RÉSEAU BIOFUELNET CANADA

POLICY BRIEF

# BIOREFINERY DESIGN

## ALIGNING FEEDSTOCKS, SUPPLY CHAINS, AND PRODUCTION TECHNOLOGIES

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## SUMMARY

Biofuels have the potential to make a significant contribution to greenhouse gas (GHG) reduction goals while creating long-term operating jobs and energy security. However, the appropriate conversion technology for biofuel production is highly dependent upon feedstock availability, feedstock properties, desired fuel properties, availability of supporting infrastructure, and fuel transportation systems. These technologies, associated in four platforms (pyrolysis, gasification, bioconversion, and emerging techniques) in the BioFuelNet Canada NCE, have shown many benefits with respect to the different available feedstocks. For example, these technologies can treat either dry (pyrolysis, gasification) or wet biomass (hydrothermal liquefaction, bioconversions).

Moreover, a wide range of products obtained by these technologies could be utilized within existing energy systems, including pipelines, the vehicle fleet, and building heating systems. However, several constraints to biofuel and bioenergy production could limit the ability of biofuels to deliver significant environmental and social benefits. The biomass supply chain is a key factor in the total cost of the feedstock. Also, biofuels are likely to be economically dependent upon attractive markets for the co-products (e.g., chemicals). Several project hurdles, including feedstock costs and co-product markets, can prove to be too significant and can prevent the implementation of projects.

In order to overcome several of the major project hurdles, we are proposing to exploit potential synergies between the platforms by using the concept of flexible modular biorefinery. Analogous to oil refineries, such biorefineries should integrate the emerging technologies to treat, on the same site, different feedstocks and the subsequently reused organic wastes. Therefore, by aligning feedstocks, supply chains, and production technologies and by treating wastes, a flexible modular biorefinery could generate affordable biofuels for a wide range of use.

# INTRODUCTION

A biorefinery is the renewable equivalent of an oil refinery or petrochemical cluster. Transportation fuels, electricity, heat, feed and value-added chemicals can be produced from renewable biomass in a biorefinery by combining and integrating conversion technologies. This model of producing multiple products at the same site has proven successful in the oil industry because low-volume, high-value products, such as specialty chemicals, can economically support the production of high-volume, low-value products, such as transportation fuels. Such an approach in the bio cleantech sector can serve to reduce greenhouse gas (GHG) emissions by making the production and use of high-volume biofuels and bioenergy more economically competitive.

Production targets for bio-based products from biorefineries must be established in concert with government policies that recognize the feedstocks and conversion technologies available to biorefinery developers. In addition, these policies need to consider the potential market, social, and environmental impacts of biorefinery design.

This methodology will encourage developers to design biorefineries that will result in achievement of the policy objectives identified by policy makers.

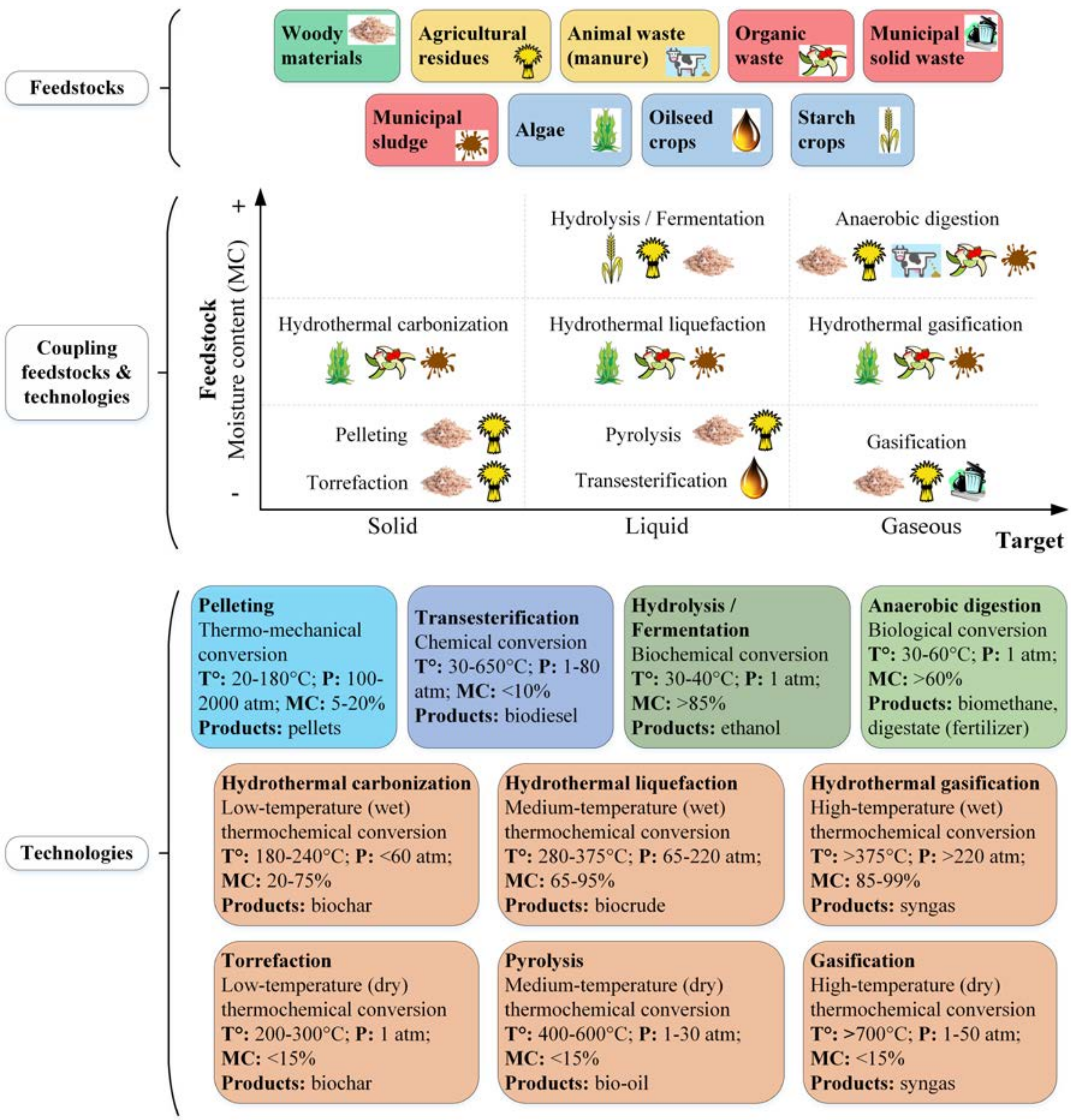
# ALIGNING FEEDSTOCKS AND DEMAND

Technology selection is crucial to successful development and operation of a biorefinery while meeting broader economic, social, and environmental objectives. Technologies can be classified into two major groups: biochemical and thermochemical conversions. Bioconversion includes all the conversions technologies using a biological agent such as enzymes, bacteria or yeasts. Such technologies usually work in aqueous solution and are therefore favorable with naturally wet feedstocks. Bioconversion technologies allow a broad range of products depending on the biological agent used. Except for ethanol production, technology maturity is currently generally low and scale-up for industrial facilities can be limited. It is favorable for low and medium-scale applications. On the other hand, thermochemical pathways use heat and pressure to break down the biomass and convert it in a range of products. The operating conditions define the nature of the products. They can be solid such as biochar and can be burned for energy or used for a range of applications such as soil amendments or activated carbon. They can be liquid such as pyrolysis oil and can be burned for energy or used for other applications such as biocrude or chemicals. Lastly, they can be gaseous such as synthetic gas (syngas) and can be cleaned and used to produce jet fuel, biodiesel, and precursors for chemicals (building blocks). These technologies can also be combined. As an example, pyrolysis can be used as a pre-treatment for gasification to optimize the product quality and the costs. Due to the energy required to convert the biomass, a dry biomass is needed for high process efficiency and manageable operating costs.

The following figure presents a diagram aligning usual biomass and potential conversion technologies. This figure summarizes the general relationship between feedstock properties, technology options, and the targeted biofuel products (solid, liquid or gaseous) (URSC, 2005). Technology selection will highly depend on the available feedstock. Feedstocks can be classified into several categories such as woody materials (green), agricultural waste (yellow), urban waste (red) and dedicated crops (blue).

In some cases, there is no single clearly defined conversion technology for a feedstock or project. Technologies can be combined or modified to match feedstocks and applications. Alternatively, pretreatment operations (e.g. size reduction and drying) allow users to modify feedstocks to suit a targeted technology. To accommodate market needs or operational developments, the ability to adapt feedstocks or technologies is a major opportunity to mitigate project and investment risks. Moreover, capitalizing on existing infrastructure, finding synergies with other activities (materials and energy), and optimizing the supply chain are essential to successful biorefinery development. In brief, a biorefinery project should prioritize a step-by-step (progressive) development and a local integration for downstream and upstream operations.

**FIGURE 1**
Diagram to align conversion technologies and feedstocks



# FRAMEWORK-CONSTRAINED BIOREFINERY

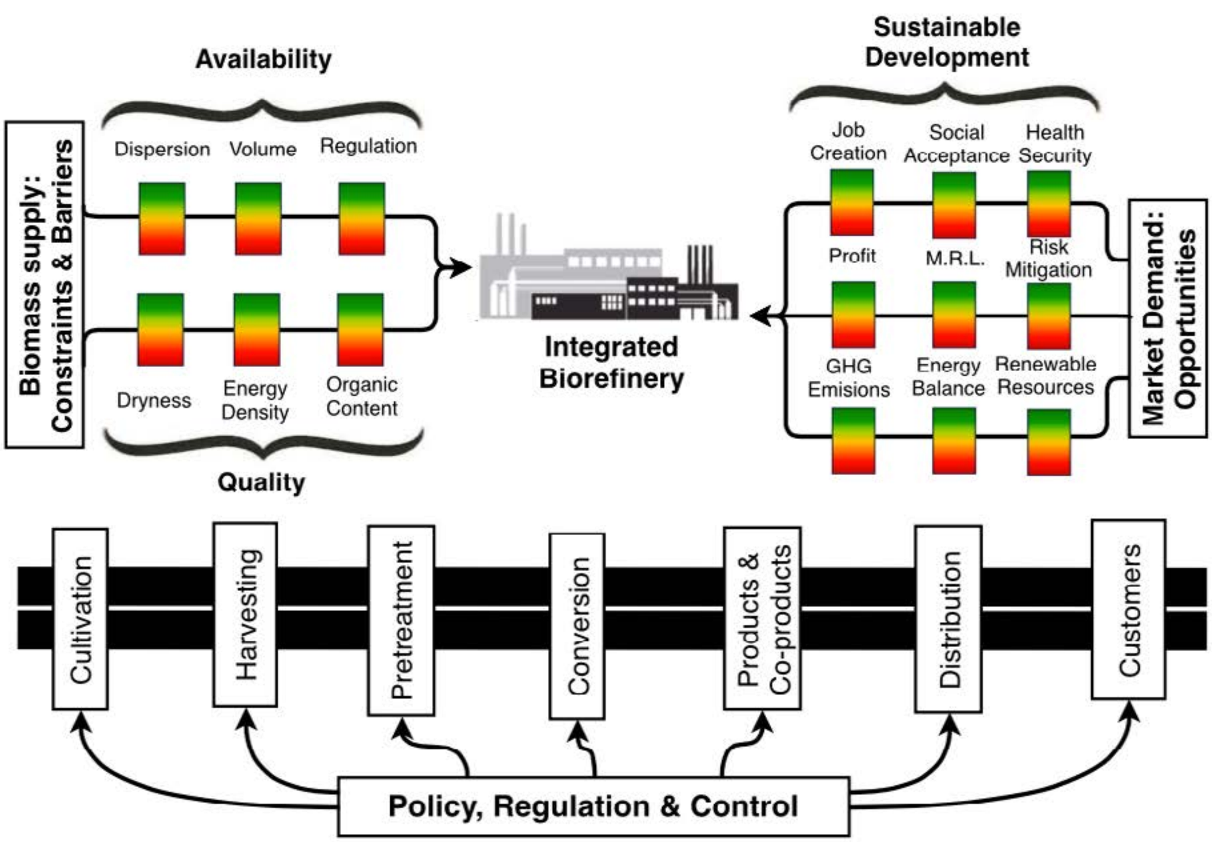
The biorefinery value chain requires consideration of many components both upstream and downstream of the actual conversion of biomass into a variety of bioproducts (Figure 2). Every biorefinery project must pursue specific market opportunities as well as aim to meet environmental and social targets established by government, public, private sector and other stakeholders. To understand the impacts of biorefinery operations, the three major steps in the production chain need to be assessed. These steps are biomass collection and preparation, biomass conversion to final products, and distribution and sales to customers.

First, the targeted biomass needs to be evaluated depending on its quality, availability, and other characteristics such as GHG intensity. Various collection and preparation strategies can be developed to link the feedstock properties with biorefinery design. Second, the choice of conversion technologies selected for a biorefinery is dictated by feedstock properties and targeted products. Third, the biofuels and bioproducts are distributed to the final consumers in order to meet their economic, social, environmental, and legal goals and requirements. Furthermore, all these steps and objectives are impacted by policies and regulations enacted by local, provincial and federal governments.

To develop a comprehensive understanding of the factors impacting biorefinery design, several key indicators must be considered. Figure 2 identifies a number of these indicators. The list is not exhaustive and indicators vary in numbers and diversity according to the feedstock and final biorefinery products. The performance of each indicator is likely to be on a continuum, as indicated by the three-color gauges, rather than a good or poor performance.

**FIGURE 2**

General framework and components of the integrated biorefinery



A biorefinery is bounded by the constraints on the feedstock, i.e. its availability and quality (Perlack et al, 2005), and by broader development goals, defined around three key areas: social, economic, and environmental (WCED, 1987). The public sector is likely to play a significant role in the form of supportive policy, which means social development and environmental goals must be taken into account at the earliest stages of planning and throughout the decision-making process. These goals also need to be considered and weighed in the context of development, operational, and financial risks.

Feedstock Availability will strongly influence the scale and the technologies deployed at a biorefinery. Availability considerations include logistics, road access, feedstock dispersion, volumes, and policies such as regulations and contracts. The importance of various feedstock availability factors may vary depending upon logistics approaches, regulatory incentives, tax credits and agreement facilitation between stakeholders. Feedstock Quality describes the inherent characteristics of feedstocks, such as the moisture content, physiochemical structure, the ash content, and the ratio of key components (cellulose, hemicellulose, and lignin).

Both Feedstock Availability and Quality indicators have a crucial impact on the conversion technology choices and on the final bioproducts. It is important to consider that preprocessing technologies can be deployed to modify both the Availability and Quality of feedstock for a specific project. For example, biomass drying and densification can enable longer distance transportation of the material, thus improving the feedstock and increasing the scale for a biorefinery project. To some extent, these preprocessing technologies modify and adapt the feedstocks to suit the needs of specific conversion technologies.

Due to the large variety of feedstocks, conversion technologies, and potential products that can be selected for a biorefinery, setting priorities and establishing a design can be challenging. Defining and detailing the constraints of a development should be undertaken at the beginning of a project. This first step in the decision-making process could help to identify and to mitigate inherent risks faced by a biorefinery development. An additional biorefinery development and operation risk-mitigation strategy could be the adoption of a flexible modular biorefinery design (King et al, 2010). Such a biorefinery could be flexible in its ability to process a variety of feedstocks, and modular in its capacity to deploy new conversion processes in concert with, or in replacement of, previously installed technologies. An ability to utilize a wide range of feedstocks for production of several products could allow a flexible modular biorefinery to adapt to the constraints previously described

# FURTHER ANALYSIS & CONCLUSION

It is essential for decision-makers to have a good understanding of the projected economic, social, and environmental impacts of a biorefinery project before pursuing its implementation. According to You (2015), Life Cycle Analysis and Optimization of the biorefining value chain is essential for decision-makers to evaluate industry performance and make informed choices about development. These tools can integrate and optimize the value chain through its complexity. This approach requires generic models to evaluate the performance of the processes technology and supply chain configuration. Thus, the purpose is to find the best implementation scenario to maximize the economics (capital costs, operating costs, financial returns, etc.) and social benefits (job creation, health & security, etc.) while minimizing the negative environmental impacts (greenhouse gases, air pollutants, material & water balance, biodiversity, etc.). According to Holm-Nielsen (2016), modeling and optimizing bio-based industries requires consideration of many qualitative and quantitative parameters along the value chain. These parameters are related to the capacity limitations (collect, transport, storage, etc.), the techno-economic performance, the stakeholder dynamics, the planning horizon and the sustainability. This complexity implies a multilevel, multiscale, multi-temporal and multiplayer modelling approach. Therefore, many strategic choices must be made to reduce the uncertainty and risk (e.g., plant capacity, technology choices, facilities locations, network design, collection sites, etc.). From a management perspective, current research examines how firms can realize economic gains together with the integration of sustainability (Van der Byl & Slawinski, 2015). In contrast, Porter & Kramer (2006; 2011) examined the concept of creating shared value and corporate social responsibility (CSR). Their research looks at how firms can align economic performance with sustainable benefits for society. However, it is not always possible to reconcile sustainability and economic goals and achieve a win-win approach. Researchers can examine how firms and sectors can address the conflicts and tensions in sustainability. Trade-offs between stakeholders will certainly be present and may consist of an agreement obtained through concessions to avoid tension and conflict in project management. Trade-offs will be used to reconcile the tension between stakeholders in various land and resource use conflicts, territorial conflicts, and multi-purpose infrastructure conflicts. It is important to decision-makers to have a roadmap of these tensions and conflicts to help developers to design a proper biorefinery that meets not only enterprise needs but sustainability for the public and the environment.

In conclusion, the bioeconomy holds significant promise for the production of various biofuels and other bioproducts. Biorefinery projects must integrate their value chain and pursue specific local and global market opportunities. These kinds of projects require consideration of upstream and downstream impacts of processes and value chains. As previously described, the main goals are to determine biomass quality and availability, to choose an optimal conversion technology and to distribute efficiently the products and co-products. The purpose is also to conciliate the economic profit and meet social, environmental, and legal requirements established by the government and other stakeholders of the public and private sectors. The establishment of the bioeconomy requires the prioritization of two major components. First, there is a crucial need to support research and development on conversion technology, with an emphasis on complementarity and synergy between process and industry. Second, accurate and standardized evaluation tools are needed to precisely characterize the framework and the biorefinery deployment. Life Cycle Analysis Optimization could be a potential solution, but this specific tool needs to be adapted to Canadian conditions. Also, it is essential that the Canadian government publish an updated biomass inventory online on an open platform with all biomass categories, volumes, owners, and other details. Finally, regulations and policies, at various levels of government, must be adapted to take into consideration the social, environmental, and economic impacts of an emerging bioeconomy. Tools that may be used could include blending standards, subsidies on investments and expenses, and tax exemptions. Large R&D programs should also involve more coordination between the different stakeholders.

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