food waste, residuals from wastewater treatment, and manure from animal feeding operations. Organic wet wastes are largely underutilized even though some of it is available for free or negative prices. Current uses for organic waste include biogas production, composting, and land applications.

He stated that the research challenges in the field of bioenergy include producing fuels with high energy content and low cost, developing industrially relevant materials with performance advantages, converting CO_2 to high-value chemicals, and manufacturing energy and carbon-efficient materials and processes. Waste offers significant cost advantages as a feedstock for fuels and chemicals. Converting waste to fuels and chemicals enables a circular carbon economy. Approximately 75 % of waste plastic goes into landfills in the USA each year, and only ~8 % is recycled. Market value and demand for these plastic wastes is very low. They could be upcycled to cost-competitive products.

An option of handling wet waste feedstocks is to produce carboxylic acids via anaerobic digestion. NREL investigated this option and hypothesized that methanogenesis could be arrested by removing carboxylic acid in situ. The key results were mathematical models showing ISPR is feasible under the following conditions: pH~3 and volatile fatty acids (VFA) titers>9.5 g/L or pH~5 and VFA titers>17 g/L. Experimental results confirmed the model's predictions. The volatile fatty acids that are recovered can be upgraded to fuels and products via biorefineries.

Waste gas can be directly converted to products because methanotrophic bacteria can use CH_4 and CO_2, commonly found in biogas, as carbon and energy sources. NREL's efforts in this field have the following goals: develop methanotrophic biocatalysts to produce diverse products, utilize metabolic engineering to increase carbon- and energy-efficiency of bioconversion, optimize CH_4/CO_2 co-conversion capacity, and optimize tuneable gas bioreactors with respect to efficiency and mass transfer. Additionally, NREL strives to perform Techno-Economic Analysis (TEA) on WtE pathways to determine the economic feasibility and to motivate research.

Dr. Meltem Urgun-Demirtas, Biomass Program Manager, Argonne National Laboratory

Dr. Urgun-Demirtas, the biomass program manager at Argonne National Laboratory, discussed valorisation of organic waste streams beyond biogas via arrested methanogenesis for organic acid production. Dr. Abdullah also discussed this topic as one of NREL's approaches to wet waste, and Dr. Urgun-Demirtas dove deeper into it. Organic acid production from organic wastes is favourable because it can be implemented at many existing plants that produce biogas.

Microbes can be tailored to produce a mixture of VFAs and lactic acid. Optimal inocula are necessary to optimize carboxylic acid production and inhibit methanogenesis. Argonne's investigations indicated that running digestors at pH less than 6.0 helped inhibit methanogenesis. Argonne has researched fermenters at various scales for this application: serum bottle bath fermentation (500 mL), bench-scale continuous fermentation (600 mL), and large-scale batch/continuous fermentation (14 L). These fermentation processes require bacteria, and it was determined that the bacteria bacillaceae contributed to lactic acid production while clostridiaceae contributed to VFA production. Lactic acid was separated from the product mixture via electrodeionization.

Argonne intends to develop new arrested in situ anaerobic digestion technology to execute production and separation more concertedly. They will focus on the 14-L system while fabricating 100-gal fermenters to progress towards a pilot-scale demonstration. They will partner with small cheese producers and breweries and intend to analyze their systems via TEA and Life Cycle Analysis (LCA).

Dr. Chad Haynes, Director of Government Strategy and Technology Partnerships, Lanzatech, Inc.

Dr. Chad Haynes is the Director of Government Strategy and Technology Partnerships at Lanzatech Inc. Lanzatech is a company that specializes in gas fermentation to produce a variety of end molecules including ethanol, isopropanol, and specialty chemicals such as ketones and other molecules that can be used as chemical building blocks to other end markets.

Lanzatech's technology relies on the genetic engineering of a particular organism that can utilize syngas (carbon monoxide and hydrogen) as its sole carbon and energy source. The syngas itself is either an industrial waste gas from processes such as steel manufacturing or can be produced via gasification of a range of carbonaceous feedstocks, including biomass and waste streams. In the presentation, Dr. Haynes showed results on syngas derived from a variety of sources including municipal solid waste (MSW). In one project located in Japan with partner Sekisui Chemical Co, Lanzatech has demonstrated the capability of their organism to convert syngas to ethanol for thousands of hours of on-stream time. Moreover, being a biological upgrading process, the organism demonstrated capability of managing fluctuations in the syngas composition (e.g. when there was a higher/lower carbon monoxide to hydrogen ratio). This abates some of the costly syngas conditioning steps that are typically associated with processes such as Fischer-Tropsch synthesis.

Strategically, Lanzatech is interested in these waste gases as they allow carbon to be recaptured and put back into the economy as opposed to the atmosphere. While the results shown in the presentation were mostly on alcohols, the other building block molecules can be used to produce biopolymers, biomaterials, and transportation fuels. Dr. Haynes provided one such example wherein ethanol derived from their genetically modified organism was catalytically upgraded to sustainable aviation fuel. This fuel was subsequently used in a transatlantic flight. This demonstrates the fungibility of ethanol and other molecules to a variety of end uses.

From an economic perspective, Dr. Haynes shared some data that illustrates the value proposition of gasification of municipal solid waste to produce ethanol as opposed to incineration. While both technologies handle municipal solid waste, the production of ethanol as opposed to heat and power can yield a 4- to 5-times increased revenue margin. In the United States, where district heating infrastructure is limited and thus demands are much lower than in Europe, this could represent an opportunity for handling mixed wastes that are not amenable to other approaches such as hydrothermal liquefaction or anaerobic digestion.

Dr. Haynes concluded his talk with a brief preview of the Soperton, Georgia demonstration plant that is currently being built to test this gasification and syngas upgrading approach on pine forest residues.

BREAKOUT SESSIONS

As indicated in the workshop agenda (Appendix A), between keynote speakers, the workshop participants took part in facilitated discussion sessions where the participants were asked a series of questions about resource and energy recovery from waste. The questions were stated in the general gathering of participants before dividing participants into breakout rooms. The facilitator in each breakout room restated the questions as the participants responded in the breakout rooms. Additionally, the participants had been emailed the discussion questions the day before the workshop to prepare responses in advance.

There were two breakout sessions: *Session 1* focused on potential and continuity and *Session 2* focused on challenges towards recycling or upcycling of waste streams. The breakout room assignments were the same for each session.

The questions asked in Session 1 were as follows:

1. What waste streams offer the most potential or are the highest priority for recycling or upcycling?
2. For priority waste streams, are there intermediate molecules that represent good beachheads for a variety of end applications?

The questions asked in Session 2 were as follows:

1. What are the top technical challenges towards recycling or upcycling of these waste streams?
2. What are the top non-technical challenges towards recycling or upcycling of these waste streams?
3. What are priority technologies for handling/managing mixed waste streams (e.g. mixed plastic wastes, commingled fractions of MSW)?

Each breakout session lasted approximately 45 minutes and took a deeper dive into challenges and opportunities for waste management worldwide. Each breakout room had a facilitator who ensured that each participant had an opportunity to respond to the respective questions. The perspective of different countries was vital given the varying policies and existing waste collection/management practices. Representatives from all six continents participated across the various breakouts, resulting in a rich discussion. The discussions were captured via Menti surveys and notes, and participant input is reflected in the session summaries below. At the end of the workshop, a member from each breakout room reported out the highlights of their respective groups from both sessions to the attendees at large.

Breakout Session Responses

BREAKOUT 1: POTENTIAL AND CONTINUITY

The questions posed to participants are stated in the previous section. Based on those questions, the discussion was logically divided into the topics "Priority Waste Streams" and "Intermediates for the Future."

Priority Waste Streams

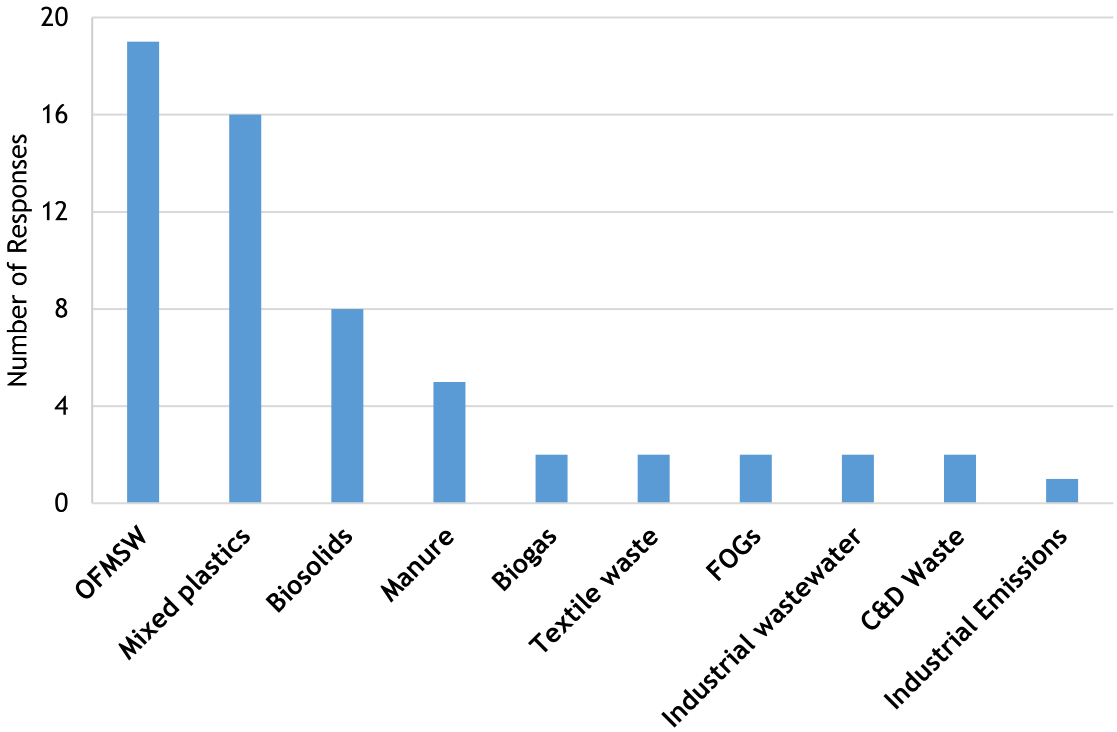

Figure 2 Poll result regarding priority waste streams

As illustrated by Figure 2, workshop attendees indicated OFMSW (Organic Fraction of MSW), mixed plastics, and biosolids as the top three waste streams that offer the most potential or are the highest priority for recycling or upcycling. A category that received significant attention during session discussion despite a low number of responses to the poll was textile waste given its abundance and low recycling/resource recovery rates.

OFMSW includes food waste and yard waste, where food waste includes kitchen trimmings and fully cooked uneaten food and yard waste includes lignocellulosic-based materials of any scale (clippings, trimmings, entire plants, etc.). Food waste is a growing problem and is a very potent environmental issue. Participants stated that Europe handles food waste by minimizing or beginning to implement separation at the source. By comparison, this point-source separation is a less frequent practice in North America. And cultural differences and attitudes about food waste were also noted as being different between these regions. OFMSW is a high priority waste stream because it is abundant and can be recycled into biogas via anaerobic digestion. Biogas can be used for heating, electricity, and in transportation applications such as shipping and public transit. Several participants noted and discussed in the United States, that food waste in particular is an attractive feedstock given its high carbohydrate content and opportunity for commingling with other waste streams.

Mixed plastics include non-bottle plastic packaging of various polymer resin types and colours. This also includes materials that contain multiple plastic resins (e.g. a coating that contains both PET and PE). While both resins, when separated, are mechanically recycled, there are very limited processes that can manage the commingled nature of these resins. Participants emphasized that recycling is currently a challenge in the USA due to poor economic contribution and lack of cultural support. In the USA, mixed plastics often end up in landfills due to a lack of sorting and the low cost of landfills. There is little motivation to recycle as an alternative to landfills given the abundance of landfill capacity. Motivation, both cultural and monetary, is vital in order to transition away from disposing of mixed plastics in landfills, especially in the USA. Mixed plastic waste is a high priority waste stream because they can be recycled and upcycled into new plastic products, enabling a more circular economy that requires less input of unused plastic.

Europe is also facing challenges with mixed plastic waste resulting from Asian import bans on these plastics. One participant noted that over 11 million tons/year of additional recycling capacity will be necessary in the European Union in order to achieve 2030 goals. Participants also discussed the interface of mixed plastic waste with policies such as the “Extended Producer Responsibility” which encourages manufacturers of packaging to consider and utilize materials that have higher potential for recycling. This policy has delivered significant increases in overall recycling rates for these types of materials. Finally, new policies, such as the impending tax on virgin plastics are anticipated to further incentivize novel recycling approaches. Nonetheless, mixed plastic waste remains a challenge in the European Union and represents a potential feedstock for chemical recycling processes such as pyrolysis, gasification, and hydrothermal technologies.

Biosolids are organic matter resulting from sewage treatment operations. Participants indicated that this waste stream is less controversial than other common ones and is less technically intense. In many countries and regions, biosolids can be recycled into fertilizer via minimally complex processes. However, some countries have implemented prohibitions on the use of biosolids for land application or fertilizers due to the presence of PFAs, pharmaceutical compounds, metals content, and pathogenic bacteria, amongst other reasons. Several workshop participants noted that the fates of these molecules are an active and rapidly evolving area of investigation and could result in more stringent regulations. In the United States, it was noted that states in the Northeast are banning the use of biosolids which is dramatically increasing the cost of waste management for municipal wastewater operations. This was identified as a key value proposition for technologies such as hydrothermal liquefaction or incineration in that these technologies may be able to destroy these toxic compounds and organisms.

Additionally, textile waste has a lot of opportunity for recycling and upcycling, mostly via second-hand use without modifications. Second-hand use of textiles should be expanded/encouraged more and, fortunately, is currently growing in popularity worldwide. Participants from around the world all noted that there are very few technologies and processes that manage textile waste, resulting in extremely low rates of resource and energy recovery. The Sysav plant in Malmö, Sweden which aims to sort and recycle more than 16 ktons of textiles/year was specifically discussed as a potential model for managing these types of waste.

The concepts of recycling and upcycling received some pointed discussion in this breakout session. There was debate over which is more important: the end use of the recycled/upcycled item or the cost of decarbonization of the relevant sector/process. Metrics that guided the discussion were cost of the final product and cost of the potential carbon offset. Large scale carbon LCAs are needed to quantify these trade-offs. Additionally, to motivate upcycling, the upcycled item needs to have a performance or value advantage over alternatives in order to support the efforts. Upcycling is challenging because it requires changing item A into item B, where item B is more valuable than item A. The question becomes, “Why was item B not made initially? Was item A even necessary?” The inherent value from manufacturing item A in the first place needs to be considered. Workshop attendees discussed that many people currently are not very motivated to buy items simply because they are better for the environment, so education about the benefits is vital to progress. The participants emphasized the need for people to produce less waste, improve recycling technology, and improve waste sorting.

Intermediates for the Future

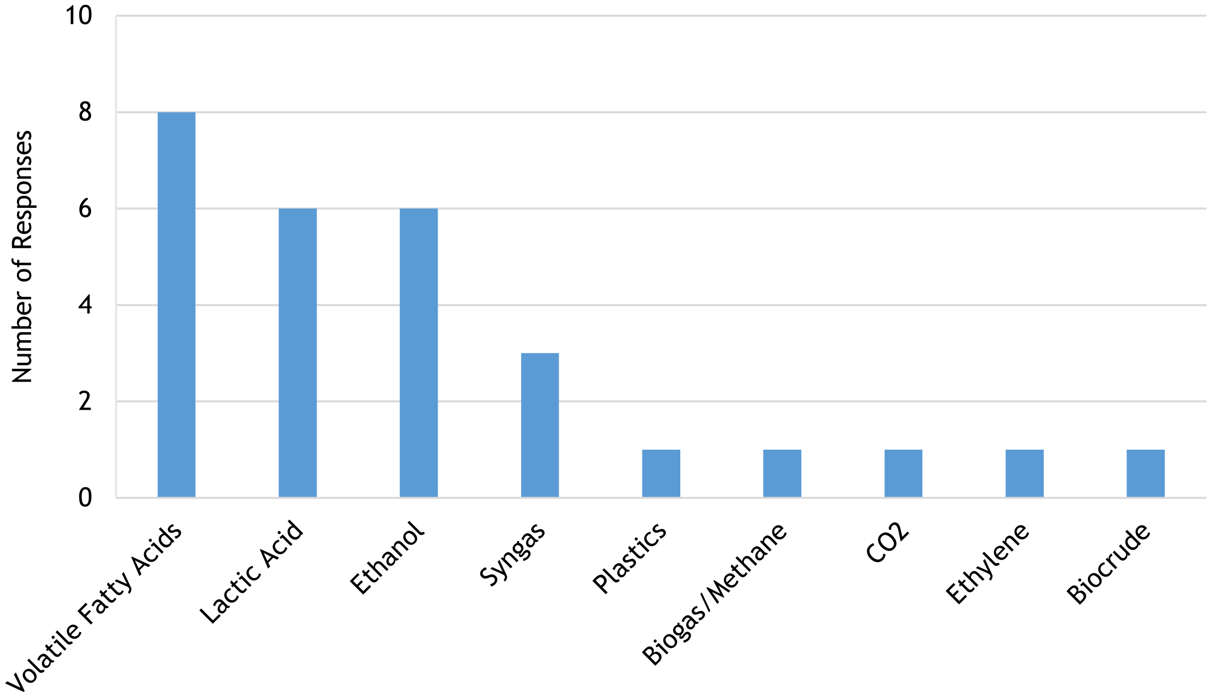

Figure3 Poll results on which intermediates that have highest potential

Workshop attendees indicated volatile fatty acids, lactic acid, ethanol, and syngas as leading intermediate molecules that represent good “beachheads” for a variety of end applications (see Figure3. The main factor that was discussed that motivated the workshop attendees' choices of intermediate molecules was economics. The top four intermediate molecules have versatile applications, which increases their economic viability and resiliency. Having a variety of end applications reduces the risk to the producer of these molecules by diversifying the markets with which they can sell into.

For example, VFA can be used for renewable fuels production, bioplastics, and biopolymer applications, all of which have a higher economic value than biogas. Biogas economics are challenging because, as countries have phased out incentives (e.g. Germany’s feed-in-tariffs), the production and usage of biogas has decreased. An additional benefit of targeting higher value products is that it can mobilize smaller scales of production and thus, smaller scales of waste (e.g. smaller wastewater treatment plants, or municipal food waste).

Lactic acid is used for food preservation, pharmaceuticals, and cosmetics. Additionally, lactic acid is the monomer of polylactic acid, which is a biodegradable and less carbon intense alternative to petroleum-derived plastics. Ethanol is used as a solvent, fuel additive, and feedstock to produce other chemicals (ethylene, ethyl acrylate, glycol ethers, etc.).

A common shared feature of the intermediate molecules described above is that they are produced through conversion methods which “funnels” the diverse range of chemical species (fats, carbohydrates, proteins, lipids) to a small number or even a single product. This then allows for a variety of subsequent polishing or upgrading via a host of different options. One participant described that their entire business is based on producing a variety of end products from organic acid feedstocks.

BREAKOUT 2: CHALLENGES TOWARDS RECYCLING OR UPCYCLING OF WASTE STREAMS

The questions posed to participants are stated in the Breakout Sessions section, before the Breakout 1 discussion. Based on those questions, the discussion was logically divided into the topics "Technical Challenges," "Intermediates for the Future," and "Approaches for Mixed Waste."

Technical Challenges

The technical challenges towards recycling or upcycling of waste streams discussed by workshop attendees were mainly separating mixed waste, designing inherently recyclable/upcyclable materials, and the waste treatment technologies that recycle the material.

Mixed waste needs to be separated in order to optimally valorise each waste stream. More research on separation techniques is needed in order to make it physically possible and economically viable. In particular, the value that a materials recovery facility can derive from the plastics or other streams is largely dependent on the quality of separations that have been achieved. One participant noted the large price spread between a “natural” HDPE stream and one that contained even a small amount of colored resins. Workshop attendees also stated that research efforts are needed to produce more materials that are “recycling-ready” or can be upcycled once their original purpose has been exhausted.

If mechanical recycling is the only option, the majority of participants concurred that there will be a relatively low ceiling in terms of recycling potential and that chemical recycling will be needed to achieve higher levels and country goals. As noted earlier, Europe urgently needs new technology as they are short by 11 million tons of recycling capacity. The workshop participants discussed the demand for improved waste treatment technologies for recycling and for all waste treatment efforts.

While incineration is not a recycling method, numerous European participants noted that it fulfils a key waste management role, particularly in countries with more stringent landfill policies. Additionally, incineration/WtE can produce a steady supply of district and industrial heating, which provides a stable supply of revenue for the incineration operation. In countries like the USA and Australia, there is not the demand nor the infrastructure for this type of heat, which makes project economics challenging in the context of relatively-cheap landfill. Despite the local factors that make incineration economically feasible, workshop participants stated that many European citizens want an alternative to landfills and incinerators. An example of the challenge of incinerators in Europe is a case in Ireland. Citizens were told to recycle via one method but then told to instead put everything into an incinerator. There was miscommunication about which waste streams would go into the incinerator. As a result, many citizens of Ireland developed mistrust of the government and scepticism about the use of incinerators. Concerted efforts are needed to attain community acceptance and social license to operate and explain how recycling and waste-to-energy go hand-in-hand, with the latter dealing with waste that cannot be recycled. The discussion around incineration also considered the possibility of nations such as the United States and Australia ‘leap-frogging’ this technology altogether, and focusing on alternative pathways (such as gasification) which offer more flexibility in terms of adopting circular economy principles.

Participants discussed that technical progress is often made through incremental technological steps instead of jumping to what would really be the best option immediately. For example, if one country has researched many recycling methods and settled on a specific technology, often specific sets of conditions, needs, and constraints informed the technological steps to reach the final technology. The problem arises when another country is unaware of the final technology in the first country and therefore is likely to repeat all the other country's efforts simply due to a lack of shared information or that it does not fully understand the situations that led to this technology choice or choices. The progression is helpful for economic viability and societal acceptance, but the slow progression is not optimal. Countries and organizations should share more information in order to speed up the technical progress worldwide, including sharing their goals to provide a more holistic view of their R&D strategies.

Non-Technical Challenges

The main non-technical challenges discussed by participants include the economics of recycled streams, lack of standardization, and educational awareness.

Participants discussed that the economics of recycled streams need to improve in order to motivate citizens. In the USA, recycling is an economic challenge due to a market collapse for recycled materials; there is low demand for recycled items and landfilling tipping fees are too low to discourage their disposal in this method. Additionally, recycling is a cultural challenge due to a lack of relevant education/information for the public. Many municipalities do not offer recycling, and even in larger cities, certain housing developments do not offer recycling to their residents. Europe has a more communal spirit that motivates their citizens to recycle.

Japan addresses the economic challenge by utilizing government-subsidized sorting, which decreases the cost of recycling, so the recycled products can be commercialized for low cost. The low cost of the product motivates consumers. Additionally, the fact that the sorting is government-subsidized means that it is taxpayer-funded. The USA does not have this governmental support for recycling/upcycling efforts, which is a barrier to progress and marketization of recycled goods. High-tech solutions to recycling may be very costly, so government intervention may be necessary. The most commonly incentivized recycled products are those that can be used as energy.

Workshop attendees discussed how government intervention can standardize waste treatment in addition to improving economic viability. Policies can help motivate action. Some examples of policies that impact waste management were discussed in the breakout session. For example, the United Nations has mandates in the aviation industry to offset carbon emissions in an effort to motivate sustainable aviation fuel production. "Green" options can seem complex and expensive to the lay person, and governments can initiate progress via policies to support efficient and sustainable options for waste management. These policies can motivate research institutions and companies to incorporate more sustainable options and can educate citizens.

A participant shared that a set of policies was implemented in a province in South Africa to prioritize decarbonization via a carbon tax for companies and a ban of organic waste landfills. Alternative treatment of the organic waste that previously went to landfills is needed, and there is an opportunity to use that waste for energy. These policies are slowly expanding throughout South Africa. While countries that have strong government involvement in waste management via policies and incentives, such as South Africa, have the benefit of standardization, they have the challenge of marketization of recycled goods because it is owned by the government. Waste management in the USA is more privatized than it is in Europe. While the privatization makes the marketization of recycled goods readily accessible, the lack of regulation makes progress challenging. Upstream approaches that minimize the amount of waste at the source me be the most cost-effective method of handling waste.

Approaches for mixed waste

Municipal solid waste consists of mixed non-recyclable waste. This waste stream is important because it is abundant and challenging to valorize. Technology is needed that can handle the heterogeneity. Gasification, pyrolysis, and incineration are current options for disposing of mixed non-recyclable waste. However, there are technical challenges and limitations to each of these.

Instead of trying to optimize the mixed waste as a whole, separating it would create more opportunities for optimal valorization. Separation is not currently economically feasible, and one dedicated technology for valorizing each stream after separation is needed. It may be beneficial to automate separation, but that would be expensive and is unlikely to be adopted in the near future.

A key discussion with regards to this question was whether nations such as the United States and Australia (both of which have limited incineration capacity), could ‘leap-frog’ that approach and transition directly to an approach like gasification or hydrothermal liquefaction. It was noted that the technological maturity of these alternatives was still too low, and thus represents too high of a risk, for this to happen at present but that it was a possibility. However, in returning to a point made earlier in the presentation, participants from the European Union noted that incineration does have a role to play and might be the only way to manage particularly difficult solid waste streams. Therefore, it was advised not to write incineration with energy recovery off in any country; rather, focus on demonstrating the different roles that different technology pathways can play in a modern, integrated waste management system, noting that there was no ‘silver bullet’ technology that can solve all problems.

Concluding Remarks

This workshop successfully brought together a wide diversity of technical perspectives on next-generation approaches to managing waste. In addition to answering some of the goal questions identified, the workshop clearly identified that there is an appetite for non-energy products to be produced from wastes. These high-value products address a key challenge by providing higher revenue margin which in turn allows for technologies and approaches that can handle the distributed nature of these waste streams. Workshop participants were nearly unanimous that the single biggest barrier in the transition from a linear to circular economy is that of economics. Therefore, development of approaches and markets to produce these versatile molecules was largely accepted as a worthwhile endeavour.

The approach is not without challenges- there are some waste streams that are not amenable to these approaches due to the presence of contaminants or impurities and existing approaches such as incineration or anaerobic digestion are likely necessary to help manage these both in the near and long term. Additionally, great progress can be made by prioritizing education and information dissemination. Consumers have a significant responsibility in this effort and their choices are critical to establishing the markets and culture that demands life-cycle thinking when products are designed and manufactured.

Appendix A: Workshop Agenda

Monday June 15th, 2020

Times given in Central European Summer Time

15:00 Introduction and context

15:10 Part I: Potential and continuity

15.15 Speaker 1 Zia Abdullah – Biomass Program Manager, National Renewable Energy Laboratory

15:30 Discussions

1. What waste streams has the largest potential for recycling and upcycling today? (20 min)
2. What intermediate molecules has the highest potential and why? (15 min)
3. Based on current regulatory and societal trends, how do you anticipate your answer differing in 5 years? In 10 years? (10 min)

16:15 Mini break

16:20 Part II: Challenges towards recycling or upcycling of waste streams

16:25 Meltem Urgun-Demirtas – Biomass Program Manager, Argonne National Laboratory

16:40 Chad Haynes – Director of Government Strategy and Technology Partnerships – Lanzatech, Inc.

16.55 Discussion

1. What are the top technical challenges towards recycling or upcycling of the materials with highest potential (from Part I)? (20 min)
2. What are the top non-technical challenges? (15 min)
3. What would be the most appropriate technology pathways for handling mixed waste streams? What is their applicability when it comes to scale? (15 min)

17:45 Summary

18:00 End of workshop

Appendix B: Related Links

Workshop on Nutrient Recovery, Stockholm, May 7, 2019: http://task36.ieabioenergy.com/publications/iea-bioenergy-task-36-workshop-on-nutrient-recovery-stockholm-may-7/

Workshop report on Technology Pathways for Energy Recovery from Waste in a Circular Economy Brisbane, November 19, 2019: https://task36.ieabioenergy.com/wp-content/uploads/sites/4/2020/06/Workshop-report-on-Technology-Pathways-for-Energy-Recovery-from-Waste-in-a-Circular-Economy-Brisbane-nov-2019.pdf