Commercialisation of Products from Biomass Conversion

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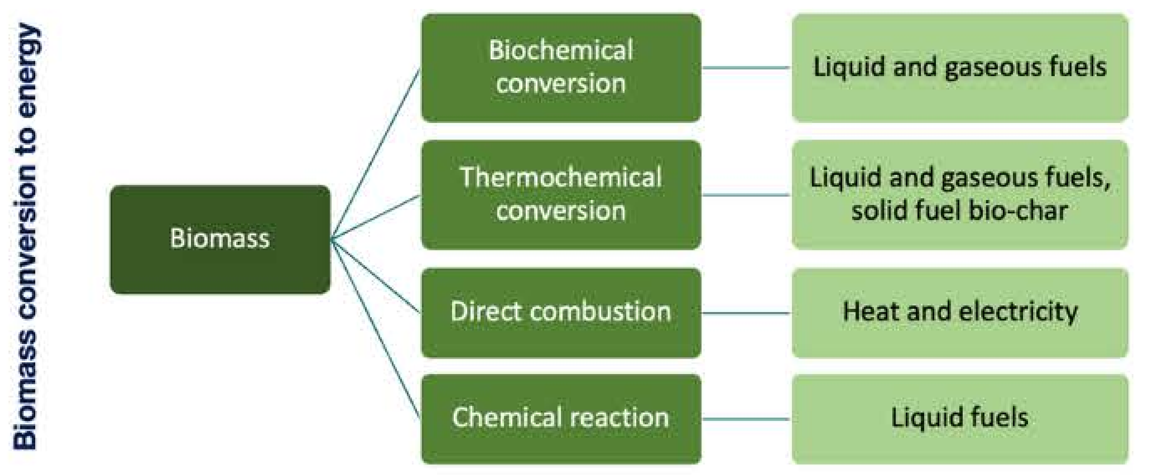
Introduction to Biomass Conversion

Biomass is organic, made up of materials that come from living organisms (e.g., plants and animals).

Common types of biomass converted to energy include:



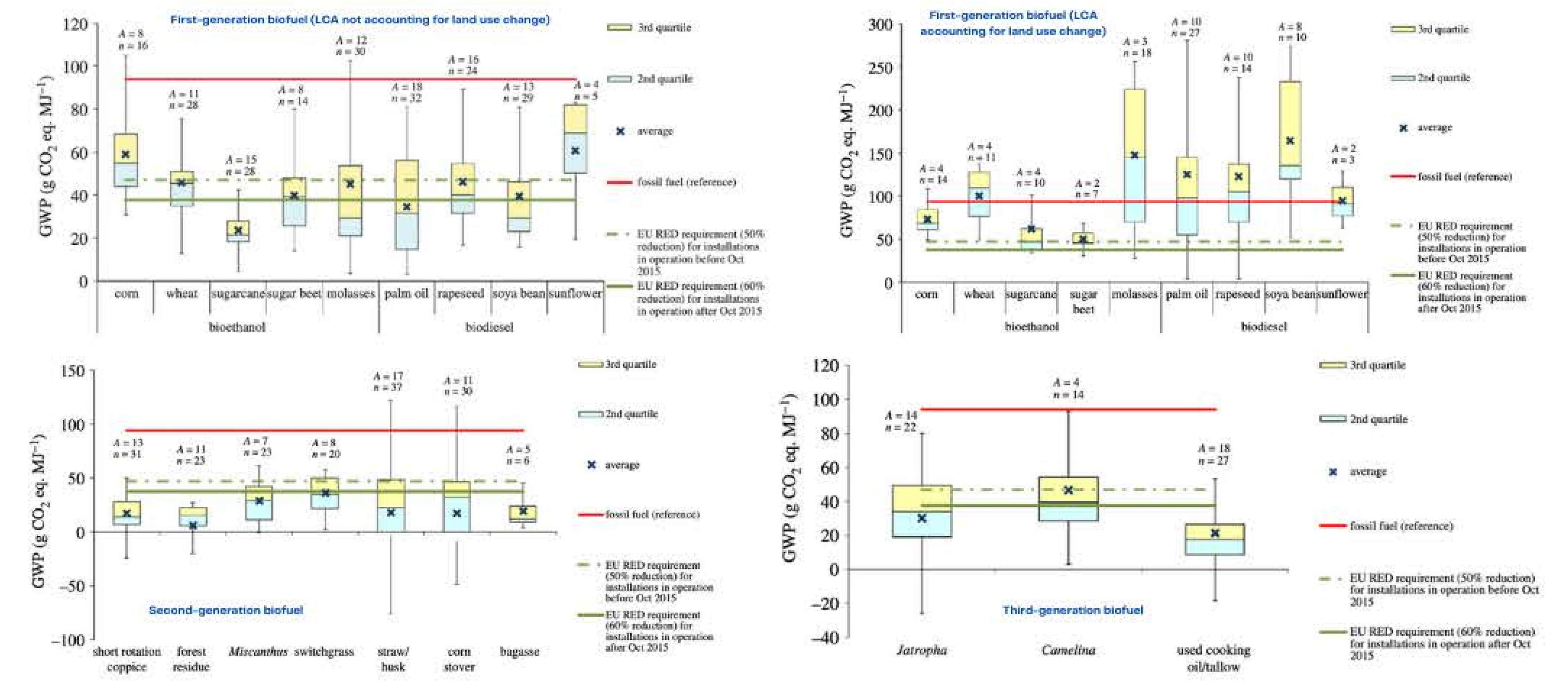
- **Biochemical conversion** involves using microorganisms or enzymes to break down biomass into sugars, which can then be fermented into biofuels (e.g., bioethanol).
- **Thermochemical conversion** involves heating biomass to high temperatures in closed, pressurised vessels.
- **Direct combustion** involves burning biomass to generate heat and electricity.
- **Chemical reaction** involves catalysts and other chemical reactions to convert biomass into biofuels and chemicals.

The Four Generations of Biofuel

	1st Generation	2nd Generation	3rd Generation	4th Generation
Inputs / Feedstock	**Edible crops** • Seeds and grains • Sugar • Vegetable oil	**Lignocellulosic biomass** • Wood waste • Agriculture source • Industrial, herbaceous, municipal waste	**Algae biomass** • Microalgae: Unicellular organism • Macroalgae: Multicellular organism	**Diverse, including genetically modified (GM) algae biomass** • Cyanobacteria, macroalgae, microalgae
Production process	**Ethanol** • Pre-treatment • Hydrolysis • Fermentation • Distillation **Biodiesel** • Mechanical/chemical separation • Transesterification • Distillation	• Thermochemical processing involves heating or burning biomass to create energy products. • Biochemical processing involves biomass pre-treatment, enzymatic hydrolysis, fermentation, and distillation to produce bio-alcohols and biomethane	• Microalgae cultivation ○ Open raceway ponds ○ Closed photobioreactor • Harvesting • Drying, pre-treatment • Biomass conversion ○ Biochemical conversion ○ Thermochemical conversion ○ Direct combustion ○ Chemical reaction	The process has the same steps as 3rd generation, with extra step of feedstock genetic modification using one of the following: • Engineer biofuel pathways in native producers • Reconstruct pathways identified in natural producers in more genetically accessible model organisms
Key outputs	Bioethanol and biodiesel	Bioethanol, biodiesel, biobutanol, biomethane, bio jet, kerosene, biohydrogen	Various, depending on conversion process, including biodiesel	Various, depending on conversion process, including biodiesel
Strengths / Opportunities	• Energy security using local feedstock • Established technology for production	• Contributes to circular economy by reusing wastes and crop residues • Minimal conflict with food production • High GHG reduction potential	• High land-use efficiency • Capability to produce various types of biofuel • High GHG reduction potential	• Higher production volume as an "upgrade" of 3rd generation • High GHG reduction potential
Weaknesses / Risks	• Land use changes • Conflict with food production • Limited GHG reduction potential	• Excessive removal of crop residues may affect soil quality and the environment • High capital and processing costs	• Uncertain GHG reduction potential • Technical challenges and uncertainty associated with capital and operational costs	• GM organisms pose significant risks to the public health and surrounding environment • Technology in early development stage, hence high costs now

Comparison of LCA Results for 1G, 2G, and 3G Biofuels

Life Cycle Assessment (LCA) is an analytical tool that measures environmental impacts at every stage of a product's value chain. Various assumptions and methods contribute to different results between studies. 2G biofuel seems to have least life cycle emission.



Jeswani, H. K., Chilvers, A., & Azapagic, A. (2020). Environmental Sustainability of Biofuels: A Review. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 476*(2243). https:// doi.org/10.1098/rspa.2020.0351

Status Quo of Biofuel in ASEAN

Country	Bioethanol blending ratio	Biodiesel blending ratio	Production capacity (2022)
Indonesia	E20 by 2025, E50 by 2050	B30 by 2020, B40 by 2030	CPO feedstock: 9.5 billion tons Produced 10.3 billion litres biodiesel
Lao PDR	10% share in TPES (blending ratio 5%-10%) by 2025 10% share in transport fuels by 2030		–
Malaysia	E10	B20 in 2023	CPO feedstock: 1.1 billion tons Produced 1.15 billion litres biodiesel
Philippines	E10 in 2023, E20 by 2040	B5 by 2020, B10 by 2040	Coconut oil: 228,000 million tons Produced 248 million litres biodiesel
Thailand	E85, E20, E10 in 2023 20-25% share in TFEC by 2037	B7, B10, B20 in 2023	Sugarcane (1.1 billion tons), molasses (3.6 billion tons), cassava (3.3 billion tons); 1.46 billion litres of bioethanol
Vietnam	E5, E10 in 2023 Biofuel to cover 13% and 25% of transport sector's fuel demand in 2030 and 2050, respectively	B5, B10 in 2023	–

- Nations above have clear biofuel policies while the remaining ASEAN countries (i.e., Brunei, Cambodia, Myanmar, and Singapore) only have blending mandates.
- Indonesia, Malaysia, Philippines, and Thailand are major biofuel producers in ASEAN.

Merdekawati, M. (2023). *ASEAN Biofuel R&D Roadmap presentation in FGD on Plans and Policies for Electric Vehicles in ASEAN Member States.*

The Framework

An evaluation framework was developed to review the viability of commercialising biofuels, represented by its supply chain steps, from viewpoint of three sustainability aspects (i.e., environment, society, economy). The framework's strength lies in its enabling quantitative evaluation of economic, social, and environmental externalities which the biofuel supply chain generates in both their measurement units and financial term. The framework comprises four levels of parameters, with Level 3 and 4 bearing higher degree of granularity in terms of measurement and information gathered.

Level 1: Key supply chain step	Pre-setup & input	Raw material sourcing	Processing / production	Storage	Distribution to points of sales	Consumption	Reporting	External factors
Level 2: Aspect	Economic			Environmental			Social	
Level 3: Indicator	Capital costs Operating costs Government incentives Revenue / outputs Certification Market competitiveness			GHG emissions Biodiversity loss Air quality Soil quality Water quality and footprint			Land rights Water rights Local food security Occupational health and safety	
Level 4: Metric	60 total metrics, 53 unique, including: *Equipment cost* *Certification fee* *Biofuel production capacity* *Amount of government subsidy* *Research and development cost*			44 total metrics, 35 unique, including: *Change in soil quality* *Ecosystem services at the site* *Reduction in vehicular GHG emissions* *Particulate matter emission from production* *Operational footprint using green water*			7 total and unique, including: *Percentage of fatalities* *Number of land conflict* *Number of water conflict* *Number of recordable injuries* *Amount of food crops used for biofuel*	
	Financial proxies to calculate the costs and benefits and, eventually, the **Integrated Return on Investment (IROI)**							

Case Studies of the Framework

Case studies were conducted to calculate the IROI and test the proposed framework using three Level 4 items: carbon revenue/loss, tax incentive, and certification cost.

	1G biofuel	2G biofuel	3G biofuel
Source of data	[a]	[a]	[b]
Feedstock	Corn	Woody biomass	Microalgae
Products & by-products	Bioethanol	Bioethanol	Biodiesel, glycerol, fertilizer, feed
Project duration	10 years	10 years	20 years
Annual biofuel production capacity	189 million L	76 million L	2 million L
Estimated GHG reduction	20% (short of 40% to fulfil EU RED's requirement of 60%)	79%	60% (assumed to meet EU RED's requirement of 60%)
Tax incentive as corporate tax waiver	21%	21%	21.5%
Fossil fuel's life cycle GHG emission	95.1 gCO_2e/MJ		
Carbon price	US$60/t$CO_2$e		
Discount rate	10%		

	1G	2G	3G
Standard ROI	15%	5%	0.06%
IROI	6%	13%	0.14%

Note
- 1G and 2G biofuel data was derived from 2011, the most recent data publicly available online.
- 3G biofuel data was modelled instead of based on real numbers due to lack of large-scale production.
- Despite ROI and IROI results, 3G biofuel has been receiving more investment from the market.

[a] Asia Pacific Energy Research Centre (APERC). (2011). (rep.). *APEC Energy Overview 2010* (pp. 1–233). Singapore: Asia Pacific Economic Cooperation.
[b] Das, P. K., & Kumar, S. (2022). *34 – Cost-benefit analysis of third-generation biofuels.* In Jacob-Lopes, E., Zepka, L. Q., Severo, I. A., Maroneze, & M. M. (Eds.), *3rd Generation of Biofuels: Disruptive Technologies to Enable Commercial Production* (pp. 785–811). Woodhead Publishing.

Potential Commercialisation Pathways in Transport Sector

As the global economy gradually transitions towards a low-carbon future, key sectors such as aviation, marine shipping, and road transport are trying to reduce their carbon emissions. Among the available solutions, biofuels emerge as a promising option in this energy transition. Potential pathways in respective sectors are explored as follows:

Industry	Aviation			Marine Shipping		Road Transport	
Pathway	Hydro-processed Esters and Fatty Acids (HEFA)	Advanced Biomass to Liquid (ABtL)	Power to Liquids (PtL)	FAME (Fatty Acid Methyl Ester)	Hydrotreated Vegetable Oil (HVO)	Bioethanol	Biodiesel (HVO, BtL)
Feedstocks	Fats, oils, grease [1G]	Agricultural and forestry residues, cellulosic cover crops, solid waste [2G]	Renewable hydrogen and CO_2	Food crops, sugar/starch, vegetable oils [1G]	Agricultural and forestry residues, cellulosic cover crops, solid waste [2G]	Food crops, sugar/starch, vegetable oils [1G]	Agricultural and forestry residues, cellulosic cover crops, solid waste [2G]
GHG emission savings	74%-84% from conventional jet fuel	66%-94% from conventional jet fuel	99% (during use phase) from conventional jet fuel	36-62% from conventional fuel	88% from conventional fuel	20% from gasoline	50% from conventional fossil fuel
Readiness (tech./econ.)	Commercially available	Components proven in condition to be deployed	Prototype proven at scale in condition to be deployed	Technologically ready; the Port of Singapore is conducting bunkering trials of biofuels for ocean-going vessels		Commercially available	Currently in research and development
Pricing	• ~ US$1500/ton • 10% mark-up on production cost	• ~ US$1800/ton • 25% more expensive than HEFA	~ US$3200/ton	FAME price is 30-50% higher compared to VLSFO	HVO's price is double the price of VLSFO	US$1,061/ton to US$2,374/ton	US$2,279/ton to US$4,306/ton
Cost structure in the future	• No significant CapEx reduction is expected • Continuous scaling may help to further bring down OpEx • Steep rise in feedstock price may drive up OpEx	Due to development of economies of scale, a more accelerated cost reduction is expected	• Substantial cost reduction can be expected for renewable electricity in the future, ~80% • Benefits from economies of scale	• Steep rise in feedstock price may drive up OpEx • Benefits from economies of scale		Steeply rising prices for feedstocks may drive up OPEX	• Fiscal incentives might accelerate feedstock-switching • Benefits from economies of scale

Aviation: Topsoe (2023), *SAF: outlook for sustainable aviation fuel*; Danicourt et al. (2023), *A realistic path to net-zero emissions for commercial aviation*; Gassman et al. (2022), *The real cost of green aviation.*
Marine shipping: Boutos et al. (2022), *FAQ on Bunkering of Biofuels for Ocean-going Vessels in the Port of Singapore*; Placek (2022), *Daily VLSFO Bunker Oil Price Worldwide 2022*; Sahu (2023), *VPS-inspected marine biofuel samples surge amid push towards sustainable shipping.*
Road transport: Doherty & Robinson (2022), *2022 Road Fuel Outlook*; OECD/FAO (2021), "OECD-FAO Agricultural Outlook"

Available Financing Options

	VC / PE Investment	Green Bonds	Green Loans
Applicability	• Non-listed company in the early / growing stage of business development	• Issuer: firms, FIs, and governments • Standards: ICMA's Green Bond Principles, CBI's Biofuel and Bioenergy Criteria	• Issuer: firms, FIs, and governments • Standards: LMA/ICMA's Green Loan Principles
Strengths	• No obligation to repay the money • Expertise from investors	• Signalling: drives market policy and direction to combatting climate change • Diversification of investment	Reputational benefit: further attracts investors upon demonstration of focus on ESG criteria
Limitations	• Share of profit • Diluted ownership • Potentially more costly than debt	• Similar price with normal bonds • Reporting can be costly • Impact is hard to identify and financially valuate	• Dependent on credit rating track record • Effort to comply with terms of the loan (e.g. ESG Provisions)
Recent example	**Viridos Inc**, US-based 3G biofuel co. • Series A - US$25 million • Breakthrough Energy Ventures, United Airlines Ventures, Chevron	**Apeiron Bioenergy**, SG-based 2G feedstock co. • Issuance of 5-year green bond raised S$50m • Proceeds used for capex and general working capital	**Repsol**, Spain-based multi-energy co. • EUR120 million raised from European Investment Bank (EIB) • Construction of advanced biofuels plant in Spain

Conclusion

- **Primary data** is essential for further **fine-tuning** of the proposed framework
- **Biofuel producers** need to be engaged to **contextualise** the framework
- **Future analysis** must incorporate more **sectoral parameters** to better determine the best sector for commercialisation